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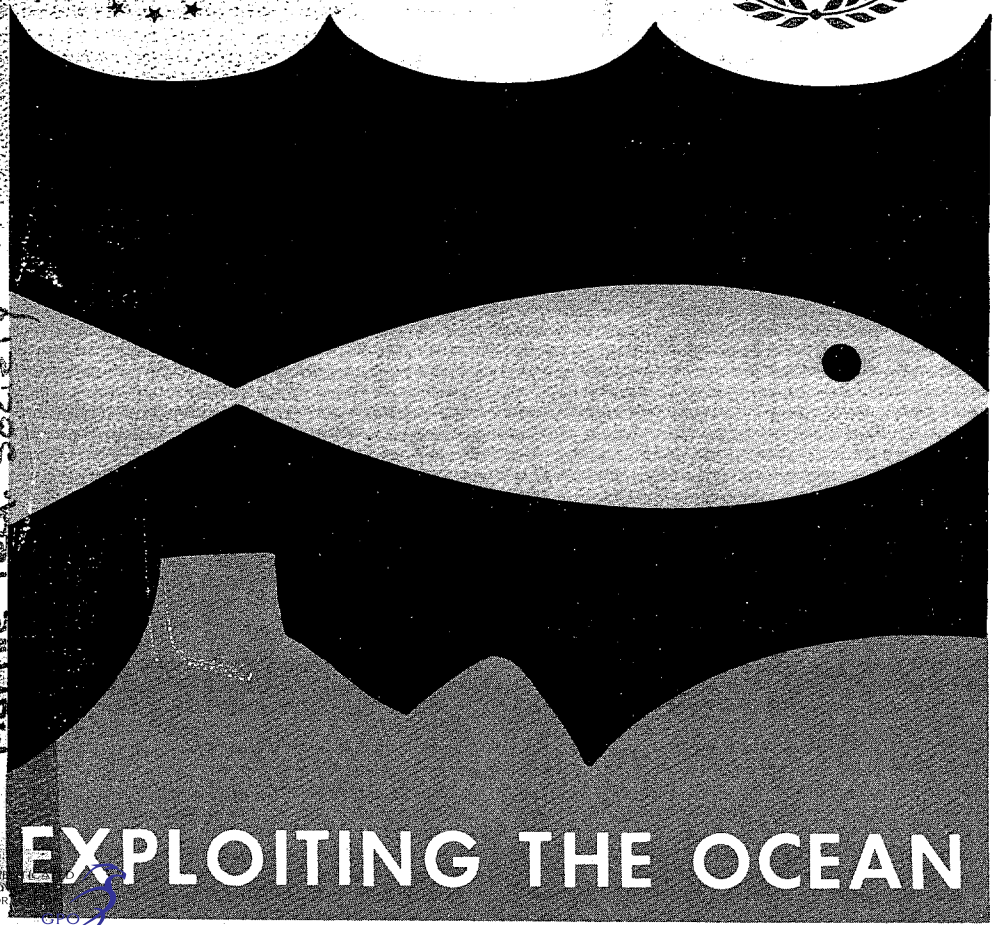

EXPLOITING THE OCEAN

Marine Tech. Society

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FOREWORD

The Second Annual Conference and Exhibit of the Marine Technology Society has been developed to help the various industrial and government interests better to understand the problems involved with expanding ocean programs, and to discuss the most practical means of achieving goals of these different activities. The following organizations were associated with the Marine Technology Society in this development:

Participants:	American Mining Congress American Petroleum Institute
Observers:	American Bar Association: Section on International and Comparative Law, Section on Mineral and Natural Resources Law
Cooperating Organizations:	American Fisheries Society American Geophysical Union Institute of Navigation National Canners Association National Fisheries Institute Tuna Research Foundation

This volume contains the text of papers presented at the conference. They are published here in order to forward the policy of the Marine Technology Society to disseminate knowledge of the marine sciences.

In organizing and developing these papers for presentation and discussion, the assisting organizations and, even more importantly the individual authors, have made valuable contribution to the knowledge and understanding of the marine sciences. On behalf of the membership of the Marine Technology Society and of all participants at the conference and exhibit, grateful appreciation for this is affirmed.

Richard C. Steere
Chairman, Transactions Committee

PREFACE

During the year past the national interest in the oceans has grown at an accelerating rate with particularly strong emphasis on resources important to our economy. It is not at all clear just what turn this increased interest will take in terms of commercial and industrial enterprise. One thing is clear, however, which this Conference Program reveals: we need much better information about the location, distribution and abundance of the resources of the oceans and about the economic factors and the technology of their removal as well as a clarification of the law regarding right of removal and ownership of the materials recovered. We hope this Conference will not only expose these issues but will provide a forum for their discussion by representatives of our federal and state governments, of industry and of the research and academic institutions concerned with the use of ocean resources for the national good.

James H. Wakelin
General Chairman
"Exploiting The Ocean"

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LEGAL ASPECTS OF OCEAN EXPLOITATION -- STATUS AND OUTLOOK*

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Abstract

The present status of the international law of the sea is found in previous decisions about the allocation of authority over, and use of, ocean areas. The principal method of exercising control over the ocean is that of extending state authority to particular, usually specifically defined, areas or zones of the ocean. Describing the law of the sea, therefore, involves the examination of decisions pertaining to internal waters, territorial sea, continental shelf, contiguous zones, and the high seas, all of which refer to zones within which authority is allocated among states in different ways. The principal provisions of the Geneva Conventions on the law of the sea, concluded in 1958, contain most of the important principles of law relating to ocean exploitation. The outlook for the future of ocean exploitation within the framework of the international legal system is projected in terms of the impact of law upon certain important ocean activities, either actual or anticipated. The possible need for clarification of the existing structure of law and for additions to such structure is examined in the context of recent and prospective developments in hard mineral mining, fishery exploitation, and claims to the ocean floor for purposes other than mining.

The task undertaken here is that of examining the present status of, and the future outlook for, legal arrangements that may affect some types of exploitation and use of the ocean and the resources therein.[1] The law with which we are specifically concerned is the international law of the sea, i.e., the law involved in relations primarily between nation-states, although other groups, including private associations and individuals, are also on occasion subject to this law as well.[2] This focus on international law is not by any means intended to imply that national law and policy are not important. Quite obviously we need wise planning for, and effective implementation of, a coherent national policy concerning ocean exploitation.[3] However, the point to be emphasized is that this national policy must be created, and its implementation occur, within an international system which requires that any interest in the world ocean, advanced by the United States (or by any other state) as meriting international legal protection, must be reciprocally recognized when that same interest and demand for protection are advanced by other states. In short, there can be no avoidance of the task of clarifying the common interests of all states of the world in the ocean, even when the immediate objective is that of ascertaining the interests of a single state, such as the United States.

It is, therefore, entirely appropriate here to center discussion upon the international law of the sea, for it is this law which seeks to secure the common interests of all states in their use of the sea. The overriding objective of the decision process we call the international law of the sea is, in most general statement, that of promoting, and permitting, the fullest, most productive, and peaceful use of the ocean by all participants for achieving all their individual goals in the greatest measure possible. With this very general statement of goal as a guide it may be possible later to offer some comment on the outlook for the law of the sea as regards ocean exploitation.

It is necessary, first, to offer brief summary of the past decisions that, as a whole, comprise the "present status" of the law of the sea. This involves, to be explicit, merely a general description of what has happened; nothing in this descriptive statement is intended to suggest what the future may be like. When predictions are considered, as they are in a later section, they are labelled as such.

The principal justification for describing the law of the sea arises, of course, because that law impinges, or may do so, upon ocean uses of various kinds. We are all aware that, traditionally, fishing and transportation were the most important ways man employed the sea for the general advantage. And today these uses are still important but others must also now be accommodated within the legal framework or, at least, contemplated in such context. These later, and potential, uses include oil exploitation, hard mineral mining, the various practices of scientific inquiry and investigation, military uses other than navigation or traditional exercises, and territorial claims to the ocean floor.[4]

Although discussion of "existing law" could proceed in terms of these actual or likely methods of ocean exploitation, clarity is probably better served by considering the ways states have actually made claims to authority over the oceans and have recognized these claims.

The principal method of asserting claims to control or to regulate activities in the ocean is that of extending or seeking to extend state authority to particular, usually specifically defined, areas or zones of the ocean. Description can, therefore, economically proceed by examining the law relating to internal waters, territorial sea, continental shelf, contiguous zones, and the high seas, all of which refer to zones within which authority is allocated in different ways. This enterprise obviously requires also that reference be made to the delimitation of the boundaries of these various areas.[5] Within this framework the main objective is to provide background for discussion of the impact of law upon certain of the activities mentioned above.

In describing the present situation frequent reference is made hereafter to the four Geneva Conventions on the Law of the Sea adopted as a result of a conference of 86 states held in 1958.[6] These treaties were the culmination of nearly a decade of consideration by some of the states and were affected most importantly by the work of the International Law Commission, a subsidiary organ of the United Nations General Assembly. The conventions deal with (1) the territorial sea and contiguous zone, (2) the continental shelf, (3) the high seas, and (4) conservation of fishery resources. The first three of these treaties

are presently in effect as between the twenty-two or more states which have signified their acceptance by ratification. The United States is a party to these three. The fourth, on fishery conservation, is not at this writing in effect but probably will be shortly and, again, the United States will be a party since it has been ratified already. States not a party to these Conventions are not bound by them, but to avoid misunderstanding it must be noted that at least two of these treaties, those on the territorial sea and the high seas, are generally regarded as expressing customary international law. The principles recorded therein are, hence, binding on states as part of this body of law. The third convention, dealing with the continental shelf, also probably reflects, in some important respects, customary law, but there may be disagreement about whether some of the detailed provisions of the convention are, in fact, already a part of customary law. The treaty on conservation is a departure from previously accepted principles and it is unlikely that states generally regard these provisions as binding on them in the absence of ratification of the treaty or, at least, explicit pronouncement of acceptance.

INTERNAL WATERS

Previous decisions fully establish that each state has full authority and control over activities within the areas of internal waters, such as ports and certain bays and gulfs. The entry of ships to such waters is, thus, in practically all instances subject to the consent of the coastal state. There are a very few situations, more or less unique, in which access to these waters may be claimed as a matter of right.[7] All resources in this area are within the complete disposition of the coastal state.

TERRITORIAL SEA

The scope of state control over the marginal waters accepted as within the territorial sea is similarly well established, though here there is one important issue that remains controverted by some. Generally speaking the coastal state has complete authority over the resources, fishery and all others including those of the seabed and subsoil, of the territorial sea. Coastal authority over the access of foreign vessels and objects to the territorial sea is also wide, but not unlimited. Foreign vessels have a right of innocent passage, which is understood to mean that vessels are normally entitled to pass through the territorial sea so long as the passage is not "prejudicial to the peace, good order or security of the coastal state." The wide range of coastal interests which might be subsumed under such terms of high-level generality as "peace, good order and security" assures the coastal state of ample, but not unlimited, authority to protect legitimate interests. In addition the "coastal state may, without discrimination amongst foreign ships, suspend temporarily in specified areas of its territorial sea the innocent passage of foreign ships if such suspension is essential for the protection of its security." Suspension cannot be made effective until after publication.

The major issue still controverted concerns whether warships are entitled to invoke the right of innocent passage. Without entering into long explanation it is believed that warships do have such a right in virtually the same sense as private or merchant vessels.

THE LIMIT OF INTERNAL WATERS

Traditionally the areas denominated as internal waters were limited, but recent decisions have opened the way to inclusion of rather large expanses of the ocean. It is now generally regarded as permissible completely to include certain indentations into the coast if the width of the opening does not exceed 24 miles in length, and if the opening is wider then the coastal state may draw a baseline at the first place the indentation narrows to 24 miles. The effect of placing the baseline further from the shore is to enlarge the area of internal waters, to extend the limit of the territorial sea and contiguous zones further out from the coast, and to affect the limit of the continental shelf in some situations.

In certain conditions of water-land conformation, the coastal state may employ a straight baseline system, using isolated bits of rock and islands offshore as points on the line. The general situation contemplated is described in Article 4(1) of the Convention on the Territorial Sea and Contiguous Zone:

> "In localities where the coastline is deeply indented and cut into, or if there is a fringe of islands along the coast in its immediate vicinity, the method of straight baselines joining appropriate points may be employed in drawing the baseline from which the territorial sea is measured."

The first application of this system, which preceded its inclusion in the Convention, occurred in Norway and, when challenged, was supported by the International Court as conforming with international law.[8] Subsequently the Convention included the above provision and it promises to furnish the basis for sometimes marked extensions of internal waters. As is probably evident the use of this system can have considerable impact on foreign fishing activities in near coastal areas.

THE LIMIT OF THE TERRITORIAL SEA

One of the two critical issues left unresolved at Geneva in 1958, and again at a later conference in 1960 convened to deal with it, was that of the permissible breadth for the territorial sea. There are two main reasons this question was widely regarded as important: both access to fisheries in coastal waters and access by military vessels to important straits are, or might be, affected by the width claimed or accepted for the territorial sea.

It is still necessary to be tentative in discussing the existence of a general consensus among states on this problem. The United States position, the one we claim for ourselves and urge on others, is that three miles is the only limit universally agreed as permitted by international law.[9] At the same time there appears to be a pattern emerging which may, perhaps sooner than later, indicate general, if tacit, agreement that a 6-mile territorial sea is permissible. There are, however, a number of states which claim a 12-mile territorial sea and a very few claim an even wider limit. In nearly universal opinion the latter claims are contrary to international law.

CONTIGUOUS ZONES FOR SPECIAL PURPOSES

There is general recognition today, as there has been for many decades, that realistic protection of coastal interests requires the state to extend certain of its regulations, applicable to foreign vessels, beyond the limit of its territory as represented by the boundary of the territorial sea. States have done so for a considerable variety of purposes and they continue to do so today. The most important of the purposes presently being sought by establishing zones of limited authority beyond the territorial sea is that of acquiring exclusive coastal access to fishery resources. This form of contiguous zone is closely associated with the question of determining a limit for the territorial sea and at Geneva in 1958 the most prominent proposals for explicit agreement on the latter issue were combined with provision for special fisheries limits beyond the territorial sea. The United States-Canadian proposal at Geneva in 1960, which failed of adoption by only one vote, would have established a 6-mile territorial sea plus a further 6-mile fishing zone which, with some qualifications, would have conferred the same rights over the fish resources there as the coastal state possesses in the territorial sea.

Although there was general willingness, if not quite the two-thirds approval required for adoption, to accept a contiguous zone for fisheries, this proposition was tied to the proposal for a 6-mile territorial sea and died when the latter was not accepted. Hence, the general provision on the contiguous zone adopted at Geneva, and incorporated in the Convention on the Territorial Sea as Article 24, does not mention fisheries as one of the purposes for which a contiguous zone is permissible. Nonetheless, the recent developments, especially in western Europe, have in substantial effect implemented the U.S.-Canadian proposal and there is reason to believe that special exclusive fishing zones are, or will be, permissible under international law.

The Geneva Convention on fishery conservation is not, in so many words, concerned with establishing contiguous zones for conservation purposes but it is appropriate to mention this Convention here for it emphasizes the notion of coastal interest in adjacent fisheries. As will be indicated further below, one of the major consequences of effective recognition of freedom of the seas as international law doctrine is that the fishery resources of the high seas are regarded as open to all who may wish to exploit them and, in converse statement, that no one political authority is competent to regulate or limit access to them except by its own nationals. The only acceptable method in customary international law for extending conservation regulations to international fisheries, those which lie beyond state territory, is that of securing agreement among all the states whose nationals exploit them. If one or several states believe it is necessary or desirable to regulate a fishery, their efforts can be frustrated if another state, whose nationals engage in substantial exploitation, refuses to cooperate. Under such circumstances the conservation efforts of the cooperating states can be wholly vitiated by the non-complying fishermen. It was to meet this problem, at least partially, that the Conservation Convention was adopted.

The scheme devised provides that under certain conditions, precedent and antecedent, the coastal state can unilaterally

promulgate certain conservation regulations for a stock or stocks of fishes if it is unable to secure agreement thereon from other states whose nationals also exploit the stocks. This is not the place to examine this Convention in detail,[10] but it is advisable to note that this permission to extend unilaterally conceived regulations is accompanied by provision for what amounts to compulsory international adjudication for determining whether the necessary conditions have been met. Again without elaborating, it is notable, to this observer at least, that the requisite conditions for permissible unilateral regulations are sufficiently demanding that many states, especially those without extensive scientific establishments in fishery matters, will find it difficult to justify their efforts at regulation. Perhaps it is no coincidence that of the four Geneva Conventions it is this one which has enjoyed the least favorable response and which is still not in effect as of this writing (February, 1966).

THE CONTINENTAL SHELF

Probably the international law relating to the continental shelf is relatively more familiar to non-lawyers than any other aspect of sea law, for, as the saying goes, this is where the action is. However, the Convention on the Continental Shelf, despite both its brevity and the apparent simplicity of its solutions, merits close examination.

The Convention seeks to accomplish several tasks: (a) establish the authority of the coastal state over the adjacent shelf or submarine region; (b) define the limit of the shelf; (c) describe the resources subject to coastal disposition; and (d) provide for the accommodation of some of the various conflicting uses to which the shelf can be put. The following seeks to describe the provisions on these points.

(a) COASTAL AUTHORITY

Convention Article 2(1) provides:

> "The coastal state exercises over the continental shelf sovereign rights for the purpose of exploiting it and exploiting its natural resources.

Perhaps the most important observation to be made about this provision for present purposes is that, contrary to some apparently informed opinion, it does not sanction the inclusion of the continental shelf (as defined in the Convention) as part of national territory. What it does accomplish is to establish that the coastal state has "sovereign rights" over the shelf for assuring exploration, and exploitation, of the natural resources to be found there. The competence thus conferred is not all-embracing and, in particular, it does not appear to include the full range of the legislative authority of the coastal state.

(b) THE LIMIT OF THE CONTINENTAL SHELF

There is wide understanding that the Convention definition of the continental shelf does not coincide with the usual geological conception. The shelf comprises, according to Article 1,

"the seabed and subsoil of the submarine areas adjacent to the coast but outside the area of the territorial sea, to a depth of 200 metres or, beyond that limit, to where the depth of the superjacent waters admits of the exploitation of the natural resources of the said areas; . . . ." The former of these two criteria is, indeed, often accepted as the conventional definition of the shelf, but as is known this is only a very rough approximation and has been said to give "a somewhat restricted and oversimplified view of the character and location of the shelf edge."[1] In any event wherever the 200 metre contour line may fall on the floor of the sea adjacent to a mainland or island coast the area within it is considered to be the shelf for the purposes of the Convention.

Quite plainly the main element of concern in this definition is the second part which is open-ended and permits expansion of exclusive coastal authority outwards as technology permits exploitation in deeper waters, including those beyond the edge of the shelf in its geological conception.

(c) RESOURCES SUBJECT TO EXCLUSIVE COASTAL DISPOSITION

The Convention provision for mineral resources is straightforward: all mineral and non-living resources of the seabed and subsoil fall within the exclusive control of the coastal state and cannot be explored or exploited without its consent. Animal resources are defined as those "living organisms belonging to sedentary species, that is to say, organisms which, at the harvestable stage, either are immobile on or under the seabed or are unable to move except in constant physical contact with the seabed or the subsoil." The range of resources within this conception has been the subject of controversy among various states.

(d) ACCOMMODATION OF CONFLICTING USES

Some years before the 1958 Geneva Conference convened it was realized that it would be required to make provision for various uses of the shelf and the waters above which could interfere with coastal control over mineral resources or with which the latter could interfere. The following is a very general account of the principles adopted to meet this problem.

In the first place, the adoption of the phrase "sovereign rights" for a particular purpose, as the description of coastal authority, does not by itself accord the coastal state primacy in the event of conflict with other uses. It was very clearly understood that there were limitations on coastal authority when conflict arose or seemed imminent. Several articles seek to spell out the general standards for accommodating these conflicts.

One of the major problems perceived at Geneva, indeed perhaps the most important contemplated at the time, was that some states might seek to use the expression "sovereign rights" over the shelf for a particular purpose as a base for extending coastal rights over the fisheries in the waters above. Whatever considerations might be adduced in favor of this method of allocating these resources, the Convention provides no support for it. Article 3 was adopted with the object of precluding any interpretation of the Convention to this effect:

> "The rights of the coastal state over the continental shelf do not affect the legal status of the superjacent waters as high seas, or that of the airspace above those waters."

By referring to the companion Convention on the High Seas, which offers definition of the rights of all states in high seas areas, it may be seen that this Article preserves not only freedom to fish in the shelf waters (for those prey not included within the definition of natural resources in Article 2 of the Convention) but also freedom of navigation.

At the same time it was widely understood and agreed that mineral exploitation of the shelf could not be stultified by absolute insistence upon non-interference with other activities in the area. It was necessary, therefore, to offer some guidelines on the extent of permissible interference with these other activities. On this point the Convention speaks in very general terms indeed, because, no doubt, it was thought impossible to furnish more specific directions for the myriads of possible situations. Article 5(1) thus provides:

> "The exploration of the continental shelf and the exploitation of its natural resources must not result in any unjustifiable interference with navigation, fishing or the conservation of the living resources of the sea, nor result in any interference with fundamental oceanographic or other scientific research carried out with the intention of open publication."

It is apparent that this provision distinguishes the treatment of conflict with navigation, fishing and conservation on the one hand and scientific research on the other. For the former, interference is permissible if justifiable, though no criteria of justification are offered, but in the latter case no interference at all is permissible. In the case of navigation, a later article makes clear that in some situations, namely in "recognized sea lanes essential to international navigation," no "installations or devices" can be established.

Scientific research is also singled out for special treatment in a later article. Apparently acting on the belief that oil exploration activities may take the guise of scientific research (as is evidently possible), the Convention provides that "the consent of the coastal state shall be obtained in respect of any research concerning the continental shelf and undertaken there." This same article seeks to spell out conditions under which the state "shall not normally withhold its consent." The high-level generality of the terms employed perhaps provide some warning of the probability of future difficulties in receiving coastal consent to research in continental shelf areas.[12]

THE HIGH SEAS

Beyond the accepted territorial sea limits of the states, the waters of the oceans are referred to as high seas. In this area the ships of all states are regarded as free to move about for all legitimate purposes without interference by other states except as may be authorized by international law. Such authorization, some of which we have previously mentioned, is not by

any means frequently available but on occasion it is. An illustrative occasion that is still regarded by some as controversial involved the conduct of hydrogen bombs tests by the United States, resulting in the closing of hundreds of thousands of square miles of open ocean to the use of other states.

Generally speaking, however, the major principle of the law regarding the high seas is that it is open to the use of all and that no single state or group of states can subject it to exclusive control for any prolonged period of time. In terms of past resource exploitation this has meant that fishing vessels can engage in operations without deference to the law of any state except the state of registration. Insofar as the ocean floor is concerned the only consequential traditional use is that of cable-laying and this too is regarded as protected by the principle of freedom of the seas.

In turning from this very brief, and necessarily incomplete, sketch of previous decisions, a few preliminary remarks are necessary about the nature of the legal process, and then the focus is turned upon certain new or intensified uses, actual or contemplated, which may give rise to international legal disputes.

It should go without saying that the previous experience in resolution of disputes, recapitulated above as the present "status" of the law, is available either for avoiding future disputes or for assisting in decision of such controversies as cannot be avoided. Nevertheless it is necessary to emphasize, in view of what appears to be misunderstanding on this point, that we need not assume this previous experience is useless in newer contexts; although contexts are always in flux, this condition attends all legal decision-making. Neither are we required to entertain the notion that past decisions can be simply extrapolated into the future in the blind belief that our heritage of law is always adequate when new conditions of interaction confront us. This conception of simple extrapolation of the past without regard to potentially significant change in conditions is also foreign to modern conceptions of legal process. It would seem to be especially alien when considering a body of law as ancient as the international law of the sea.

Hence the task involved here is the familiar one of confronting past formulations of authoritative policies with emerging and different problems not directly anticipated by previous decision-makers and of asking whether new prescriptions and policies, or different interpretations of old, should be devised to promote basic community goals.

To raise questions of this kind or to suggest new or different solutions than those previously found acceptable does not at the same time require, or imply, the necessity of adopting any particular procedure or method for seeking these solutions. If observers express concern about the potential inadequacy of the previous international law of the sea, there is no need to see in this an urgent call to impetuous action.

But failure to make preparation for possible action seems most unwise, especially since important initiatives in international law could be taken by any state or group of states. This latter consideration, incidentally, helps place in appropriate perspective the expressed position of the United States State

Department which is that the Department is unaware of a need for study of any international law or relations problem relating to the development of the natural resources of the ocean.[13] Although adoption of the stance of the ostrich is regretable in the primary department of the government responsible for foreign policy, it is at least fortunate that this dismal attitude appears to be unique to this department.

The numerous possibilities in developing ocean exploitation could pose such a variety of more or less important legal problems that some selectivity is necessary in discussing future prospects. Exercising more or less arbitrary choice, the following remarks center upon mineral exploitation, fisheries, and potential claims to acquire portions of the ocean floor for purposes other than mineral exploitation.

A. MINERAL EXPLOITATION

The question of international legal arrangement for hard mineral exploration and exploitation is much discussed by a variety of people and no doubt much studied by corporate counsel. Insofar as lawyers are concerned, however, there are almost no published statements or reports assessing the situation--this, of course, is because the lawyers directly involved are either house counsel or retained by clients and neither of these groups is likely to become vocal about his specific problems. It is left, apparently, primarily to the academic lawyer, and to the engineers and fishermen, to speculate on these matters in public. This state of affairs is unfortunate and probably could be remedied if the lawyers, and their clients, thought they could benefit from freer communication. In my opinion they could both benefit from more open discussion and avoid the dangers of disclosing proprietary information. If matters remain as they are, the hazard is that public consideration of the legal problems involved in ocean mineral mining will be too abstract to shed much light. Perhaps speakers at this M.T.S. meeting will begin to remedy these difficulties.

The initial issue regarding ocean minerals has been framed as whether such resources may be appropriated by a single state (or group which will be protected by some state) or whether they must be regarded as beyond such appropriation, i.e., they must be open to all who may wish to exploit them.[14] This form of query may not seem particularly useful since it appears to pose as exclusive alternatives two courses of action which can, in fact, be employed simultaneously. That is to say: the mineral resources of a particular, relatively small, ocean area could be regarded as subject to exclusive appropriation while, at the same time, all other areas are open to similar exclusive appropriation by anyone who has the capacity to exploit and who does engage in exploitation within a reasonable period.

If some form of limited exclusive appropriation is likely to eventuate, it seems useful to query, further, whether these ocean resources are to be acquired for the gain of a single group only, namely the appropriators, or whether this aspect of ocean exploitation can be made directly to benefit the world community as a whole. The alternatives posed here are whether the protection and regulation of ocean mining is to emanate from each state which has public or private groups engaging in this venture, or whether ocean mining is to be subject to organized public international regulation or, even, exploitation. The possibility last mentioned, that of having the exploitation

of hard minerals under ocean waters carried out by a public international group, is the least likely to eventuate. Since it seems such a remote possibility there is no need now to assess whether this system would be desirable according to certain criteria. In longer term perspective, however, such inquiry could be most worthwhile.

Another possibility is much more frequently recommended, that of allocating these resources for exploitation by individual public or private entrepreneurs through an established international organization. Thus, sometimes it is said that the United Nations is the appropriate body to exercise the authority to allocate these resources and to derive some financial benefit therefrom. The assumption underlying this approach is, apparently, that all states would join together and by agreement confer the authority on the United Nations, or on an especially constituted organization devoted to this specific purpose, to prescribe the conditions under which private or public groups could acquire rights to exploit and undertake mining and processing operations. There are, of course, a great many permutations in organization and in detailed procedures which can be imagined if an international solution of this kind were to be adopted. Assessing these numerous possibilities is beyond the purpose of this discussion, however it is desirable to call attention to the financial aspects of this suggestion for it is often assumed both that large sums of money would then become available to the international institution and that it is desirable to support the U.N., as presently constituted, in this way. There is, in the first place, good reason to doubt that these ocean resources represent a great source of wealth for the U.N. or a special international organization. For the foreseeable future, at least, it is probable that the problems of making ocean mining competitive with conventional land mining will preclude imposing substantial royalties or fees upon these enterprises.

But assuming there might be some, even substantial, income for the international group, the existing political situation in the United Nations suggests that any international arrangement, especially if the United Nations is involved, must insure that the new wealth is expendable only for non-political purposes. The recent dispute over the financing of peacekeeping operations, which is still not satisfactorily resolved, and the continuing great disparity in the General Assembly between the voting power of the majority and their control of resources necessary to support the operations of the U.N. which they authorize by their votes are the principal factors leading to this conclusion. It is presently inconceivable that either side in the Cold War would acquiesce in a United Nations which has an independent source of finances and which can be dominated by a large group of states with little power or wealth of their own.[15] Hence, if the international organization approach were otherwise desirable, it must be carefully designed to cope with this difficulty. The point here is not to suggest that this difficulty is insurmountable but merely that hopes for stronger international political institutions are unrealistic if based on the expectation of income from this source and that ocean development is not likely to be expedited by looking to existing international institutions.

In discussing future prospects so far as the legal environment for ocean mining is concerned, the role of the observer is distinctly a modest one, especially in connection with predictions about what will happen. Lawyers directly concerned with

clients' problems are far better equipped with the information upon which predictions can be based. And officials with government responsibilities would seem natural sources of advice on the future. But, as noted above, the private lawyers do not appear to be talking, at least in public, and the U.S. State Department, the critical executive agency for this purpose, takes the position that this is not a problem worth investigation.

Should the question of protection of ocean mining soon become an urgent one the principal issue seems to be whether there are any current international law prescriptions which might be useful and effective. Some possibilities warrant consideration. It would be possible to begin with the proposition that these resources, insofar as they are beyond the jurisdiction and control of any state, have much the same legal characteristic as other high seas resources, such as the ocean waters and fish. This would mean that mineral resources of the ocean floor are common property, open to exploitation by all comers and subject to appropriation by the first taker. Given certain conditions it seems very possible that initial mining ventures could be made secure through this approach. The critical condition is that exploiters are likely to be relatively few, at least initially, so that in practical effect there would be no need to protect against encroachment by others upon the area subjected to exploitation. The only problem, and it would not seem difficult, is in protection of the operation itself, presumably the ships from which equipment would be operated. Even assuming the ship were to remain virtually stationary, or move about only very slowly, there are ample legal principles available for insuring non-interference. The flag state, the United States presumably but it could be any state, is entitled to assert sole authority over the craft and the ships of other states are not competent to exercise any control over the ship. Possibly it would be contended that ships of this type, serving primarily as platforms for conducting operations on the bottom below and therefore moving about very little, would constitute hazards to navigation and impede free navigation by them. This does not seem to be a serious matter. We already permit the emplacement of thousands of drilling rigs and platforms in areas of the high seas and the accommodation made necessary between these installations and shipping is regarded as wholly compatible with a realistic conception of freedom of movement on the ocean.

Assuming the prospects for intensive exploitation of ocean areas made it seem likely that conflicts would arise over acquisition of rights, the notion of common property might be modified and made the basis for protecting the mining enterprise. If, as John Mero asserts, the mining venture requires an investment in a particular area, because the mining equipment itself or the processing machinery must be tailored to suit a particular location or a particular kind of nodule,[16] then some kind of exclusive appropriation must be asserted by the enterprise or on its behalf by a state. As noted above this would require some modification of the notion of the common property characteristic of the resources. At least small parts of the total resources would have to be regarded as subject to exclusive appropriation. But as many have observed it is now believed that the mineral resources occur over so vast an area that for practical purposes open access would still be preserved. The removal of a small area for exclusive acquisition by one exploiter would still leave immense areas open to others.

If this approach were desirable as a means of promoting use of these resources the question remains about how it is to be accomplished. Here too we have some experience to build upon. We are all familiar with the procedure employed to lay claim to the important resources of the continental shelf, namely by means of a unilateral proclamation by the President of the United States. It seems to be quite feasible to utilize the same method for acquiring control over high seas mineral resources in specific areas. The details of such a proclamation depend, of course, on the needs of the projected enterprises. The direction and extent of the claimed control over the resources of an area would have to be enunciated, as well as the conditions under which the enterprise would have to be operated in coordination with other uses of the areas concerned.

The limits of the legal conception of the continental shelf are of course relevant in disucssing ocean mining operations. As mentioned above, the Convention on the Continental Shelf contains an open-ended definition which contemplates that the coastal states' limited sovereign rights will expand outward as technology permits exploitation to expand outward. The question this raises is at what point the coastal state must cease reliance, if it must cease reliance, on the Convention in asserting a claim to hard mineral resources and base its claim upon some other method of allocating them. Despite the literal wording of the Convention there are insufficient grounds for regarding it as authorizing unlimited expansion of coastal control outward. In the first place the policies which were sought in the convention rested upon the notion that the contiguity of the shelf to a particular coastal state engaged its interests in higher degree than those of other states. Efficiency of exploitation, the economics of the enterprise and the impact of nearby off-shore activities on the coastal state's society were all thought to support the assumption of exclusive control by, or its grant to, the coastal state. At some point as activity moves outward and away from any particular state these factors lose their cogency as indicia of a need for controls in a particular state identified as coastal. Because no determinable line is clearly indicated by the factors mentioned, the solution to the dilemma may have to be in terms of purely arbitrary designation, as, for example, of the 1500 or 2000 foot contour line. Many difficulties in this supposed solution are rather easily discerned and principal among them is that states are not likely to be willing to agree on limits of exclusive control without knowledge of what it costs to do so. In other words, until we secure more accurate knowledge of the ocean environment states will be reluctant to concede a limit on their exclusive control.

It may be helpful to note in this connection that this convention provision can usefully be read in the context of the kinds of exploitation the Conference was concerned about. It is plain, if summary records yield such evidence, that the Conference was concerned with only one type of exploitation, oil-drilling from surface installations. The two preparatory documents produced for the Conference, both by Dr. M. W. Mouton, from the Netherlands, focussed almost solely on the technology of oil exploration and exploitation.[17] Indeed it is made explicit that hard mineral exploitation was not even considered as a bearing on possible expansion of the shelf limit:

> "In view of a certain fear of an ever outwards-moving boundary line of the legal 'continental shelf' an inquiry was also made into the question whether the ocean floor contains any exploitable minerals. The answers indicate that the sediment carpet covering most parts of the ocean floor does not contain minerals in any concentration worthwhile exploiting.
>
> "In one place manganese ore has been found, but since this is available on land in sufficient quantity, exploitation from the ocean is not necessary and would not pay. The sediment carpet, being extremely thick, will in most places make exploitation of layers underneath impossible. In the few places where the sediment is thinner or non-existent, formations may be found with prospects of exploitation. Intrusions, such as the Mid-Atlantic Ridge, might have mineral deposits associated with them. The depth will, however, be an insurmountable obstacle for exploitation for a long time to come, quite apart from the commercial prospects which seem non-existent."[18]

These passages from the main preparatory document for the 1958 Geneva Conference are not offered to affirm the statements made therein but to provide additional support to the inference drawn from the summary records that the Conference was not concerned with the aspects of mineral exploitation that cause some disquiet today.

One final comment regarding ocean mining derives from the possibility that the relative proximity of a port may have a bearing upon the choice of exploitable deposits. If assurance of continued access to a particular port is important for a specific undertaking it would appear to be prudent to consider that access by foreign vessels to ports is not a matter of right unless explicit agreement to a right of entry is secured from the state concerned. Since most attention, so far as deep sea mining is concerned, focuses on the tropical Pacific it could be wise to pay particular heed to political developments in this area and, especially, to the possibilities of complete independence for some of the island communities. The transformation of political status from colony or self-governing territory to complete independence could conceivably have repercussions for mining operations dependent upon port facilities in the new states.

B. FISHERY EXPLOITATION

Changes in the legal environment are but one influence among many having significant impact upon the conduct of fishing operations and it is doubtful if the demands leading to new legal claims have run their course. The major legal change, past and future, consists of the expansion in the areas over which states assert exclusive rights of access to fisheries. In seeking this expansion, supposedly necessary to protect local fishermen from more efficient competitors, states utilize three principal techniques either separately or in combination: adopting the straight baseline system for delimiting internal waters and territorial sea with the objective

of enlarging the former and extending the latter over areas hitherto open to free exploitation, widening the area claimed to be within the territorial sea, and establishing a contiguous zone for fishing which extends beyond the territorial sea. It should be emphasized that these techniques can be used simultaneously to reinforce each other and in combination the expansion of exclusive access can be considerable. Although all these methods have the common effect of permitting greater exclusive access, each has different consequences in other respects, especially that involving use of a new straight baseline system. The effect of this extends to the delimitation of all other boundaries of state authority in the ocean, territorial sea, contiguous zones, and, in some situations, even the continental shelf.

It is not possible to make confident general assertions about the compatibility of specific applications of these methods with international law. The 1958 Convention on the Territorial Sea does contain the provision, noted above, permitting the use of straight baselines in certain circumstances, hence states do have criteria for assessing the lawfulness of particular systems. As seems obvious the various systems adopted will all be different and each must necessarily be appraised independently of the others. The one certain proposition to be advanced is that even with the criteria available disputes over particular claims are very probable. This probability approaches near certainty for certain claims, such as those by archipelago states, such as the Philippines, to draw baselines connecting the outermost islands and to declare all waters within the lines to be internal waters. Although this specific illustration refers to a situation for which the Territorial Sea Convention does not provide, i.e., for states composed entirely of islands, this Philippine claim may be contrasted with the new English baseline system which, while it greatly expands internal waters, does not seek to use the outermost islands as base points for the system. If this had been done, additional very large high seas areas would have been converted into internal waters.

The expansion of exclusive access by means of creating special fisheries limits beyond the territorial sea is becoming so common that it suggests a definite trend toward recognition that such zones are in accord with international law. The same may be said for limited enlargements of the territorial sea beyond three miles. It is not necessary to regard either of these extensions as desirable policy to judge that their frequency records the emergence of new, or at least somewhat different, principles of international law.

Taking the position that these specific methods of seeking to allocate marine fisheries exclusively to one community are not desirable as a general policy should not be understood as support for the proposition that these resources should continue to be regarded as open to competitive exploitation. The conditions that seem likely to prevail in the future appear to assure that the fisheries will be under even more intensive exploitation, by far more sophisticated methods, than they are now. Even if the potential food resource in the ocean is never realized to the full, and it need not be assumed that it would be desirable even to try to achieve such a level of exploitation, more and more states are likely to exert more and more effort to reap benefits from the fisheries. It seems fair to

say, as have a great many more expert observers, that the major problem attendant to this development will be that of achieving an equitable allocation of the fisheries through some means of controlling access to them. This, I take it, is what is meant by the recurrent pleas for more effective international "management" of these international resources. The immensity and complexity of this task is not underestimated. Indeed the contemporary expansion of exclusive fishery limits by the means mentioned above provides contemporary evidence both that states regard the prospect of an allocation scheme as hopeless and prefer to rely instead on crude methods of excluding competitors in order to be assured of some part of the resource and that these states are unwilling, and perhaps unable, to engage in a competitive scramble for the resource. This expansion also possibly testifies to the belief that if a system of allocating high seas fisheries can be devised, the expanded exclusive fishing area gives the state concerned an assurance of a greater part of total resource available.

It is appropriate to refer in this connection to the 1958 Conservation Convention since some contend that in this instrument we now have the means of achieving proper regulation of the resource. The most interesting point to be noted about these recommendations is the complete absence of explanation about how this treaty is to be used for the purpose of allocating resources. Nothing in the treaty even remotely concerns itself with positive criteria for allocation; to the extent the treaty is relevant for this purpose it will be a hindrance not a help. Of course it can be said, and has been said, that by requiring negotiations between coastal and non-coastal states, supported by the sanction of compulsory arbitration, the treaty provides an incentive for agreement upon allocation of particular stocks. Perhaps the treaty will work this way, but if states value unimpeded access to particular stocks, or better access than the coastal state proposes, they may be willing to take their chances of defeating the proposed coastal conservation measures in the subsequent arbitration or of obtaining a recommendation from the tribunal for more favorable measures. If, as the Convention directs, the tribunal can approve only those measures which are non-discriminatory, in form and in fact, possibly the complainant state may feel there are advantages in litigation. Furthermore if the proposed measures do in fact effect an allocation of resources and are somehow approved by the arbitral tribunal, the latter will of necessity employ standards for allocation derived from some source other than the treaty since none are provided therein. If these events transpire, the contribution of the Conservation Convention can only be characterized as indirect, as providing a mechanism by which management criteria can be created on a case-by-case basis.

A few concluding remarks are in order about prospects for the development of criteria for allocation of these resources. First, unless previous experience is vastly improved upon the prospects are dismal indeed. Only two of the multilateral international conservation agreements contain provisions for allocating a resource and one of these, in the North Pacific treaty between Japan, Canada and the United States, reflects a rather unique situation which is characterized most importantly by the unusual circumstances attending the conclusion of the agreement. Moreover, even apart from doubts about this application of the abstention principle, the viability of this arrangement is now also in question. If prospects for continuation of

the North Pacific treaty in its present form are not bright, only frail expectation can be entertained for wider adoption of this principle of allocation. The fur seal treaty is the other agreement establishing a method of sharing the yield but no one pretends that the factors accounting for this arrangement occur generally. Among the bilateral treaties the salmon agreement does provide for a division of the catch but if the value of this experience, as observers remark, is to emphasize the importance of the homogeniety of the states concerned as a factor accounting for the agreement on dividing the catch then all we have learned is that agreements on allocation are going to be very difficult to achieve in the great majority of situations.

Second, this relative absence of useful experience is an accurate barometer of the amount of attention devoted to the problem. If the dispute potential of conflicting demands for access to fisheries is as high as some think, then the lack of study of this problem, academic, industrial and especially governmental, is at best extremely regrettable, and at worst disgraceful. Some of this neglect is understandable since the state of knowledge of the resource requires improvement and investment in this task is also a priority matter. But in accounting for what is, I believe, an overemphasis on biological research into fishery exploitation in comparison to inquiry into political, social and economic elements, a major explanation is found in the unwillingness, until recently, of the biologists to concede that their approach was not the exclusive remedy. This particular obstacle has probably been largely overcome in the last decade but we still await significant increase in the resources committed to study from the wider perspectives mentioned. There are some signs, at least, that awareness of this problem is now spreading. The recent elevation of the Fisheries Division to a more prominent and prestigeful position within FAO and the recognition in FAO of the importance of economic considerations is promising. The Bureau of Commercial Fisheries now devotes more attention to international economic aspects. The academic world too, including law schools as well as economic departments, has begun to place emphasis on this matter of allocating international resources. And within the internation fishing commissions it is evident that the focus of attention has widened somewhat in recent years to embrace considerations other than the physical state of the resources. Even with these improvements, however, the effort is still grossly inadequate in relation to the potential losses both from continued inefficient exploitation and from what might be unnecessary controversies.

C. ACQUISITION OF THE OCEAN FLOOR FOR PURPOSES OTHER THAN MINERAL EXPLOITATION

Virtually all that has been written or, at least published, about legal aspects of the ocean floor in the regions beyond the continental shelf is in terms of mineral exploitation and there is little or nothing beyond casual comment to be found on the issue of claims to an area for other or more comprehensive purposes. No involved process of thought is required to discern the reasons for this. The ocean floor has been used, to be sure, for a century for one specific purpose, the laying of submarine cables, but the legal questions involved in this activity have never involved any claim to exclusive use. The legal problems which did emerge were concerned only with the

conflict between fishing operations and the cables and these issues were resolved almost a century ago and partially reiterated in the Convention on the High Seas in 1958. The latter not only incorporates certain provisions of the 1884 Convention on the protection of cables, without prejudice to the continuing effectiveness of other provisions, but explicitly records in Article 26 that "All states shall be entitled to lay submarine cables and pipelines on the bed of the high seas." The Convention on the Continental Shelf also makes provision for these instrumentarities on the shelf in seeking to provide for freedom of use compatible with coastal rights over the shelf.

But even apart from mining operations, previously discussed, the recent dramatic changes in conditions of access to the deeper regions, and contemplated progress in overcoming the many obstacles, suggest that it might be worthwhile to devote some thought to more extensive claims to the floor, ranging from complete incorporation as national territory to more limited assertions, but still exclusive, of usage and authority. Initially, at least, the regions which appear most attractive for active utilization are the large number of seamounts found in all the oceans, since the acquisition of information and knowledge concerning the environment in shallower regions is now being actively pursued both in the United States and elsewhere. And it seems reasonable to believe that the more accessible ocean features, which would include some seamounts, will be employed before serious attention is devoted to deeper areas. Apparently not only are there large numbers of seamounts but the possibilities of productive use are numerous, for one commentator has declared that "The number of applications to which a manned seamount base could be put is limited only by the imagination of marine scientists."[19] The reference, it may be emphasized, is only to manned bases, although unmanned bases are not at all excluded.

For purposes of the present discussion the most significant employment of seamounts would be for military activities, a category that includes a considerable range of operations with varying impact on expectations regarding the kind of state authority required vis-a-vis other participants in ocean use. The military potential of seamounts perhaps could extend to the emplacement of weapons systems or equipment indispensable to the operation of systems located elsewhere, including the waters surrounding the base. Other uses would appear to be considerably less strategic in nature such as the installation of experimental devices or temporary habitations, the conduct of research for direct military benefit, and the construction of shelters housing communications and navigation equipment. It may be a complicating factor, or even one simplifying the supposed legal problems, that some uses, especially those last mentioned, contribute not only specifically to military operations but also to general ocean development. Still other military applications might be the operation of repair facilities and supply depots. And suggestion has been made that strategically located seamounts could be useful in missile and space operations, as in permitting recovery of nose-cone and payload components. Perhaps it might also be considered desirable to use such submerged bases for some tasks that could be performed as well on land but which for special reasons would benefit from a submerged location.

Scientific research, only remotely useful to military operations, could be promoted on seamounts in a number of productive ways because of unique conditions there. One inherent, valuable characteristic of seamounts stems from the obvious fact that it is enveloped in water and the further fact, according to recent report, that the water serves as a barrier to background radiation. From this it is concluded that "experiments in radiology, genetics and contamination could be conducted without heavily shielded laboratories."[20]

The depth of seamounts below sea level is another feature of the situation that might be turned to good account since this permits emplacement of remote data collection systems in a safe location below the turbulent surface waters and currents which wreak havoc with research buoys stationed therein. One observer also anticipates that "Geophysicists and oceanographers would have a stable, quiet platform from which to conduct long-term investigations of submarine acoustics, seismic sea waves (tsunamis), microseismic activity, heat-flow and other physical phenomena."[21] Investigations in marine biology and no doubt numerous other disciplines could be pursued effectively from stations on seamounts.

1. POTENTIAL CLAIMS

Perhaps the most important factor affecting the kinds of claims to exclusive use and regulation to be expected consists of the specific purpose or purposes for which a portion of the ocean floor is to be devoted. Certain of the military usages could very well entail the claim to subject an area to the most comprehensive and exclusive control a state could exert. Thus, for the most strategic uses, encompassing at least weapons systems or associated equipment, it is at least conceivable that states would regard it as important to occupy the area and to treat it for all practical purposes as part of national territory. Such treatment would embrace the exclusion of non-national vehicles either from the immediate area and perhaps from access to a surrounding region suitable for surveillance. If the exclusion were to extend to surface waters the possibility of controversy would probably be greatly magnified.

Other military uses might be regarded as less critical and necessary protection might be secured by lesser assertion of authority, considering the latter in terms of the scope of the activities affected, or the extent of the area involved, or the duration of any authority claimed. Some research aimed at producing direct military benefits might be conducted with efficient advantage even though other activities were carried on in the same area.

General scientific research, such as a manned oceanographic laboratory or an unmanned installation of instruments, would appear to generate claims to exclusive authority in terms of the kinds of research conducted. Some types might require quiet and isolation, requiring extensive assertion of authority and others might not.

2. FACTORS RELEVANT TO POLICY

The basic policy question is whether it is desirable, from the standpoint of the general community interest, to permit states

to claim exclusive use and authority over specified parts of the ocean floor and, if so, what degree of such use and authority should be permitted. The suggestion is that such acquisition ought to be considered lawful when the claim is reasonable in light of all relevent factors in the context. Some of the factors which are considered to lend support to this conclusion may be considered briefly.

The more important factors involve the scope of the competence claimed, such as those pertaining to the objectives sought; the characteristics of the situation in terms of the location and extent of the areas concerned, and the duration of the claim; the degree to which others are sought to be affected; and the outcome of the activity involved.

The purpose or objective sought by the claimant state would appear to have an important, sometimes determinative, bearing on the permissibility of acquisitions. Certain goals, though pursued by unilateral claim to submarine territory, may be rather widely shared among many participants, including states, private associations and individuals. For example, the establishment of a subsea installation as a laboratory for certain scientific experiments or as a strategically located oceanographic research facility could promote purposes sought also by groups associated with different states. Even if exclusive use is necessary and even if certain other activities in the region are precluded, the benefits sought from such use do not pertain exclusively to the claimant state. The general proposition this expresses is that the degree of exclusiveness or inclusiveness in the specific objectives of acquiring a seamount should be weighed carefully in assessing the reasonableness of a claim.

As mentioned previously, seamounts are expected to be found in all the oceans but they are at this time known to occur in most intensive concentration in the Pacific. In current estimate the 1400 known seamounts in the Pacific are but ten percent of the total in that basin alone. The significance of these numbers for policy is in the possibility that the regions for potential acquisition may be very numerous, especially for unmanned stations. Many seamounts are probably less appealing as sites for manned installations due to the problems posed by depth. But for either type of station the acquiring state might be enabled, because of the large number of possible sites, to exercise considerable selectivity and to choose on the basis of criteria related to the general interest in the use of the ocean. Specifically, selection of sites could be affected by the remoteness of a region from consequential conflicting, or potentially conflicting, uses and by the relative proximity of various submarine regions to the territory of the claimant state. A wide range of choice might also indicate the importance of selecting locations which are remote from particular, non-claimant states. One factor relevant to the lawfulness of a particular claim to acquire a submarine area might be the degree of provacation implied in the selection of a site adjacent to another state.

The extensiveness of the area involved includes both the size of the seamount or other region and the extent of any additional water area over which control is sought. Claims to seamounts with small surface area might be looked upon more favorably

than a claim to a very large part of the ocean floor, especially if superjacent uses are wholly or partially precluded. Although seamounts may never reach a large size, so that the acquisition of territory is limited to localized areas, it may still be important whether the claim extends to the waters above the seamount or region. States are more likely to accept claims to exclusive use of the floor than those pertaining also to the waters above. The principal reason, mentioned below also, is that the latter would be more likely to affect other uses.

A particular claim may vary a great deal in terms of its duration, from assertion of permanent authority (though the degree of authority may be limited) to a temporary demand of a few weeks or months. It seems rather obvious that this feature of a claim may have significance when related to possible impacts upon the activities of others. In the beginning of ocean exploitation, the phase we are now in, states may look with askance upon claims of indefinite duration, for these, if recognized, could ultimately entail highly undesirable interference with uses presently unforeseen. However, when other factors are weighed in combination even permanent claims might be adjudged reasonable.

The kind and degree of interference with others explicitly or implicitly demanded by a particular claim is of prime importance in appraisal of its reasonableness, as well as for general conclusions about the policies at stake in this context. Obviously claims to exclusive use which seek to displace only such other hypothetical use as might simultaneously be made of the identical location raise fewer difficulties than claims involving exclusion of other activities in a wider area. Assuming that preclusive effects are not in fact involved, the former type of claim would appear to promote policies of encouraging full use and at the same time not offend any other policy. The greater the degree of impact on other productive activities the larger the burden of persuasion on the claimant state to justify the reasonableness of its claim. One of the reasons for suggesting it is lawful to acquire regions of the ocean floor is that it seems likely that particular claims will not have impact on other uses.

The outcomes of emplacing stations, manned or unmanned, upon the ocean floor will probably differ for the various participants. The use of these areas for military purposes may be, or may not be, deeply disturbing to the opponents of the claimant state in the sense that the opponent feels deprived as a result of the threat perceived. Security is a value which many believe, unfortunately, can only be acquired at the expense of someone else. But, on the other hand, and despite this view regarding security, even military installations on the ocean floor may have more inclusive beneficial impact than merely protection of the claimant state, since the stability such installations could conceivably assist in creating would extend to all potentially involved. Certain kinds of floor stations are easily imaginable which might produce nothing but good for everybody, even though the immediate benefits accrue to a particular community. The extent to which outcomes have widely sharable benefits is obviously important for policy. It is even more important if such an outcome is explicitly sought by the claimant.

One final point may be conclusive on desirable policy concerning acquisition of the submarine regions of the high seas and that is the degree of analogous acquisition in past practice and the likelihood that states will in fact acquire such areas in the future. The alacrity with which states have allocated the continental shelves among themselves and the fact that mineral exploitation of the shelf must necessarily on occasion displace other uses provides a clue to the attitude that seems likely to be adopted as other submarine regions become accessible for productive use for mineral exploitation and other types of activity. There is the major difference, of course, that the shelves have been allocated to states only for particular purposes and not for all purposes, i.e., the shelves are not part of national territory. However, the regions beyond the shelf which may be open to effective use, other than for mining, are not thought to be extensive and in view of their remoteness more far-reaching claims to authority may be regarded with equanimity. Insofar, at least, as states determine that great benefit can be realized from exclusive acquisition of a portion of the floor beneath the high sea, and that such acquisition imposes only minor burden on others, it seems unrealistic to expect them to refrain from doing so and from protecting and supporting that claim.

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*The author acknowledges assistance in aid of research and publication from the Mershon Social Science Program of the Mershon Center for Education in National Security, The Ohio State University.

1. The range of potential problems is extensive and this paper is limited to but three general subjects: hard mineral mining, fisheries, and territorial claims to the ocean floor. On the first two of these, recent detailed studies are available: Mero, The Mineral Resources of the Sea (1965); Johnston, The International Law of Fisheries (1965); Christy and Scott, The Common Wealth in Ocean Fisheries (1965). For suggestions of other potential legal difficulties see Burke, Ocean Sciences, Technology and the Future International Law of the Sea (1966).

2. It is now recognized that the traditional notion, still not completely dispelled, that only states are subjects of international law is inaccurate descriptively, and furnishes neither desirable guidance for policy nor reliable basis for projecting future events.

3. A convenient summary of recent legislative efforts in this direction, and commentary thereon by informed persons, is in Hearings on National Oceanographic Program Legislation, Subcommittee on Oceanography of the House Committee on Merchant Marine and Fisheries, 89th Cong., 1st Sess. (1965).

4. For contemporary writing upon some of these problems see the Proceedings of the 1966 Law of the Sea Institute, scheduled for publication in 1967.

5. See, generally, for comprehensive discussion organized as this paragraph suggests, McDougal and Burke, The Public Order of the Oceans (1962).

6. For an extensive collection of national and international documents, official governmental statements, views of writers, and assorted memoranda, bearing on the Geneva Conventions see 4 WHITEMAN, Digest of International Law (1965).

7. This right of access, apart from specific agreement, arises when a straight baseline system incorporates certain waters as internal. See discussion on this system below and see also Convention on the Territorial Sea and Contiguous Zone, Article 5.

8. Anglo-Norwegian Fisheries Case, 1951 I.C.J. Rep. 116.

9. At both the 1958 and 1960 Geneva Conferences the United States departed from this traditional position to support a 6-mile territorial sea, under certain conditions. When these proposals failed to obtain the necessary two-thirds approval for Conference adoption, the U.S. announced continued adherence to a 3-mile territorial sea. See, generally, 4 WHITEMAN, op. cit. supra note 6, at 88-137.

10. See, generally, McDougal and Burke, op. cit. supra note 5, at 968-1007; Johnston, op. cit. supra note 1, at 344-57, 411-30.

11. Lyman, A Review of Present Knowledge Concerning the Continental Shelves of the Americas, in Geological Survey Bulletin 1067, p. 29 (1958).

12. See, for more detailed discussion, Burke, Technology and Ocean Law, 1966 Proceedings, Law of the Sea Institute.

13. See letter, dated May 3, 1965, from Douglas MacArthur II, Assistant Secretary of State for Congressional Relations to Chairman Bonner, House Committee on Merchant Marine and Fisheries, in Hearings, op. cit. supra, note 3, at 102.

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15. See, generally, Padelford, Financing Peacekeeping: Politics and Crisis, 19 Int. Org. 444, and especially 454 (1965).

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17. Mouton, The Breadth of the Safety Zone for Installations Necessary for the Exploration and Exploitation of the Natural Resources of the Continental Shelf, U.N. Doc. No. A/Conf. 13/26 (1958) and Mouton, Recent Developments in the Technology of Exploiting the Mineral Resources of the Continental Shelf, U.N. Doc. No. A/Conf. 13/25 (1958).

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19. Palmer, Seamounts Will Act as Platforms, Undersea Technology, August, 1965.

20. Ibid.

21. Ibid.

GEOLOGICAL METHODS FOR LOCATING MINERAL DEPOSITS ON THE OCEAN FLOOR

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ABSTRACT

Geological considerations of the potential mineral resources on the ocean floor indicate that primary igneous mineral deposits are unimportant as compared with sedimentary mineral deposits. This difference is due to the thick cover of Tertiary sedimentary strata on most continental shelves and the general lack of deep weathering and erosion of igneous and metamorphic rocks in the few places where they are exposed on the continental shelves.

The chief sedimentary mineral resource of the ocean floor at present and probably in the future is oil and gas, which are almost restricted to thick marine sedimentary sequences. The only other minerals that have been recovered commercially are the heavy concentrates of placers (tin, diamonds, iron, gold) and cheap supplies of shell and other sediments in shallow nearshore areas.

Much interest has been focused on ocean-floor deposits of phosphorite and manganese oxide, but the low quality of the deposits and the uncertainties in the costs of mining delay their possible exploitation.

INTRODUCTION

This Marine Technology Society contains many members who are great optimists about the potential of the oceans to supply mineral resources in quantity at costs that are competitive with resources from the land areas of the world. Perhaps the optimism is an occupational hazard of those whose livelihood is the selling of devices or services for marine exploration or exploitation. The truth probably lies between the beliefs of these optimists and the beliefs of the less well represented pessimists who have found neither gold nor diamonds in their thousands of ocean-floor samples. Let us attempt to set some general limits on our expectations of the ocean's bounty by using geological methods. Other limits are set by political and legal restrictions (Shalowitz, 1962) and by mechanical and economical factors that will change in time.

Tangible resources of the ocean can be grouped into biological, chemical, and geological ones. Practically impossible to evaluate are other aspects such as transportation, recreation, military, and supply of water for desalination. Figure 1 shows that biological resources are presently the most exploited ones, and that during 1964 the United States harvested only about six per cent of the value of the world's crop of fish, mammals, and algae from the ocean. It also

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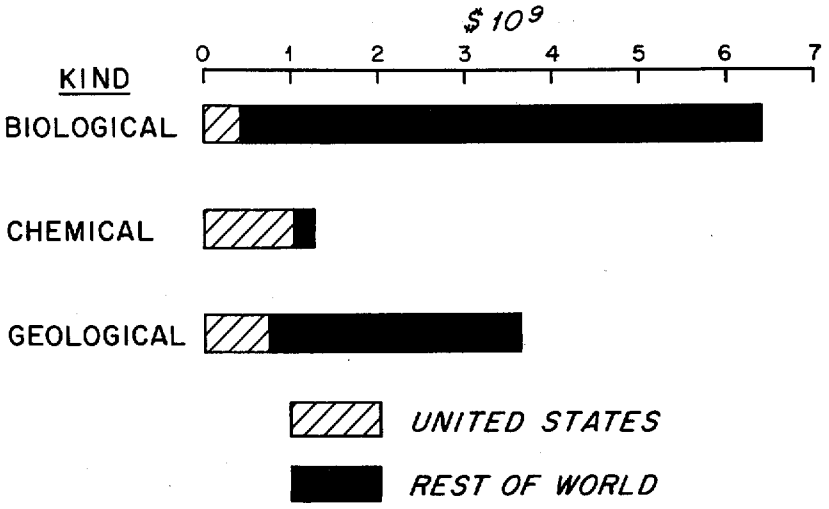

Figure 1. Value of marine resources recovered from the ocean during 1964. Data are from Gaber and Reynolds (1965a) and Weeks (1965a, 1965b).

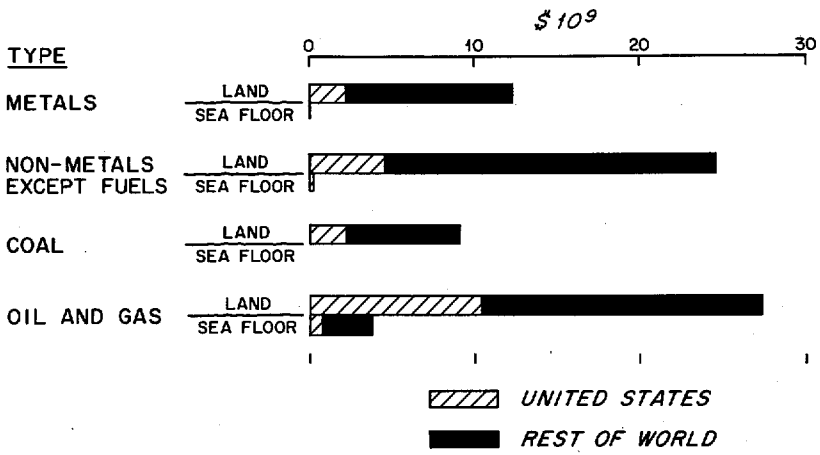

Figure 2. Value of geological resources mined during 1964. Data are from D'Amico (1965), Gaber and Reynolds (1965a), and Weeks (1965a, 1965b).

recovered less than one-third of the salt (NaCl) but nearly all of the magnesium and bromine that was chemically extracted from sea water. This report, however, is supposed to be concerned with the geological resources that are on the sea floor or far beneath it. In this field the United States recovered 20 per cent of the total world value, with United States' capital responsible for much of the remaining 80 per cent--such as products of the submarine oil fields of Lake Maracaibo and the Persian Gulf.

The most important of the geological products obtained from the ocean floor adjacent to the United States is oil and gas ($700 million for 1964) and the closely associated sulfur from offshore salt domes ($15 million) (Fig. 2). Shell deposits dredged from shallow bays yielded $30 million in 1964. In proportion to recoveries from land, the offshore products are relatively small, but they are rapidly increasing in quantity and value. Ocean-floor recoveries from other areas of the world include besides oil and gas the more exotic tin, diamonds, iron, and gold--but altogether their value was only $10 million during 1964. Why have the resources from off the United States not included diamonds and gold? Why does oil and gas dominate on most continental shelves? How does the type of resource control the method of geological exploration? In order to answer these questions we should consider the geology of mineral deposits.

ORIGIN OF MINERAL DEPOSITS

Mineral deposits are classififed here in a way slightly different than the usual geological way, as an adaption to the marine environment. Most fundamental of all are the primary igneous mineral deposits, because some can be mined directly as ores and others have served as original sources for other kinds of ore deposits. These primary igneous deposits include magmatic segregation, pegmatites, deep-moderate-and-shallow veins, and contact metamorphism. All are virtually restricted to intrusive igneous and associated metamorphic rocks. Outcrops of these kinds of rocks are known at only three places on the continental shelf of the United States: the Gulf of Maine, Monterey Bay, and off the Golden Gate in California (Fig. 3). At none of these places have samples exhibited valuable mineralization.

Many primary mineral deposits on land are too low grade to be mined as ores until after they have been enriched by weathering and erosion. Enrichment may take two forms: (1) solution and concentrated redeposition of the valuable mineral (copper, silver) accompanied by erosion of some of the worthless residue left at the surface, or (2) solution and removal of the worthless material leaving at the surface a residual concentrate of the valuable mineral (iron, bauxite, diamonds). Both enrichment processes require many million years of exposure to weathering and erosion; thus, they are much less likely to be important on the ocean floor (even on the continental shelf) than on the long-exposed land areas. In fact, most igneous rocks that have been dredged from outcrops on the ocean floor are so fresh that any incipient weathering is a curiosity.

A mineral deposit somewhat related to secondary concentration by solution and redeposition is produced by long-distance transportation and redeposition within sedimentary strata by ground water (lead, uranium). Although fresh ground-water has been found in drilled samples of sedimentary strata 100 km at sea (Bunce and others, 1965), its probably low hydrostatic pressure head must cause especially slow circulation that greatly reduces the likelihood of the development of such mineral deposits on the ocean floor.

Three kinds of direct sedimentary origin for mineral deposits are common. One is the placer deposit (gold, tin, diamonds) that is formed where streams or waves and currents cause heavy minerals to be selectively deposited in isolation from relatively worthless lighter minerals that are carried away. The minerals must previously have undergone extensive weathering and erosion from their original position within igneous and metamorphic rocks. Because the ocean floor lacked sufficient weathering and erosion, few if any placer deposits should have originated on it. Instead, placers on the ocean floor should be extensions of well-known ones on land--such as the gold of Alaska, the tin of Malaya and Cornwall, and the diamonds of Southwest Africa. Placers are unrelated to the composition of their substrate, but they occur only near their primary igneous or metamorphic source rocks.

A second kind of sedimentary mineral deposit is a chemical or biochemical precipitate. The best example is manganese oxide in the form of nodules and crusts on the ocean floor. The manganese is independent of the type of substrate, being found on or in deep-sea sediments and on volcanic rock and limestone of seamounts. An essential condition for its formation is a slow rate of deposition of detrital or biogenic sediments because of their diluting effect. Two other sedimentary mineral deposits are phosphorite and glauconite, but the origin of each is complicated in some ocean-floor deposits by the inclusion of some material from reworked older deposits. Nevertheless, all three materials (manganese oxide, phosphorite, and glauconite) can be primary sedimentary deposits formed by precipitation from sea water. Their depth ranges overlap, but manganese nodules and crusts are best known from the deep-sea floor, and phosphorite and glauconite are mainly from the outer part of the continental shelf and the top of isolated banks.

The last and most important sedimentary deposit to be considered here is oil and gas, which begin as organic matter grown largely by phytoplankton near the ocean surface. The organic matter is partly transformed through ingestion by small and large marine animals and by bacteria. Eventually it is buried deep beneath detrital and biogenic sediments where further modification to oil and gas is followed by migration into structural or stratigraphic traps from which it may be released to the earth's surface through seeps or drilled wells. Alteration of the organic matter also causes most of the sulfate in the associated brines to be converted into elemental sulfur; deposits of this sulfur associated with salt domes can be melted by injected steam and pumped to the surface.

In summary, the ocean floor is primarily a depositional region in which weathering has been insignificant and erosion minor in comparison with the possibly several kilometers of total weathering and erosion on land (Gilluly, 1964). Supergene enrichment or residual enrichment of primary igneous mineral deposits should therefore be far less important on the ocean floor, even on the continental shelves, than on the continents. Even the unenriched primary igneous mineral deposits are likely to be deeply buried under a blanket of Late Cretaceous to Recent sediments that covers most of the shelves off the United States (Fig. 3) and probably the shelves of most of the rest of the world (Fig. 4) except where it was removed by Pleistocene glaciers. Accordingly, let us turn our attention more to the sedimentary mineral deposits than to the igneous ones.

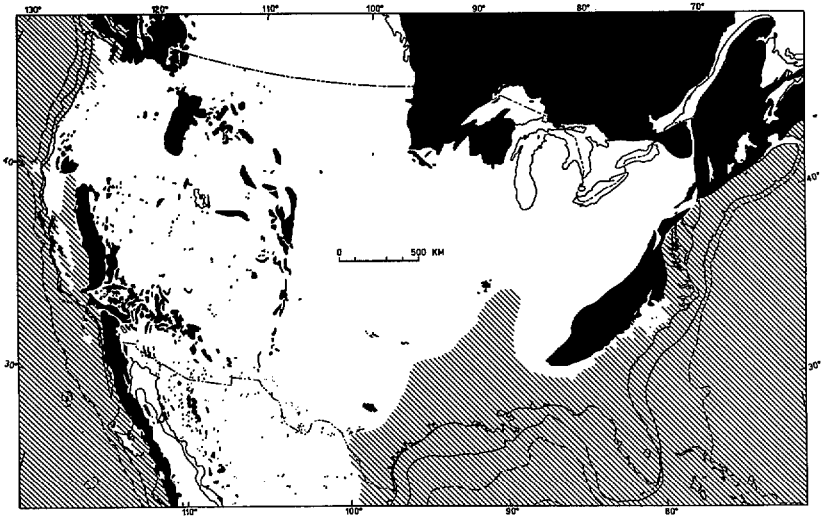

Figure 3. Simplified geological map of the United States and its adjacent continental shelves. Solid black indicates areas of exposed intrusive igneous and associated metamorphic rocks; cross-hatching indicates areas of marine Tertiary sedimentary strata whether exposed or covered by later sediments. From Goddard (1965).

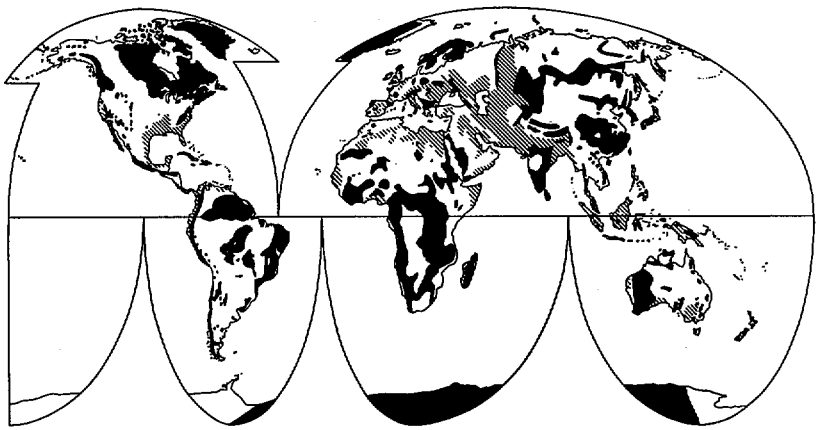

Figure 4. Simplified geological map of all continents. Symbols are the same as for Figure 3, but the geology of the shelves is omitted because of inadequate data. Sources are Beyschlag (1929), Director of the Geological Survey of India (1959), Goddard (1965), Hamilton (1963), Isakov (1953), Lobeck (1942), Lombard (1963), Nalivkin (1955), Stose (1950), Tectonic Map Committee, Geological Society of Australia (1960), and Warren (1965).

SAND AND GRAVEL

Probably the simplest sedimentary deposits are those of sand, gravel, and shells. In areas of high population concentration these materials are needed for construction, earth fill, road material, and some minor miscellaneous purposes. About $890 million worth was mined in the United States during 1964 according to D'Amico (1965, Table 1). Only a small percentage came from the ocean floor, because of easier availability from stream valleys and older strata; however, Gaber and Reynolds (1965a, 1965b) reported the recovery of $30 million of shell from offshore--probably almost entirely from shallow bays of Florida, the Gulf of Mexico, and California. In addition, many new building sites are made by filling parts of salt marshes with dredged sediment, but the value of the sediment is difficult to compute owing to the concomitant intent to deepen channels for navigation through other parts of the marshes. In some countries (Israel and Jordan, for example) sand for making concrete blocks has been mined so extensively that some beaches have virtually disappeared. In order to avoid similar losses of United States' beaches, the Coastal Engineering Research Center (U.S. Army) contracted for surveys of suitable construction sand and gravel farther offshore during 1964-1965.

Extensive sampling of the surface of the continental shelf off the Atlantic coast by a joint undertaking of the U. S. Geological Survey and the Woods Hole Oceanographic Institution revealed a blanket of relict sand covering almost the entire width of the shelf (Fig. 5) (Emery, 1965). Relict gravels also are present locally (Schlee, 1964). The sand and gravel were deposited during times of glacially lowered sea level when large quantities of sediment were contributed to the ocean and when waves and currents were able to winnow out most of the clay and silt, leaving the coarser material as a sort of crude placer. Similar relict sands have been found on the continental shelves off the Gulf and Pacific coasts of the United States and off Brazil, China, Israel, and other countries (Emery, 1961). Surface samples and bottom photographs provide the best data for locating the sands and gravels, but vibrocoring or drilling, supplemented by seismic reflection profiles are needed for determination of thicknesses. Mining and transportation should be cheap, commensurate with mining costs on land that permit the sand and gravel to be sold at about $1/ton. As the population along the coast increases (such as for the coming megalopolis between Washington, D.C. and Boston) demand for offshore supplies of sand and gravel probably will increase markedly.

Concentrations of heavy minerals such as gold, tin, diamonds, and platinum are more classical types of placer deposits than are ordinary sand and gravel. They require much more wave and current energy to be transported than do the quartz and feldspar that comprise the bulk of sand deposits. Thus, most valuable heavy mineral deposits form in high-energy shore zones. Changes in sea level during deposition caused the heavy minerals to be distributed in a thin and discontinuous blanket deposit interbedded with sand and gravel or lying just above bedrock. The main contribution that geology can make to the discovery of heavy-mineral placers is through knowledge of source areas and inferences about direction of movement in the shore zone. Evaluation must depend upon coring or drilling, coupled with seismic measurements of thickness of overlying sands and gravels.

TABLE 1

VALUE OF GEOLOGICAL RESOURCES MINED FROM THE OCEAN FLOOR DURING 1964 IN COMPARISON WITH THE VALUE OF THE SAME RESOURCES MINED ON LAND[1]

10^6

RESOURCE	FROM OCEAN FLOOR		FROM LAND	
	UNITED STATES	*REST OF WORLD*	*UNITED STATES*	*REST OF WORLD*
SAND, GRAVEL, SHELLS	30	?	860	?
IRON	0	0.7	800	4500
GOLD	0	?	50	1500
TIN	0	5	0.02	600
DIAMONDS	0	4	0	?
PHOSPHORITE	0	0	160	215
MANGANESE OXIDE	0	0	3	420
OIL AND GAS	700	2900	10,500	17,000
SULFUR	15	0	100	140

[1]GABER AND REYNOLDS (1965b), WEEKS (1965a), AND D'AMICO (1965)

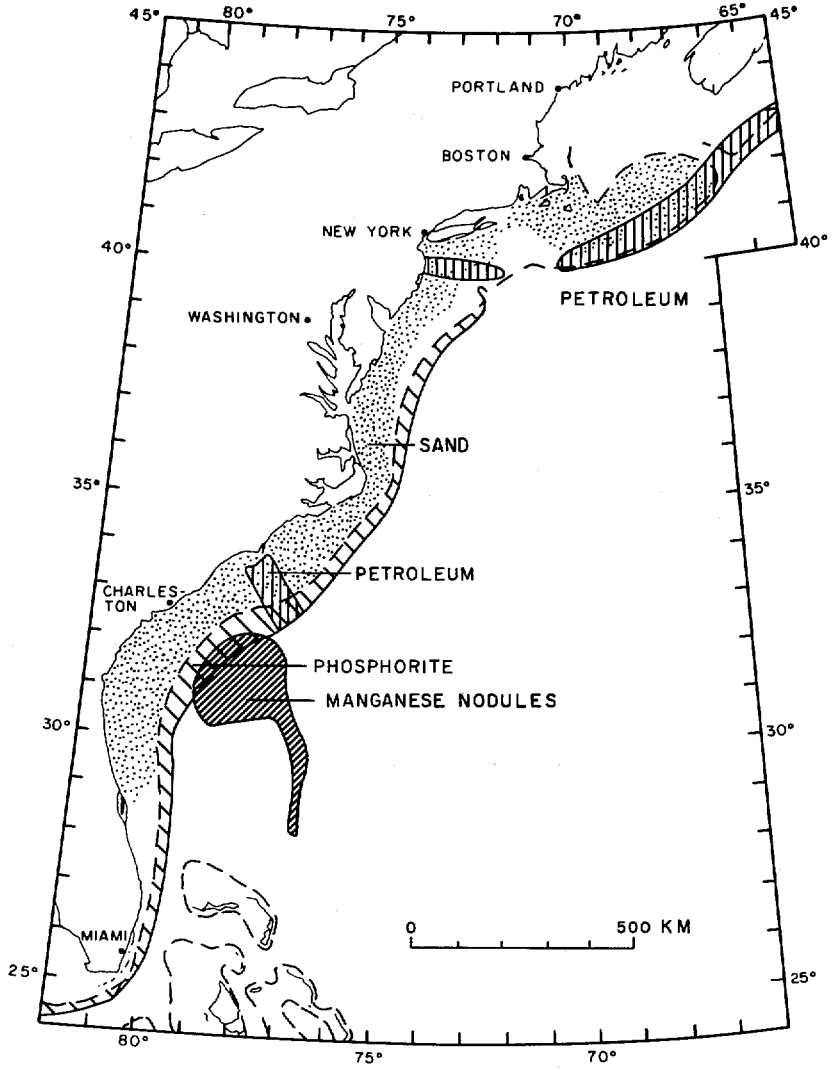

Figure 5. Distribution of the most favorable areas for some potential mineral deposits off the Atlantic coast of the United States.

PHOSPHORITE

Phosphorite, a complex calcium phosphate containing some fluorine, has long been used as a source of phosphate for fertilizer and chemicals. During 1964 phosphorite valued at $160 million was mined in Florida, Tennessee, and Idaho (and adjacent Montana, Utah, and Wyoming). At the present rate of mining, more than a thousand years' supply is present on land in the United States. A major part of the cost per ton at the point of use is for freight charges. If phosphorite can be mined from the sea floor near the point of use, the cost of mining can be greater than on land and yet the operation can be profitable. To-date, however, no commercial production from the ocean floor has been reported.

Phosphorite was discovered in samples dredged from Agulhas Bank off Africa by H.M.S. Challenger in 1873 (Murray and Renard, 1891, p. 391). In 1937 it was found in samples from the tops of banks and locally from the outer parts of the mainland and island shelves off California by Dietz, Emery, and Shepard (1942). Subsequently, it was found off Florida (Gorsline and Milligan, 1963). In these areas (Figs. 5 and 6) and others it occurs as pellets, nodules, and crusts ranging up to about 60 cm in length and 75 kg in weight. Few analyses show P_2O_5 greater than 30 per cent, whereas the P_2O_5 in most of the phosphorite being mined on land is 31 to 36 per cent (Mero, 1965, p. 58).

Prospecting for phosphorite can be guided by the known control exerted by rate of phosphate deposition and rate of dilution by detrital sediments. Precipitation appears to be fastest in sea waters having a high concentration of dissolved phosphate--generally areas of great upwelling which support high concentrations of phytoplankton. The areas of greatest upwelling corresponding with deposits of phosphorite lie above shelves at mid-latitudes on the eastern sides of oceans (Fig. 7). Related high-phosphate waters occur in east-west trending belts at both low and high latitudes, but phosphorite deposits are not associated, probably because of the great depth of the ocean floor below these zones. The areas of upwelling are characterized by low rainfall on adjacent lands and absence of large rivers; thus, the rate that detrital sediments are contributed to the ocean is not great. A further decrease in the rate of deposition of detrital sediments is produced by the topographic isolation from the sediment sources by offshore banks. After potentially rich areas of the ocean floor are selected on the basis of upwelling and isolated topography, the next step is field prospecting. Because phosphorite probably is restricted to a thin layer on the ocean floor, surface sampling is adequate. The best tools are large dredges and clear bottom photographs, perhaps supplemented by underwater television. Data provided by these tools are probably adequate to establish the volume of the deposit. At present, however, the question of profit in mining depends upon the costs of ocean-floor mining and of beneficiation, or processing, of the deposits. Estimates of these costs vary so much that opinion is strongly divided about whether the ocean-floor deposits can be competitive with the land ones (Mero, 1965). One commercial test off southern California was aborted by the presence of an associated naval ordnance dump. We await the results of other tests with interest.

MANGANESE OXIDE

Manganese largely for metallurgical purposes is presently in short supply in the United States. Only $3 million worth of manganese was mined in this country during 1964, in comparison with about $420 million from the rest of

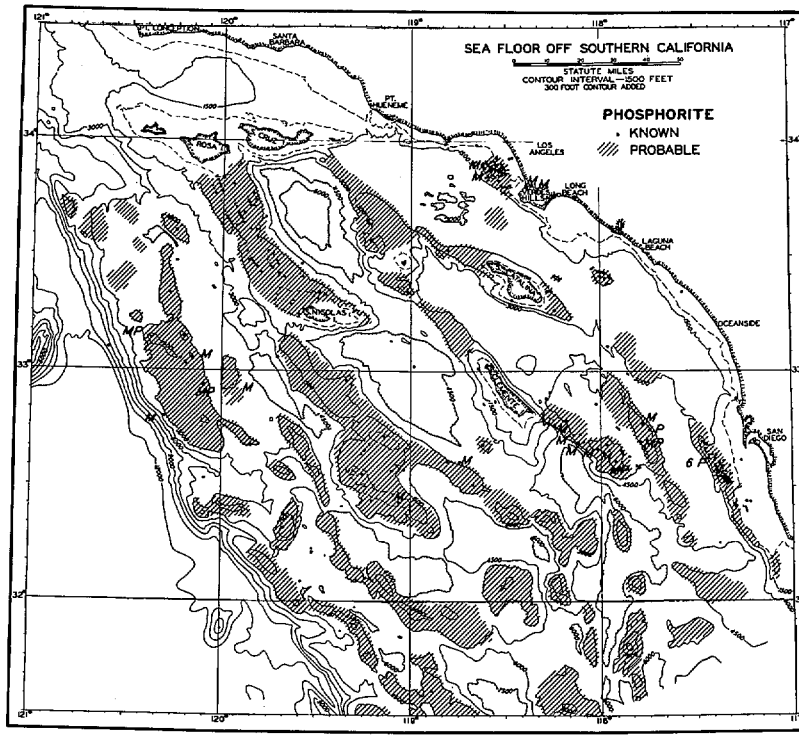

Figure 6. Distribution of phosphorite off southern California. From Emery (1960, p. 69).

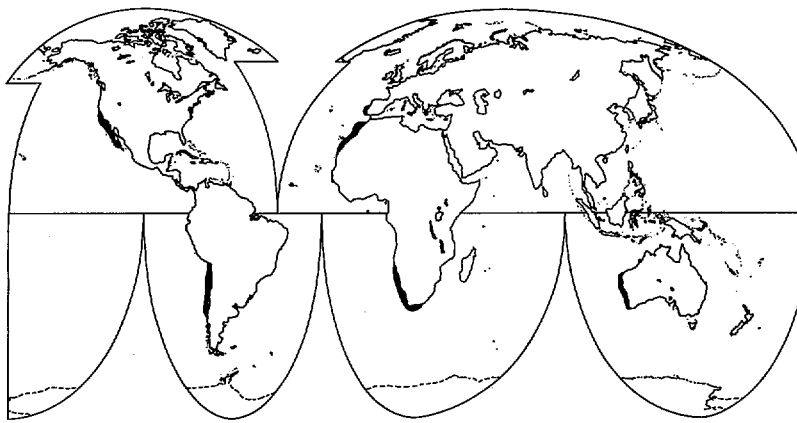

Figure 7. Most favorable areas for ocean-floor deposits of phosphorite on the basis of continental shelves associated with upwelled water rich in dissolved phosphate and absence of diluting sediment from rivers and glaciers.

the world. Imports during 1964 amounted to about $100 million worth of ores averaging more than 35 per cent manganese (DeHuff, 1965). Because of insufficient domestic production, the government offers a subsidy amounting to 50 per cent of approved exploration costs.

Nodules of black manganese oxide have been known for about one hundred years to occur on the ocean floor. In fact, some of the best descriptions and pictures of the nodules were published in the reports of the famous Challenger Expedition of 1872-76 (Murray and Renard, 1891). The nodules from the ocean floor are widespread as a surface or near-surface deposit, but they are not very rich in manganese. Mero's (1965) 181 analyses for worldwide samples average 18 per cent manganese; those for the Blake Plateau off the Atlantic coast of the United States average 13 per cent of total weight. Only six of the analyses contained more than 35 per cent of manganese. For all analyses silicon averages 8.1 per cent. The usual method of extraction by chemical reduction allows silicon to withhold about twice its weight of manganese; thus, most or all of the manganese must be considered a waste product of the nodules until a better method of extraction becomes economical (Institute of Marine Resources, University of California, 1965, pp. 13-1 to 13-29). According to Mero (1965), the associated 0.2 to 2.0 per cent of copper, nickel, and cobalt may justify the mining of manganese nodules, but these concentrations correspond to only marginal or low-grade ore deposits.

Manganese nodules and crusts are widespread on the deep-ocean floor, appearing in many photographs and samples by American, Soviet, and British expeditions. They are concentrated at the surface but do occur at depths of at least a few meters (Bender, Ku, and Broecker, 1966). The origin of the deposits is not well known, thus their distribution cannot be inferred from origin but only by empirical methods. These methods fail to predict the patterns of distribution and concentration, and so recourse must be made to dredges, large grab samplers, corers, and cameras. Using such devices, Pratt and McFarlin (1966) outlined in detail an area of manganese oxide on the Blake Plateau (Fig. 8) that previously was sampled by Mero (1965) and others. The middle of the area has a pavement-like concentration of crusts, and it is surrounded by an annular area in which nodules are concentrated. Phosphorite nodules present at the landward side of the area of manganese oxide may be coincidental--a result of proximity to the known phosphorite deposits on the adjacent continental shelf and the gentle slope between the shelf and the Blake Plateau. Probably detailed mapping of nodules and crusts of manganese oxide in other oceanic regions will reveal distribution patterns that are different but perhaps as complex as that of the Blake Plateau. Whether the nodules can profitably be mined in any region is uncertain, but the author is pessimistic about the matter.

OIL AND GAS

Most of the world's oil and gas comes from Tertiary marine strata. These strata underlie coastal plains of all continents, and where the geology is known, they thicken seaward beneath the adjacent continental shelves (Fig. 3). This thickening increases the likelihood of future discoveries of oil and gas resources on the shelf within suitable structures or stratigraphic traps. Most present production is from seaward extensions of structures originally discovered on land (southern California, Lake Maracaibo, Persian Gulf), or from structures having a distribution pattern related to similar structures previously discovered on land (salt domes off Louisiana and Texas). In only a few

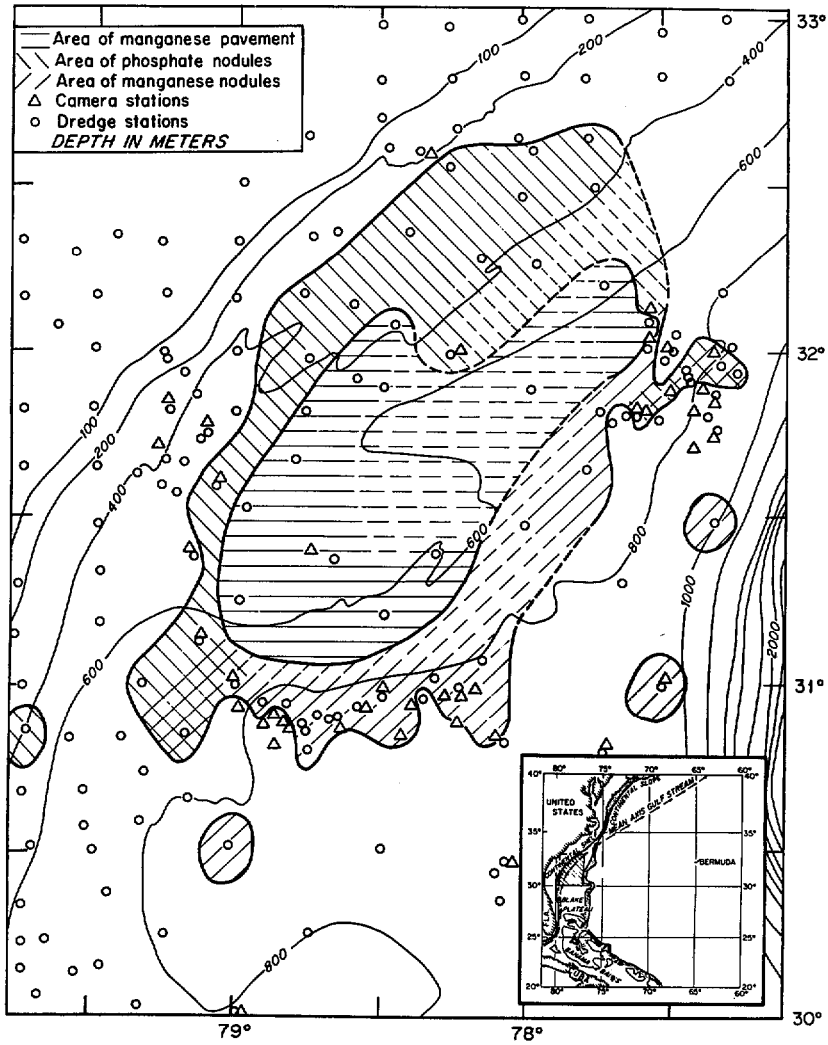

Figure 8. Distribution of manganese oxide crusts and nodules off Georgia and Florida. From Pratt and McFarlin (1966).

instances (Australia, Persian Gulf) has production developed from ocean-floor discoveries of structures unrelated to those of the adjacent land.

Wells on the ocean floor cost considerably more than wells on land; thus the prospecting for suitable structures is more rigorous than on land. The chief geophysical method is a form of seismic profiling, commonly supplemented by magnetic or gravimetric surveys. Final tests require actual drilling and examination of the strata. Both geophysical and geological studies must be detailed and closely spaced because of the small percentage of the continental shelf that is occupied by individual structures.

This Society probably has no particular interest in the results of such detailed studies as are necessary to identify and delimit potential oil-bearing structures, but it may like to see the results of a general seismic reflection survey of the entire Atlantic coast of the United States. Forty-four profiles made at right angles to the continental shelf (Uchupi and Emery, in press) reveal a thickness of 200 to 800 meters of Tertiary strata beneath the continental shelf (Fig. 9). The beds continue farther seaward beneath the continental slope and locally beneath the continental rise. Seaward growth of the continental shelf from 5 to 10 km between Nova Scotia and Cape Hatteras to more than 35 km in the area of the Blake Plateau off Florida and Georgia occurred during the Tertiary. The profiles also depict many buried erosional surfaces. Geological testing of the geophysical results was accomplished by a series of six holes drilled during 1965 off northern Florida to maximum depths of 320 meters into the bottom beneath maximum water depths of 1032 meters (Fig. 10).

The bulk of the prism of sedimentary strata overlying basement rocks off the Atlantic coast is believed to be Cretaceous limestones and shales. Seismic refraction measurements summarized by Drake, Ewing, and Sutton (1959), Hersey, Bunce, Wyrick, and Dietz (1959), and Antoine and Henry (1965) reveal major variations in the total thickness of these strata. Greatest thicknesses off New England occur in two trenches that may join to form a single trench south of Cape Hatteras. The ridge between the two trenches may contain minor structures and traps whose identification may lead to offshore oil fields along the Atlantic coast. An extension of this ridge off eastern Canada is actively being explored by several oil companies. Other potential oil fields may be associated with large cross structures known off New York (Drake, Heirtzler, and Hirshman, 1963) and southwest of Cape Hatteras (Hersey, Bunce, Wyrick, and Dietz, 1959) (Fig. 5).

At present, oil companies are producing annually about $700 million worth of oil and gas from the continental shelves off Louisiana, California, and Texas. Bonus payments (leases), rentals, and royalties for this production have found their way into federal, state, and coastal community treasuries. Revenue to the federal treasury alone for the years 1960 to 1964 was $1,234 million, considerably more than the $469 million that was returned to the ocean in the form of support for oceanography during the same period (Fig. 11). One can confidently predict that future activities by oil companies will produce a steady rise in the recovery of offshore oil above the present 16 per cent of the total number of barrels produced from all of the world's oil fields. Probably offshore production will rise to 25 per cent of the total during the next 25 years.

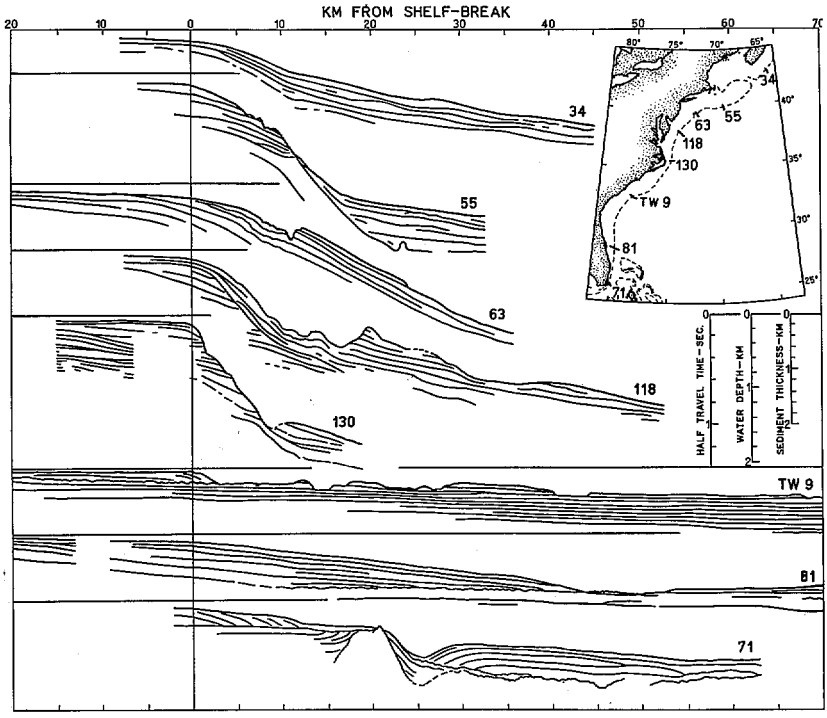

Figure 9. Seismic profiles off the Atlantic coast of the United States. From Uchupi and Emery (in press).

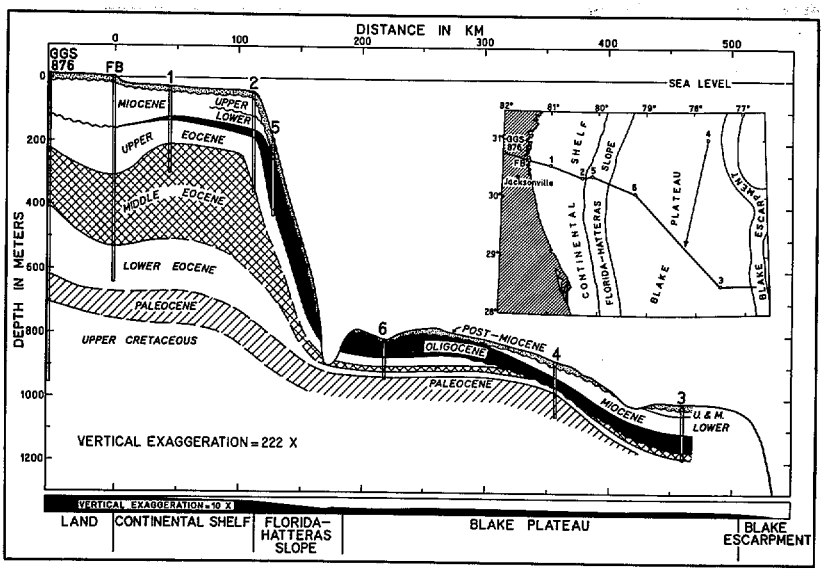

Figure 10. Results of drilling off Georgia by JOIDES (Joint Oceanographic Institutions' Deep Earth Sampling program). See Bunce and others (1965) for additional details. Discovery of oil and gas accumulations must be based upon similar drill holes positioned according to results of geological and geophysical surveys.

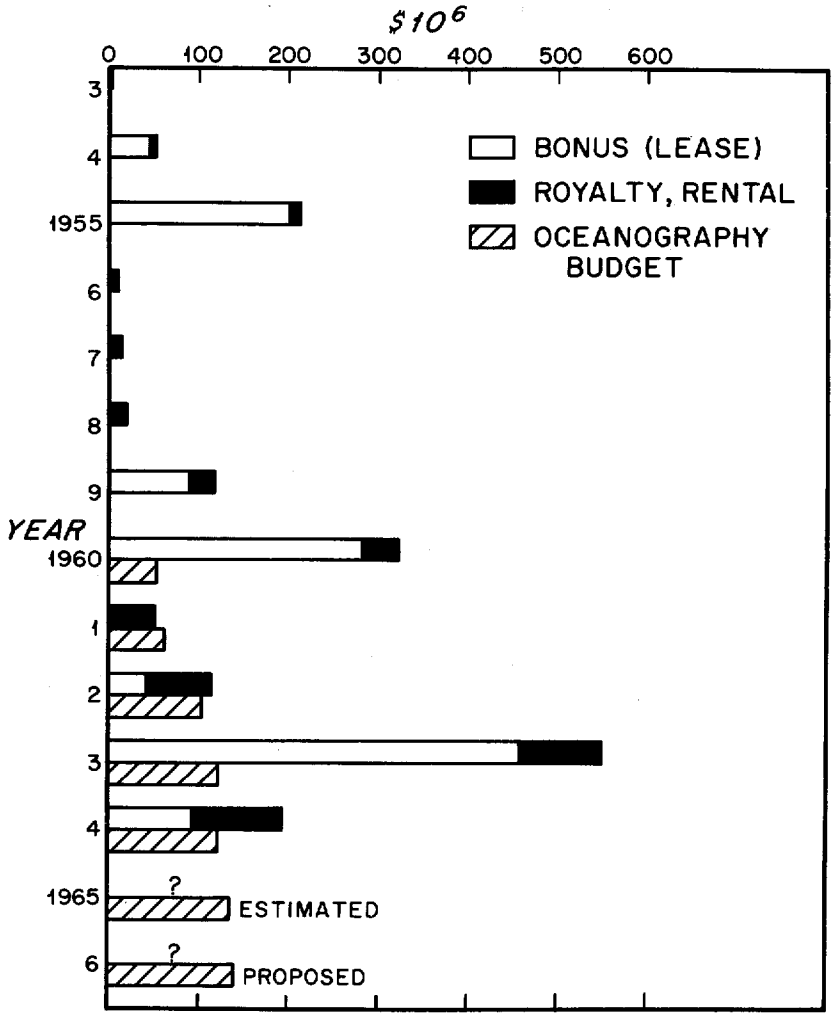

Figure 11. Federal revenue from oil, gas, and sulfur compared with federal support of oceanography. From Conservation Division (1965) and Interagency Committee on Oceanography (1961, 1962, 1963, 1964, 1965).

CONCLUSIONS

Mineral deposits on the ocean floor have been considered by many men as surrounded with a kind of mystery akin to that given all mineral deposits during medieval times. The fact that the deposits are covered by water should not blind us to the need for geological investigations to locate them. Elaborate instrumentation may help, but often it hinders, and it cannot substitute for geological thinking based upon data obtained by conventional techniques. A good example is provided by oil companies that have been highly successful in their use of modifications of the same techniques and the same geological thinking that are used on land to locate oil fields on the ocean floor. Oil, gas, and associated sulfur dominate the inventory of successful recoveries from the ocean floor around the United States and off the coasts of other countries as well. The reason for the importance of oil and gas is the typical presence of thick Tertiary sedimentary strata beneath probably most continental shelves. In addition, once the wells have been completed production of oil and gas requires little supervision unlike, for example, any form of strip mining.

Most published lists of potential mineral resources of the ocean floor are dominated by heavy mineral placer deposits. These are real and some have been mined, but all are extensions of placers known on the adjacent land and derived from nearby igneous or metamorphic source rocks. Where suitable source rocks are unknown on land, a search for heavy mineral placers on the ocean floor is unprofitable. Sand and gravel deposits also constitute a form of placer, because the originally accompanying silt and clay has been winnowed away; moreover, sand and gravel can be derived from many kinds of abundant source rocks. Though cheap per unit weight compared with diamonds and gold, sand and gravel is probably a far more important mineral resource of the ocean floor owing to its abundance and general lack of cover.

Phosphorite and manganese oxide are abundant as nodules and crusts in certain areas of the ocean floor, but only in thin blankets. In the author's opinion, their generally great depth of water and great distance from shore, coupled with the low concentration of the desired elements, are heavily weighted against profitable exploitation. Engineering breakthroughs in efficient recovery from the ocean floor or the assignment of large subsidies can change this forecast, but improvements in methods of beneficiation of the material are more likely to bring vast low-grade deposits on land into competition.

Primary igneous mineral deposits may be present on the ocean floor but probably with little secondary enrichment. They are most likely to be found off coasts having abundant exposures of igneous and metamorphic rocks on land and where a cover of sediments or of sedimentary rocks is absent or thin. No continental shelves that have been well studied to-date qualify, but perhaps some shelves at high latitudes are worth field investigation because Pleistocene glaciers may have removed sedimentary covers. Nevertheless, if the rocks on the adjacent land contain no valuable primary igneous mineral deposits, a good hard look at the general geology of the ocean floor should precede expensive diamond drilling.

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SELECTING AREAS FAVORABLE FOR SUBSEA PROSPECTING

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Abstract

Submarine mining technology is well enough developed to permit production of rich deposits of several minerals almost anywhere they can be found. The search for these exceptional deposits can be expensive, however, and it is desirable to narrow the target for prospecting by identifying areas favorable for their occurrence.

Geologic and oceanographic principles are adequate to define some submarine provinces favorable for the occurrence of several important minerals, particularly those in two broad groups: 1) minerals genetically related directly or indirectly to sea water and 2) residual minerals of terrigenous origin. Most important among the first group are those related to upwelling nutrient-rich waters--phosphorite, oil, several minor elements, and oceanic salines--and for these many favorable areas can be defined from existing knowledge of oceanic circulation. Residual deposits include sand, gravel, gold, diamond, monazite, ilmenite, cassiterite and other resistates, and alumina-rich clays and other hydrolyzates. Some favorable provinces for these minerals can be defined from analysis of local source terrane, climate, geomorphology, and tectonics. A third group of minerals--high-grade, localized hot-springs deposits of manganese oxides, iron-sulfides, and other minerals--is also a target for prospecting but one more difficult to define; knowledge of submarine volcanism may help.

The demonstrated utility of available submarine prospecting methods indicates that the incentive of a profitable target can be matched by the capability for finding it. Much can be accomplished by reconnaissance surveys, but full realization of the submarine mineral potential requires geologic mapping as a base for both prospecting and exploration. Inasmuch as the presently valuable mineral deposits are largely confined to the shelf environment, it would be desirable to extend systematic geologic mapping and related geophysical surveys over the continental shelves.

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INTRODUCTION

The potential mineral resources of the ocean and the rocks beneath it include dozens of minerals (Mero, 1965; Hess, 1965; Byrne, 1964; Pepper, 1958). For many of these, the prospecting problem is not as pressing now as mining, beneficiation, recovery, or utilization problems. With millions of square kilometers of the ocean floor already known to contain manganese nodules, and other large areas known to contain glauconite, calcareous ooze, or siliceous ooze, there is not much reason to be concerned about finding additional deposits of the same kind until economical means are found to recover and use those already known.

The prospecting problem, however, is extremely important for most of the minerals that are now being produced from the sea bottom or that will be produced in the near future (for current production, see Gaber and Reynolds, 1965). For oil and gas, sulfur, and many placer minerals, extractive technology is already developed to the extent that they can be produced nearly anywhere on the shallower parts of the continental shelves from deposits of sufficient size and quality. And several less valuable materials, including sand and gravel, shells or other forms of calcium carbonate, salt, and phosphorite are or could be produced from sizeable deposits of good quality in areas where scarcity permits a higher cost. Even manganese could be produced economically now if deposits similar in quality and composition to those mined on land could be found on the sea bottom, for they would not present the difficult processing problems posed by the deep-sea nodules. In the practical world of marine mining, then, the problem of finding concentrations of minerals that can be produced at competitive costs is one of first-rank importance.

Minable deposits of these valuable minerals are rare, and most of them are relatively small, even tiny in size compared with the extent of the terrane in which they occur. Fortunately, there are effective techniques and instruments for use in finding them in the submarine environment. Dredging and coring devices are now relatively well advanced, as are submarine photographic and television techniques. Means to allow the prospector to make direct observations on the sea bottom are rapidly developing. A wide variety of geophysical methods are also available for use in marine prospecting, and some of them are valuable as direct ore finders. The magnetometer and radiation detectors are already in this class, and McCulloh's (1966) recent work indicates that high-precision gravimeters may be useful in detecting anomalies that are produced by accumulations of oil and gas. Some of the oil companies are using scanning devices that measure hydrocarbon content of sea water as a means of identifying submarine petroleum seeps, and detectors for silver, gold, beryllium, and other metals are becoming available and may be adaptable for marine use.

The success already achieved in submarine exploration for oil and gas, sulfur, tin, and diamonds demonstrates the utility of these field procedures and instruments in prospecting, and clearly shows that the incentive of a profitable target can be matched by the capability for finding it. The ocean, however, is a big place, too big to scan systematically even with direct ore finders. Moreover, in view of the difficulty and high cost of marine prospecting, the limitations of presently available extraction technology, and the unfavorable geologic character of large parts of the ocean floor, presently findable and workable deposits of many minerals are relatively much less abundant than on land. Those searching for presently minable subsea mineral deposits must therefore find effective means to cut the odds against discovery. One of the best ways to do this is to reduce the size of the prospecting target to the most favorable areas, and it is to this subject--the use of available data

and principles in selecting favorable mineral provinces--that we will devote our principal attention here. In particular, we will focus on three groups of minerals: 1) those that are genetically related to upwelling nutrient-rich waters, 2) residual minerals of terrigenous origin, and 3) localized hot-spring deposits of manganese oxide and other minerals.

MINERALS GENETICALLY RELATED TO UPWELLING

The process known as upwelling, in which deep, cold, nutrient-rich waters rise to the surface, produces a chain of chemical, biologic, and climatic phenomena that are reflected in a considerable variety of depositional products of direct or indirect economic importance, including phosphorite, oil shale, oil and gas, several saline minerals, sulfur, and a number of minor metals associated with phosphorite and black shale. Knowledge of this genetically related rock assemblage and of the processes involved has come partly from the study of the ocean and its present sediments (e.g., see Murray and Renard, 1891; Sverdrup et al, 1946; Dietz et al, 1942; Brongersma-Sanders, 1948, 1957) and partly from the study of fossil marine phosphorites and associated sediments (Kazakov, 1937; McKelvey et al, 1953, 1959; McKelvey, 1959, 1963; Cheney and Sheldon, 1959; Sheldon, 1964a). During the last several years, these relations have been successfully applied to the search for phosphate on land in several countries (Sheldon, 1964b), and they may be even more useful in marine prospecting. The fundamental processes and products are as follows (mainly repeated from McKelvey, 1963).

The solubility of phosphate in sea water increases with decreasing pH and temperature (Sverdrup and others, 1946, p. 241 and 788), and for this reason it is most concentrated in deep cold waters. Nitrate, the other critical nutrient element in the sea, closely parallels phosphate in its distribution; to some extent silicate (a nutrient element for some organisms) does also (idem, p. 242, 245). Oceanic circulation, which mainly reflects atmospheric circulation brought about by solar heating combined with the rotation of the earth, deep plows the sea and brings these nutrient-rich waters to the zone of photosynthesis in local areas.

In an idealized ocean, the main elements of the current system consist of a large circulating gyral in each hemisphere (fig. 1); water cooled in polar latitudes moves toward the equator along the east edges of the ocean, and water warmed in equatorial latitudes moves poleward along the west edges (see also Fleming 1957). In this system, cold nutrient-rich waters are brought to the surface in four situations: 1) where a current diverges from a coast, or where two currents diverge from each other. The effects of cold currents moving toward the equator in bringing cold phosphate-rich water along the coast are abetted by the seaward movement of coastal surface water that results from the combined effects of prevailing wind and Coriolis force, for as the surface water moves seaward, deep cold water wells up to replace it; 2) where two currents meet to produce turbulence; 3) along the west edge of poleward-moving density currents; 4) in high latitudes where highly saline water from the tropics tends to sink as a result of winter cooling.

Pronounced climatic, biologic, and geologic effects accompany this deep plowing of the sea, especially in the areas of upwelling produced by divergence. The presence of cold waters along coasts produces coastal fogs and humid-air deserts. Some of the driest areas of the world are of this type--humid air, perhaps some hygrophytic vegetation, but no rain. The Peruvian and southwest African deserts are present-day examples.

The naturally fertilized waters that lie alongside these deserts are the lushest gardens of the sea, for the upwelling cold waters support tremendous quantities of organisms (Sverdrup and others, 1946, p. 786-787; Ryther, 1953),

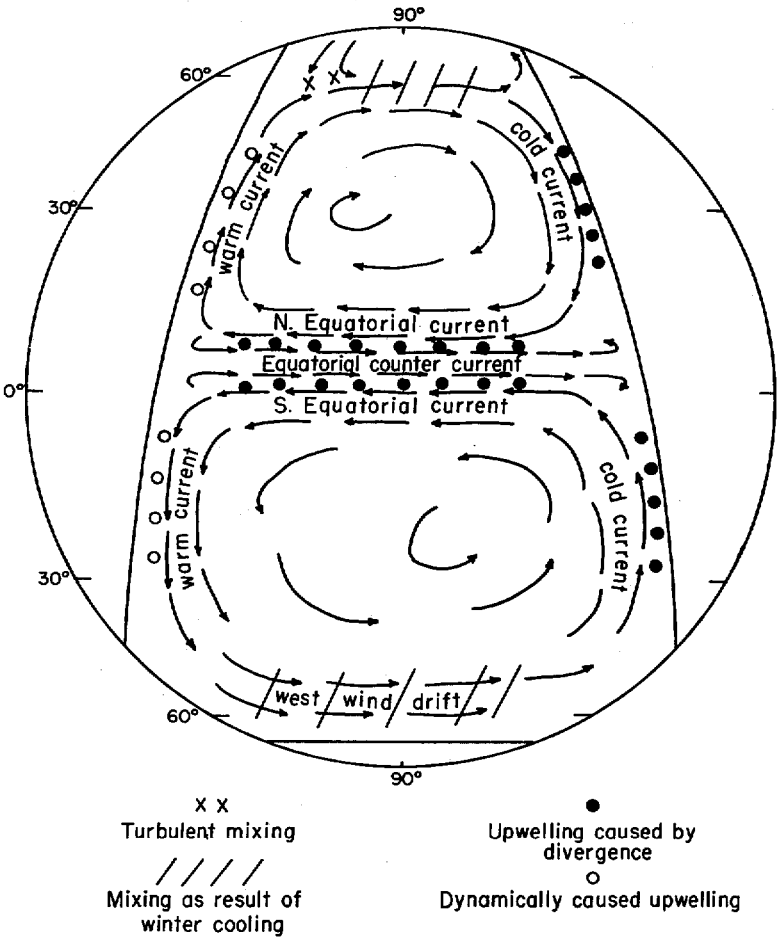

FIGURE I. SURFACE CURRENTS IN AN IDEALIZED OCEAN, SHOWING AREAS OF ASCENDING, NUTRIENT-RICH WATER (See Fleming, 1957)

with diatoms and other phytoplankton at one end of the food chain, and fish, whales, and fish-eating sea fowl at the other. Blooms of dinoflagellates (red tides) and diatoms are characteristic biologic phenomena in upwelling areas, as are the mass mortalities of fish that accompany red tides and may be a consequence of them (Brongersma-Sanders, 1957).

The geologic phenomena accompanying upwelling are perhaps most complex of all. Phosphate in the upwelling water becomes less soluble as the pH and temperature increase near the surface and is precipitated either inorganically or biochemically. In either case, the mineral formed is apatite, a complex calcium fluorophosphate that characteristically also contains minor but perhaps commercially significant amounts of several elements, including uranium and rare earths. Because phosphate is a relatively minor constituent of sea water, concentrations of apatite only develop in the absence of diluting clastics and carbonates. This prerequisite is not uncommonly met, however, in areas of pronounced coastal upwelling for the waters are too cold for carbonate deposition and the aridity of the adjacent land does not favor a high influx of clastics.

Some of the organic matter produced in the zone of photosynthesis is winnowed away and dispersed or destroyed by surface currents, but much of it settles to the bottom, producing reducing conditions even along the open sea (Brongersma-Sanders, 1948). The abundance of the organic matter and the reducing conditions favor the accumulation of oil, gas, sulfur, and several metals, particularly vanadium, molybdenum, zinc, and nickel. In this same general environment, silica is precipitated biochemically through diatoms, silico-flagellates, and sponges; carbonates are precipitated either chemically or biochemically in warmer coastal waters; and salines may form in lagoons that extend into the adjacent deserts. And, of course, guano and guanotized rock are also characteristically associated with this environment.

These several phenomena may be observed today in many areas of upwelling, especially those along the western margins of the continents, and nearly all the phosphate deposits known on the present sea bottom lie in such areas of divergent upwelling (fig. 2). The geologic effects are well illustrated by the Permian Phosphoria Formation and associated rocks in the western United States, and by many other phosphorite formations. For example, the sedimentary facies that are found in this environment are summarized in figure 3, which represents an idealized section of rocks deposited synchronously in the Phosphoria sea in Idaho and Wyoming. As shown there, dark carbonaceous shale typically grades shoalward into phosphatic shale, phosphorite, and dolomite; chert; several facies of carbonate rock; and saline deposits and light-colored and red shale.

Epeirogenic movements cause these environments to shift laterally. As the sea transgresses and regresses the lateral sequence shown in figure 3 is produced, in whole or in part, in the same or in reverse order in vertical section; over the region as a whole shoalward facies overlap and intertongue with deeper water facies in vertical section. An example of such an intertongued sequence of sediments is shown by the reconstructed cross section of the Phosphoria Formation and its stratigraphic equivalents in figure 4. Some of the beds of the Phosphoria are oil shales, but in the main, petroleum is now found in the fringing carbonate facies, where it is believed to have migrated from the shale (Sheldon, 196_). As indicated in figure 3, the upwelling environment is significant in the origin of petroleum, not only in producing large quantities of source materials and creating the reducing conditions necessary for their preservation (Smith, 1954), but also in producing as facies equivalents the reservoir rocks and sealing beds necessary for the entrapment of petroleum.

The assemblage of sediments illustrated in figures 3 and 4 is typical of marine phosphorites associated with strong, divergent upwelling, such as

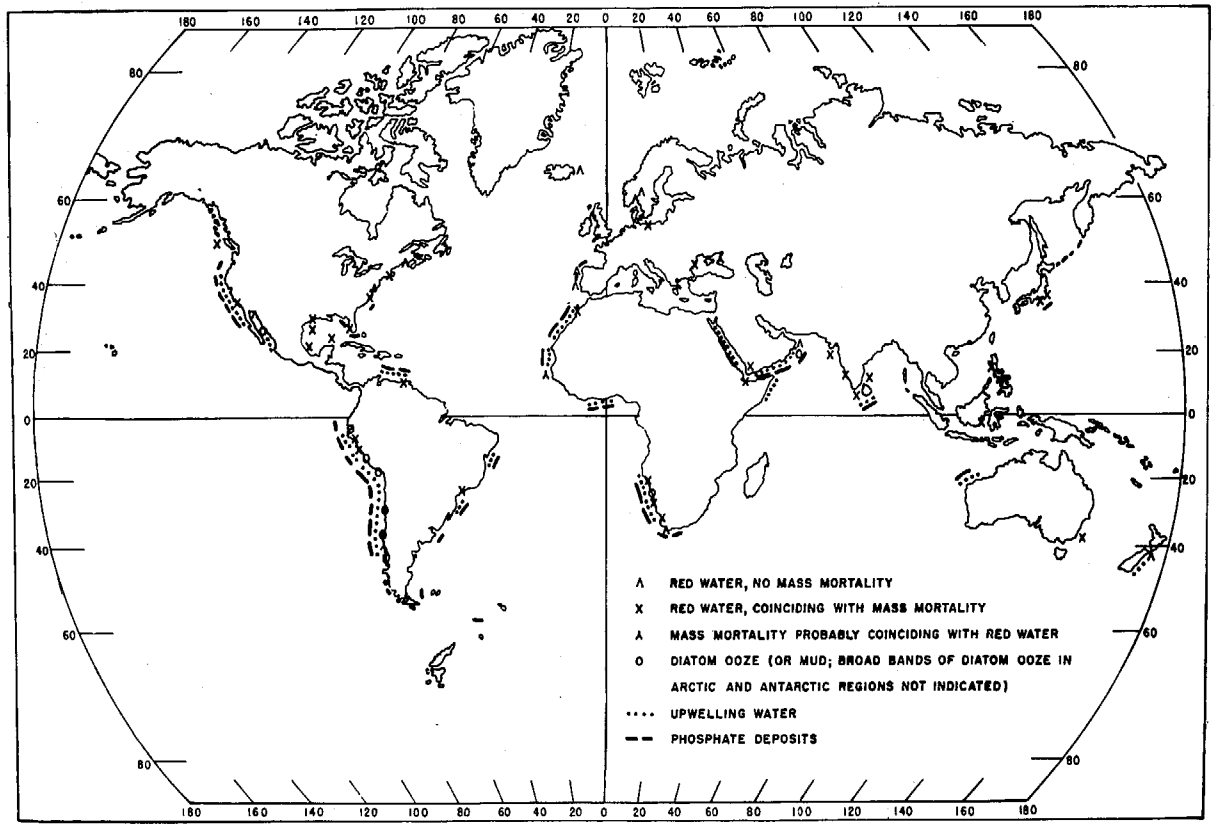

Figure 2. Distribution of upwelling water and related phenomena in modern oceans (modified Brongersma-Sanders, 1957, to include data on the distribution of phosphate deposits).

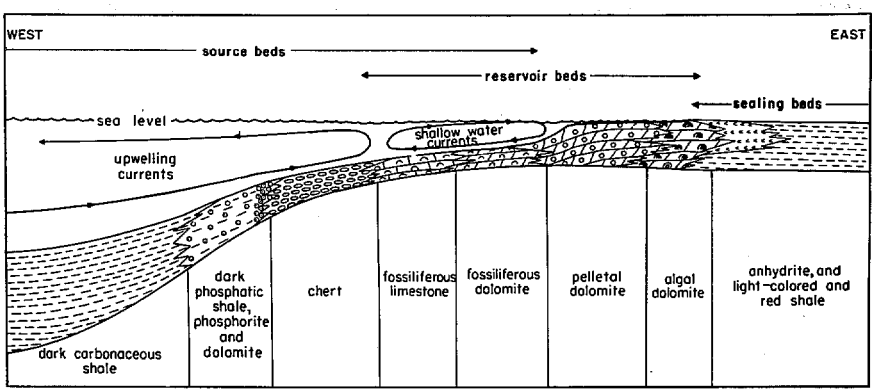

Figure 3 — Lateral sequence of environments and sediments in the Phosphoria sea (Cheney and Sheldon, 1959).

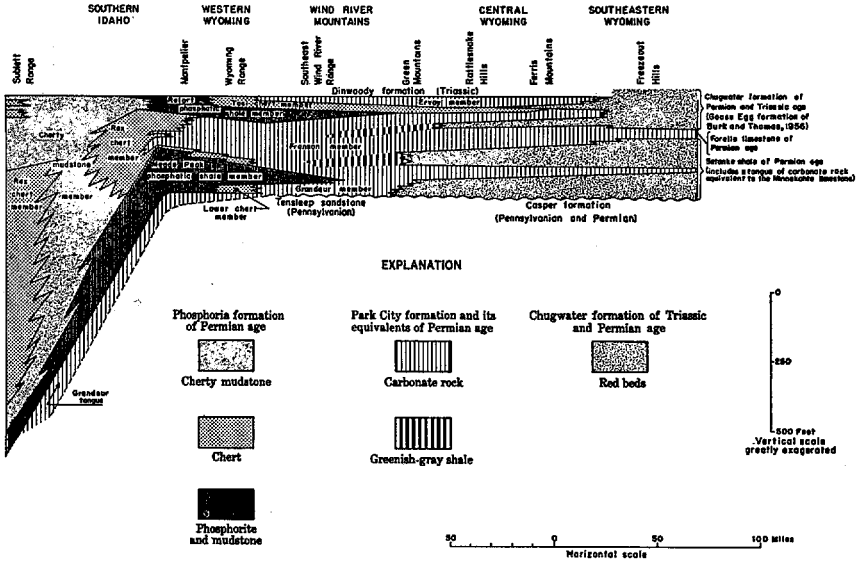

Figure 4.— Stratigraphic relations of the Phosphoria, Park City, and Chugwater formations in Idaho and Wyoming (McKelvey and others, 1959).

occurs along the west coasts of the continents. Another phosphorite assemblage, consisting of phosphatic limestone or sandstone without associated black shale or chert, appears to form along the eastern margins of the continents. These deposits, illustrated by those of Miocene age in southeastern United States and the Receife area, Brazil, may have formed in areas of dynamic upwelling or turbulent mixing along the western edge of the warm currents that occur along the west side of the oceans (fig. 1). Alternatively, they may have been deposited in estuaries, similar to those of the present day along the coast of Georgia, where the phosphate content of the water is built to high levels by organisms that "trap" phosphate brought by rivers or by tidal exchange with the ocean (Pevear, 1966). Judging from the fossil record, primary deposits of this type are low grade; workable deposits are those that have been later upgraded by weathering and submarine reworking and even these are generally less phosphatic than those associated with divergent upwelling.

These relationships have been successfully applied in recent years to the search for phosphate in several countries (McKelvey, 1963; Sheldon, 1964b), using both oceanographic and geologic clues. There are still promising possibilities for applying these relationships to prospecting on land, but they are equally applicable to prospecting in the marine environment. The localities in which phosphate has been dredged from the sea bottom (fig. 2) are prime prospects, of course, particularly those on the west coasts of the continents or in other areas of strong upwelling. Upwelling environments in general are favorable, whether or not phosphate has already been reported from the sea bottom. Most of the areas of prominent upwelling have probably already been identified, but additions and refinements probably will be made as more knowledge of marine circulation is gained, and such future developments will be worth watching for their bearing on prospecting.

Whether or not submarine phosphorite can be mined economically in close competition with land deposits is perhaps debatable, but for countries that do not have land deposits, those offshore should prove valuable. Chile is a prime example of a country that apparently has rather poor prospects for land deposits but excellent prospects for good deposits offshore. The critical question, as always with low-value deposits, is not whether submarine phosphorite can be produced for the world market but whether it can compete with world sources in the local market.

Most of the phosphate dredged from the sea bottom thus far consists of nodules and crusts that contain a maximum of about 29 percent P_2O_5. Experience with fossil deposits tells us that this may be about the maximum grade expectable, for the somewhat higher P_2O_5 content found in many land deposits generally seems to be due to enrichment by weathering. Many of the occurrences of phosphate shown on fig. 2 probably will be found to consist of only a thin surface layer of crusts of nodules, too poor for profitable recovery except where better sources are far removed. In some areas, however, we should also expect to find submarine deposits of phosphate pellets a few feet to, rarely, several tens of feet in thickness, and in places, successive layers should be found beneath the sea bottom. Some phosphorite will be mixed with organic matter, some with diatoms and other siliceous organic remains, and some with sand. With regard to phosphatic sands, it is well to keep in mind that they can occur as beaches and bars. Phosphorite pellets have a density of about 3.0 and are concentrated as placers under favorable circumstances. The offshore bar near Santa Rosalia, Baja California (Wyatt, 1956) is a good example of such a deposit. The total phosphate content of such sands may be only a few percent, but the phosphate grains can be concentrated cheaply. This type of occurrence should be kept in mind in examining placers primarily valuable for other minerals. For example, phosphate is known to occur off the coast of Southwest Africa; do the diamond-bearing placers there also contain recoverable quantities of phosphate?

It is possible that saline deposits may be found at shallow depths beneath the sea bottom in some areas of upwelling, and it is also possible that potassium- and magnesium-rich brines may be found in estuaries and ground water in the coastal deserts adjacent to strong areas of upwelling. Such brines have been discovered in recent years in the Sechura desert of Peru, and they should be sought elsewhere, particularly in Baja California, and along the west coast of Africa.

The organic-rich muds that should be associated with some phosphate deposits on the present sea bottom have been little explored thus far, but from knowledge of fossil deposits some of them may be presumed to be rich in hydrocarbons (Brongersma-Sanders, 1948), sulfur, and minor metals. Even though there may be no present commercial interest in hydrocarbons in muds on the present sea bottom, the upwelling province generally has excellent prospects for oil and gas, both on the continental shelf and the adjacent coastal plain. By no means is all petroleum derived from source beds deposited in the upwelling environment; in fact, the petroleum in most fields probably has no genetic relation to upwelling. Nevertheless, the rate of production of organic matter in the upwelling environment is much greater than that in other environments (Ryther, 1963; Wooster and Reid, 1963), and the petroleum fields that appear to be genetically related to such source beds (some of those of California and Venezuela, for example) are extremely rich. The areas of upwelling shown on fig. 2, particularly those of divergent upwelling, are therefore favorable provinces for offshore petroleum exploration.

Another submarine terrane, not necessarily related to upwelling, that deserves consideration for its petroleum potential is that beneath the deep ocean floor and continental slope (Hess, 1962, McKelvey, 1966). Thus far these environments have barely been mentioned as possible petroleum-bearing provinces, but the success of the Mohole drilling indicates that they may soon become accessible to the drill. The question is, then, do they contain petroleum? It is easy to think of reasons why they do not contain significant amounts--the thin sedimentary section, high chance of destruction of organic matter prior to burial, probable lack of warping or folding over many areas and consequent lack of drive for migration and of traps for accumulation. But the ocean floor is complex geologically. We may assume that much, perhaps even most, of it does not contain recoverable petroleum, just as most of the land area does not, but this could leave a still enormous province. Consider, for example, the nutrient-rich waters along the equatorial currents and those in polar regions that are so productive of organisms. Consider the possible local accumulation of moderately thick sediments generated within the ocean by volcanic, chemical, or biochemical processes, or brought to it by turbidity currents. And consider evidence for diastrophic movements of the ocean floor, suggested by its topography and by geophysical observations. Areal coincidence or concatenation of these phenomena might well lead to the accumulation of petroleum. And with the possible lateral shift of ocean currents over geologic time with polar migration and continental and island development, favorable environments might be widely distributed.

Oil seeps are known in the Gulf of Mexico beyond the limits of the continental shelves (Pepper, 1958), and numerous structures suggestive of salt domes have been identified there in the Sigsbee Deep and on the upper continental slope (Ewing, Worzel, and Ewing, 1962; Ewing and Antoine, 1966; Murray, 1966). The Mozambique Channel between Madagascar and the African continent is believed by Pepper and Everhart (1963) to be underlain by a large synclinorium, and seismic profiling has identified many areas in all the oceans in which there appear to be sediments 4 to 5 km in thickness (Ewing and Tirey, 1961). It is not possible yet to say that these or other structures contain recoverable petroleum, and it may be some time before petroleum exploration on the deep ocean floor is practical. But in view of the magnitude of future needs for petroleum, the possibility that

recoverable petroleum occurs beneath the ocean floor surely deserves serious study.

RESIDUAL DEPOSITS OF TERRIGENOUS ORIGIN

Residual deposits of terrigenous origin include sand, gravel, gold, platinum, diamond, monazite, cassiterite, magnetite, ilmenite, rutile, scheelite, chromite, and other resistates; and aluminum-rich clays and other hydrolyzates. Of these, it is the heavy mineral placers that are of chief current interest, and that will be the principal subject of the discussion here.

Placers in the marine environment are mainly confined to the inner edge of the continental shelves in beaches, raised beaches, submerged beaches, offshore bars, and buried river channels. In some areas, however, there are offshore deposits related to bottom topography and offshore currents rather than to beach or alluvial processes (Griggs, 1945).

The geographic distribution of placers is controlled by a number of variables that may be essentially independent of one another, including: petrography of the source terrane, climatic and tectonic history in both source terrane and depositional environment, present and ancestral drainage pattern, and present oceanic circulation. In attempting to define areas favorable for submarine placers, one of the simplest and surest approaches is to begin with the known beach placers (see Hess, 1965, for a good summary). Figure 5 shows those that are past or present producers, and most of these localities would be prime targets for exploration offshore. It was this type of clue, for example, that led to the recent discovery of diamonds off the coast of Southwest Africa (Bascom, 1964) and that has stimulated exploration for gold off the coast of Alaska. One promising lead of this type has been identified by W. C. Overstreet (Olson and Overstreet, 1964, p. 30), who points out that "the interesting possibility, apparently as yet unexplored, exists that in the Gulf of Mannar area, shallow-water deposits along Adams Bridge between India and Ceylon may contain monazite. Beach placers are present on opposite shores of the Gulf. Currents setting northeastward through the Gulf may effect along-shore transport of monazite and concentrate it, as a great natural riffle, on the beaches near and in the shallow water of the Adams Bridge area." Also of much interest to the prospector are occurrences of beach placers not yet under production (fig. 5); there are many of these, and some may well provide clues to workable offshore deposits.

Drowned channels of rivers that contain placers upstream, or of rivers that cross terranes known to have lode deposits may also be considered favorable areas. The offshore tin deposits of Billiton, Indonesia (Van Overeem, 1960), and some of those of Thailand are drowned alluvial deposits discovered from this kind of evidence.

Beyond these clues provided by known mineral deposits, there are some general principles that may help define broad areas promising for marine placers. Nearly all valuable placer minerals are formed by igneous, hydrothermal, or metamorphic processes, so of course the regional proximity of source terranes that contain intrusive igneous and metamorphic rocks is a generally favorable feature, even though many individual placers are formed by the reworking of older marine or alluvial deposits. The presence of older coastal plain sediments seaward from the source terrane is also a favorable feature, for such deposits often form a protore from which the present beach sands are concentrated (W. C. Overstreet, unpub. data). For example, belts of monazite-bearing sediments back up the beach placers in India, southeastern United States, and Brazil, and older sediments are in part the source of the chromite beach placers of Oregon (Griggs, 1945) and the ilmenite placers along the southern coast of Queensland, Australia (Gardner, 1955).

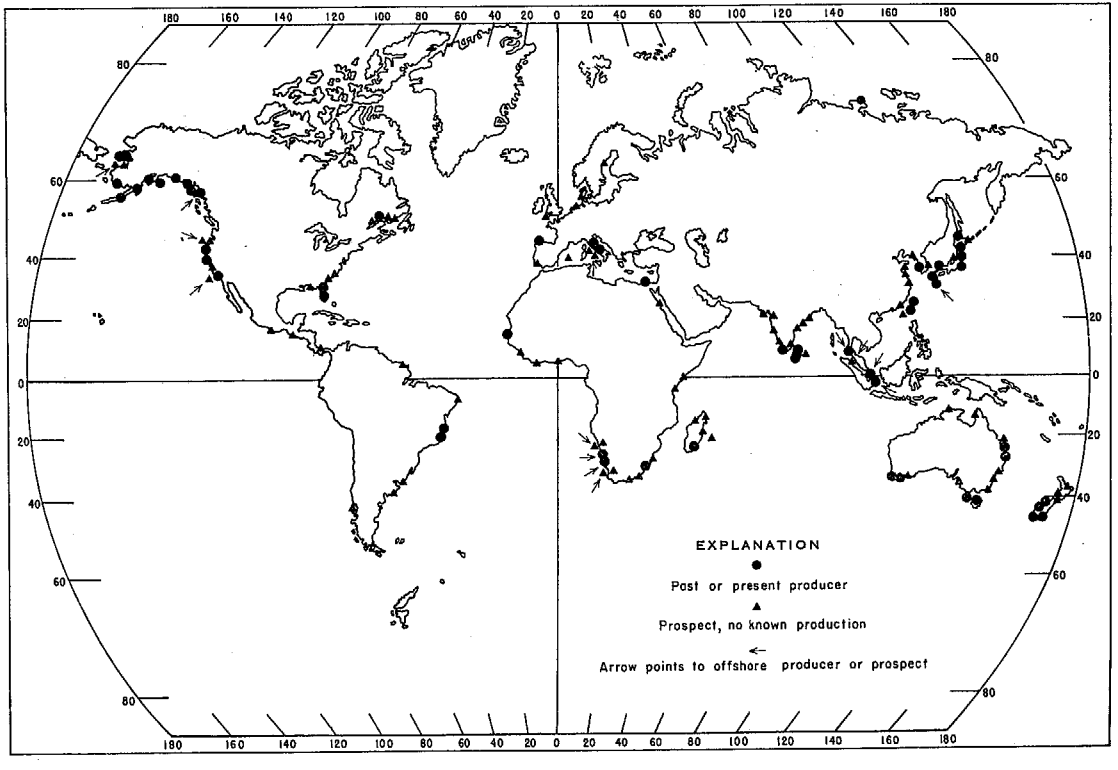

Figure 5. World distribution of coastal placer deposits

Equally important is the climatic history of the source terrane. Deep chemical weathering sets the stage for placer development by decomposing many of the silicate minerals of the host rock and increasing the ratio of the heavy, valuable mineral grains to the light, nonvaluable ones. It is significant that many of the world's great placer districts--India, Ceylon, Thailand, Indonesia, and Brazil, for example--are in areas of tropical or subtropical climate (W. C. Overstreet, unpub. data); other placers, such as those in California, were derived during periods of deep weathering in the Tertiary (Chaney, 1932; Jenkins, 1935). In a totally different climate, rapid physical disintegration of host rocks accomplished through frost weathering is also effective in liberating heavy minerals from source terrane. According to David Hopkins (oral communication, 1966), frost weathering is a key agent in the formation of Alaskan placers. Glaciation, however, particularly continental placiation, generally makes a negative rather than positive contribution to placer formation, for it mixes and hence dilutes rich source materials with the lean on a vast scale. Workable placers, therefore, are rarely derived from drift and are uncommon in glacial outwash (Jenkins, 1935).

Aside from submerged residual and alluvial placers, the marine placers are concentrated by waves and currents, and it has long been observed (Raeburn and Milner, 1927, p. 48) that big seas and a persistent wind direction are favorable for the development of placers on modern beaches. Strong alongshore currents also may lead to the development of placers, perhaps a long distance from the source terrane. Grain size is commonly reduced during such transport, and there is some tendency for enrichment in rutile and zircon in the heavy-mineral assemblage as weak minerals (e.g., gold, magnetite, and monazite) are destroyed by abrasion, solution, or attrition.

The efficiency of the bedrock or substrate in trapping heavy minerals is also an important factor in the localization of placer deposits (McKinstry, 1948, p. 227) and may be an element worthy of scrutiny in prospecting, particularly in searching for minable deposits within favorable areas. Rocks whose surfaces tend to be pitted or cracked are more effective traps than those with smooth or homogeneous surfaces.

Tectonism may also influence the formation of marine placers. In the fossil record, the most pronounced basal conglomerates are associated with transgression, and in modern placers in areas where there are several shorelines, the richest deposits are generally associated with the highest beach. Shorelines of submergence, particularly where open, heavy seas are transgressing deeply weathered favorable source terrane, are good areas for prospecting, whether or not beach placers are already known to occur in the area.

Aluminum-rich clay and bauxite in the marine environment are not of much interest now, but they may have some potential. Along with the heavy residual minerals, they are best developed in areas of deep weathering. Known deposits over the world are mainly in areas of tropical and subtropical weathering, and Goldberg (1964)has shown that even in the deep sea, sediments at low latitudes are enriched in hydrolyzate minerals. It goes without saying that residual clays and hydraulic placers are locally antithetic, even though both may be found within the same climatic environment. Residual clays may be preserved on the bottom in transgressing seas where wave and current action is not intense, and transported clays may be looked for in deeper, quieter water than is favorable for the concentration of placers.

HOT-SPRINGS MANGANESE DEPOSITS

Interest in manganese in the marine environment has focused largely on the manganese oxide nodules, which are extremely widespread in both deep (Mero, 1965) and shallow (Manheim, 1965) water. Extensive though these deposits may be, they are comparatively low grade and pose difficult recovery problems. There is a potential in marine sediments, however, for

a different kind of deposit; the thick, high-grade deposits of manganese oxides or carbonates associated with submarine hot springs or volcanic exhalations. D. F. Hewett (1966) has described these deposits rather fully from the fossil record, and has presented ample evidence for their hot-spring origin. Iron and manganese precipitates have recently been identified from the submarine Banu Wuhu volcano, Indonesia (Zelenov, 1964), and hot brines from which iron oxides, manganese oxide and carbonate, and other metals are precipitating have been found in deeps of the Red Sea (Miller et al, 1965). Manganese-rich nodules of this apparent origin have also been found off the southeastern coast of Japan (Niino, 1959). Judging from the fossil record, some strata-bound iron sulfide (Kinkel, 1966), iron oxide, and cinnabar deposits may also be of hot-spring origin, and other metals are not uncommonly present with the manganese oxides.

The origin of the deep sea manganese nodules has been controversial, but is not at issue here. Regardless of how the scattered and widely distributed nodules may form, there is no doubt that some manganese deposits do form in the submarine environment from hydrothermal solutions related to centers of volcanism. From the evidence of the fossil deposits, some of these should be of high quality, range from a few to scores of feet in thickness, and should be composed of either manganese oxide or manganese carbonate, often in a nonnodular texture (Hewett, 1966). Unlike many of the nodule occurrences, which are scattered over wide areas and accumulate very slowly, the stratified deposits are lens shaped and are confined to areas a few or a few tens of square miles or less in size, and they apparently accumulate relatively rapidly. High-grade deposits of this type probably contain only a fraction of the total manganese and other metals in the deep-sea nodules, but many could be mined now if found, and they constitute a practical target for current exploration. Areas of active or recently active volcanism are the prime regional targets for such deposits, and within them points or trends (in shallow water perhaps identifiable as thermal anomalies by aerial infrared surveying) of hot-spring discharge may be clues to the location of specific deposits.

CONCLUSION

The sea bottom represents an enormous future source of minerals, for even if only a fraction of it is underlain by usable deposits its great size insures a tremendous potential. Even though the marine minerals industry already has an annual production worth nearly $4 billion, it is still in its infancy, and the potential of the marine environment is largely unexplored.

The success already achieved in submarine exploration for oil and gas, sulfur, tin, and diamonds demonstrates the utility of available field procedures and instruments in prospecting and clearly shows that the incentive of a profitable target can be matched by the capability for finding it. Full use of available data and principles to select the most favorable areas for prospecting should both improve its effectiveness and reduce its cost.

In seeking to narrow the prospecting target, it is perhaps worth emphasizing that it is the continental shelves and the shallower parts of the sea that are not only most accessible to exploration and mining, but that contain most of the presently valuable deposits. For the more distant future, the entire ocean floor is fair game, and if parts of it should prove to contain petroleum and if means are found to prospect and mine hypogene minerals such as may exist in some of the submarine ridges, the deep ocean may yield a variety of important minerals. It appears, however, that large areas of the sea floor are likely to contain not much more than a very narrow spectrum of low-grade and low-value deposits--nothing to compare in variety or richness of concentration with many minerals in the

shelf environment. For the immediate future, then, activities directed toward subsea mineral prospecting and development should focus on the shelves.

Within highly favorable areas, reconnaissance prospecting can be highly effective, and it need not await the availability of geologic maps and related data. Prospecting on the sea bottom, as on land, will be most effective, however, when it can be carried out in the light of good understanding or areal geology. Recognizing the shelf as the broadly favorable area of the marine environment, it would, accordingly, be highly desirable to extend systematic geologic mapping and related geophysical surveys at scales of 1:1,000,000 and larger over the continental shelves.

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REVIEW OF MINERAL VALUES ON AND UNDER THE OCEAN FLOOR

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ABSTRACT

For consideration of mineral deposits, the ocean can be divided into several regions, the beaches, seawater, the continental shelf, the deep-sea floor, and the rocks underlying the ocean floor. In the offshore beaches are found placer deposits of gold, platinum, diamonds, magnetite, ilmenite, zircon, rutile, cassiterite, scheelite, calcium carbonate, sand and gravels, and columbite. Reserves of economic mineral deposits in the offshore beaches have never been defined adequately, but are estimated to be several times that of the known onshore beaches. From seawater is obtained bromine, magnesium, common salt, potash, magnesium compounds, soda gypsum, uranium and fresh water. Seawater is also a potential economic source of sulphur, borax and fluorine using present technological methods of extraction. A recently developed technique may make seawater a potential source of many minerals. Reserves of any material taken from seawater are essentially unlimited. The continental shelves hold deposits of calcareous shells, phosphorite, glauconite, barium sulphate nodules, and placer deposits of heavy minerals in submerged river channels. The economic phosphate reserves of the shelf are estimated to be in excess of 200 billion tons. The subsea floor rocks contain deposits of oil, gas, sulphur, salt, coal, iron ore, and, possibly, other mineral deposits in veins as on land. On the deep-sea floor are found essentially unlimited deposits of manganese, nickel, cobalt, copper, iron, molybdenum, vanadium, diatomaceous earth, limestone, and other metals. In most cases, deposits of the minerals found in the deep sea are forming at rates greatly in excess of present day world consumption of these materials.

Introduction

While the ocean contains innumerable mineral deposits, only a fraction of these deposits can be considered economically exploitable at the present time. Nevertheless, those deposits which are economically exploitable are of sufficient volume to provide the world with its total consumption of many industrially important minerals for thousands of years at present rates of consumption. Given this knowledge, why is it that the minerals industry is moving so cautiously into the offshore? It is not because the deposits of solid minerals are not in the offshore area for they definitely are. And, in many cases they are very high-grade deposits. It is also not because these offshore mineral deposits are difficult to find, for sea-floor accumulations of gold, diamonds, platinum, tin, manganese, nickel, cobalt, copper, phosphorite, and so on are among the least difficult of mineral deposits on earth to discover and explore. The bulk of these deposits are

either lying directly offshore of deposits exploited from the adjacent onshore area or they are lying exposed at the surface of the sea floor. It is also not because these deposits are difficult to exploit for gravels, sands, and nodules lying exposed at the surface of the offshore sediments are among the least difficult of materials on earth to mine.

When considering, however, that almost 60 years elapsed between the time offshore oil deposits were discovered and the time they were being exploited on a large scale, it may be premature to assume that the mining industry is moving too slowly into the offshore area. For many of the sea floor mineral deposits have only comparatively recently been recognized for their economic value. Then too, while the offshore oil deposits are substantially no different in their geologic character than those onshore, many of the offshore solid mineral deposits are. Ocean miners, consequently, are faced with a doubly difficult task of dealing, not only with a new environment in which to work, but a new type of deposit as well. Thus, the major reasons for the default of the mining industry in moving aggressively into the offshore can apparently be summed up as due to a lack of dissemination of adequate information as to the nature of the mineral deposits of the sea and due to underdeveloped technologies for extracting many of the minerals found therein. We must also include in this default the extreme caution of the minerals industry throughout the world in approaching new technologies. It is, however, a caution bred from the hazards of working with an environment that is difficult to understand, capricious in its reaction to men's efforts to subdue it, and only grudgingly yielding of its riches.

THE DEPOSITS OF THE SEA

Annually, the rivers of the world dump hundreds of millions of tons of material into the sea. Most of the clastic sediments rapidly settle to the seafloor in near shore areas. The dissolved load of the rivers, however, mixes with seawater and is gradually dispersed over the total oceanic envelop of the earth. While the kinetics of chemical reactions in the sea is generally almost immeasurably slow, because of its immense size, the ocean is acting on a significant scale to separate, recombine, and eventually concentrate on the seafloor many of those minerals which are found to be necessary in an industrial society. As a result of this concentrating process, the ocean floor holds many mineral deposits which, if found on the continents, would be considered high-grade ores.

Because of the nature of the minerals contained therein, it is convenient to consider the deposits of the sea as occurring in several environments: 1) marine beaches; 2) seawater; 3) continental shelves; 4) subsea-floor consolidated rocks; and, 5) the deep-sea floor. Minerals are presently mined from all of these regions save for the deep-sea floor which has only recently been recognized

as a repository for mineral deposits of unbelievable extent and truly significant economic value. The types of minerals found in the offshore areas are indicated in Table I.

Marine Beach Deposits

Because of the crushing, grinding, and concentrating action of the ocean surf, much of the processing of minerals in the beaches has been done by nature. What mining and processing is left to do is, in general, uncomplicated and inexpensive. Beach deposits of unusually low-grade, thus, are often economic to exploit. From marine beaches come diamonds, gold, magnetite, columbite, ilmenite, zircon, scheelite, monazite, platinum, and silica, to mention the most important commercial minerals. Beaches have been mined for many years in some areas of the world with periodic storms, in some cases, replenishing the mined out areas such as in Ceylon where the same areas of the same beaches are mined on a seasonable basis. In general, however, present beach deposits tend to be of a limited extent. In the offshore areas, however, can generally be found a series of beaches which contain minerals of the same type as the onshore beaches. During the Ice Ages, sealevel was appreciably lowered as the ocean water was transferred to the continental glaciers. Because of the cyclic nature of the Ice Ages and the intervening warm periods, a series of beaches were formed in areas offshore present beach deposits. Thus, the offshore potential is generally much greater than the onshore for mineral production. With recently developed sonic devices, it is not difficult to locate and delineate these submerged beaches. At the present time, it is quite impossible to assess the total mineral content of the offshore beaches, however, it is safe to assume that this potential is at least five to ten times the onshore potential.

An interesting facit of beach deposits it that they tend to contain mineral streaks that are abnormally rich. Along the south shore of the Seward Peninsula in Alaska, beach deposits have been located which contain as much as $250 worth of gold per cubic yard of gravel (Brooks, et al., 1901). While these paystreaks tend to be limited in size (normally yielding less than about $1 million in total values) they are highly economic to exploit and, thus, most important as capital resource generators. Because of the large number of beaches to be found in the offshore area, it can be expected that the number of these high-grade paystreaks will also be large and that the total values contained therein will be substantially more than found in the present sea level beaches. While the techniques of finding and blocking out such deposits are rather sophisticated, it is only recently that industry has considered the problems involved in exploiting these offshore placer deposits. Offshore mining technology, however, is developing at an accelerating pace, and it can be expected that substantial advances will be made in this field in the next few years.

Table 1

Mineral Deposits of the Sea

Region	Minerals of Interest
MARINE BEACHES	Placer deposits of gold, platinum, diamonds, magnetite, ilmenite, zircon, rutile, columbite, chromite, cassiterite, scheelite, worlframite, monazite, quartz, calcium carbonate, sand and gravels.
CONTINENTAL SHELVES	Calcareous shell deposits, phosphorite, glauconite, barium sulphate nodules, sand and gravels, placer deposits in drowned river valleys of tin, platinum, gold, and other minerals.
SUBSEA-FLOOR ROCKS	Oil, gas, sulphur, salt, coal, iron ore, and, possibly other mineral deposits in veins and other forms as in the rocks on land.
SEAWATER	Common salt, magnesium metal, magnesium compounds, bromine, potash, soda, gypsum, and potentially, sulphur, strontium, borax. Most other elements can be found in seawater and given recently developed extraction techniques seawater is a potential source of uranium, molybdenum, etc.
DEEP-SEA FLOOR	Clays - for structural uses, possibly also for alumina, copper, cobalt, nickel and other metals. Calcareous Oozes - as cement rock and other calcium carbonate applications. Siliceous Oozes - as silica and in diatomaceous earth applications. Animal Remains - as a possible source of phosphates and metals such as tin, lead, silver, and nickel. Zeolites - as a source of potash. Manganese Nodules - as a source of manganese, iron, cobalt, nickel, copper, molybdenum, vanadium, and possibly many other metals.

Seawater

Seawater is generally considered to have dissolved in it all of the natural elements. Covering an area of about 140 million square miles at a mean depth of about 2.5 miles, the sea holds about 330 million cubic miles of water. Seawater contains an average of about 3.5 percent of elements in solution, thus, each cubic mile of seawater, weighing about 4.7 billion tons, holds about 166 million tons of solids. Nine of the most abundant elements constitute over 99 percent of the total dissolved solids in seawater. Only four of these elements are commercially extracted at the present time to a notable extent; sodium and chlorine in the form of common salt, magnesium and some of its compounds, and bromine. Several calcium and potassium compounds are produced as by-products in salt or magnesium extraction processes, and, with the continued interest in fertilizer production, the day is probably not far off when potash will be commercially extracted from the sea.

The commercial extraction of any element or compound from the sea, of course, immediately makes reserves of that material unlimited, and such is the case for magnesium and bromine, the bulk of which are extracted from seawater for consumption in the United States. Bromine is almost purely a marine element; over 99 percent of the bromine in the earth's crust is in the ocean. There is about $0.02 worth of bromine per ton of seawater, thus, when being processed for this element, seawater is probably the lowest-grade ore known. More significant, the $0.02 per ton of contained element value is probably the lower limit of ore grade when considering seawater as a source of any element by using conventional extraction techniques, that is, by taking the water out of the ocean, pumping it through a plant, adding some reagent to the water, performing a chemical or physical separation technique, and exhausting the barren seawater in a manner so as not to contaminate the incoming seawater.

Unconventional techniques have recently been developed, however, which may permit the recovery from seawater of many elements with a concentration much less than that of bromine. The National Physical Laboratory in Great Britain recently announced the development of a technique which permits the recovery of uranium from seawater at a cost competitive with that of winning uranium from low-grade continental ores. This technique utilizes an ion exchange resin which is highly selective for uranium ions in the presence of the vast excess of other ions present in seawater, and tidal currents to flush the seawater through the resin beds. There is about $0.0001 worth of uranium per ton of seawater, however, considering the nature of this process, we cannot assume that this concentration is at all a lower limit to the value of an element that can be extracted from seawater using this technique. Table 2 lists several of the elements that may be extracted by this process. Extension of this technique to any other of

Table 2

Chemical Analyses of Sea-Floor Phosphorite Off California

Element	Southern California Offshore Area	Northern California Offshore Area	Florida Phosphate Rock, Typical
P_2O_5	31.9	32.2	31.3
CO_2	4.8	4.8	3.67
Fe	1.9	0.88	1.0
Mg	0.56	0.44	0.22
SiO_2	4.25	7.43	9.55
Al	3.46	1.74	0.67
F	3.51	3.34	3.70
Cl	0.028	0.027	0.020
Ca	33.08	32.0	32.8
Na	1.41	1.45	0.16
K	0.36	0.26	0.13
Moisture	1.54*	1.26*	-

*Samples were crushed, pulverized and dried at 100°C to constant weight prior to analysis.

the elements in seawater, of course, immediately makes reserves of that element, as far as world consumption is concerned, unlimited. It would be entirely practical to anchor porous bags of these resins in areas of the ocean of high current flow or in the outfall of the cooling systems of seaside power plants or possibly to tow such bags behind merchant ships. Imaginative engineering such as the British have brought to bear on this matter, thus, could turn seawater into a major source of almost all minerals necessary to industrial societies.

Another concept which should be evaluated when considering seawater as a source of minerals is that of orebodies within seawater itself. As concerns the major elements dissolved in seawater, seawater is fairly uniform in composition. Where the trace elements are concerned, seawater is not of a uniform composition. Values of gold in seawater as high as 60 mg per ton have been found. Such a concentration works out to be about $0.06 worth of gold per ton of seawater. Even using conventional extraction techniques, a body of seawater containing 60 mg of gold per ton could be considered a high-grade gold mine if that body of water were of sufficient size. Thus far, very little work has been done to assess the size of these "high-grade" bodies of water within the ocean. In his general reconnaissance of the ocean, Haber (1927) found that the average content of gold in seawater was only about 0.004 mg per ton, or about 4×10^{-6} worth of gold per ton.

Recently a body of water was found in the Red Sea that contains from 1000 to 50,000 times as much of such elements as iron, copper, manganese, and lead as does normal seawater (Miller, et al., 1965). Given the evaporating conditions of the desert along the Red Sea, this body of water can probably be considered a mine of these elements and possibly several others. There are other bodies of water, notably the Mediterranean Sea, in which such "orebodies" can possibly be found. Thus, it is possible to consider the seawater in the same context as the land as far as mineral deposits are concerned, that is, that the sea is not uniform in its composition, any more than the solid crust of the earth is uniform in its composition. Deposits, or bodies of water, of unusually high concentrations of elements exist in the sea as in ore deposits on land.

FRESH WATER

Fresh water, although not normally considered a mineral, is, potentially, one of the most important materials that can be extracted from seawater. In a few areas of the world such as Curacao Island and Kuwait for economic reasons, and Guantanamo Bay for political reasons, fresh water for domestic and industrial purposes is extracted from seawater. In the United States, a number of plants have been constructed and placed into operation to study the various methods of extracting fresh water from the ocean. In gen-

eral, the production cost of the most efficient of the processes capable of recovering fresh water on a large scale from seawater at present is several times the cost of obtaining it from the ground or water sheds. Proposed large-scale nuclear reactor plants, which would produce electrical energy in conjunction with fresh water, however, appear to have very favorable production costs, especially in water short areas such as Southern California. Removal of water, of course, leaves the seawater enriched in salts and frequently higher in temperature. In conjunction with a seawater conversion plant, therefore, it would probably be profitable to operate a minerals extraction facility. Preliminary calculations have indicated that the production cost of fresh water can be lowered several cents per thousand gallons by extracting minerals from the effluent of such plants. If operated on a scale necessary to water some of the world's great seaside deserts, however, the production of minerals from seawater conversion plant effluents would grossly exceed present world consumption of a number of minerals such as salt or mganesium, but would produce disposable quantities of potassium, sulphur, or boron minerals.

Continental Shelves

The continental shelves of the world cover an area of about 10 million square miles or about 20 percent of the above water continental area of the earth. As the rocks of the continental shelves are basically similar to those of the adjacent continental areas, it can be expected that the mineral producing potential of the shelf rocks should be similar to that of the onshore orcks. And, in the case of petroleum, at least in the Gulf of Mexico area and off California, such is proving to be the case. Because of their cover of water, however, the continental shelves hold other types of mineral deposits which are economic to exploit with present day methods.

CALCAREOUS DEPOSITS

Calcareous shells are mined from offshore deposits in a number of locations, notably in the Gulf of Mexico, in San Francisco Bay and off Iceland. Since 1940 over 60 million tons of shells have been recovered from the area off eastern Texas for use in various chemical processes. One notable use is in the manufacture of lime for use in the precipitation of magnesium from seawater at the Dow Chemical Company plant at Freeport, Texas.

An interesting shell deposit is mined about five miles off the southwest coast of Iceland to provide the raw material for a local cement industry in that country. A shoal of rock lying west of the deposit is home to a large population of various kinds of shelled animals. The winter waves break the shells free, crushing and grinding them. Tidal currents sweep the particles into Faxa Bay. The influx of shell material far exceeds the rate of extraction; thus, this deposit is a replenishing mineral deposit as opposed to land mineral deposits which are generally considered as depleting resources when mined. This renewing feature is

a common, and highly significant, feature of mineral deposits in the sea.

Calcareous deposits are also mined off the coasts of Hawaii and the Bahama Islands.

GLAUCONITE

Glauconite is an interesting authigenic mineral found in considerable quantity in various offshore locations. Frequently, it is found in deposits relatively uncontaminated with other materials. Being fine-grained and having no overburden would allow mining costs of less than $1 per ton for this material. Containing from four to nine percent of K_2O, the sea floor glauconite might be a source of potassium for agricultural fertilizers considering that its occurrence off the coasts of a number of nations would appreciably lower transport costs in moving this material to market. Glauconite is also used as a soil conditioner, in which application, the sea floor material could be utilized without expensive upgrading processes.

PLACER DEPOSITS ON THE SHELF

In Malaysia, Thailand, and Indonesia, tin is mined from river placers onshore to the present sealevel. These deposits in many cases extend into the offshore areas. About ten dredges are presently operating in the Southeast Asian offshore tin fields and several new dredges are under construction for future operations in this area. Such deposits are beginning to show up with increasing frequency, mainly because of the use of new seismic prospecting methods which allow rapid delineation of these sea-floor features even though the valleys and adjacent ridges are now completely buried by sediments. Drowned river valleys may also hold substantial placer deposits of gold and platinum off Alaska and of diamonds off the mouth of the Orange River in South-West Africa.

What is the estimate of the values in these offshore river channels? This value is almost impossible to ascertain given the present data, however, we can expect it to be at least equal to the onshore potential considering the enormous extent of the continental shelf in the areas where such offshore placers are being found. If sealevel were to be lowered about 300 feet, an area almost as large as above water Alaska would show up in the Bering Sea, and, in Southeast Asia, such a lowering of sealevel would uncover a land area as large as Australia.

SEA-FLOOR PHOSPHORITE

Of some interest at present are the phosphorite deposits found on the shelves off the coasts of many nations of the world. Thus far, phosphorite deposits have been found off Peru, Chile, Mexico, the west and east coasts of the United States, off Argentina, South Africa, Japan, and on the submerged parts of several islands around the Indian Ocean. At least 50 percent of the continental shelf area of Australia is presently under concession for phosphorite exploration. Such deposits, if found in this area, would be extremely valuable because the soils in Australia are

phosphate-poor, forcing that country to import large quantities of this material

Off California, the sea-floor phosphorite occurs as nodules which vary in shape from flat slabs, several feet across, to oolites. The nodules are commonly found on the sea floor as a monolayer at the surface of coarse-grained sediments. The composition of the phosphorite from the California offshore area is surprisingly uniform. As indicated in Table 3, these offshore phosphorite deposits contain economically attractive amounts of phosphorous. While it is estimated that there are about one billion tons of phosphorite in the California offshore area (Emery, 1960), probably not more than 100 million tons of this phosphorite would be economic to mine at the present time. Much of this offshore phosphorite is found in topographic environments from which it would be extremely difficult to recover and much of the near shore phosphorite is intermixed with gangue materials from which it would be difficult to separate at a reasonable cost. Still, the 100 million tons which are probably economic to mine would constitute a 200 year reserve at the present rate of consumption in the state of California. World-wide tonnage estimates of offshore phosphorite would probably be at least 100 times the amount estimated to be in the Southern California offshore area.

Just recently, a new type of sea-floor phosphorite deposit has shown up off the west coast of Mexico. This fine-grained, unconsolidated deposit of marine apatite lies in about 70 meters of water. Its total extent has yet to be assessed, however, its known dimensions are at least 60 by 160 kilometers in lateral extent. Its depth has also yet to be determined, however, a seismic probe survey indicates a depth of this deposit of at least 20 meters. The grade of this deposit is not overly spectacular, averaging possibly about 15 percent apatite, however, one section of the deposit covering an area of about 20 by 30 kilometers assays as high as 40 percent apatite. The only overburden on this deposit is water and the technology of mining it has been worked out in the shell mining operation off Iceland. The apatite grain size distribution is quite limited and, since most of the gangue materials are contained in a clay-sized fraction, phosphate material from this deposit should be quite easy to concentrate to an acceptable grade. Considering only the high-grade section of this deposit, there should be at least 200 billion tons of recoverable phosphate materials which is about 4,000 years reserves at the present rate of world consumption of this very important mineral commodity. The very recent discovery of this deposit was almost totally accidental. No one was looking for it. How many other such deposits can be found on the continental shelves of the world? We really won't know until we start looking for them in earnest.

Table 3

Status of Economic Extraction Technologies for Various Minerals from Seawater

Material	Concentration in Seawater (mg/l)	Total Amount of Material in Seawater (Tons)	Value of Material in a Ton of Average Seawater ($)	Reserves of Material at Present World Consumption Rates (Millions of Years)	Status of Extraction Technology*
NaCl	29,500	45.6×10^{15}	0.31	+1000	E.
Magnesium	1,350	2.1×10^{15}	1.00	+1000	E.
Sulphur	885	1.4×10^{15}	0.03	200	E.
KCl	760	1.2×10^{15}	0.024	300	E.
Bromine	65	100×10^{12}	0.02	1000	E.
Borax	50	70×10^{12}	0.003	700	N.E.
MoO_3	0.1	25×10^{9}	0.0003	1	P.I.E.
U_3O_8	0.006	10×10^{9}	0.0001	0.5	E.I.E.
Silver	0.0003	5×10^{8}	10×10^{-6}	0.1	E.I.E.
Gold	0.000004	6×10^{6}	4×10^{-6}	-	P.I.E.
Tin	0.003	5×10^{9}	6×10^{-6}	0.1	P.I.E.
Nickel	0.002	3×10^{9}	4×10^{-6}	0.01	P.I.E.
Copper	0.003	5×10^{9}	6×10^{-6}	0.001	P.I.E.
Cobalt	0.0005	1×10^{9}	1×10^{-6}	0.1	P.I.E.

*E. = Economic with present extraction techniques.
N.E. = Not economic with present conventional extraction techniques.
P.I.E. = Possibly economic with ion exchange extraction techniques.
E.I.E. = Economic at present with ion exchange extraction techniques.

SAND AND GRAVEL

Probably the most prosaic of mineral commodities is sand and gravel, however, from a tonnage standpoint, it is easily the most important mineral commodity mined in the world. All industrial societies need copious quantities of this material in the manufacture of concrete, for fill, and for a myriad of other uses. Until recently, such material was generally extracted from pits near the market. Zoning regulations, however, are making the opening of new pits near cities impractical. In many areas, construction gravels are now costing the user as much as $6 per ton, about 75 percent of this charge being transport costs. Especially along seaboard areas is the shortage of construction gravels acute.

The offshore areas, of course, are well supplied with sand and gravel deposits, and, in some areas, notably off England, exploitation of these deposits has been initiated. Off the northeast coast of New Jersey an extensive deposit of this material has recently been discovered (Schlee, 1964) which deposit could easily supply the New York area at very favorable rates. Because much of the world's population is concentrating in the seacoast areas, the offshore gravel deposits will become increasingly important sources of this material. Estimates of offshore reserves of gravels cannot be realistically made at this time, however, data are now being gathered which should shortly allow cursory estimates to be made for the United States east coast area and for the Southern California area.

An important application for offshore sand and gravel is in the building or replenishing of beaches. Off Florida, sand is mined to replenish eroded beaches on Jupiter Island. In California authorities are finding it more economic to build addtional beach area for recreational purposes rather than buy waterfront footages which may cost in excess of $1 million per acre.

Subsea-Floor Consolidated Rocks

In areas offshore England, Japan, Newfoundland, and Finland, coal and iron ore are mined from subsea-floor rocks. These deposits are generally exploited by sinking shafts in the onshore rocks and driving drifts out under the sea and into the orebodies. Offshore methods, however, are used to discover and delineate these orebodies.

Sulphur deposits are also found in the offshore areas, notably in the caps of salt domes. One such deposit was located while drilling for oil about seven miles off Grand Isle, Louisiana. This deposit is now mined by the Frasch process from the largest steel island ever built by man in the sea. Much of the sulphur of the United States is produced from salt domes in the onshore areas around the Gulf of Mexico. Indications are that the concentration of salt domes offshore in this area is about the same as that onshore and it can be expected that the proportion of those domes containing mineable deposits of sulphur is about the

same also. Just recently, a group of about 10 companies bid an aggregate of over $33 million for leases on about 75,000 acres of potentially sulphur porducing ground about 60 miles off Galveston, Texas. One of the successful bidders on one tract in this area plans to start exploration drilling within the next few months.

The rocks of the continental shelf are basically similar in their geologic character to the rocks of the adjacent land area and it can be expected that the mineral producing potential is the same also. While we can expect to find vein and bedded mineral deposits within the rocks of the continental shelf, unless they can be exploited by conventional methods via shafts and drifts, it is unlikely that these deposits can be economically exploited with our present level of offshore mining technology.

The Deep-Sea Floor

It is the pelagic areas of the ocean, however, where nature is working on a truly grand scale to separate and concentrate many of the elements that enter seawater. The minerals that are formed in the deep sea are frequently found in high concentrations as in these areas of the ocean there is relatively little clastic material deposited to dilute the chemical precipitates. Eventually, the common igneous rocks of the continents may serve as a source of the minerals needed in any industrial society. The pelagic sediments of the ocean, however, will probably be considered first for these sediments contain an average of about ten times the amount of the industrially important metals as do the igneous rocks of the continents. These ocean-floor sediments also possess other advantages when being considered as a material to mine, that of being politically free and royalty free materials, they are widely distributed near most markets and are available to all on an equal basis. In addition, they are fine-grained, unconsolidated, and in a water atmosphere which makes the use of automated hydraulic systems for recovery practical.

RED CLAY

Red clay covers about 102 million square kilometers of the ocean floor. At an average depth of about 200 meters, there would be some 10^{16} tons of red clay on the ocean floors. At an average rate of formation of five millimeters per 1,000 years, the annual rate of accumulation of the red clays is about 5×10^{8} tons. Table 4 lists some statistics concerning the amount of and rate at which the elements are annually accumulating in these sediments. While, from a mineral resource standpoint, the composition of the red clays is not particularily exciting, this material may have some value as a raw material to be used in the manufacture of products such as construction materials or it may, in the future, serve as a source of various metals. While the average assay for alumina is about 15 percent, individual samples of red clay have assayed in excess of 25 percent alumina. Copper contents as high as 0.20 percent have been found in some red clays.

Table 4

Statistics on Amount of and Rate of Accumulation of Various Elements in Red Clay*

Element	Abundance in Red Clay (Weight Percent)	Amount in Red Clay (Trillions of Tons)	Rate of Accumulation in Red Clay (Millions of Tons/Year)	World Rate of Consumption (Millions of Tons/Year)	Ratio (Amount in Red Clay) / (Annual Consumption) $\times 10^6$	Ratio (Rate of Accumulation) / (Rate of Consumption)
Al	9.2	920.	46.	4.72	200.	10
Mn	1.25	125.	6.3	6.7	19.	1
Ti	0.73	73.	3.7	1.3	56.	3
V	0.045	4.5	0.23	0.008	550.	28
Fe	6.5	650.	32.5	262.5	2.5	0.1
Co	0.016	1.6	0.08	0.015	110.	5
Ni	0.032	3.2	0.16	0.36	8.9	0.5
Cu	0.074	7.4	0.37	4.6	1.6	0.1
Zr	0.018	1.8	0.09	0.002	900.	45.
Pb	0.015	1.5	0.08	2.4	0.6	0.03
Mo	0.0045	0.45	0.023	0.040	11.	0.6

*After Mero, 1965.

Nickel, cobalt, vanadium, lead, zirconium and several of the rare earth elements show up in red clays in amounts of several hundredths of a percent. An interesting aspect of the red clays is that the valuable minerals are generally contained in grains with a size range of 0.5 to 1 millimeter while the gangue materials are generally contained in clay-sized particles. Thus, a sizing process could easily produce a concentrate of the valuable metals from these ocean floor clays.

CALCAREOUS OOZES

Calcareous oozes cover some 128 million square kilometers of the ocean floor or about 36 percent of its total area. The average thickness of the calcareous ooze layers has been estimated to be about 400 meters. Thus, there should be at least 10^{16} tons of calcareous oozes in the ocean. These oozes are estimated to be forming at an average rate of about 1 centimeter per 1,000 years, thus, each year some 1.5 billion tons of calcareous ooze is added to the ocean floor. Limestone, for which these oozes could be substituted, is presently mined at an annual rate of about 0.4 billion tons worldwide. If only ten percent of the ocean-floor deposits proved mineable, the reserves would be about five million years at our present rate of consumption. More interesting is that the calcareous oozes are accumulating about four times as fast as the world is presently consuming limestone.

SILICEOUS OOZES

Siliceous oozes cover about 38 million square kilometers of the ocean floor. At an assumed thickness of about 200 meters, there should be some 10^{15} tons of these oozes on the ocean floor. Normally, these oozes could serve in most of the applications for which diatomaceous earth is used, that is for fire and sound insulation, in lightweight concretes, as filters, as soil conditioners and so forth.

MANGANESE NODULES

Probably the most interesting of the oceanic sediments, especially from an economic standpoint, are the manganese nodules. These small, black to brown, friable concretions were discovered to be widely distributed throughout the three major oceans of the world almost 100 years ago by the famous Challenger and Albatross expeditions. It is estimated that there are some 1.5 trillion tons of manganese nodules on the Pacific Ocean floor alone and that they are forming in this ocean at an annual rate of about 10 million tons. Averaging about four centimeters in diameter and lying loose at the surface of the sea-floor sediments in concentrations as high as 100,000 tons per square mile, the manganese nodules, from all calculations thus far made, are indicated to be highly economic to mine at the present time. Grading as high as 2.5 percent copper, 2.0 percent nickel, 0.3 percent cobalt, and 36 percent manganese, all in the same deposit, or as high as 2.1 percent cobalt or

50 percent manganese in other individual deposits, the ocean-floor manganese nodules would be considered as high-grade ores if found on the continents. Another interesting aspect of these nodules is that, over large lateral distances, their composition varies markedly. Thus, the mine site can be shifted into those deposits with a mix of metals that is most amenable to market conditions. Flexibility such as this in choosing the grade of material to be mined is a great advantage and one which the mining industry does not normally have in land mines.

Table 5 lists statistics concerning the amounts of various elements in the nodules and the land deposits. Even if only ten percent of the nodule deposits prove economic to mine, it can be seen that many elements are accumulating in the manganese nodules now forming on the Pacific Ocean floor faster than they are presently being consumed, in fact, three times as fast in the case of manganese, twice as fast in the case of cobalt, as fast in the case of nickel and so on. As is the case with many mineral deposits of the sea, the manganese nodules would be a renewable resource. The fact that many deposits of the sea are renewable resources is, of course, of academic interest only, for the reserves of the minerals contained in presently mineable deposits are generally measured in terms of hundreds of thousands or millions of years.

Although the sea can certainly be claimed as a potential source of many important industrial minerals, it is not now, nore will it ever be, the source of all the minerals needed in an industrial society. Transportation economics will probably always dictate that such minerals as common salt will be mined near the market. Within the next several decades, however, I feel that the ocean will be an economic source of important quantities of such materials as potash, nickel, copper, cobalt, manganese, gold, platinum, limestone, silica, diamonds, rare earths, iron ore, titanium, sulphur, fluorine, molybdenum, zirconium, vanadium, phosphates, lead, and uranium, in addition to the salt, magnesium, bromine, tin, oil, gas, iron ore, and limestone which are now extracted from the sea on an economic basis.

Whether or not the sea becomes a great mineral storehouse for humanity, of course, will be entirely based on the effort we choose to put into it. In an entirely new enterprise, vision and faith are factors, sometimes of more importance than even capital. But simply on an economic basis, the sea-floor deposits merit serious consideration of all groups in the mining industry concerned with providing society with necessary mineral commodities at the lowest price possible consonant with good business practices.

Table 5

Reserves of Metals in Manganese Nodules of the Pacific Ocean*

Element	Amount of Element in Nodules (Billions of Tons)	Reserves in Nodules at Consumption Rate of 1964 (Years)	Approximate World Land Reserves of Element (Years)	Ratio of (Reserves in Nodules) / (Reserves on Land)	Rate of U.S. Consumption of Element in 1964 (Millions of Tons/Year)	Rate of Accumulation of Element in Nodules (Millions of Tons/Year)	Ratio of (Rate of Accumulation) / (Rate of U.S. Consumption)
Mg	25.	600,000	L**	-	0.04	0.18	4.5
Al	43.	20,000	100	200	2.0	0.30	0.15
Ti	9.9	2,000,000	L	-	0.30	0.069	0.23
V	0.8	400,000	L	-	0.002	0.0056	2.8
Mn	358.	400,000	100	4,000	0.8	2.5	3.0
Fe	207.	2,000	500	4	100.	1.4	0.01
Co	5.2	200,000	40	5,000	0.008	0.036	4.5
Ni	14.7	150,000	100	1,500	0.11	0.102	1.0
Cu	7.9	6,000	40	150	1.2	0.055	0.05
Zn	0.7	1,000	100	10	0.9	0.0048	0.005
Ga	0.015	150,000	-	-	0.0001	0.0001	1.0
Zr	0.93	100,000	100	1,000	0.0013	0.0065	5.0
Mo	0.77	30,000	500	60	0.025	0.0054	0.2
Ag	0.001	100	100	1	0.006	0.00003	0.005
Pb	1.3	1,000	40	50	1.0	0.009	0.009

*After Mero, 1965.

**Present reserves so large as to be essentially unlimited at present rates of consumption.

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REVIEW OF AVAILABLE HARDWARE NEEDED FOR UNDERSEA MINING

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ABSTRACT

In any mining system, five basic steps are involved. These are: location of the deposits, evaluation of the ore-body, extraction of the ore, beneficiation, and transportation. Current available hardware is reviewed with emphasis on the evaluation and extraction phases. The review considers the types of deposits that will be mined under the sea. These fall under two basic categories: consolidated and unconsolidated deposits analogous to hard rock and alluvial deposits on land. This classification is further subdivided into surficial deposits which are those exposed on the sea floor and in situ deposits which are contained in the sediment or rock beneath. Current undersea mining operations are limited to underground mines worked conventionally from land or island base, in situ solution mining from off-shore platforms and shallow alluvial deposits close to shore worked by dredging. In all cases, the hardware involved is adapted from mining and petroleum industry tools. As is normally the case, each ore deposit represents an unique situation. Therefore, it is emphasized that no one method will fulfill the systems requirements for all mining operations. Available tools are many and varied and hardware requirements become well established as new deposits are sought and discovered. The ultimate success of future undersea mining operations depends strongly upon the selection or development of the optimum equipment and systems for the particular task.

INTRODUCTION

The prospects of finding and recovering minerals from the shelves, slopes and basins of the ocean have generated considerable interest. While it is still very early in the phase of this new activity, some good beginnings have been made. The activities vary from broad economic and technical studies to actual operations at sea. At the present time, it would be hazardous to guess at what rate undersea mining will grow, or what size the industry will ultimately become. If one is to learn anything from history, it is that enough attention will be given this new activity in the forthcoming years to provide a reasonable and sound basis for satisfactory growth.

A review of the offshore oil industry reveals some interesting guide lines that may provide assistance in projecting a reasonable growth structure. However, one must be careful in any analogy and recognize the similarities and differences. Hindsight is a wonderful thing, and it is very easy to rationalize now, for instance, that the growth of the offshore oil industry was practically assured. Very few believed this fifteen to twenty years ago. However, it was the extension of the oil field into the shallow waters off the Coast of Louisiana that provided the path for growth. For years, the drilling companies had been operating in swamps, bayous and rivers of Louisiana. The land drilling rigs were adapted to barges, piers and platforms. Very little was new except some of the operating procedures. It wasn't until

the water depth increased beyond the practical limits of fixed platforms and barges that the jack-up and semi-submerged platforms came into existence. The offshore oil industry has demonstrated considerable ingenuity in adapting extensive land know-how and equipment to the ocean environment on the continental shelf. We now are witnessing the beginnings of a look beyond the continental shelf. Seismic profiles indicate the possible existence of oil in many parts of the basin of the Gulf of Mexico. It may be a few years before it is technically feasible and economical to explore or produce from such deep fields, but their possible existence acts as a goal for continuously increasing the ability to operate in deeper water.

One need not postulate that undersea mining will evolve in a pattern similar to the offshore oil industry. However, it may be worthwhile to review where conditions are similar and where they are different.

The projected increasing demands for many minerals should provide, as it did in petroleum, a necessary attention to the undersea areas. The probable existence of minerals in commercial quantities in some areas in the shallow water of the coastal regions will provide an evolutionary path for development. The extension of ore deposits from land into the shallow waters as a counterpart of the oil fields of Louisiana exists in several areas of the world – the two most well known are the diamonds of Southwest Africa and the tin of Southeast Asia. In the case of the tin dredging in Southeast Asia, the evolution of offshore waters is beginning to take place with the apparent adapting of land techniques. There was more of a step function or change in the diamond operations off Southwest Africa. Here the environment of rugged coast line and generally rough seas demanded a new approach to diamond mining. Certainly such ores as manganese nodules which are not known to exist in shallow waters, will require an essentially new mining system. In spite of this, the principles and techniques developed in offshore oil platforms and modern dredges may provide some necessary elements of these new systems.

It is worthwile to state a few of the important dissimilarities between the offshore oil industry and the potential undersea mining industry.

The market, or total dollar volume of petroleum exceeds by an order of magnitude or more, most other minerals. This has a strong impact upon the amount of risk capital available for development. It also is reasonable to state that ore deposits, their composition and location have a variation considerably greater than petroleum. This is true at least in the effect these deposit characteristics have upon the methods of locating and mining them. Therefore, operating methods and equipment should vary considerably.

In this review one must of necessity limit the categories of equipment for practical reasons. Boats and ships that may be converted for survey and mining are not reviewed, nor is the large variety of general oceanographic equipment.

With this as a background, I believe a review of available hardware needed for undersea mining will provide the required foundation for projecting the probable development of future equipment. One can divide the essential operations of land and marine mining into five separate activities:

(1) The location of the deposits;
(2) The evaluation of the deposits;

MINERAL DEPOSITS OFFSHORE

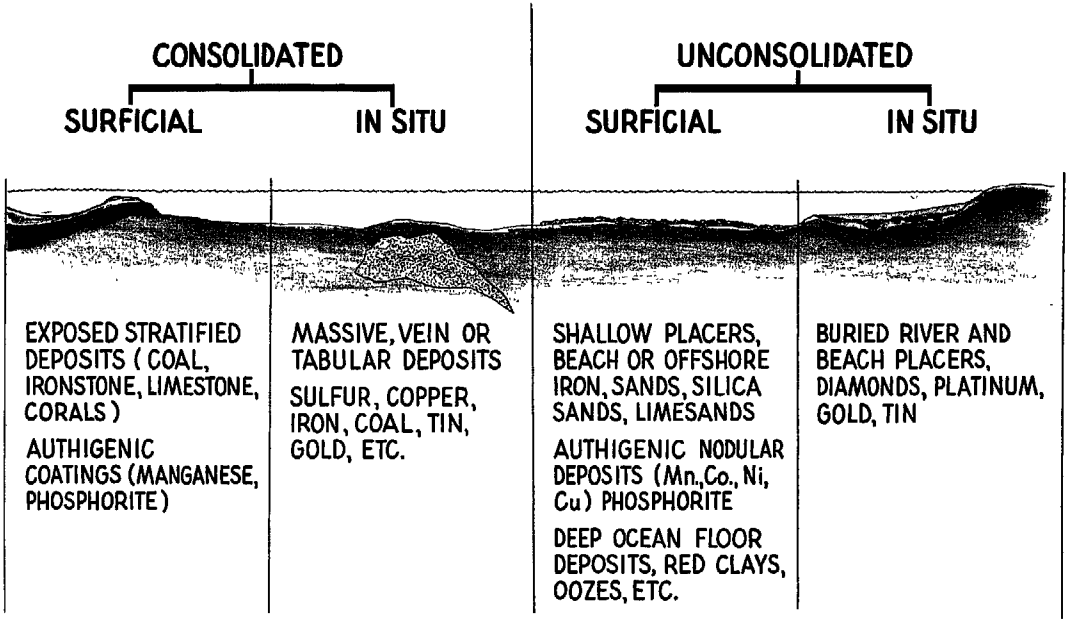


Figure 1

(3) The extraction of the ore;
(4) The beneficiation, and
(5) The transportation.

THE LOCATION OF THE DEPOSITS

Before proceeding, it might be desirable to review the environment of the mineral deposits to be expected off shore. Figure 1 is a graphic illustration in which the deposits are subdivided into consolidated and unconsolidated, and further subdivided into surficial and in situ classifications. Starting at the right hand side of the chart, in the shallow water the deposits which are believed to be the easiest to recover are the buried river and beach placers, including, diamonds, platinum, gold, and tin. These minerals are the heavy group and normally can be found resting on bedrock or impermeable clay covered by sediment. The unconsolidated surficial deposits include the shallow placers either on beach or off shore, including iron sands, silica sands or lime sands. A second grouping includes the authigenic nodular deposits. The phosphorite nodules normally are found in the shallower water of the continental shelf and the manganese deposits normally in the deeper waters. A third grouping includes the deep ocean floor deposits of red clay and oozes. The consolidated in situ deposits are the massive, vein, or tabular deposits including sulphur, copper, iron coal, tin, gold, etc. The consolidated surficial deposits include exposed stratified deposits such as coal, ironstone, limestone, and corals, and authigenic coatings of manganese and phosphorite. At the present time information available on marine mineral deposits is largely limited to the unconsolidated surficial deposits. Because of this, the discussion will be limited to available equipment that can be used, either directly or without great modification, to the mining of these deposits.

Probably the two most important factors of direct bearing upon hardware in marine mining are the depth of water at the mine site, and the sea state condition of the water surface. Dredging for many years has been accomplished in shallow protected water. This environment is quite different from the open seas and the importance of this difference on design and operation of reliable equipment cannot be too strongly emphasized. Therefore, two characteristics – stability and mobility, may at times be the dominent characteristics of an ocean mining system. Other factors of importance are subsurface waves and currents which have been discovered in recent years and about which little is known at the present time. The sea environment also creates a problem for accurate positioning and location, particularly when the operations are out of sight of land. While there are many other differences between land mining and undersea mining, these are believed to be areas where the environment produces the greatest differential.

The activities and hardware used in the location of the deposits can be divided into three different categories: ship operation, survey and sampling. Because of the extensive amount of oceanographic, hydrographic and geological work that has been done at sea, especially since World War II, an extensive variety of hardware has been developed and is available for ocean mineral survey work. This applies specifically to seismic survey equipment, magnetometers, and gravity meters used extensively by the offshore oil exploration industry. In addition to this, there is a wide variety of equipment such as sampling tools, underwater television, cameras, and standard oceanographic equipment applicable to sea floor studies.

Ship Operations

One of the most important factors in the location of undersea minerals is accurate navigation. Ore bodies must be relocated after being found and must be accurately delineated and defined. The accuracy required depends upon the phase of operations. Initially, in general surveys, errors of a thousand feet or more may be tolerated. However, once an ore body is believed to exist in a given area, maximum errors of less than 100 feet are desirable. These maximum tolerated errors may be further reduced to a few feet in detailed ore body delineation and extraction. The positioning accuracy desired is dependent upon many factors, costs, operating procedures, characteristics of ore body, etc.

The development of electronic navigation systems starting with World War II provides, in many cases, systems with the required accuracy (Table 1). There are basically two types as shown in Figure 2. Hyperbolic pattern systems with a master and two slave stations at surveyed sites on shore, require a receiver aboard the survey vessel. There are many types available, of which the best known are Loran and Decca. There is no limit on the number of units or ships that can use the system simultaneously. Accuracy depends upon type of system, the location of the ship in the pattern and the distance of the ship from the stations.

The ranging system uses a master station aboard ship with two slave stations at surveyed sights on shore. In general only one ship can use this system at any one time.

There are a variety of types available for use with accuracies from 3000' down to approximately 3'. Loran, Lorac, and Decca are permanently installed in various locations throughout the world as shown in Figure 3. Small portable systems are available for local use that provide high accuracy within 30 to 50 mile ranges.

Positioning

During coring and mining operations, the vessel must be held steady over a selected spot on the ocean floor. The two procedures that have been fairly well developed are the multiple anchoring system, and the dynamic positioning system.

Illustrated in Figure 4 is a three point anchoring system of value for a coring vessel working close to the surf. A series of cores may be obtained along the line of operations by winching in the forward anchors and releasing the stern anchor. Good positive control over the vessel can be obtained with this system. If conditions warrant, a four point anchoring system may be used. Increased holding power can be obtained by multiple anchoring at each point.

Illustrated in Figure 5 is a dynamic positioning system. It is useful in deeper water where anchoring may not be practical or allows too much movement of the ship. The ship is kept in position by use of auxiliary outboard propeller drive units. These can be placed both fore and aft to provide excellent maneuverability. The sonar transponders are held submerged at a depth of minimum disturbance. Ranges are obtained from the ship to the transducers by use of sonar. The auxiliary power units are then controlled to keep the ranges at a constant value. This can be done manually or automatically by use of a computer.

*TABLE OF ELECTRONIC POSITIONING SYSTEMS

Name	Range Naut-Miles	Accuracy Feet	Signal Type	System	Users	Area Coverage	Manufacturer	
			Long Range>500 Miles					
Loran A	8-1400	1000'	Pulsed	Hyperbolic	Multi	See Chart	Various	
Loran E	1500	500'	Pulsed	Hyperbolic	Multi	See Chart	Various	
OMEGA	6000	3000'	Pulsed	Hyperbolic	Multi	Experimental	Omega	
CONSOL	700	36-144,000	C.W.	Azimuthal	Multi	Not in general use	?	U.K.
DELRAC	3000	60,000	Pulsed	Hyperbolic	Multi	Not in general use	Decca	U.K.
TRANSIT	Worldwide	High	C.W.	Sattelite	Multi	Experimental	A.P.L. (U.S.N)	U.S.
			Intermediate Range 100-500 Miles					
Loran B	250	45-300	Pulsed	Hyperbolic	Multi	See Chart	Various	
Loran A	200	10-150	C.W.	Hyperbolic	Multi	See Chart	Seiscor	Okla.
Loran B	300	10-150	C.W.	Hyperbolic	Multi	See Chart	Seiscor	Okla.
Decca Navigator	250-500	1500-12000	C.W.	Hyperbolic	Multi	See Chart	Decca Navigator Co.	Eng.
Decca Survey	200	25-300	C.W.	Hyperbolic	Multi	See Chart	Decca Navigator Co.	Eng.
Low Ambiguity Decca	150-400	25-250	C.W.	Ranging	1	Local	Decca Navigator Co.	Eng.
Decca 2 Range	150-	12-	C.W.	Ranging	1	Local	Decca Navigator Co.	Eng.

Table 1

*TABLE OF ELECTRONIC POSITIONING SYSTEMS

Name	Naut-Miles	Accuracy Feet	Signal Type	System	Users	Area Coverage	Manufacturer	
Decca Hi Fix	200	3-	C.W.	Hyper or Range	1	Local	Decca Navigator Co.	Eng.
E.P.I.	400	195-1500	Pulsed	Ranging	1	Local		
D.M. Raydist	100-250	1-150	C.W.	Range-Hyperbolic	2	Local	Haystings Raydist Inc.	Va.
RANA	84-129	60-120	C.W.	Range	?	-		France
HIRAN	550	2 (?)	C.W.(?)	Range	1	Local	Raydist (?)	U.S.
			Short Range>100 Miles					
Radar	30	300	C.W.	Range or Azimuth	1	Local	Multi	
P.R.S.	50	150	C.W.	Ranging	1	Local	Alpine Geophys. Co.	Tex.
R.O.F.	50	5000	C.W.	Azimuth	Multi	Local	Multi	
Hi Fix	30	12-100	C.W.	Ranging	1	Local	Decca Navigator Co.	Eng.
Shoran	30	30-50	Pulsed	Ranging	1	Local	Raydist (?)	
Hi Fix	40	25-150	C.W.	Hyperbolic	Multi	See Chart	Decca Navigator Co.	Eng.
Hydrodist	25	5	C.W.	Ranging	1	Local	Hastings Raydist (?)	
M.P.F.S.	30	< 50	C.W.	Azimuthal	Multi	N. Canada		Canada
Raydist	75	15-150	C.W.	Composite	2	Local	Haystins Raydist	Va.

Table 1 (Contd)

*TABLE OF ELECTRONIC POSITIONING SYSTEMS

Name	Range Naut-Miles	Accuracy Feet	Signal Type	System	Users	Area Coverage	Manufacturer	
Auto Tape	60	3+	C.W.	Ranging	1	Local	Cubic Corp.	U.S.
Mini Fix	30	2.5-7	C.W.	Ranging or Hyperbolic	1	See Chart	Decca Navigator Co.	Eng.
Doppler Navigator		Very Accurate	C.W.	Sonic Ranging	1	Local	Raytheon Co.	R.I.
Deep Submergence R.O.F.	10	5 degrees		Azimuth		Local	Oceanographic Eng. Co.	Calif.
Electro Tape	< 50	> 0.01	C.W.U.H.F.	Ranging	1	Local	Cubic Corp.	U.S.

*Based upon information published or made available by the manufacturer.

Table 1 (Contd)

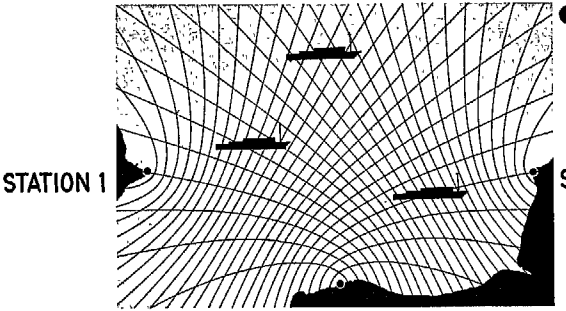
*NAVIGATION & SHIP POSITIONING: DEPTH RECORDERS

Manufacturer	Name of System	Depth Ft	No. of Scales	Accuracy	Recorder	Subbottom Penetration	Weight lbs
Alden Electronics & Impulse Recording Equip. Co. Inc. Mass.	P.S.G.R.	18000	12		Yes	Yes	
		18000	12		Yes	Yes	
		18000	12		Yes		
Alpine Geophysical Associates, Inc. N.J.	PESR (Precision Echo Sounder Recdr.)	24000	6	.01% Freq. Shift	Yes	Yes	125
					Yes		
Apelco Calif.	Depth Sounder/ Recorder	360	2	5%	Yes	No	8
		360	2	5%	No	No	8
Bludworth Marine Div. S.E.C. N.Y.	Survey Depth Recorder	245	4	2%	Yes	No	31
		245	4	0.5%	Yes	No	39
Daystrom Inc. Elec. Div. N.Y.	Depth Indicator System	3000	3	1%	No	No	
E.D.D. Corp. N.Y.	Depth Recorder	24000	3	—	Yes	-	370
	Survey Depth Recdr.	920	4	0.5%	Yes	-	
Electro Acoustic G.M.G.H. W. Ger.	Echograph	1080-3960 420-	8		Yes	No	130-750
	Fischlupe	1800	2		Scope	No	94-176
	Miniscope	490	4		Scope	No	30-45
Ocean Sonic, Inc. Calif.	Precision Sonar Recorder	12000	7		Yes	Yes	
Raytheon Co. Electrographic Sys. Dept R.I.	Precision Fathometer Recorder	24000	3	0.04%	Yes	No	175
	Depth Alarm	10-150	1		No	No	22
Litton Industries, McKiernan Terry Marine Div. N.J.	PDR (Precision Depth Recorder)	24000	3		Yes	No	250
		36000	8		Yes	Yes	250

*Based upon information published or made available by the manufacturer.

Table 2

BASIC OFFSHORE ELECTRONIC LOCATION SYSTEMS



●HYPERBOLIC

HYPERBOLIC PATTERNS.
MASTER & BOTH SLAVES AT FIXED POINTS ASHORE.

RECEIVER

MASTER STATION

●RANGING

TWO-RANGE.
MASTER STATION ABOARD SHIP, BOTH SLAVES AT FIXED POINTS ASHORE, ONE VESSEL ONLY CAN OPERATE IN THIS MANNER.

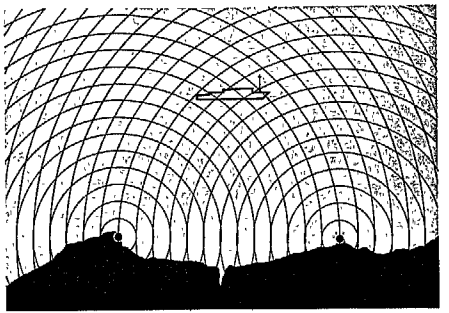


Figure 2

WORLD WIDE ELECTRONIC NAVIGATION SYSTEM

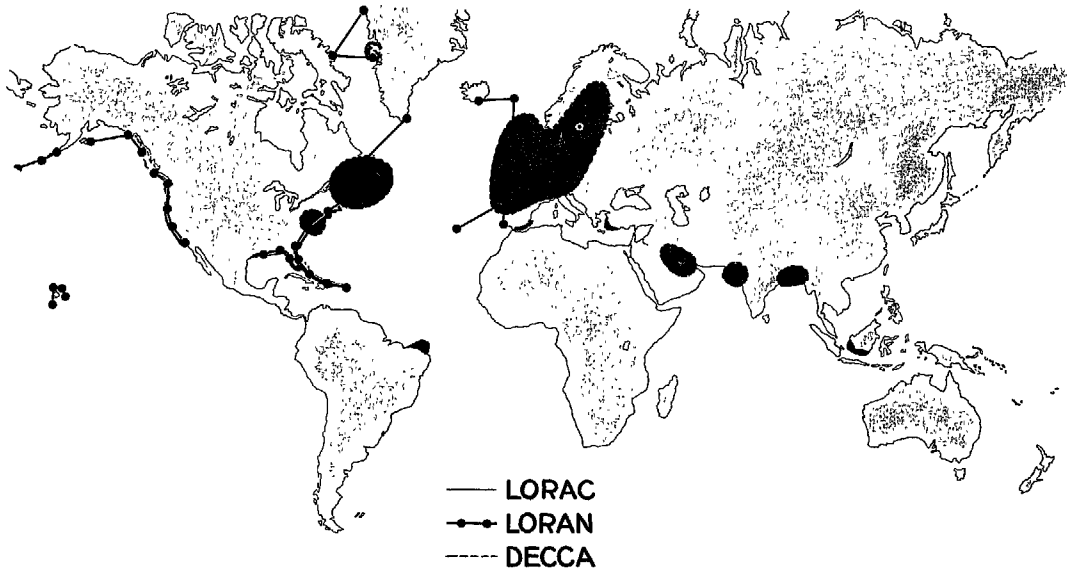


Figure 3

3 POINT ANCHORING SYSTEM

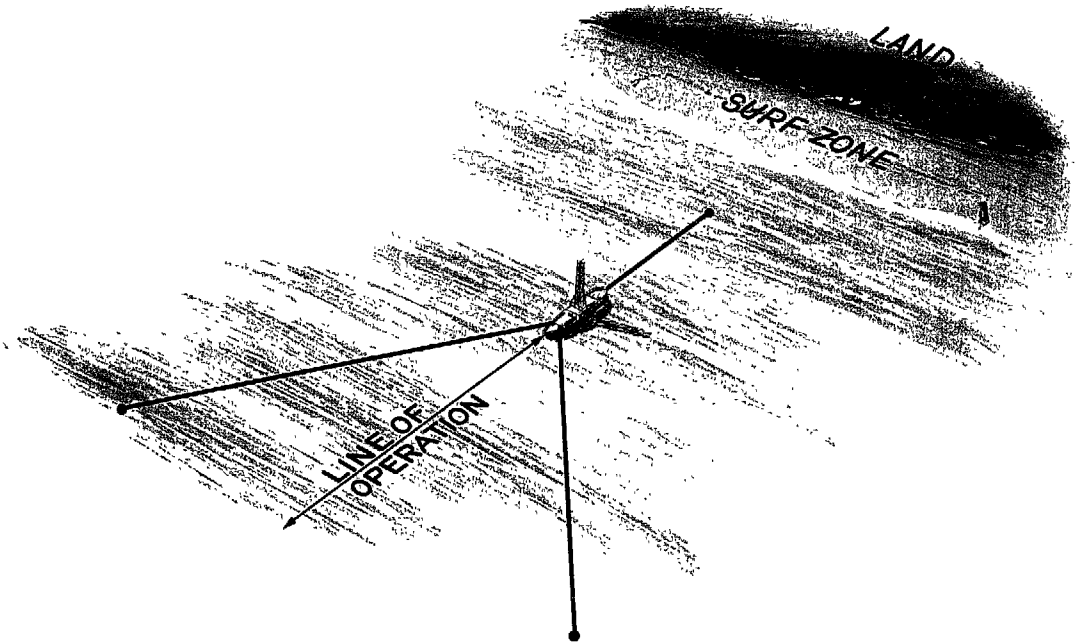


Figure 4

DYNAMIC POSITIONING SYSTEM

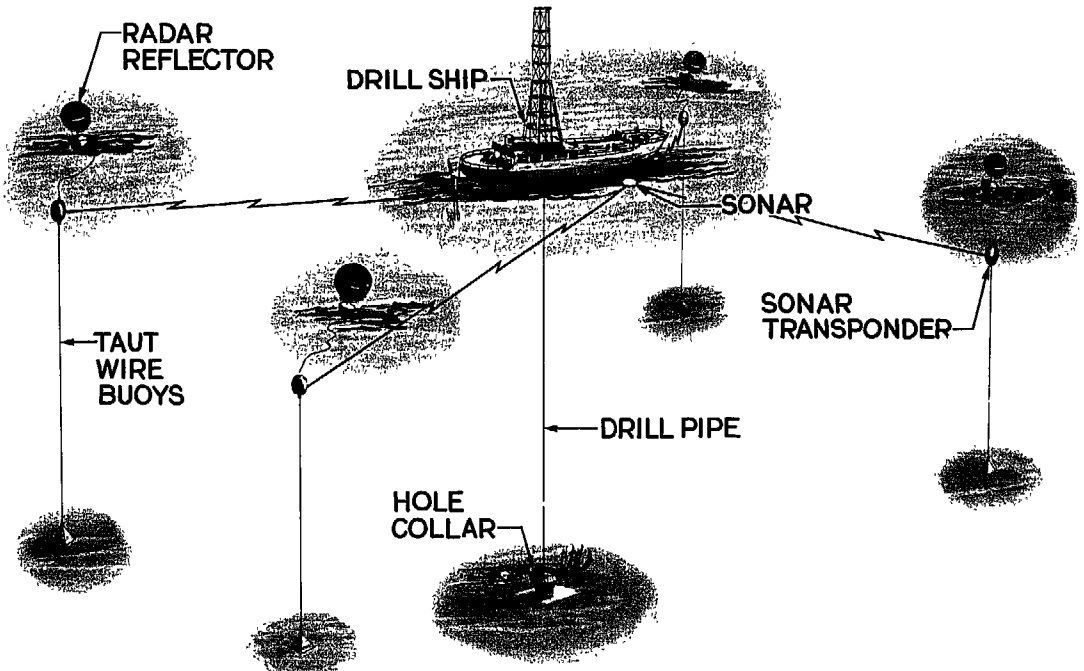


Figure 5

Survey

The primary aids to exploration for mineral deposits at sea are depth recorders, bottom sampling devices, sub-bottom profilers, magnetometers, and sub-bottom sampling systems. Examples of available hardware are shown in Tables 2, 3, and 4.

Their use is dependent upon the characteristics of the ore being sought.

Depth Recorders

For the initial topographic survey of the sea floor, and as an aid to navigation, in inshore waters, the depth recorder (Table 2) is indispensable. It is usually carried as standard ship's equipment, but the precision recorders having a high accuracy are most useful in survey work. In the same range of accuracy, the choice will depend greatly on the economics of the system.

Bottom Sampling Devices

Many hundreds of variations of these devices exist for sampling the sea bottom. The choice is dependent on the requirement of the survey, but for the qualitative sampling of mineral sands, a grab type sampler such as the Shipek, where spillage is held to a minimum, is considered to be better than most. Nodular deposits are best sampled by a towed dredge which may be constructed for the particular job.

Sub-Bottom Profilers

In the search for marine placer deposits of heavy minerals, the sub-bottom profiler is probably the most useful of all the exploration aids. It is one of several systems utilizing the reflective characteristics of acoustic or shock waves.

These systems (Table 3) with the exception of the Westinghouse bottom scanner, provide sub-bottom profiles of the sea floor to maximum depths of 25,000 feet. The continuous seismic profilers are a development of standard geophysical seismic systems for reflection surveys, used in the oil industry. The normal energy source is explosive, and penetration may be as much as several miles.

More recently developed are the sub-bottom profilers, which use a variety of energy sources including electric sparks, compressed air, gas explosions, acoustic transducers and electromechanical (Boomer) transducers. The return signals as recorded, show a recognizable section of sub-bottom. Shallow layers of sediment, configurations in the bedrock, faults and other features are clearly displayed and require little interpretation. The maximum theoretical penetration is dependent on the time interval between pulses and the wave velocity in the sub-bottom. A pulse interval of 1/2 sec. and an average velocity of 8,000'/sec. will allow a penetration of 2,000', the reflected wave being recorded before the next transmitted pulse. The actual penetration achieved is dependent on the wave velocity, the pulse frequency and the pulse energy. The resolution of the recorded data is dependent on the pulse frequency and the recorder sweep rate. Band filters are commonly used to clarify the recorded signal.

*GEOPHYSICAL PROFILING: WAVE REFLECTION SYSTEMS

Manufacturer	Name of System	Sediment Penetration	Power	Energy Source
Alden Electronic & Impulse Recording Equipt. Co. Mass.	PGR (Precision graphic recorder & seismic profiler)	< 200 feet	20,000 joules	Spark Explosive
Alpine Geophysical Assoc. Inc. N.J.	Seismic Reflection Profiler	4-5 Km		Explosive
	CSP (Continuous Stratification profiler)	2,000 feet	Variable	Spark
Bolt Associates, Inc. Conn.	S.B.P. PAR Pneumatic Sound Source	> 100 feet	Variable	Pneumatic
Chesapeake Inst. Corp. Ma.	Towflex Towed Hydrophone Array for Seismic Profiling	Recorder Only Deep		Explosive
Edgerton, Germeshausen & Grier Inc. Mass.	Boomer	1000'	> 500 joules	Electro-Mech.
	Sparkaray	> 400'	1,000 joules	Spark
	Seismic Subbottom Profiler	Shallow	Variable	Acoustic Transducer
Geotechnical Corp. Tex.	SUBot (Subbottom Profiler)	5,000'	3,600-25,000 joules	Spark
	SSP (Seismic Section profiler)	> 5,000'	> 100,000 joules	Explosive & Gas
	GASSP	10-15,000'	High	Gas Explosion
Geophysical Service, Inc. Tex.	Seismic	Deep	Various	Various
Huntec Ltd. Can.	Hydrosonde MK 2A (subbottom profiling)	Shallow	140 joules	Spark
Westinghouse Underseas Div.	Ocean Bottom Scanner	Surface Only	Low	Acoustic Transducer

Table 3

*GEOPHYSICAL PROFILING: WAVE REFLECTION SYSTEMS

Manufacturer	Name of System	Sediment Penetration	Power	Energy Source
Rayflex Exploration Co. Tex.	Sonoprobe	< 50'	3 KW	Acoustic Transducer
U.E.D. Earth Science Div.	Ocean Bottom Seismic Recording System	Recorder Only Deep		Explosive

*Based upon information published or made available by the manufacturer.

Table 3 (Contd)

Penetration and resolution are widely variable features on most models of wave velocity profiling systems. In general, high frequencies give high resolution with low penetration, while low frequencies give low resolution with high penetration. The general range of frequencies is at the low end of the scale and varies from 150 to 300 cps, and the general range of pulse energy is from 100 to 25,000 joules for non-explosive energy sources. The choice of system will depend very much on the requirements of the survey, but for the location of shallow placer deposits on the continental shelf the smaller low powered models such as the Rayflex Sonoprobe and the Huntec Hydrosonde have been used with considerable success.

Figure 6 is an illustration of a profile obtained of a river bottom. The record is split around the coring which is used to confirm the interpretation of the record and provide evidence of the existence of the sought-after mineral.

Magnetometers

With the advent of the fluxgate, proton precession and lately, the rubidium vapor magnetometer, all measuring the earth's total magnetic field to a high degree of accuracy, this instrument has become much more useful in the field of mineral exploration.

Anomalies indicative of mineralization such as magnetic bodies, concentrations of magnetic sands and certain structural features can be detected. Although all three types are adaptable to undersea survey work, the precession magnetometer is more sensitive and more easily handled than the Fluxgale, and the rubidium vapor type has an extreme degree of sensitivity which enhances its usefulness when working from the sea surface. Of those manufactured in the United States, the Varian range is considered very highly for marine work.

EVALUATION OF THE ORE BODY

Once an ore body is indicated by geological, geophysical or other means, the next step is to sample it in area and in depth.

Systems for Sub-Bottom Sampling

Sub-bottom sampling systems (Table 4), may be classified by the method of penetration of the bottom. (Figure 7)

Impulsive

Penetration is actuated by gravity, hydrostatic pressure, or explosion and takes place in one motion.

Percussive

Penetrative force is applied as a repetitive impulsive load. The frequency of the impulse may vary from a few cycles per minute as in the churn drill to several thousand blows per minute in the high speed, hard rock, percussion drills. The application of the latter type of machine offshore has been restricted to blast hole drilling.

Vibratory

All material has a natural frequency of vibration related to the velocity of sound waves through it. The application of a

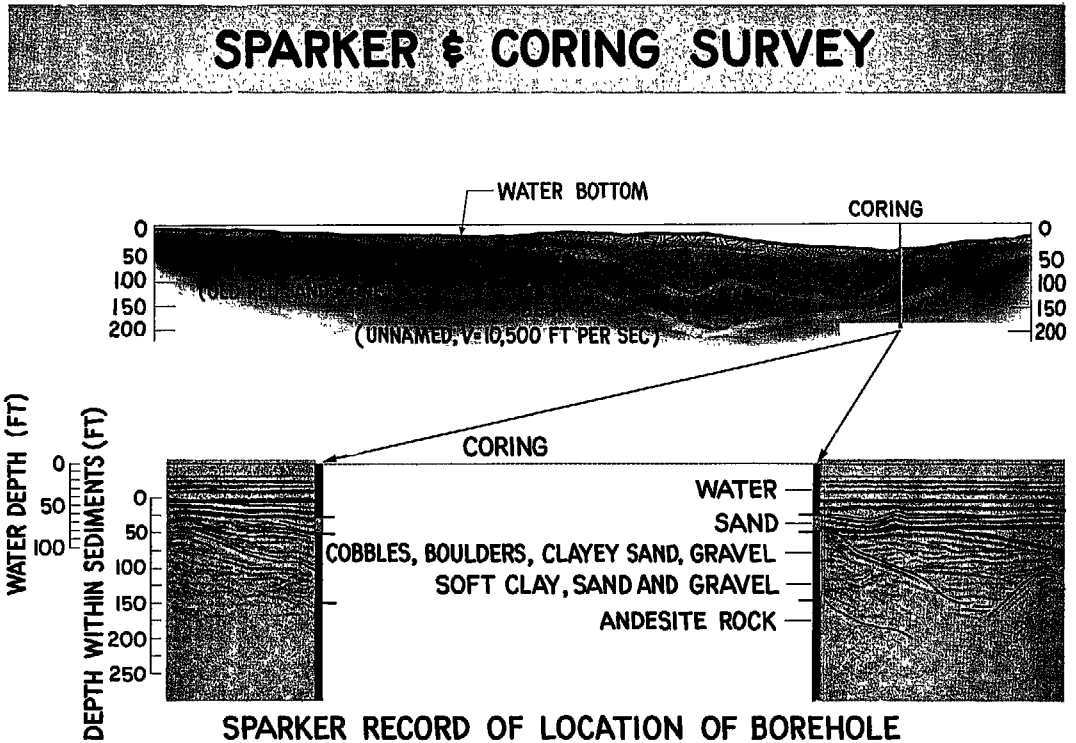

SPARKER & CORING SURVEY
WATER BOTTOM
CORING
0
50
100
150
200
(UNNAMED, V= 10,500 FT PER SEC)
CORING
WATER DEPTH (FT)
DEPTH WITHIN SEDIMENTS (FT)
WATER
SAND
COBBLES, BOULDERS, CLAYEY SAND, GRAVEL
SOFT CLAY, SAND AND GRAVEL
ANDESITE ROCK
SPARKER RECORD OF LOCATION OF BOREHOLE

Figure 6

*TABLE OF SUB-BOTTOM SAMPLING SYSTEMS

Name	Manufacturer	Depth of Water	Depth of Hole ft.	Diameter Hole in.	Power Reqmts.	Platform	Operators	Type of Ground
Impulsive								
Kullenburg Corer		No limit	100	2-1/2	Gravity & Hydrostatic	Ship	2	Mud
Phleger Corer	Hydro Products, Calif.	No limit	2	1-3/8	Gravity	Ship	1	Mud
Box Corer	Hydro Werkstatten, W.G.	No limit	6	12	Gravity	Ship	1	Sand
Moore Free Corer	Hydro Products, Calif.	No limit	10	2-5/8	Gravity	Free	1	Mud
Percussive								
Becker Hammer Drill BDT 150	Becker Mfg. & Drilling Inc. Can.	100'	150'	hole corer (5-1/2" o.d. <3' o.d.)	~500 HP	Barge	13	Overburden
Hyd. Jet Sampler	U.S.B.M.	-	< 100'	1-13/16 o.d. (EX)	<10 HP	-	2	Overburden
60 L Spudder	Bucyrus Erie, Wisc.	-	1500'	6-8"	65 HP	-	2	Overburden & Sed
28 L Spudder	Bucyrus Erie, Wisc.	-	2500'	to 15"	78 HP	-	2	Overburden & Sed
36 L Spudder	Bucyrus Erie, Wisc.	-	3500'	to 15"	175 HP	-	2	Overburden & Sed

Table 4

*TABLE OF SUB-BOTTOM SAMPLING SYSTEMS

Name	Manufacturer	Depth of Water	Depth of Hole ft.	Diameter Hole in.	Power Reqmts.	Platform	Operators	Type of Ground
48 L Spudder	Bucyrus Erie, Wisc.	-	6000'	to 15"	219 HP	-	3	Overburden & Sed
Vibratory								
Vibracore	Alpine Geophysical Ass. N. J.	<600	<16	1-3/8" <6" o.d.	Air Vibrator	Ship	3	Unconsol. Seds.
Vibratory Corer	Ocean Science & Eng. Co. Calif.	<200	20'	2-1/2" i.d.	Batteries 15-20 HP	Ship	2	Unconsol. Seds.
Deep Corer	Ocean Science & Eng. Co. Calif.	150'	100'	6-5/8" o.d.	320 HP Diesel Hydro	Ship 100'		Overburden
Sub Core Drill	Geo. Wimpey & Co. U.K.	200'	20'	3"	N.K.	Bottom	2+ diver	Consol.
Underwater Drill	Acker Drill Co. Inc. Pa.	60'	24'	12"	Air	Barge	4+ diver	Cast Iron
Flexo Drill	Institut Francais du Petrole	600'	100'	6"	25 HP Electro Drill	Bottom	2	Consol.
Térébel	Institut Francais du Petrole	3000'	3280'	8"	300 HP Diesel Hydro 250 HP Diesel Elec	Drill Ship		Consol.
Turbodrill	Dresser Industries	12000'	23000'	2" core 10" o.d.		Mohole		Consol.
Submergible Core Drill	Koken Boring Co. Japan	>600'	45'	1-5/8"	5 HP Electric	Bottom		Consol.

Table 4 (Contd)

*TABLE OF SUB-BOTTOM SAMPLING SYSTEMS

Name Name	Manufacturer Manufacturer	Depth of Water	Depth of Hole ft.	Diameter Hole in.	Power Reqmts.	Platform	Oper-ators	Type of Ground
Marine Rotary Corer	LMSC/IMC	600'	8'	2-1/4" o.d.	3 HP Electric	Bottom	2	Consol.
Rockeater	Ocean Science & Eng. S.A.	< 200'	20'	27"	500 HP Diesel Electric	Drill Ship		Over-burden
Glomar Sirte	Global Marine Exp. Calif.	600'	20000'	to 15"	Steam	Drill Ship		Consol.
Glomar IV	Global Marine Exp. Calif.	-	20000'	to 15"	Diesel	Drill Ship		Consol.
Glomar III	Global Marine Exp. Calif.	-	20000'	to 15"	Diesel	Drill Ship		Consol.
Glomar	Global Marine Exp. Calif.	> 600'	20000'			Drill Ship		Consol.
Cuss I	Global Marine Exp. Calif.	12000'	> 600'			Drill Ship		Consol.
Rincon	Global Marine Exp. Calif.	250'	6000'			Drill Ship		Consol.
Western Expl.	Global Marine Exp. Calif.	250'	6000'			Drill Ship		Consol.
Submarex	Global Marine Exp. Calif.	1500'	25000'			Drill Ship		Consol.
La Ciencia	Global Marine Exp. Calif.					Drill Ship		Consol.

Table 4 (Contd)

*TABLE OF SUB-BOTTOM SAMPLING SYSTEMS

Name	Manufacturer	Depth of Water	Depth of Hole ft.	Diameter Hole in.	Power Reqmts.	Platform	Oper-ators	Type of Ground
Oscillatory								
Beach Corer	Ocean Science & Eng. S.A.	-	15'	36"	N.K.	Tractor	1	Over-burden
Jetted								
Hydrop	Alluvial Mng. & Shaft Sinking Co., U.K.	200'	20'	36"	500 HP Diesel Hydr.	Bottom	3	Unconsol.
Hydroprobe	LMSC/IMC/MMTC	150'	15'	3-1/2" o.d.	15 HP Air Hydr.	Bottom	2	Unconsol.
Combination								
Banka Drill	Conrad Stork, Holland	30'	100'	4"-6"	8 men	Raft	8	Over-burden
Overburden Drill	Atlas Copco, Sweden	30'	150'	5"	500 HP Diesel Air.	Raft	2	Over-burden
Benoto Hammer Grab	Sir Bruce While, Wolfe, Barry & Partners U. K.	50'	>100'	14-55"	>500 HP	Pontoon	3	Over-burden & rock

*Based upon information published or made available by the manufacturer.

Table 4 (Contd)

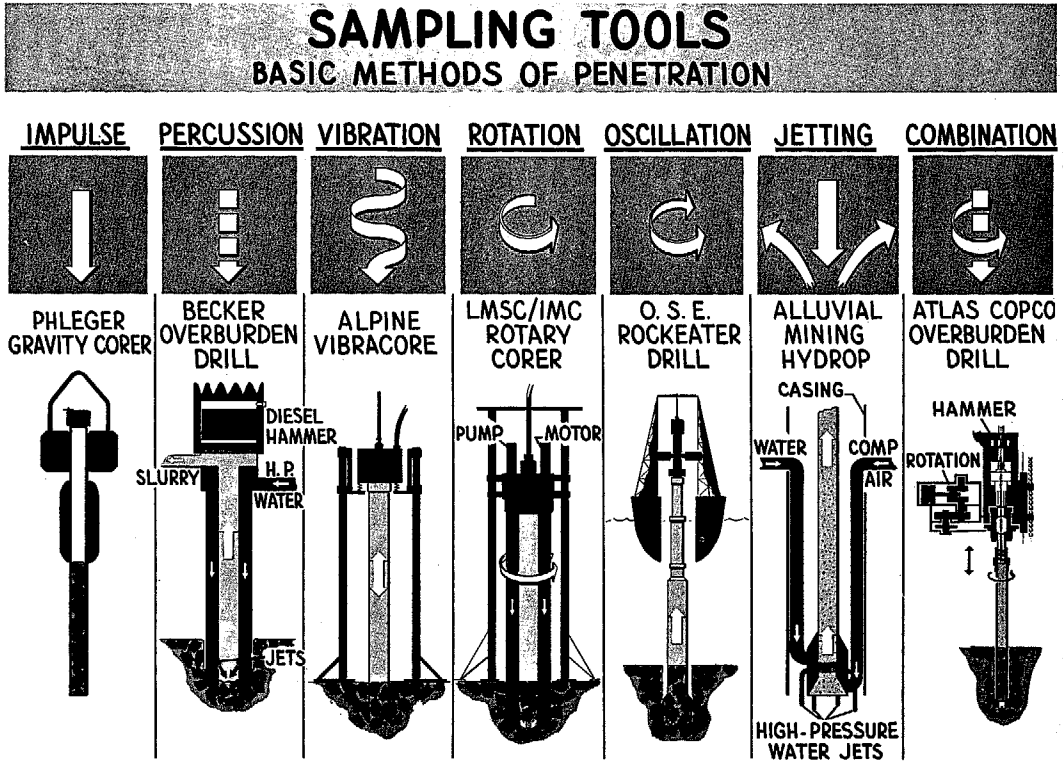

SAMPLING TOOLS
BASIC METHODS OF PENETRATION
IMPULSE
PERCUSSION
VIBRATION
ROTATION
OSCILLATION
JETTING
COMBINATION
PHLEGER GRAVITY CORER
BECKER OVERBURDEN DRILL
ALPINE VIBRACORE
LMSC/IMC ROTARY CORER
O. S. E. ROCKEATER DRILL
ALLUVIAL MINING HYDROP
ATLAS COPCO OVERBURDEN DRILL
DIESEL HAMMER
H.P. WATER
SLURRY
JETS
PUMP
MOTOR
CASING
WATER
COMP AIR
HIGH-PRESSURE WATER JETS
HAMMER
ROTATION

Figure 7

continuous vibrational impulse to a coring tube or rod will assist it to penetrate at rates which are partially dependent on the frequency of vibration. Such methods have been used in pile driving with success and more recently in core drilling in sands and unconsolidated material. Much has still to be learned about the relationships between the factors involved such as the vibrational amplitude and frequency, and the physical properties of the material, but the method has encouraging possibilities.

Rotary

Rotary drilling is the most widely applied method of ground penetration outside of the mining industry. A steady thrust is applied to a continuously rotating drill bit which may be of solid, annular or auger type. All types of ground may be penetrated by rotary drilling, the applied variables being the type of bit, the speed of rotation and the thrust.

Oscillatory

Oscillation of an annular core barrel under a steady thrust may assist penetration. It is rarely used because of its limited advantages over rotation.

Jetted

If high pressure jets of water or air are allowed to impinge on unconsolidated material, an excavation will be formed. Controlled penetration of a sample tube may be achieved by this method.

Combination

Any of the above methods may be combined to take advantage of the best features for particular types of ground. Percussion and rotation are frequently combined both, generally, increasing in rate with increasingly hard ground.

As penetration of the sampling mechanism is effected, it is necessary to remove the material from the hole. The material, which constitutes the sample may be in the form of dry cuttings, wet slurry or solid core. This may be flushed continuously from the hole with air or water or it may be removed intermittently with a bailer or grab. (Figure 8)

In normal flushing, the cuttings or mud are forced up the annulus between the drill rod and the sides of the hole. In reverse flushing which has gained rapidly in popular use, the material is removed from the hole through the center of the drill string. The center hole generally has a smaller area than the annulus, hence velocities are greater; there is less mixing of the sample and no contamination from the sides of the hole. Solid cores are removed intermittently in rigid core barrels or in some cases continuously in a form of flexible sleeve. In loose or soft ground, samples are badly disturbed by the movement of the core barrel and successful coring requires not only special equipment such as the rubber sleeve core barrel (Christensen), but considerable drilling skill as well.

Once removed from the hole, the collection and reorientation of the sample relative to its position in the ground is necessary, particularly in the valuation of ores. With solid cores this is no particular problem, but with loose material it can be a very

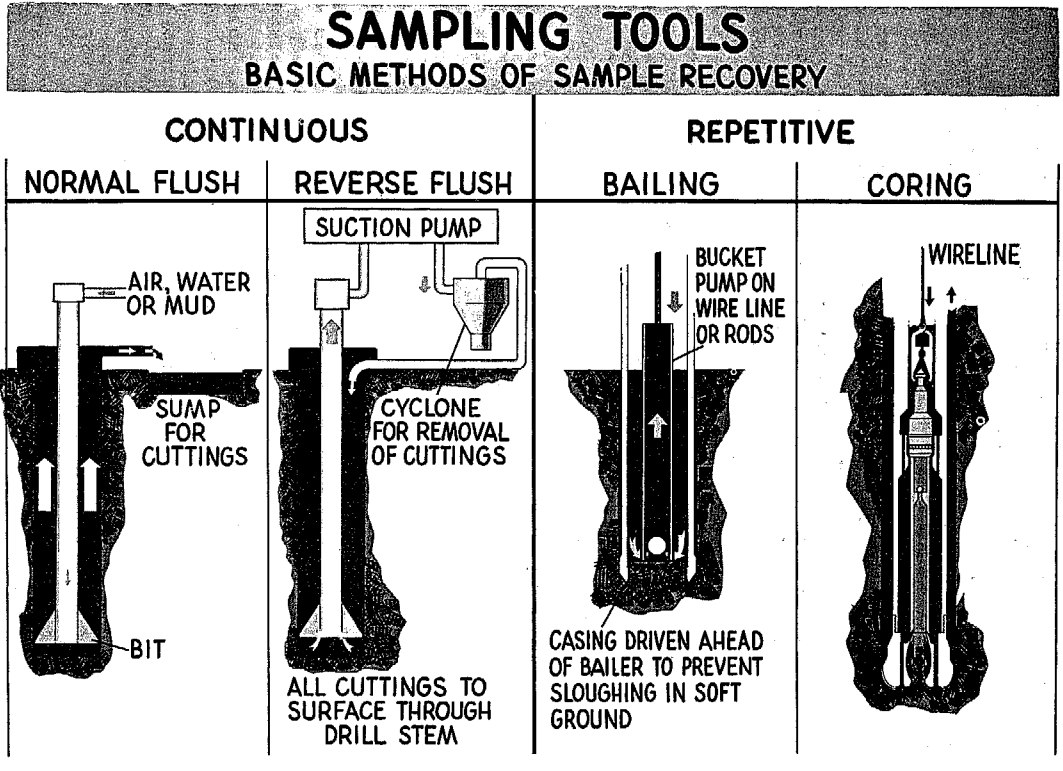

SAMPLING TOOLS
BASIC METHODS OF SAMPLE RECOVERY
CONTINUOUS
REPETITIVE
NORMAL FLUSH
REVERSE FLUSH
BAILING
CORING
AIR, WATER OR MUD
SUMP FOR CUTTINGS
BIT
SUCTION PUMP
CYCLONE FOR REMOVAL OF CUTTINGS
ALL CUTTINGS TO SURFACE THROUGH DRILL STEM
BUCKET PUMP ON WIRE LINE OR RODS
CASING DRIVEN AHEAD OF BAILER TO PREVENT SLOUGHING IN SOFT GROUND
WIRELINE

Figure 8

major one. Taking intermittent samples of the material as it comes out is satisfactory for some purposes, but where a complete and continuous record is required, reverse flushing and removal of the cuttings by cyclones offers a satisfactory solution.

Sampling equipment should be chosen, developed or designed for a specific set of conditions and the sampling system may incorporate any combination of the above methods of penetration, removal and collection of the material. Major variables to be considered are ground type, mineral type, depth of hole, depth of water and reliability required. No one machine will suit all conditions and it would be optimistic to assume that one could be built. In general, the more valuable the mineral, the less prolific it is and the greater is the volume of sample required. Diamonds are an extreme example of this situation, and large diameter rotary drills or jetting devices are required for high volume sampling. Extremely heavy minerals, such as gold and the platinum group, are greatly affected by pounding and vibration which causes them to migrate in the vicinity of the hole causing dilution or salting of the sample.

For placer deposit sampling on land, the low speed rotary percussive drill (Banka type) appears to have the best record for accuracy. It is essential when sampling unconsolidated material of this nature that the hole be cased, and that the casing be driven well in advance of the cutting tool. The presence of boulders or buried tree stumps, common in many alluvial deposits, increases the difficulties of obtaining an accurate sample. Most of these problems are enhanced when working offshore, although some of them, such as the presence of a water table interface, always a problem when sampling unconsolidated materials, are eliminated altogether. No doubt the greatest question mark lies with the method of mounting the sampling device. Most adaptations of land sampling systems are mounted on a drilling vessel. The trend may be toward self-contained sampling devices which rest on the bottom, with only a flexible line connecting them with their control vessel. Several excellent systems of this kind are in use and they are particularly adaptable to rough water – the greatest deterrent to drilling at sea. One simple axiom is obvious; if it will not sample accurately on land it will not sample accurately at sea so adequate controlled testing prior to its use at sea is of prime importance. There are at least 25 different basic designs of sampling equipment available at the present time, and over 150 manufacturers are listed in the mining literature alone. Many more are listed in the civil engineering, petroleum industry, and oceanographic literature. There is little in the way of hardware which has not already been thought of, if not built. The fullest use should be made of existing material, but the ultimate choice will depend on the specific sampling problem to be resolved.

Some of the sampling systems in Table 4 which are of particular interest are discussed below.

Becker Overburden Drill

The Becker BDT 150 was designed specifically for overburden drilling. It consists of a double walled drive pipe 5-1/2", o.d. and 3" i.d. overall. The pipe is driven into the ground by means of a diesel operated hammer mounted on top of it. Air or water is injected down the annulus between the inner and outer pipe and is jetted inside the casing a few inches above the

cutting shoe. The cuttings are carried by the air or water up through the inner pipe and are discharged and collected at the top in a cyclonic separator. The center tube is continuously open, and tube samples may be taken at any time by dropping a tube or wire line corer down from the surface. This drill has been adapted for offshore work and gives a measured 80-100% sample recovery. The accuracy of the sampling has not been proven at sea, but it is assumed to be high. Penetration rates are high, averaging 100 feet per hour in gravels, sands and boulders. At Nome, sampling gold deposits, Shell drilled through 50 feet of ice and water into 60 feet of gravel, boulders and sand on the ocean floor. Although core recovery was 80% complete, the extent of the gold recovery cannot be estimated. A barge mounted unit is also engaged offshore in Thailand sampling cassiterite deposits. Up to 70 feet of overburden is being drilled through 95 feet of water and recoveries of 85% reported. There are two major problems in using this drill offshore. One is the necessity for very calm waters due to the bulk and unwieldiness of the surface rig. Wave height of 2' are reported as a safe maximum. The other is the difficulty in retracting the drill. The hammer action is not reversible and jacks are used to ply the pipe from the hole. In Thailand it was not possible to use the barge for leverage because of the danger of sinking it. A large foot pad and casing pipe resting on the sea floor, was set over the drill, and the top of the casing which projected above the water surface, used as the lever fulcrum. This is a fast acting sampler but its small diameter and pounding action may limit its accuracy in the sampling of precious metals.

O.S.E. Deep Corer

The O.S.E. ship mounted system uses a rotary hydraulic vibrator which is clamped to the casing. The clamp has the advantage of keeping the top of the casing open at all times for wire line coring. Air or hydraulic bailing can be accomplished within the 6-inch casing using flexible hoses. The entire rig is operated by 8, 45 gpm, 2000 psig diesel hydraulic pumps. The vibrating head and power tongs are raised in the derrick by means of a hydraulic ram mounted in the main skid. Cables in the derrick are attached to a yoke on the ram. The hydraulic ram is linked to a wave compensating device. Vibration is variable up to 80 cycles per second and 100,000 lbs. impaction. Penetration is expected to exceed 100 feet in semi-consolidated gravels. A hydraulic power swivel is used for making and breaking joints and also allows rotary drilling without vibration if desired. The casing is removed from the hole by reversing the vibratory action. Although the rig is not yet completed, it incorporates several unique features and promises to be a useful addition to marine sampling hardware.

Submergible Core Drills

There are several drills of this nature presently available, notably those manufactured by Geo. Wimpey & Co., Great Britain, Koken Boring Co., Japan, and Lockheed Missiles & Space Co./ International Minerals & Chemical Corp./U.S. Bureau of Mines consortium in the United States. They are all essentially a simple self contained rotary core drill mounted in a framework which can be lowered to the sea floor and powered from the surface ship. They vary in detail only, and are capable of taking cores in all materials as on land. They are all limited by their small dimensions.

Flexo Drill

Some 30 years ago, a bottom hole drill with a flexible drill pipe wound on a reel, drilled to a depth of 2000 feet. Lacking a suitable down-hole motor, the system was not further developed, until the Flexo-drill designed by the Institut Francais du Petrole. The system comprises a down hole motor, weight, and drilling bit, a flexible drill stem, equipment for winding and handling the drill stem and equipment for surveying operations. Two units have been constructed – one, self contained except for the electric power supply, which operates on the sea floor and the other which is ship mounted and used a turbo-drill. Both systems have been successfully tested and are most suitable for consolidated material.

O.S.E. Rockeater Drill

This drill designed for the sampling of alluvial diamond deposits at total depths of less than 100 feet has the capability of rotation as well as oscillation. It is capable also of jetting and removing the sample by reverse flush methods. In normal working, a 27 inch diameter core was removed from maximum depth of 20 feet of overburden.

Hydraulic Probes

A number of these rigs are now available and give exceptionally good results where they have been used in unconsolidated sediments, sands and gravels. They consist of a heavy steel casing fitted with high pressure water jets at the shoe, vibratory devices, to aid penetration, and a water venturi, air lift and/or suction lift to raise the material from within the casing to surface. Penetration and discharge of the sample are continuous. Adaptations of this method with large diameter casings (up to 6') and diver-held pumps also have been used successfully in shallow deposits.

Banka Type Drill

These consist of a casing, generally 4" to 6" in diameter, which is caused to penetrate overburden by rotating with a heavily applied static down thrust. Removal of the sample from within the casing is by bucket pump, bailer or grab. These machines are generally manpowered but, in the evaluation of placer mineral deposits are highly efficient. This is no doubt due to the slow movement of the mechanism which does not disturb the ground through which it passes. Mechanized editions are available and are used successfully.

EXTRACTION OF THE ORE

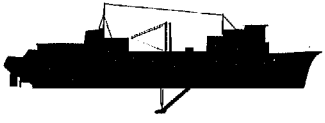
While the mineral deposits of the continental shelf include both consolidated and unconsolidated materials as well as oil and gas, we give consideration here only to the unconsolidated mineral deposits derived from continental sources and located in marine beaches and nearshore areas. There are at least 70 minerals which may be concentrated in alluvial deposits. Most of them are heavy and have a high resistance to weathering.

Mineral deposits will vary, one from the other, and the choice of mining method will depend on many factors. These include the size and nature of the deposit, the nature and depth of the overburden including water cover, the relation of the ore to bedrock,

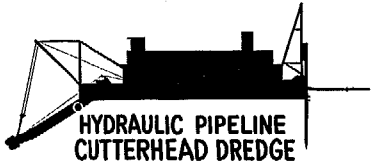
BASIC DREDGE TYPES

DREDGES WHICH OPERATE HYDRAULICALLY

DUSTPAN DREDGE

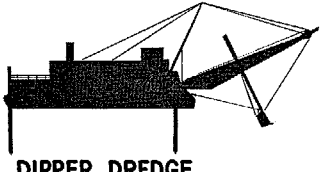


SELF-PROPELLED
HOPPER DREDGE



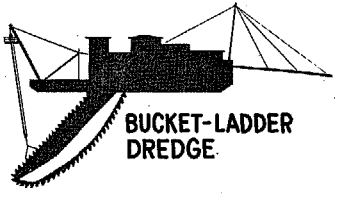
HYDRAULIC PIPELINE
CUTTERHEAD DREDGE

DREDGES WHICH OPERATE MECHANICALLY



DIPPER DREDGE

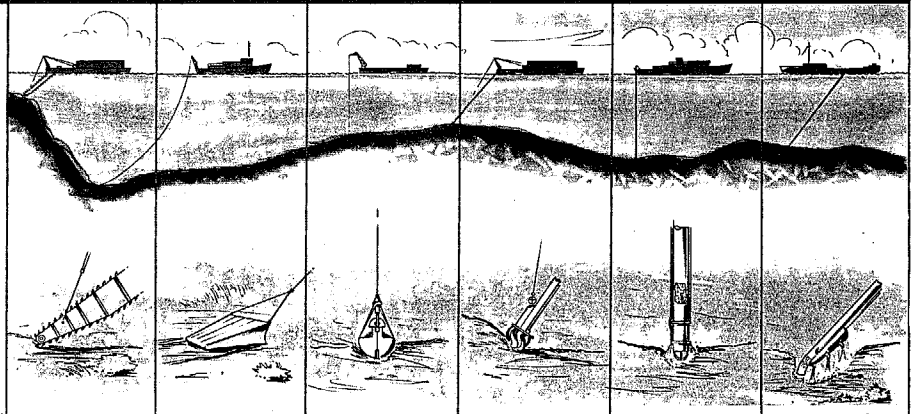
CLAMSHELL DREDGE



BUCKET-LADDER
DREDGE

Figure 9

METHODS OF MARINE ORE EXPLOITATION



TYPE OF DREDGE	BUCKET LADDER	DRAGLINE	CLAMSHELL	HYDRAULIC*	AIR LIFT*	HYDRO JET*
WORKING DEPTH (FT)	30-100	0-5000	60-200	30-100	60-1500	0->200
NATURE OF BOTTOM	MED HARD ROCK	UNCONSOLIDATED	UNCONSOLIDATED AND CLAYS	MED HARD ROCK	UNCONSOLIDATED	UNCONSOLIDATED
THROUGHPUT YD^3/HR	100-2500	1-400	60-1500	60-4500	1-800	150-4000
COST PER YD^3 (¢)**	3.4-62	<50	4.4-28	10-19	<100	<2.5-6.0
CAPITAL COST ($)	1-3M	LOW	<500,000	5000-3M	UP TO 1.7M	25,000-1.3M

* EACH OF THESE SYSTEMS MAY BE USED WITH OR WITHOUT A CUTTER HEAD

** COSTS ARE FOR ACTUAL OPERATIONS AT LESS THAN 200 FOOT DEPTHS

Figure 10

*DATA ON OPERATING DREDGES

Company		Dredge Type	Capacity	Capital Cost	Area	Period	Op. Depth	Total Thru-Put Cu. Yd. Solids	Cost/Yd. Cents
Bucket Line									
Yukon Gold Copr. Ltd. Patio Consolidated	Au	Bucket Line	13.5 ft^3		Colombia	1962	91	5,934,000	6.4
	Au	Bucket Line	11 ft^3	$2,090,426	Narino, Bolivia	1963	54	1,750,000	62.4
Tongkah Harbor	Sn	Bucket Line	15 ft^3			-		-	-
Indonesian State Mines	Sn	Bucket Line	14 ft^3	2,800,000	Billiton & Singkep		60-100		
Tronoh Mines, Ltd.	Sn	Bucket Line	(x4)			1963		10,974,000	13.4
Ayer Hitam	Sn	Bucket Line	(x2)		Selanger Malaya	1963	Deep	6,922,000	15.3
	Sn	Bucket Line				1961	Deep	5,289,000	20.4
Tanjong	Sn	Bucket Line (x1)			Perak, Malaya	1963		2,026,000	18.8
Petaling	Sn	Bucket Line (x5)			Selangor	1964		8,298,000	20.2
Grab									
Aokam Tin	Sn	Grab	4 yd^3		Phuket		100-120'	1,500,000	28.3
Yawata Iron & Steel	Fe	Grab	10.5 yd^3		Ariake Bay	1962	45		27.7

Table 5

*DATA ON OPERATING DREDGES

Company		Dredge Type	Capacity	Capital Cost	Area	Period	Op. Depth	Total Thru-Put Cu. Yd. Solids	Cost/Yd. Cents
Karl Epple Co. Stutgart	S&G	Grab	2.0	34,200	Germany	1962	33-132	.63- .34 m	7.0-14.2
	S&G	Grab	4.8	106,000	Germany		33-132	2.60-1.30 m	4.4- 8.8
Suction									
U.S. Copr. of Engineers	S & Clay	Suction	8-20"(x20)	636,000(x1)	U.S.A.		55	110,000,000	10.9
Alum Copr. of Amer.	Overb.		24"	800,000	Surinam		45	1,800,000	19.6
Water Lift									
Phillips "Mud Hog"	S&G	Water Lift	150 yd^3/hr.	25,000	Calif.	1965	400(?)	111,500	6.0
Mining Equpt. (London) Ltd.	S&G	Hydro-pneu-matic	200 yd/hr.	100,000	United Kingdom	1966	300	NK	3.0
Combination									
Marine Diamonds	Di	Air/ Water Lift		1,700,000	SW Africa	1963		1,404,000	122.0
Terra Marina	Di	Air/ Water Lift	400 m^3 solids/hr.	1,260,000	SE Africa	1965			
Kaiser Construction	S&G	Suction/ Hydrojet	200 yd^3/hr.	400,000	Ghana	1962	200		

*Based upon information published or made available by the manufacturer.

Table 5 (Contd)

production requirements, logistics, weather and sea states, and so on. These factors can only be ascertained after a thorough investigation of the particular ore body. In this case, we can only postulate an ore body and describe some of the methods from which a choice would be made. In deposits offshore, many adaptations will be required of existing equipment and methods, but except in deep water, say beyond 200 feet, these would not require any form of technological breakthrough.

Types of Dredges

Alluvial deposits offshore are mined by dredging using bucket ladders, draglines, clamshells, hydraulic dredges and air or water lift. None of these systems is new in concept and not all have been successfully used in mining operations, but each is applicable to particular cases. See Figures 9 and 10 and Table 5.

Bucket Ladder Dredges

Mining with the bucket ladder is a continuous process with excavation accomplished by using an endless chain of steel buckets which dig into the ground below the level of the floating dredge. This technique, used in many civil engineering and construction machines for excavating trenches for foundations, ditches, and canals, was possibly among the first of the automatic production lines.

Bucket capacities of mining dredges vary from 2 to 20 cubic feet with up to 54 cubic feet proposed giving monthly capacities in the range of 60,000 to 1,500,000 cubic yards. Digging may be carried out to depths of 100 feet below water line and, on occasion, to 150 feet. Concentration of the mineral values is carried out on board the dredging vessel and tailings are discharged to the rear. Since most mining operations are carried out for high gravity minerals of low volumetric concentration, the tailings constitute the major part of the through-put of the plant.

Dredging capacities are dependent on the bucket size, the horsepower, and the digging conditions. They normally average from about 150,000 to 400,000 cubic yards per month.

Power on the dredge is required to actuate the bucket line, control the winches, and run the pumps and other plant, such as trommels, jigs, and concentrating tables. Electric power is often supplied by cable from shore, but in out-of-the-way places, diesel electric plants and even steam generators are used.

Draglines and Clamshells

Because of its simplicity, the dragline is often used in the sampling of deep sea deposits, at depths as great as 30,000 feet; but there is no record of it being used for mining offshore, except in the recovery of beach sands above the high water mark. Recent studies indicate that as a method of commercial dredging for nodules in deep water, it might be applicable to a depth of 5,000 feet, but would not be efficient in cleaning the bottom. Very large and unwieldy buckets would be necessary for such an operation and control of the dredge sweeps would be difficult.

Clamshells, or grab dredges, being suspended from wire ropes are similar in concept but are becoming much more widely thought of as a mining tool. Grabs were first introduced in 1865 and later the multiline grab was developed. Its great advantage was that it

could be opened underwater if caught on an obstruction. Since then, many general advances have been made in the design and digging efficiency of grabs, and today, the four-rope heavy excavating type can be regarded as one of the world's foremost digging tools. From a tonnage viewpoint, it probably handles more material than any other single mechanism. Outputs of 800 to 1,000 tph are common with a single grab, and 30-ton capacity grabs with outputs of 1,500 tph are already beyond the drawing board stage.

Hydraulic Dredges

The use of hydraulic dredges in mining is confined mainly to the removal of overburden in the mining of unconsolidated sand and gravel deposits. However, recent improvements in size and capacity of suction dredges for civil engineering has been substantial. The increase in mining operations offshore and proposals to vacuum-clean the deep sea floor for nodules point to an inevitable revival of interest in the hydraulic dredge as a mining tool. One of the fundamental problems in suction dredging is the continuous entry of the maximum amount of solids into the suction pipe. Hydraulic (or suction) dredges may be built with or without cutter heads. Those with cutter heads are used to dig into consolidated alluvium or soft to medium hard rock, and those without cutter heads are used to remove unconsolidated sands, muds, and silts. Most mining operations use cutter heads to break up the ground and direct the flow of solids into the suction pipe. These heads are of various designs, but are normally of the rotating, hollow bit type, placed directly in front of the suction pipe. The pipe and rotating shaft are attached to a rigid ladder which is raised or lowered in front of the dredging vessel. Dredges are now built with a rotating suction pipe which has the cutter head directly attached. The dredging vessel is generally anchored at the stern by hawsers, or by spuds driven into the bottom and the vessel is swung in an arc from the point of anchorage, to give a maximum sweep to cutting head.

Without the cutter head, various methods are utilized to gather the material into the suction pipe. The types of head in use include plain suction, the dust pan type, and the drag head. These are used from dredging vessels with the suction head held stationary, thrust forward, or dragged. Water jets to agitate the solids are often used with the plain suction head but they tend to agitate the lighter material and wash away the heavy minerals from the nozzle. A ladder mounting may be used for the suction pipe of the dust pan dredge, but drag heads are generally attached to a rigid suction pipe which swings down from the side of the vessel and is suspended at the head. Joints are also used where extra pipe flexibility is desirable.

Suction dredges generally operate at depths of 30 to 90 feet, but are being built to operate at depths up to 250 feet. Preliminary designs have been made for hydraulic dredges to mine the nodular deposits at depths of 4,000 feet and greater. Velocity head and entrance loss to the suction pipe are independent of dredging depth, but at greater depths, increases in the friction head and in the head required to support and move the column of mixture, will obviously require the submergence of the pumping unit.

Hydraulic dredges generally have a high capacity. A 10-inch dredge with 400 hp. on the pump and a 75 hp. cutter will conservatively pump 250-cubic yards per hour in unconsolidated

material and 50 cubic yards in soft rock. A 30-inch dredge with 8,000 hp. on the pump 2,500 hp. on the cutter will pump 4,500 cubic yards per hour in unconsolidated materials and up to 2,000 cubic yards in soft to medium-hard rock. Operating costs will range from $15,000 a month of 22-hour days for the 10" dredge to $100,000 for the 30 inch. Capital costs are in the region of $225 to $275 per installed horsepower.

Air Lifts

The air lifts work on the principle that air injected into the bottom of a pipe, submerged at least 60% of its length in water, will produce a density differential in the pipe. The air-water mixture in the pipe will then flow upwards under the influence of the hydrostatic head and this flow will cause a suction at the bottom end of the pipe which can be very substantial. Air lifts have been used in the past for numerous civil engineering projects where simplicity of construction is the keynote. Since they consist of only two pipes, they may be constructed in any field shop and require only compressed air to operate. However they are extremely inefficient.

Hydro-jet Dredges

The hydro-jet employs the Venturi principle whereby a water jet at high pressure and high velocity is injected upwards into the dredge pipe near the head and a flow induced in the system. This may be supplemented by air injection or a centrifugal booster pump placed at a higher level. Because the jet pump is always at the bottom of the dredging ladder it can operate at any depth. It may therefore take over from the suction dredge at depths beyond the limit of the latter. Because the dredged material does not pass through the high pressure centrifugal pump and because high pressure cutter jets are normally incorporated to break up the ground being dredged, there are few wearing parts and subsequently maintenance costs are low. Several firms make dredges based on this principle and they are used for the mining of gold, sand and gravel. Small hand held units have been successfully operated by skin divers in the mining of gold from river bottoms in California and Colorado. In South West Africa, Marine Diamond Corporation has developed and successfully applied techniques for operating the hydro-jet in combination with airlifts, and it is also used in combination with pump and airlift on the sampling vessel Rockeater. Mixtures of up to 40% solids are not unusual with this system.

Beneficiation

At the present time, in most alluvial mining operations employing dredges, beneficiation is carried out on board the dredging vessel or on a floating barge nearby. The majority of these plants are maintained on enclosed ponds with little or no water motion. Because of the more violent motions of floating platforms in the open sea, beneficiation is restricted to those processes which do not require complete stability during their operation. Such processes as washing, sizing, comminution, flotation, amalgamation, course gravity and magnetic separation may all be adequately performed, while the use of tables, spirals, and standard magnetic and electrostatic sand separators would not be suitable without adaptation.

Sea going plants are presently in use for the production of cassiterite, magnetite, and diamond concentrates and for washed and

sized sands and gravels. In shallow water (less than 200 feet) jack leg or similar platforms in contact with the bottom might be employed to obviate the effects of motion.

TRANSPORTATION

In the mining of offshore deposits, transportation becomes one of the lesser problems. Since the area is amenable to floating mining vessels, it also will allow for transportation by sea, and much advantage can be gained by the flexibility of this system. Pipe line discharge to the shore is sometimes used where it is expedient to have the material onshore, but in most cases the valuable concentrate is but a small portion of the material handled and more simple handling methods can be used. Despite the above, transportation factors should be given early consideration in the economic analysis of any deposit. Particularly in remote areas, the cost of handling and transportation must be weighed against the cost of reducing the bulk by on site beneficiation. Many other factors, such as the availability of power, docking facilities, distance to smelter, and production rates will influence decisions in these matters. There are a variety of ore-carrying ships that should be adaptable with minor modifications.

In summary, the exploration, ore delination and mining tasks vary considerably depending upon the sea environment, sub soil and ore body characteristics. Considering these factors, there exists a considerable variety of equipment that has application to undersea mining. Some equipment such as that used to accomplish precision navigation, position keeping, and sub-bottom profiling are adequate for the tasks on the continental shelves. More limited in capability are present dredge and coring systems. However, continued experience in operations with existing hardware will form the basis for modification and development of more efficient and specialized systems.

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PETROLEUM RESOURCES OF THE CONTINENTAL MARGINS OF THE UNITED STATES

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Abstract

Only a small part of the continental margins of the United States can be credited at the present time with potentially large accumulations of petroleum; however very little of the total area is known to be non-prospective. Estimates of this petroleum potential vary greatly, reflecting our poor understanding of the geologic structure and geologic history of these offshore areas and the difficulties inherent in guessing the amounts of any undiscovered mineral resource.

Approximately 2 billion barrels of petroleum liquids and 5-1/2 trillion feet^3 of natural gas have already been produced from the U. S. continental shelves, and another 3-1/2 billion barrels and 22-3/4 trillion feet^3 have been proved by drilling. An additional 3 billion barrels and 27 trillion feet^3 probably await drilling in known reservoirs, and it is possible that 8 to 26 billion barrels and 33 to 113 trillion feet^3 remain to be discovered. The ultimate petroleum potential of the U. S. shelves may thus range from more than 15 to 35 billion barrels of petroleum liquids, and from 90 to 170 trillion feet^3 of natural gas. The volume of petroleum ultimately produced will depend largely, however, on our ability to explore and produce it and the economic incentives to do so.

To date, the petroleum industry has drilled more than 8,250 wells offshore, has invested more than $6 billion in these marine efforts, and has accounted for more than $3-1/2 billion in direct payments to federal and state treasuries. Petroleum exploration and production is at best an expensive and risky business, and immense sums of money will be needed for future marine ventures. However, we have every reason to expect a continued expansion of effort in finding and recovering our marine petroleum resources.

GENERAL ASPECTS OF U. S. CONTINENTAL MARGINS

The surface of the earth consists essentially of two topographic surfaces - the average height of the continents and the general depth of the ocean basins. The boundaries between these areas comprise the continental margins of the world. They are among the principal geologic features of the earth, but they are probably the most poorly understood. The volume of water now in the oceans slightly exceeds the capacity of the ocean basins, and it is even possible that the broad continental shelves which we see today are unique in the history of the earth (Figure 1).

The seaward edge of the continental shelf is normally marked by a sharp increase in slope, known as the "shelf edge." By convention the edge of the shelf is considered to be at 100 fathoms, but in fact it ranges from less than this to much more. The steeper surface beyond the shelf is the "continental slope," normally considered to extend to a depth of about 1,000 fathoms, beyond which the more gentle surface of the "continental rise" ideally slopes into the deep ocean basins.

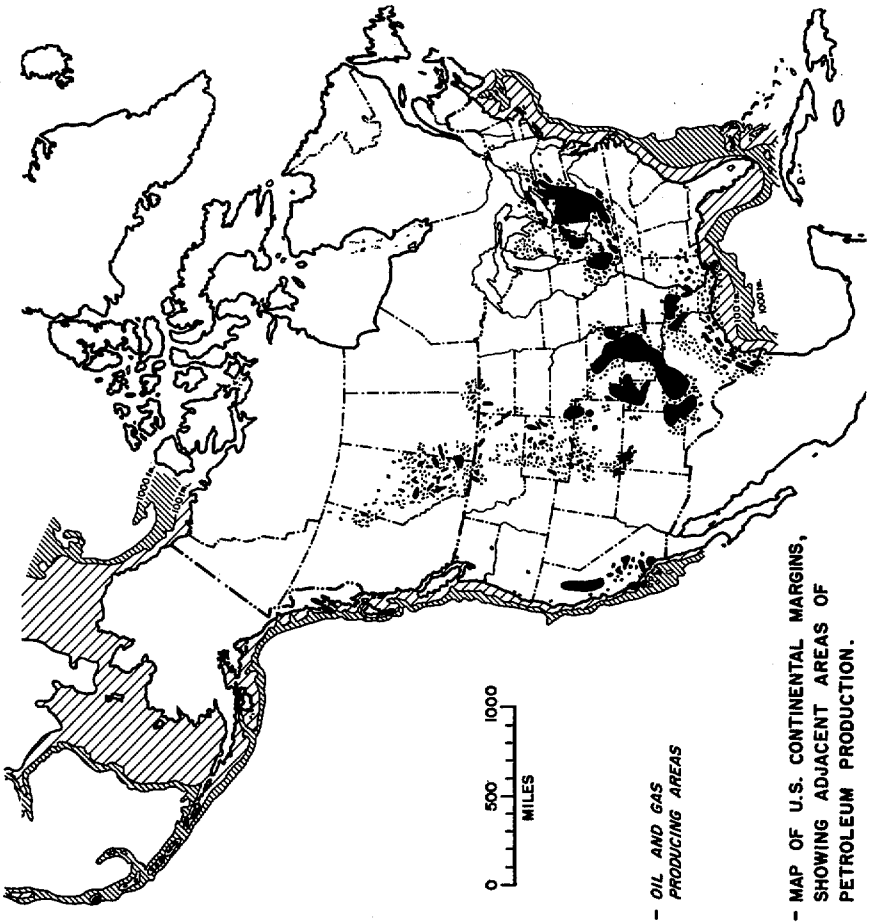

0
500
1000
MILES
OIL AND GAS
PRODUCING AREAS
FIG. I - MAP OF U.S. CONTINENTAL MARGINS,
SHOWING ADJACENT AREAS OF
PETROLEUM PRODUCTION.

Figure 1

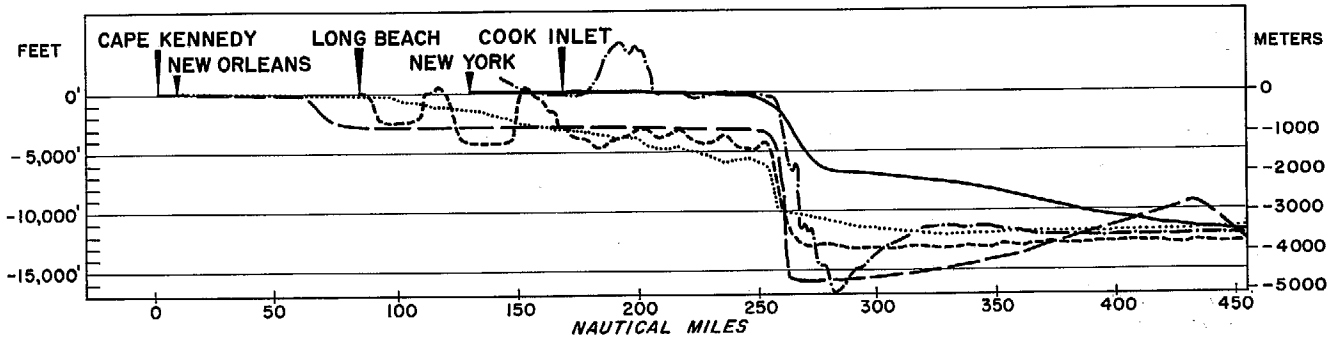


Figure 2

WATER DEPTH AND AREA (IN THOUS. MILES^2)

	0-200 M	200-1,000 M	1,000-2,000 M	TOTAL
ATLANTIC MARGIN	124	28	12	164
FLORIDA MARGIN	78	51	18	147
GULF OF MEXICO	68	27	33	128
(LOUISIANA)	(25)	(10)	(10)	(45)
PACIFIC MARGIN	23	27	26	76
ALASKA PACIFIC	82	29	13	124
(GULF OF ALASKA)	(25)	(7)	(3)	(35)
ALEUTIAN SHELVES	16	28	28	72
BERING SEA SHELF	364	10	10	384
(BRISTOL BAY)	(50)	(1)	(1)	(52)
ARCTIC MARGIN	120	55	100	275
TOTAL	875	255	240	1,370

FIG. 2 - TOPOGRAPHIC PROFILES AND AREAS OF U.S. CONTINENTAL MARGINS.

Only the northern Atlantic Seaboard in the United States approximates this ideal continental margin (Figure 2); all of the others are distinct. A broad borderland at a depth of about 500 fathoms adjoins the east Florida shelf; the floor of the northern Gulf of Mexico slopes gently to even greater depths beyond the shelf break; isolated depressions at depths to 1,000 fathoms occur within the continental margin off southern California. Each of these variations is a result of a different geologic history and geologic structure, and each area poses distinct problems for the exploration and development of its petroleum resources.

There are approximately 875,000 miles^2 of continental shelf bordering the United States. An added 495,000 miles^2 lies in waters between 100 and 1000 fathoms. The geology is almost entirely unknown beyond the continental shelf, and estimates of the petroleum potential of these outer areas are presently beyond reasonable speculation.

NATURE OF PETROLEUM AND PETROLEUM RESERVES

One of the most important aspects of petroleum is that it occurs as a liquid or a gas, and as such it is free to move easily through the porous rocks of the earth's crust. This freedom of migration obviously complicates exploration, but it also allows petroleum to accumulate in local traps in quantities large enough to justify extraction - just as the schooling of herring allows them to be extracted from the sea economically.

The total volume of oil or gas in any local accumulation is commonly known as petroleum "in place." The amount of this petroleum that can be recovered depends largely upon three factors: Physical - the nature of the reservoir rock, the type and composition of the petroleum, the source of pressures within the reservoir, etc.; Technologic - the engineering techniques available for drilling and producing the petroleum under a variety of adverse conditions; Economic - the cost of exploring, drilling, producing, transporting, refining, and marketing the petroleum, as compared with its worth or market price. The volume of recoverable petroleum from any reservoir is the "recoverable reserves."

Obviously the volume of any petroleum already recovered from a reservoir is the most accurately known component of the ultimate reserves. Some of the remaining reserves have been "proved" by the drilling of wells; these also are known fairly accurately. Less accurate are estimates of recoverable reserves in undrilled parts of the reservoir and reserves available by improved recovery techniques yet to be applied. These are known as "prospective reserves." The least accurate estimates are of recoverable reserves in accumulations that have not yet been found. These are "speculative reserves," and obviously they are most speculative in regions where there has been no drilling.

Thus, in estimating the ultimate recoverable petroleum reserves of any area, we are faced with reliabilities ranging from known volumes already produced to highly speculative estimates of yet-to-be-found accumulations. Without question, the continental margins of the United States fall very largely in the unknown and highly speculative category.

PUBLISHED ESTIMATES OF ULTIMATE PETROLEUM RESERVES

Inasmuch as the geology of continental margins is very poorly known, and the technology and economics of operating in these areas is very problematical, it is reasonable to expect that

ULTIMATE OFFSHORE OIL AND N.G.L. RESERVES

(BILLIONS OF BARRELS)

	ATLANTIC COAST	CALIF.	GULF COAST	UNITED STATES	NORTH AMERICA	WORLD
PRATT, 1947				(33)		1000
WEEKS, 1950						400
U.S.G.S., 1951, 1954		2	13	>15		
EGLOFF, 1952				(50-100)		(500-1000)
SCHULTZ, 1952				<30		
CARMICAL, 1955				>15		
HUBBERT, 1956				20		
ATWATER, 1959			> 3.5(La.)			
JOHNSTON, ET AL, 1959	7.7					
HUBBERT, 1962, 1965				(25)		400
WEEKS, 1965					(137)	700
RUBEL, 1966		>7				

ULTIMATE OFFSHORE NATURAL GAS RESERVES

(TRILLIONS OF CUBIC FEET)

	ATLANTIC COAST	CALIF.	GULF COAST	UNITED STATES	NORTH AMERICA	WORLD
TERRY, 1950				50		
U.S.G.S., 1954		3.5	65	68.5		
KASTROP, 1955			(70)			
HUBBERT, 1956				(150)		
ATWATER, 1959			> 21.5(La.)			
JOHNSTON, ET AL, 1959	46.2					
HUBBERT, 1962, 1965				(125-150)		
WEEKS, 1965					(348)	(1,740)

RECENT ESTIMATES OF TOTAL RESOURCES

	U.S. TOTAL		WORLD TOTAL	
	OIL ($\times 10^9$ BBLS.)	GAS ($\times 10^{12}$ FT.^{3})	OIL ($\times 10^9$ BBLS.)	GAS ($\times 10^{12}$ FT.^{3})
HUBBERT, 1962, 1965	205	1,000	1,500	7,500
HENDRICKS, 1965	460	2,000	(2,900)	(15,000)
WEEKS, 1965 (OFFSHORE ONLY)			1,000	(1,740)

FIG. 3 – PUBLISHED ESTIMATES OF OFFSHORE PETROLEUM RESOURCES.

Figure 3

estimates of potential reserves should vary widely and that they should be based on a variety of techniques and assumptions (Figure 3).

The available information dates from 1947 when W. E. Pratt estimated that the continental shelves of the world might yield as much as a trillion barrels of oil. Shurr and others (1960) interpreted this estimate as indicating that the proportionate share for the U. S. (excluding Alaska) is 33 billion barrels. Since 1947, there have been numerous estimates directly and indirectly related to the continental shelves of the United States. These estimates range from 15 to 100 billion barrels with the majority being in the range 20 to 30 billion barrels.

With regard to natural gas reserves on the U. S. continental margins, the published estimates date from 1950 and range from 50 to 150 trillion feet^3 with a mean figure of 100 trillion feet^3.

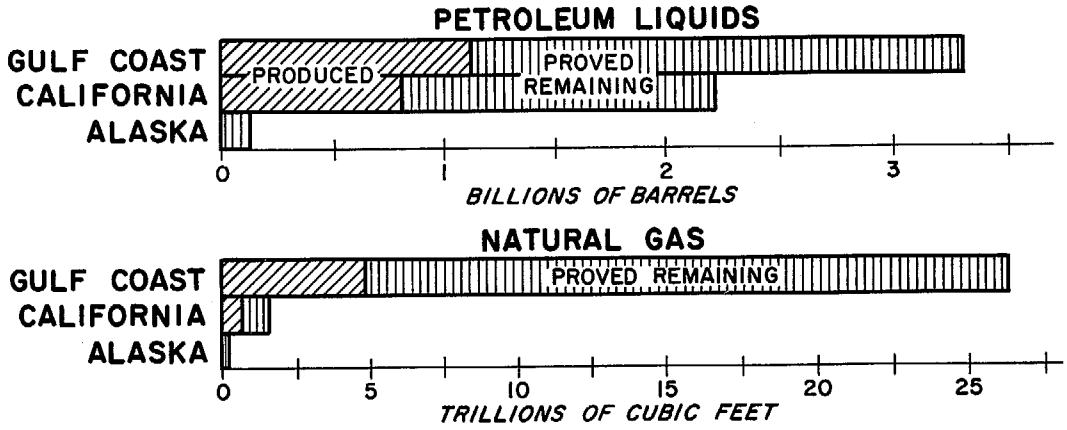
To put these estimates in perspective, they should be considered in the light of recent estimates of the ultimate petroleum potential for the entire U.S., including the continental shelves. Hubbert (1962, 1965) has estimated this to be 205 billion barrels of liquids and 1000 trillion feet^3 of natural gas (excluding Alaska). On the basis of the published estimates and the mean figures cited above, 10-15% of the ultimate U. S. oil reserves and 10% of the ultimate U. S. gas reserves would appear to be on the continental shelves. Another recent estimate of ultimate U. S. oil and gas reserves has been made by Hendricks of the U.S.G.S. (1965). His estimates are more than twice those of Hubbert's, which would reduce the continental shelf percentages considerably. However, Hendricks' estimates appear to be unrealistically high. Weeks (1965) has estimated the world's offshore petroleum potential to a water depth of 1000 feet at 1000 billion barrels of petroleum liquids and 1740 trillion feet^3 of natural gas (on BTU oil-equivalent basis).

Each of the estimates shown in Figure 3 is based on different factors and flavored with differing personal opinions, so that it is difficult if not impossible to compare one directly with another. However, the great range in estimates fairly reflects our ability to guess the ultimate reserves of the continental shelves. There is always a tendency to make dogmatic statistical projections simply because it is uncomfortable to have to work with uncertainties, but unfortunately there is no known method for making entirely reliable estimates in unexplored areas. The human factors of experience and judgment become especially important in such cases.

CUMULATIVE PRODUCTION AND PROVED RESERVES

Most of the offshore production to date has resulted from the seaward extension of known petroleum areas; in fact many of the reservoirs are partly beneath the water and partly under land. Obviously it is difficult in such cases to separate offshore reserves and production from those onshore. For our broader purposes, such distinctions are somewhat academic since a change in sea level of only a few tens of feet would radically change these figures at the present time.

Note: Offshore statistics commonly are not available separately from adjacent onshore areas, and it has been necessary here to abstract and approximate these data from many sources.

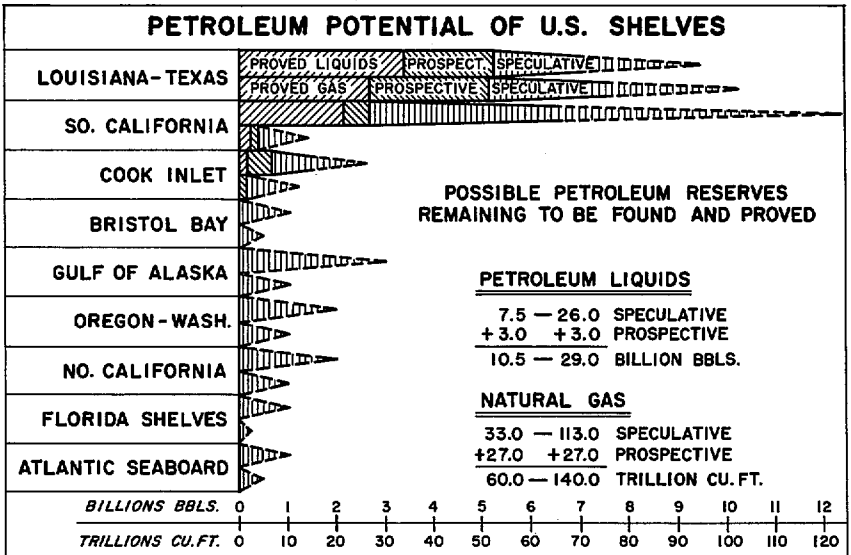


PROVED PETROLEUM RESERVES

	PETROLEUM LIQUIDS (MM BBLS.)			NATURAL GAS (BILLIONS CU.FT.)		
	CUMULATIVE	REMAINING	TOTAL	CUMULATIVE	REMAINING	TOTAL
GULF COAST	1,116	2,177	3,293	4,958	21,700	26,658
CALIFORNIA	800	1,400	2,200	500	1,000	1,500
ALASKA	-	100	100	-	50	50
TOTAL	1,916	3,677	5,593	5,458	22,750	28,208

Figure 4

FIG. 4 - PROVED PETROLEUM RESERVES OF THE U.S. CONTINENTAL MARGINS.



	LIQUIDS (BILLIONS BBLS.)		GAS (TRILLIONS CU. FT.)	
	PROSPECTIVE	SPECULATIVE	PROSPECTIVE	SPECULATIVE
LOUISIANA-TEXAS	2.0	2.0 — 4.0	25.0	25.0 — 50.0
SO. CALIFORNIA	0.5	4.0 — 10.0	1.0	2.0 — 10.0
COOK INLET	0.5	1.0 — 2.0	1.0	5.0 — 10.0
BRISTOL BAY	—	0 — 1.0	—	0 — 5.0
GULF OF ALASKA	—	0 — 3.0	—	0 — 10.0
OREGON-WASH.	—	0 — 2.0	—	0 — 10.0
NO. CALIFORNIA	—	0 — 2.0	—	0 — 10.0
FLORIDA SHELVES	—	0.5 — 1.0	—	1.0 — 3.0
ATLANTIC SEABOARD	—	0 — 1.0	—	0 — 5.0
TOTAL	3.0	7.5 —26.0	27.0	33.0 — 113.0

FIG. 5 - UNDEVELOPED AND UNFOUND PETROLEUM RESERVES OF THE U.S. CONTINENTAL MARGINS.

Figure 5

Most of the known petroleum in the prolific Gulf Coast marine area lies off Louisiana; less than 1% of the proved oil reserves and less than 4% of the known gas reserves lie off Texas. All of the offshore California reserves are along the coast near Los Angeles, where the offshore part of a single giant reservoir holds more than a billion barrels of remaining reserves and has already produced more than 350 million barrels. All of the producible petroleum in Alaska is in the valley of Cook Inlet, but production has just begun from reservoirs beneath the waters of the Inlet. (Perhaps Cook Inlet should not be included here at all since it is not a shelf geologically or legally. However, it is beset with the same problems of exploration and production as other marine areas.)

These offshore regions have already produced about 2 billion barrels of oil and 5-1/2 trillion feet^3 of gas and have a proved remaining reserve of more than 3-1/2 billion barrels of petroleum liquids and 22-3/4 trillion feet^3 of natural gas (Figure 4). The known petroleum resources of the U. S. continental margins are therefore slightly more than 5-1/2 billion barrels of oil and 28 trillion feet^3 of natural gas. This amounts to about 5% of the known U. S. oil and gas resources, indicating that slightly more than 15% of future discoveries will have to be on the continental shelves in order to average out to a minimum figure of 10% of ultimate U. S. reserves as indicated by earlier published estimates discussed above.

PETROLEUM RESOURCES REMAINING TO BE DEVELOPED

The volume of reserves in undrilled parts of reservoirs is often difficult to estimate, but far more difficult are speculations regarding the recoverable volume of petroleum that has not yet been found; we can only provide here a range of estimates for areas that have not been explored at all (Figure 5).

It is possible that another 2 billion barrels of oil will eventually be proven in fields already found in the Gulf of Mexico, and possibly twice this amount will yet be found. Unproved gas may equal that already found and produced, and perhaps twice this remains to be found - gas appears to become more dominant farther from shore.

Estimation is more difficult in California where the geology is more variable and where the drilling has been confined close to the shoreline. Probably only a small amount of the petroleum already found has not been proved by drilling - perhaps 1/2 billion barrels of oil and 1 trillion feet^3 of gas. Possibly twice the amount already proved will be found as exploration extends seaward (or about 4 billion barrels), but another Wilmington field cannot be considered as likely. If the isolated basins of this shelf are as prolific as those onshore, we could expect at least 10 billion barrels. These same proportions apply to natural gas, which is normally produced in this area in conjunction with the oil.

It is likely that 1/2 billion barrels have already been found beneath Cook Inlet, and perhaps two to four times this amount is yet to be found. Gas is abundant in this area and it is not unreasonable that a trillion feet^3 have already been found, or that 5 to 10 times this amount will eventually be discovered.

These three producing regions obviously account for only a very small part of the U. S. continental margins, but the potential of any one of these cannot be projected into unexplored areas. Each of these regions has had a distinct geological history.

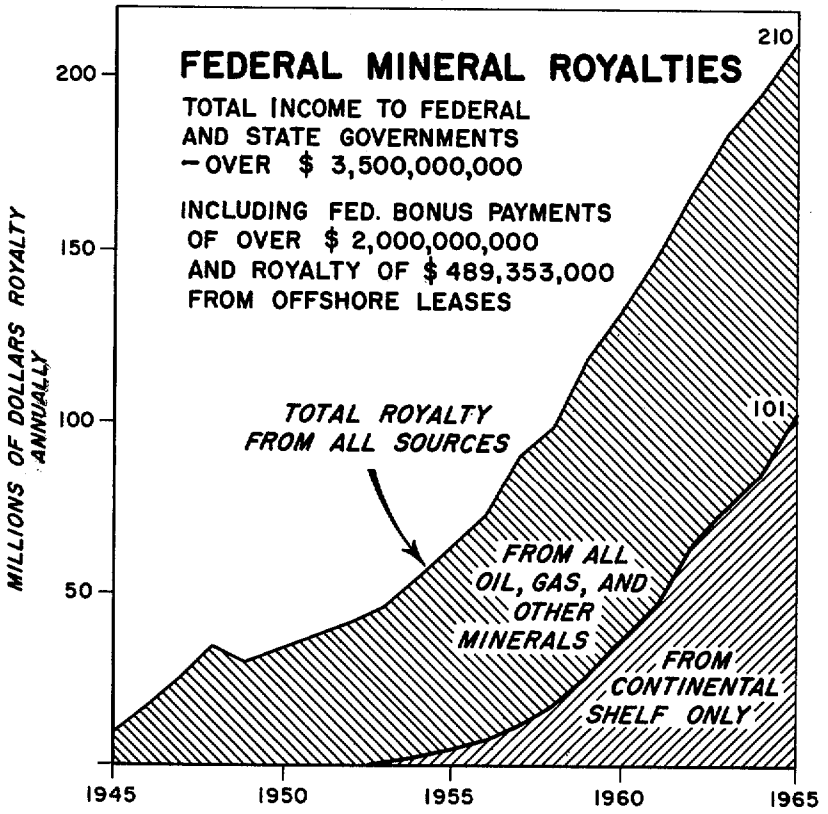


FIG. 7 - FEDERAL MINERAL ROYALTIES.

Figure 7

estimates since we know almost nothing of the geology of these areas. It is to be expected, however, that with reasonable incentives these deeper regions will also be actively explored in the foreseeable future. Other possible changes of the future cannot now be accounted for in these estimates; e.g. radical innovations in technology, changes in the economic balances, modifications of federal administrative policies, etc.

PAST MARINE PETROLEUM OPERATIONS

As an indication of what will be necessary to develop these potential marine resources, let us review briefly what has been required to develop those we already have (Figure 6). Offshore oil was first produced sometime between 1894 and 1899 in the Summerland Field, California, through wells drilled from wood wharves or directionally seaward from the beach. The first field to be produced from a man-made island was Belmont in 1953-1956. Several other islands, as well as permanent platforms have now been added to the southern California shelf.

Petroleum operations in the Gulf of Mexico began in 1936 in the High Island Field, Texas, and in 1938 in Louisiana's Creole Field. Each of these was an extension of onshore production, and drilling was carried out from wharves, submersible barges in protected waters, or drilled directionally seaward from the shore. The first seismic work beyond sight of land was in 1944; the first well was drilled beyond sight of land in 1946; and the first offshore pipeline was completed in 1951. Production has now been established at least 70 miles from shore.

Offshore petroleum was discovered in Cook Inlet in 1962, leading to the subsequent discovery of several other fields. These will be produced from fixed platforms specially designed to withstand the tremendous tidal currents throughout the year and the moving ice in the winter. The first production offshore began to flow at the close of last year.

A major problem in the orderly development of these marine resources has been the controversy between the federal and state governments concerning jurisdiction and royalties of these areas. The first suit between these governments was filed in 1945, and others followed in 1948. A start was made in resolving these disputes by passage of the Submerged Lands Act in 1953, but the dispute in California waters has only recently been resolved by a Supreme Court decision and the problem in the Gulf of Mexico remains unsettled. The increase in production after 1953 is apparent in Figure 6. Since that time, the Louisiana shelf has produced about a billion barrels of oil.

The interest of the state and federal governments in marine petroleum production is obvious from Figure 7. The rapidly increasing governmental revenue is indicated by the fact that the federal government has received nearly $1/2 billion from royalties alone since 1953, and that such royalties now account for nearly half the total royalty received by the federal government from the production of all U. S. minerals. The total payments to state and federal governments for bonuses, rents, and royalties from petroleum exploration and production offshore exceeds $3-1/2 billion to date.

These payments to government are a significant factor in the economics and feasibility of marine operations. The bonus payments alone have amounted to a third of industry's total cost of offshore operations and more than half of the total exploration

The continental shelves of Alaska adjoining the Arctic Ocean and the Bering Sea are very large - about half the total U. S. shelf area. We know very little about the geology of these regions, but the technologic and economic problems would be tremendous for operating in these remote, stormy, and largely ice-covered areas. The southern Bering Sea Shelf appears to offer the most reasonable opportunities, geologically and operationally. It is not impossible that this area may eventually yeild a billion barrels of oil and 5 trillion feet^3 of natural gas.

The shoal areas among the Aleutian Islands do not seem to offer attractive geological conditions, nor does the Pacific margin of the Alaska Peninsula and the southeastern archipelago south of Juneau. The Gulf of Alaska, however, has known seepages of petroleum. Quite a few expensive coastal wells have been drilled here without success, but the large size of this area could make it equivalent in potential to Cook Inlet, eventually yielding perhaps 3 billion barrels of oil and 10 trillion feet^3 of gas. However, operations would be very expensive and it is possible here, as in all unexplored areas, that there may be no commercial oil accumulations at all.

The Washington and Oregon shelves are presently being explored and a few offshore wells have been drilled in the vicinity without apparent success. If petroleum has formed and accumulated in this area, we might expect as much as 2 billion barrels of oil and 10 trillion feet^3 of gas. Similar amounts may be found off coastal California, but we cannot reasonably expect to find such large reserves as those known in the southern part of the state. It is possible also that these Pacific areas may largely yield gas instead of oil.

The largest part of the Gulf of Mexico has already been discussed. The west and east shelves of Florida, including the deeper Blake Plateau, are entirely distinct geologically from the marine areas off Louisiana and Texas. There is a small amount of petroleum presently being produced onshore in Florida, and although highly speculative it is possible that at least 1/2 billion barrels of oil will be found on the western shelf (including coastal Alabama and Mississippi) and perhaps twice this amount off all of Florida. Gas reserves may range up to a few trillion feet^3.

The Atlantic Seaboard has an apparent geologic history which is difficult to interpret in terms of petroleum potential, but it does not appear to be as attractive as other areas. Perhaps a billion barrels of oil and 5 trillion feet^3 of gas might be expected.

ULTIMATE PETROLEUM RESOURCES

It would seem then that the continental margins of the U. S. may contain unproven and unfound petroleum resources in the range of about 10 to 30 billion barrels of liquids and 60 to 140 trillion feet^3 of natural gas (Figure 5). If the 5-1/2 billion barrels and 28 trillion feet^3 of proved resources are added to this, the ultimate offshore petroleum potential may range from more than 15 to about 35 billion barrels of petroleum liquids and from nearly 90 to about 170 trillion feet^3 of natural gas. For comparison, the total U. S. production for 1965 was 3.3 billion barrels of liquids and 16 trillion feet^3 of gas.

These estimates should not be interpreted as limits (the actual petroleum ultimately produced could be greater or less), but merely as a range within which present estimates can reasonably be made. The areas beyond the shelf edge have not been incorporated in these

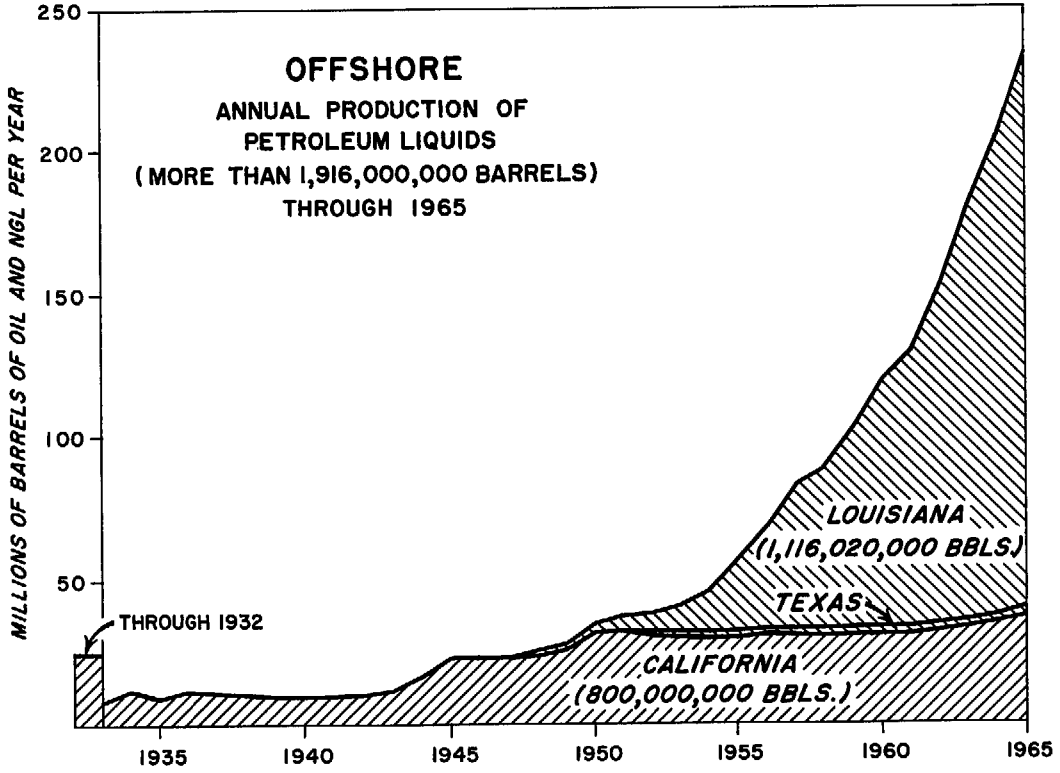


Figure 6

FIG. 6 – ANNUAL PRODUCTION OF PETROLEUM LIQUIDS FROM THE U.S. CONTINENTAL MARGINS.

Figure 8

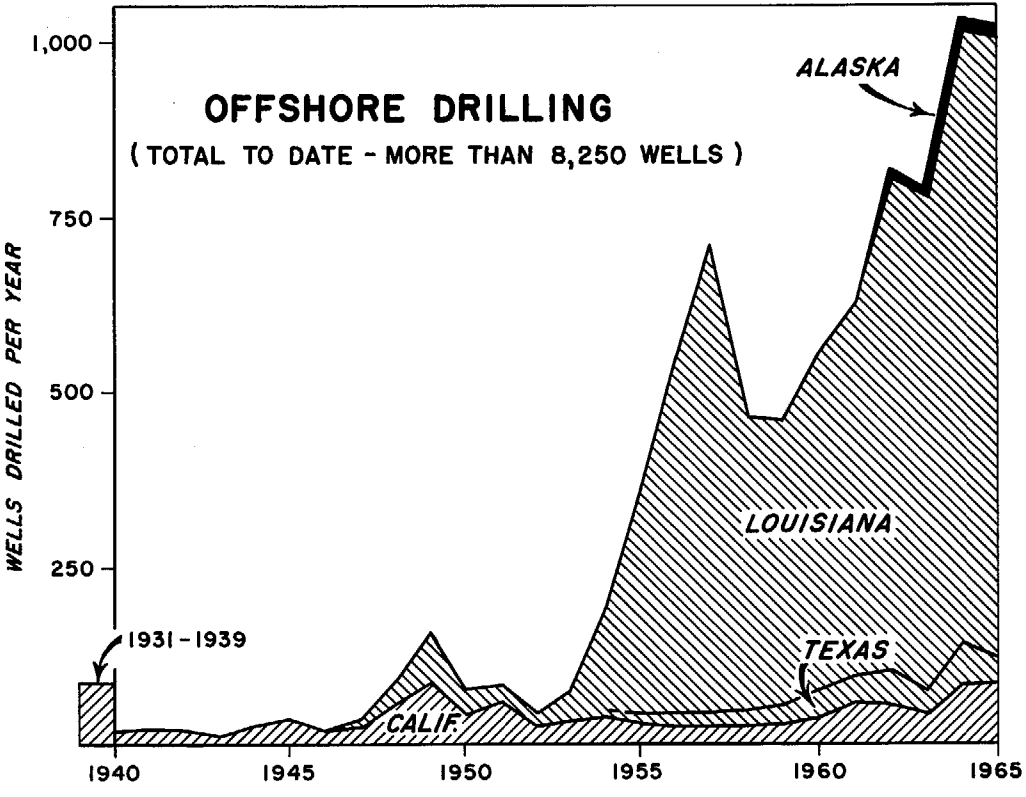


FIG. 8 - ANNUAL OFFSHORE DRILLING ON U.S. CONTINENTAL SHELVES.

costs. It becomes especially stringent when the leases acquired are for a term of only five years.

In addition to the petroleum production and direct revenue to the government already mentioned, other economic benefits result from the industry's marine efforts. The petroleum industry now accounts for about 1/8 of the total U. S. sulphur production, much of it from the Gulf Coast, and a federal bonus of $33.7 million was recently paid to develop sulphur deposits off Texas. A new chemical plant is to be built in Alaska to utilize the natural gas of that remote area. About 150 mobile drilling vessels of all types are now operating or under construction, valued at $3/4 billion. The economic value of the complex support facilities and specialized service companies associated with these marine efforts has never been estimated.

These economic rewards have not come easily or cheaply, however. For example, it has required the drilling of more than 8,250 wells (Figure 8), and before long, drilling operations alone in the Gulf of Mexico will be consuming $2 million per day. Advances and innovations in technology are an ever-present need. A fixed platform is now being built for production in 300 feet of water, and already there are probably 50 ocean-floor completions in water deeper than 250 feet. This is especially difficult since the equipment must serve for the life of the field (20-50 years). Core holes have been drilled in several thousand feet of water, and deep wells have been drilled successfully in more than 600 feet of water. The risks of such operations are high. In the last three years, offshore losses have amounted to at least $56.5 million, including $12 million as a result of hurricane Hilda (1964) and $22 million from Betsy (1965). The total industry investment in marine operations on the continental margins of the U. S. now exceeds $6 billion (Figure 9).

FUTURE OF MARINE EXPLORATION AND PRODUCTION

Secretary Udall has estimated that we will have to add 83 billion barrels of petroleum liquids and 450 trillion feet^3 of natural gas to our proved reserves by 1980 in order to maintain our present reserve/production ratio. This will require an average annual addition of 5.5 billion barrels and 30 trillion feet^3, much greater than past average additions. Certainly a large part of these new reserves must come from beneath the waters of the unexplored continental margins.

At best, petroleum exploration is an extremely costly and risky business, and the capital needed to find these new resources will far exceed that spent in the last 15 years. Industry will be hard-pressed to provide such capital financing out of proceeds as it has generally done in the past. It will be a major technologic challenge to recover these resources from the deeper waters of the continental margins and immense sums of money will be needed for this gamble. Far more money has already been invested in the oceans by petroleum companies than by all other industries, and it is likely that this will continue to be true in the future.

However, there are few barriers - whether natural or technologic - which cannot be overcome given reasonable incentive. Assuming that this incentive is not impared or destroyed, we can look forward to an expanding, challenging, and exciting future in the development of the marine petroleum resources of the United States.

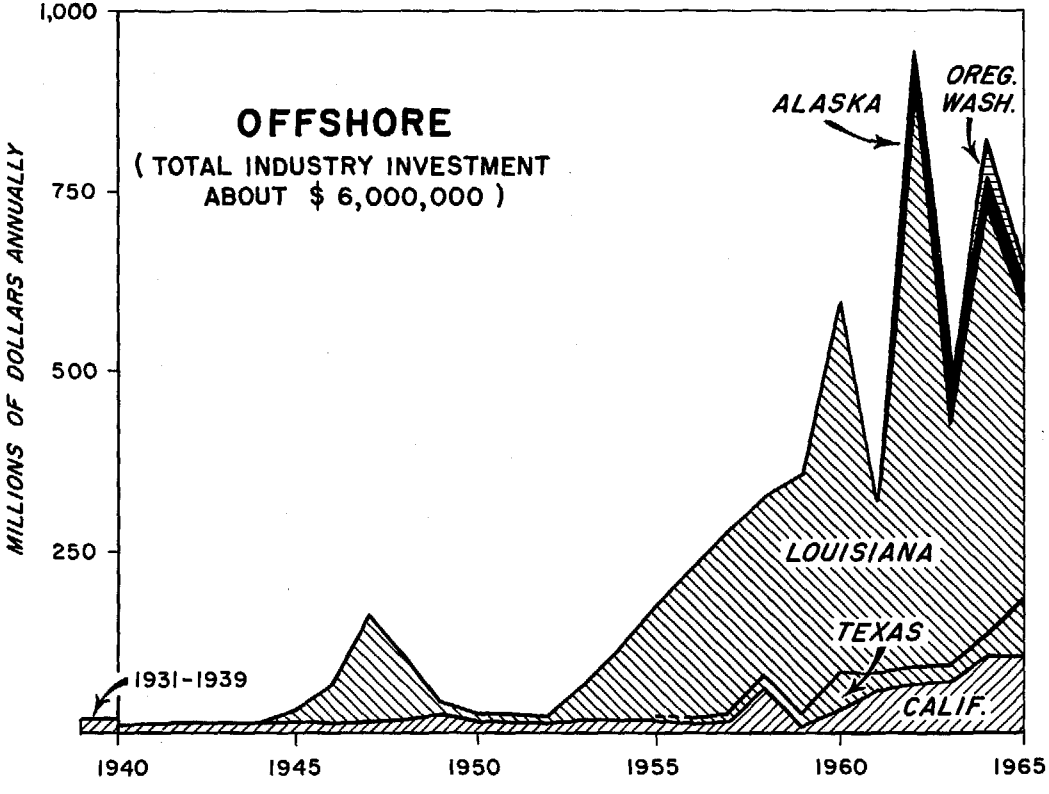


Figure 9

FIG. 9 - INDUSTRY INVESTMENT IN THE U.S. CONTINENTAL MARGINS.

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Exploration Engineering and Instrumentation Problems in the Marine Environment

B. W. Davis

Abstract

The fluid dynamics of towed bodies is considerably more complex than that of free falling bodies. Besides the normal drag, turbulence and separation effects common to free falling bodies, the towing device acts as a random forcing function. The forcing function will often have both periodic and non-periodic components superimposed on the natural effects produced by the fluid on the towed body.

The fluid mechanics becomes further complicated if the towed body itself is complex. An example of a complex towed body is a "neutrally buoyant" streamer used in marine exploration for petroleum. Its length is often greater than 1-1/2 miles and its mass greater than seven tons. The fluid drag induces an approximately linearly decreasing tension which varies with speed from several thousand pounds at the front to a negligible amount at the tail of the streamer. The tow depth of the streamer will vary as its buoyancy changes with variation in temperature and salinity of the water. These factors are all critical to performance and to reliability of seismic data collection.

Three different innovations in streamer design have resulted in significant improvement in performance and reliability. A system for automatically ballasting the streamer while it is under tow was developed during 1965. With this system, accurate control of the streamer depth can be maintained electronically from the towing vessel. A recently developed acceleration cancelling hydrophone has provided significant gains in sensitivity and signal to noise ratio. Modular streamer construction provides rapid section decoupling and improvement in connector reliability.

INTRODUCTION

A marine seismic streamer is a flexible tube which houses an array of acoustical sensors, usually piezoelectric or magnetostrictive elements. The tube is filled with a light-weight liquid to provide buoyancy and acoustic coupling to the sensors. It is usually towed behind a ship at a constant speed. In petroleum exploration, continuous tow speed of streamers normally is 5-7 knots at a water depth of 30-50 feet. The drag induced tension on the towed body is taken up by one or more wire ropes running through the streamer. The diameter of the streamer is fixed by balancing the negative buoyancy of the solid members of the streamer with the positive buoyancy of the liquid inside the streamer. Streamer length will vary from a few hundred feet to 8,400 feet, depending on the seismic energy source being used and the survey area. Typically, 24 channels of seismic data are recorded from 24 active sensor groups having

ten or twenty hydrophones in each group (Figure 1). The simplified order of progression of processing seismic data starting with the sensor signals and ending with the structural maps is illustrated in Figure 2.

FACTORS AFFECTING PERFORMANCE AND RELIABILITY

Criteria used for measuring performance of seismic data acquisition equipment is signal/noise ratio. The S/N and sensitivity of the hydrophone determine the dynamic range of the data collection system. Surface reflections from the water-air interface also make tow depth of the sensor array an important factor in performance. There are many sources of noise, but the predominant contributors are mechanically induced by the towing vessel and by the fluid through which the streamer is towed.

Mechanical loading from fluid drag, cyclic stresses and environmental conditions control the reliability of a marine streamer. Fatigue failure of stress members, fatigue of signal wires at connector terminals, salt water intrusion and corrosion are factors which have limited reliability of marine streamers. Research efforts in defining the problems and development engineering have resulted in significant advances in performance and reliability of seismic data acquisition equipment in a marine environment.

MECHANICALLY INDUCED NOISE

Mechanically induced noise occurs when a hydrophone group is caused to move transversely from its nominally horizontal position and when it is accelerated longitudinally. Mechanical vibrations are introduced to the streamer from the tugging action of the boat and the strumming of the highly stressed lead-in. The strumming is forced from vibration of the towing vessel and fluid acting on the lead-in as it cuts laterally through the water. Extremely minute vertical displacements will generate large noise signals as a result of variation in the hydrostatic head. Acceleration forces associated with a likewise small displacement of the hydrophone create a sufficient strain in the crystal to also generate significant noise signals. It is the transverse vibrations which produce large noise signals. If a single hydrophone is forced to vibrate sinusoidally in a plane at right angles to the streamer with one degree of freedom, its motion can be expressed by:

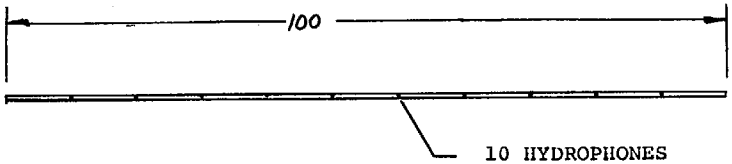
$$x = -A \sin \omega t$$

$$\dot{x} = -A\omega \cos \omega t$$

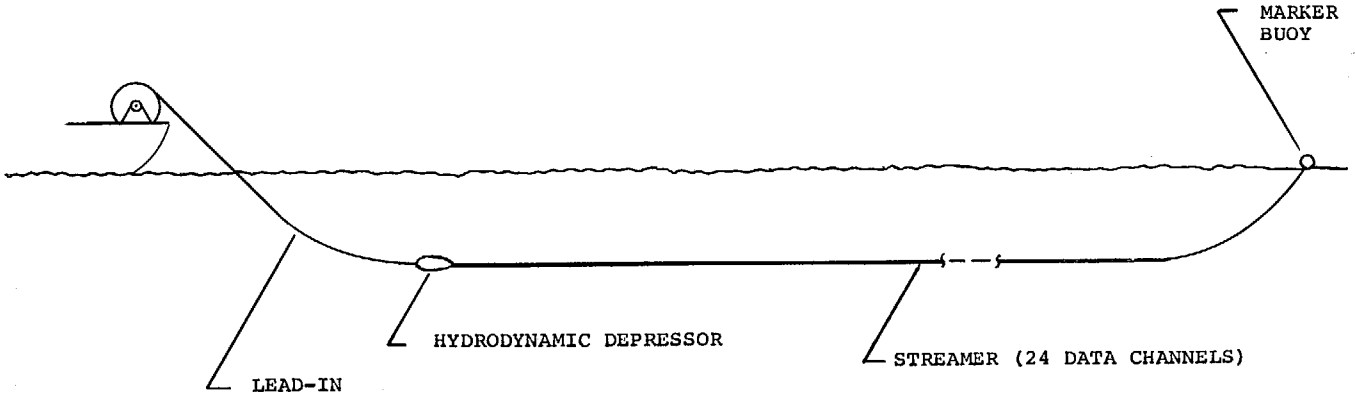
$$\ddot{x} = A\omega^2 \sin \omega t$$

where x, A, ω , and t are, respectively, displacement in inches, amplitude in inches, angular speed in radians/second, time in seconds. It is noted that acceleration is 180° out of phase with displacement. However, assuming the hydrophone is directly fluid coupled to the forcing function, both positive and negative acceleration will generate a compressive hoop stress in the crystal. If the hydrophone is polarized so that a compressive stress generates a positive voltage then the voltage output, $e_a(t)$, would be described by:

$$e_a(t) = \epsilon_s \cdot \Delta s(t) + f(t,T)$$

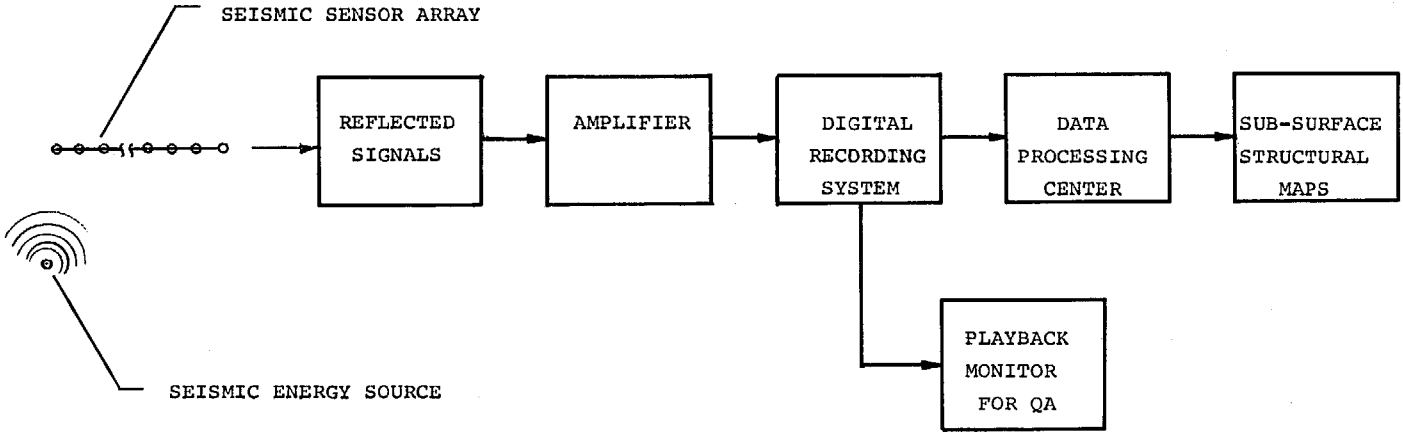


(TYPICAL STREAMER SECTION)



TYPICAL TOW CONFIGURATION OF A MARINE SEISMIC STREAMER

FIGURE 1



SIMPLIFIED FLOW OF SEISMIC DATA

FIGURE 2

where:

ϵ_s = crystal stress sensitivity (volts/lb/in^2)

$\Delta s(t)$ = time varying change in stress (lbs/in^2)

$= \frac{m}{A_x} A\omega^2 \sin \omega t$

A_x = cross sectional area of crystal (in^2)

m = mass of crystal

Therefore,

$$e_a(t) = \epsilon_s \cdot \frac{m}{A_x} A\omega^2 \sin \omega t + f(t,\tau)$$

The function, $f(t,\tau)$, is present in the acceleration noise equation because of the discharging nature of the crystal. From a static condition, a crystal will generate both a positive and negative voltage from application of only positive pressure if the period of the induced pressure is longer than the time constant, τ, of the crystal discharge. This is illustrated in Figure 3.

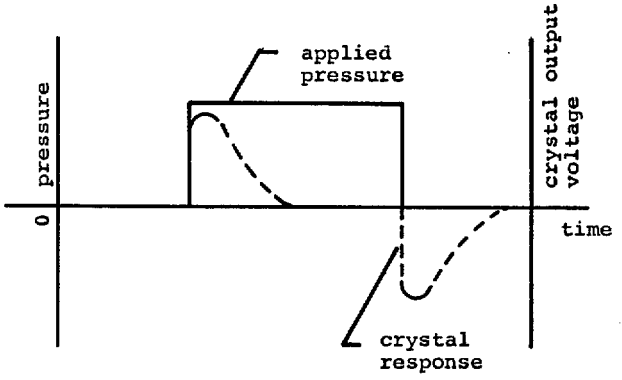


FIGURE 3

However, if it is assumed that:

$$\tau > \frac{1}{2\pi\omega}$$

$f(t,\tau)$ can be neglected and the acceleration noise voltage reduces to:

$$e_a(t) = \epsilon_s \cdot \frac{m}{A_x} A\omega^2 \sin \omega t$$

The pressure sensitivity, ϵ_p (microvolts/microbar), is related to stress sensitivity by:

$$\epsilon_s = 0.068\ \epsilon_p \cdot \frac{A_x}{A_f}$$

where,

A_f = projected area of the crystal normal to its longitudinal axis (in^2)

Therefore, $e_a(t)$ in terms of pressure sensitivity is:

(1) $$e_a(t) = 0.068\ \epsilon_p \cdot \frac{m(A\omega^2 \sin \omega t)}{A_f} \cdot 10^6 \text{ microvolts}$$

The noise in microvolts generated by change in hydrostatic head, $e_h(t)$, is given directly by:

$$e_h(t) = \epsilon_p \cdot \frac{0.068(A \sin \omega t)(0.44)}{12} \cdot 10^6$$

(2) $$e_h(t) = \epsilon_p \cdot \frac{A \sin \omega t}{400} \cdot 10^6$$

The predominant noise energy is in the 5-15 cps band when towing at 5-7 knots. In this band, the acceleration generated noise is somewhat greater than the noise generated by variation in the hydrostatic head. For example, at 5 cps and a displacement amplitude of 10^{-4} inch, acceleration noise is:

$$0.068\ \epsilon_p \frac{mA\omega^2}{A_f} 10^6 = 29 \text{ microvolts}$$

for a hydrophone with a sensitivity of 15.4 microvolts/microbar and a projected area of 1.5 in^2. The corresponding noise generated by variation in hydrostatic head would have an amplitude of:

$$\epsilon_p \cdot \frac{A}{400} \cdot 10^6 = 3.85 \text{ microvolts}$$

As the frequency increases, it can be seen from equations (1) and (2) that the acceleration noise will be dominant over the noise generated by hydrostatic head change.

ACCELERATION-CANCELLING/DISPLACEMENT-IMPEDED HYDROPHONE

Small hydrophones can be built and suspended in a streamer in such a way that it is essentially isolated from the transverse vibration of the streamer. By doing so, a significant reduction in noise can be achieved without sacrificing sensitivity of the hydrophone.

If a round tubular hydrophone is suspended in the streamer according to the schematic illustrated in Figure 4, where the forcing function is coupled through a spring to the center of the hydrophone, the amplitude of transverse vibration of the hydrophone can be reduced.

The forcing function acting through the spring on the center of the hydrophone will tend to cancel acceleration generated noise because the bending will result in compression on one half of the

tube and expansion in the opposite half. This is exaggerated schematically in Figure 5. However, it will not be completely acceleration noise cancelling because the acceleration force will tend to superimpose an overall compressive stress on the bending stress.

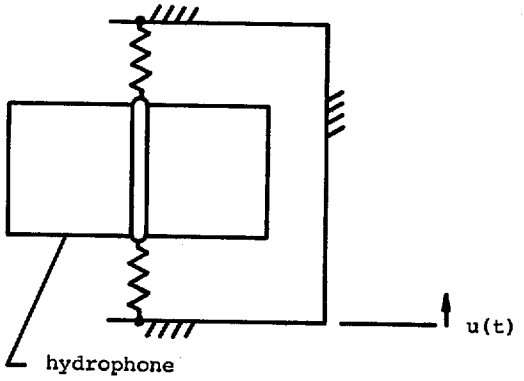


FIGURE 4

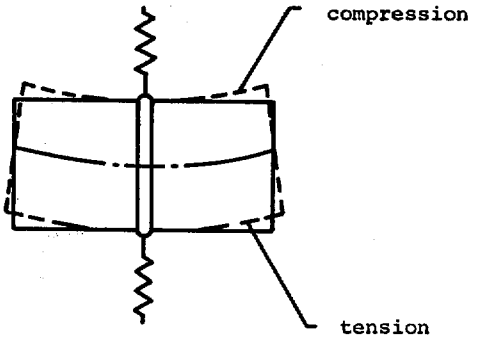


FIGURE 5

In an effort to predict the behaviour of the hydrophone isolation system, a simplified mathematical model was utilized. As further data on the nature of the inputs to the streamer are available, a more extensive and thorough mathematical model may be necessary to predict system response.

The one dimensional model is shown schematically in Figure 6; k_e represents the spring constant for an equivalent linear spring; c_e is the equivalent viscous damping coefficient; m is the mass of the suspension. The system input is denoted by u(t), applied displacement to the streamer, and the response by x(t), displacement of the hydrophone.

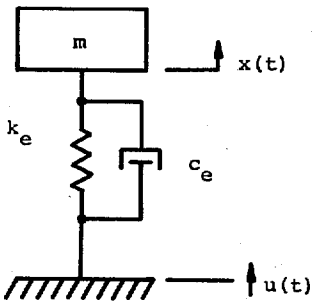


FIGURE 6

If it is assumed that u(t) can be represented by:

(*) $$u(t) = u_o \sin \omega t$$

where, u_o = maximum displacement from equilibrium; ω = the circular frequency, then the steady-state response is given by:

(**) $$\frac{x(t)}{u_o} = A \sin (\omega t - \psi)$$

where,

$$A = \frac{1 + (2\zeta \omega/\omega_n)^2}{(1 - \omega^2/\omega_n^2)^2 + (2\zeta \omega/\omega_n)^2}^{1/2}$$

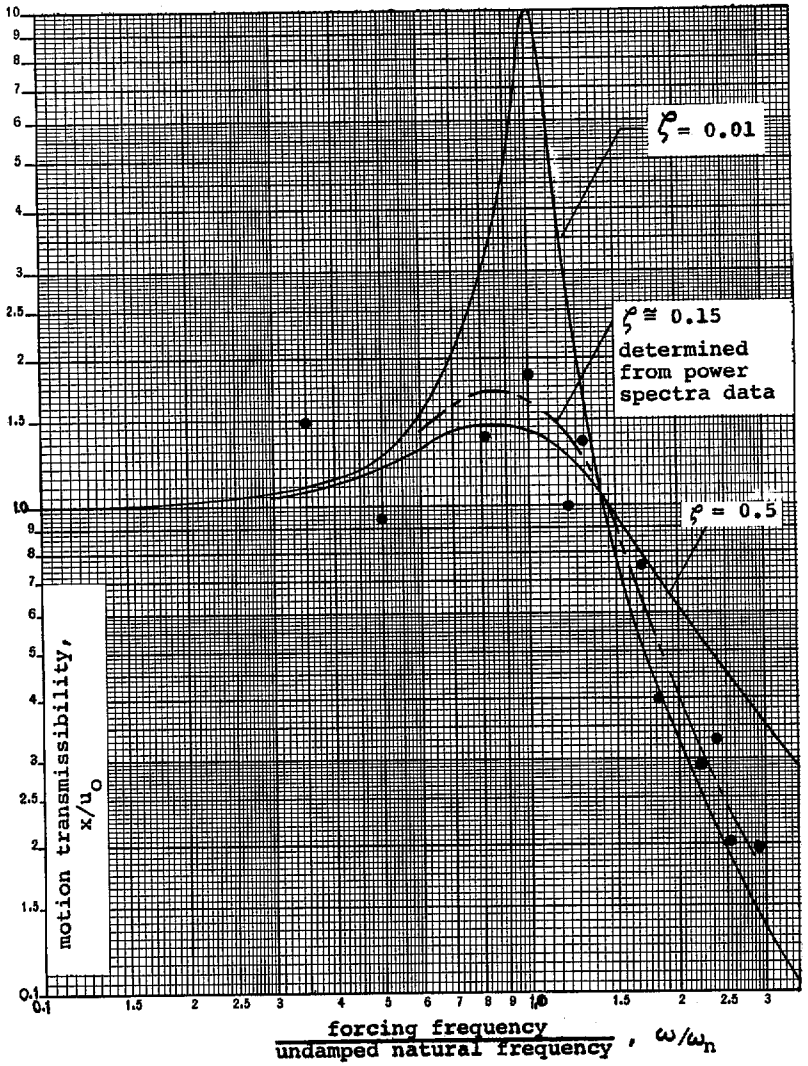
(*) This input is assumed for illustration purposes.

(**) Harris, C. M., and Crede, C. E., "Shock and Vibration Handbook", Vol. 1, Mc-Graw-Hill, New York, 1961, pp 2-14.

FIGURE 7

MOTION TRANSMISSIBILITY

RIGIDLY-MOUNTED HYDROPHONE & ELASTICALLY-SUSPENDED HYDROPHONE



$$\psi = \arctan \frac{2\zeta (\omega/\omega_n)^3}{1 - \omega^2/\omega_n^2 + 4\zeta^2\omega^2/\omega_n^2}$$

A = motion transmissibility

ψ = phase angle

$\zeta = \frac{c_e}{c_c}$ fraction of critical damping

ω_n = undamped natural circular frequency

The motion transmissibility, A, is shown in Figure 7 as a function of ω/ω_n.

The experimental points shown in Figure 7 show a comparison of the motion transmissibility between a rigidly-mounted hydrophone and an elastically-suspended one. Constants used in making the comparison are:

$$\omega_n = \sqrt{\frac{k_e}{m}}$$

$$= 188 \text{ rad/sec} = 30 \text{ cps}$$

The ratio x/u_o was evaluated at each frequency from power spectra; x from the elastically-mounted hydrophone spectrum and u_o from the rigidly-mounted hydrophone spectrum. Average power over the complete spectrum was the same for each hydrophone.

Two conclusions may be drawn from this simplified analysis:

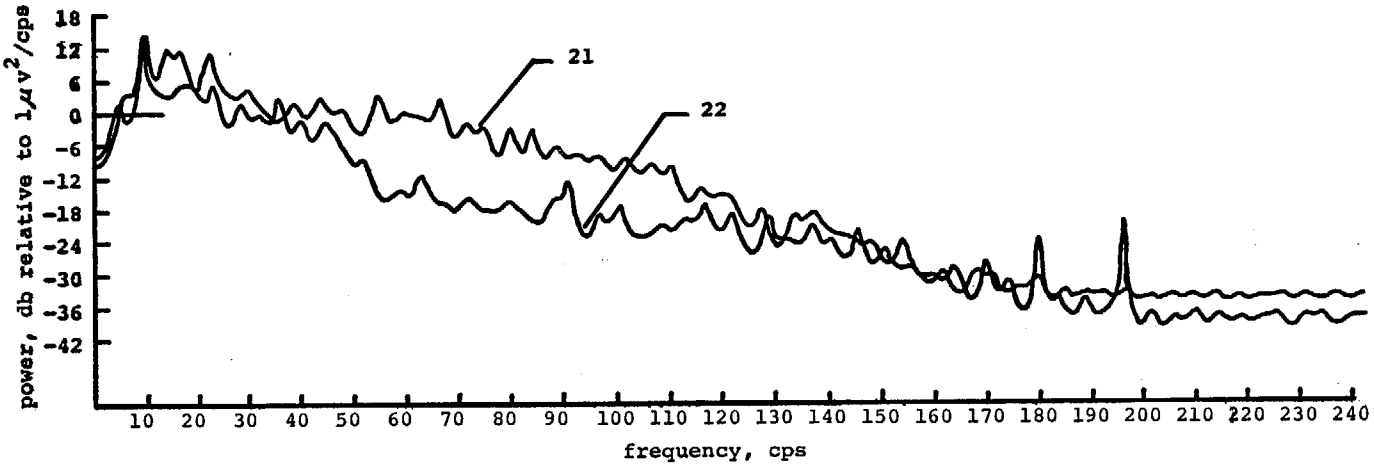
The suspension is lightly damped - approximately 10% critical damping.

Better lower frequency (less than 50 cps) response is attainable by lowering the suspension's natural frequency.

The power spectra shown in Figure 8 illustrates the improvement gained from a spring suspension hydrophone system. The power spectra curve identified as "No. 21 " was from a rigidly-mounted hydrophone and power spectra curve "No. 22 " was from a spring suspended system with a 30 cps natural frequency.

AUTOMATIC STREAMER BALLASTING

Maintaining proper depth of long streamers is generally very difficult because of change in density of sea water as a result of the variation in salinity and temperature of the sea water. The ocean is a dynamic mixture of liquid and solids. Its dynamics cannot be explicitly defined for a small area. Currents, salinity, temperature and density normally will not be constant for any given area throughout a 24-hour period. This is especially true for relatively shallow water near shore line with streams where it is often desirable to collect marine geophysical data.



TOW NOISE POWER SPECTRA (BOAT SPEED 6-7 KNOTS)

FIGURE 8

Proper streamer depth will enhance signal response. Seismic reflections from the air-water interface in the seismic band will reinforce the primary reflection if the streamer depth is properly maintained. A streamer towed near the surface will have considerable noise introduced from surface turbulence. The danger of damaging a streamer is always present, if it is towed near the bottom.

STREAMER RESPONSE TO A WATER DENSITY CHANGE

It is not uncommon for the density of sea water to change 0.1 lb/ft^3 while moving through a distance of three miles in an area within 5-10 miles of a shore line. For a 7,000 foot long by 2.5 inch diameter streamer weighing 7.5 tons, this would induce an unbalanced force of 24 lbs., enough to cause a 50-60 foot change in towing depth. The rate of change of depth is governed by the equation:

$$F = C_D A_s \frac{PV^2}{2}$$

where,

C_D = drag coefficient

A_s = projected area of streamer (ft^2)

P = density of sea water ($slugs/ft^3$)

V = velocity (ft/sec)

F = unbalanced buoyant force (lbs)

The unbalanced buoyant force changes with time, however. If it is assumed that the 24 pounds buoyancy change occurred at a linear rate in three miles when the ship's speed was 650 ft/minute, and if the drag coefficient is assumed to be constant at 1.2, the rate of change in streamer depth during this interval is given by:

$$V(t) = 60\left(\frac{2F}{C_D A_s P}\right)^{1/2} \text{ ft/min} \quad (3)$$

$$= 1.44\, t^{1/2} \text{ ft/min}$$

Therefore, the streamer would be expected to change in depth, S, according to the integral:

$$S = 1.44 \int_0^t t^{1/2} dt$$

Evaluating the integral between the limits of 0-10 indicates the streamer depth would change about 30 feet during the first 10 minutes.

The ideal situation is to be able to control the streamer depth by having the capability of changing its buoyancy from the boat while it is still under tow. An electromechanical system to serve this purpose was developed whereby the buoyancy of several streamer sections can be changed continuously by varying the displacable volume of the sections. Each section can be controlled independently. The variable buoyancy sections are spaced a few hundred feet apart throughout the length of the

streamer. Each section is capable of varying the buoyancy by 45-50 pounds in approximately 10 minutes. The length of the streamer determines the number of ballasting sections required.

To have complete depth control, the ballast system was designed to produce a streamer depth response time rate greater than the maximum time rate expected for a maximum change in ocean conditions. Response rate can be determined from equation (3).

$$V(t) = 60\left(\frac{2F}{C_D A_s P}\right)^{1/2} \quad \text{ft/min}$$

If five ballast sections are employed in the 7,000 foot streamer described above, the buoyancy can be altered at a rate of 25 lbs/minute. Theoretically, the streamer depth could be changed according to the integral:

$$S = 7.2 \int_0^t t^{1/2}\, dt$$

Evaluating the integral between the limits 0-10 minutes,

$$S = 7.2 \int_0^{10} t^{1/2}\, dt$$

shows that the depth could be changed approximately 150 feet in 10 minutes. However, in practice this is not possible because of the streaming characteristics of a long flexible towed body. Practically, the depth can be altered at a sufficient rate to compensate for the most extreme water density variations in the Gulf of Mexico.

ACKNOWLEDGEMENTS

I would like to acknowledge the help of Dr. Roy Johnston in preparing this paper and particularly for his analysis of the hydrophone isolation system.

I am also indebted to the Science Services Division of Texas Instruments, Incorporated for permitting me to publish this paper.

POSITION DETERMINATION UNDER THE SEA

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Abstract

Accurate position determination by a manned submersible in deep water is important when a controlled search of a bottom area is required to make certain scientific studies or to locate some specific object. The visibility is limited by the turbidity of the water and the power of the flood lights. Visibility of 20 feet is considered good at the ocean bottom; to insure successful operations the accumulated error of the navigation system should be less than 20 feet over eight hours of operation. Several navigational methods are discussed covering the range from the very simple aids to the more sophisticated equipments. Acoustic methods are the best at present but generally not entirely satisfactory. The state of the art is advancing and the situation should improve rapidly.

The searches for USS THRESHER by TRIESTE in 1963 and TRIESTE II in 1964, since they were actual operational assignments rather than experimental or purely research dives, contributed to a fuller understanding of the major problems of navigation by manned submersibles in deep water. These problems, in varying degrees, exist in any diving operation.

Several approaches have been studied in an attempt to develop self-contained navigation aids which could feasibly be installed aboard manned submersibles to improve the accuracy and speed of their operations and to some extent reduce the almost overwhelming obstacles they encounter in the deep underwater environment[1]. The following sections will summarize and briefly discuss both the problems and the attempts which are being made to solve them. In some cases, details of the THRESHER operations are included as a useful frame of reference.

Escort surface craft for locating the dive site, and acoustic tracking systems, are of course vital in initiating and supporting a dive operation. However, the concern in this paper is primarily with devices and instruments on the submersibles themselves, rather than with aids which are external to the craft.

In developing navigational aids for submersibles, any approach must first take into account the inherent constraints of the craft itself. Equipment aboard submersibles must be able to operate accurately at temperatures from 30°F to 110°F, and withstand immersion in salt water without damage from corrosion. Inside the sphere, equipments and devices must maintain their reliability and accuracy in a high-humidity environment. Maneuverability or safety of the craft must never be impaired. Small manned submersibles present further problems, as their space, total payload, and available power are limited; extra batteries or inverters must count as part of their payload, since some equipments require power which would not be adequately supplied by available dc batteries or ac power supply

The opinions and assertions contained herein are the private ones of the writer, and are not to be construed as official, or as reflecting the views of the Navy Department or the naval service at large.

The external sensors and wiring must withstand high pressures of thousands of pounds per square inch. Equipments must be actually pressure-tested, because some equipments built according to valid theoretical designs have failed in the pressure chamber. For a safety factor of at least two, a good rule is to test each equipment for 24 hours at a pressure in pounds per square inch numerically equal to the maximum operating depth of the vehicle in feet. For example, if the submersible is certified for 6000 feet, the 24-hour pressure test should have a pressure of 6000 psi or greater.

OPERATIONAL REQUIREMENTS

Underwater, limited visibility presents severe operational problems. Below 1000 feet the sea is in complete darkness, so visibility is possible only from the flood lights carried on the craft. Depending on the turbidity of the water and the power of the lights, visibility can range from zero to 30 feet or more. Aboard the bathyscaph the observer could usually see 80 to 100 feet ahead when she was running very close to the bottom. When 30 to 40 feet from the bottom, the details on the bottom became very indistinct. This indicates that the transparency of the water on the bottom at 10 or 15 feet may be greater than in the water further above the bottom. The practical effect is to limit how far above the bottom one can run and still distinguish the details necessary to accomplish a mission.

Dead-reckoning navigation was not sufficiently accurate for the THRESHER search. An aircraft gyro gave the headings to one degree but the bottom currents were variable in direction and ranged in magnitude from zero to one knot. Consequently, the set of the craft was not constant. Locating reference "landmarks" is not easy. In the THRESHER search during 1963 sometimes as much as two hours elapsed between sightings of the plastic reference markers that will be discussed later. The unknown sets and limited visibility impose a practical navigation requirement for no more than 20 feet of accumulated error over eight hours of operation.

Manned submersibles need good sonar obstacle-avoidance equipment to give warning in sufficient time to avoid a disastrous collision. Operating areas have practically never been adequately mapped. One of the first operational requirements is to get good bathymetry to define the operating terrain. Rough terrain is often encountered. In the THRESHER area at depths of 8000 to 8500 feet, there are slopes of 15° with occasional rocks as big as automobiles.

Figure 1 illustrates the bottom bathymetry in the THRESHER area. Contours of the hills and valleys are shown only superficially; obviously, an echo-sounder obtaining data two miles above the area with a 30° beam cannot define the bottom in detail. The heavy lines in Fig. 1 were obtained[2] from an interpretation of side-looking sonar records obtained from a "fish" towed 200 feet from the bottom. Fig. 2 is a composite of some of the records from which interpretations were derived. These particular records have a resolution of six feet in both directions. The sweep is from the center out and the records show a bottom width of 1200 feet to each side of the "fish." Higher resolution could be obtained with a different mode of operation such as towing the fish 20 feet above the bottom. Of course, towing over an unknown bottom presents problems and very likely the equipment would get hung up on the first available

cliff or upslope. However, when closer to the bottom, the resolution can be less than a foot in both directions but the coverage only 200 feet to each side of center.

A search may be directed to a small object, as in the case of the bomb recovery off Spain, or involve a wider area as required by the THRESHER operation. In either case, navigation must be sufficiently accurate to direct the submersible to within sighting distance of the point of interest.

NAVIGATIONAL METHODS

Several navigation methods are feasible but equipments should be made small, lightweight, and trustworthy to be of use for the small manned submersible.

At first it might seem logical that during a series of dives a familiarity with the bottom would be developed and could assist in navigation. It is true that some gross features are recognizable and broad types of features and rocks become familiar, but identification of particular ones is very uncertain. As an analogy, consider an observer placed at random in an almost featureless rolling desert on a moonless night, with a flashlight allowing him to see about 30 to 40 feet. He is allowed to walk (a speed which would be "fast" for a manned submersible while observing) and examine the terrain for a period of six hours. Next night or a week later he might be placed at random initially at some other spot as far as 1000 yards away, in a 20-knot wind (which might approximately parallel the disturbing effect of bottom current for the submersible). Somehow he would be supposed to store the hours of information for immediate retrieval. Of course, the analogy would be even better for a scuba diver with a powerful search light, diving on a moonless night on some available guyot in the Pacific.

SIMPLE METHODS

The usual aircraft gyro is adaptable to the small manned submersible. The gyro can be turned on before the dive. After it has stabilized it can be gated at the correct bearing furnished by the gyro of the escort ship and can then be used throughout the dive to obtain the headings to the nearest degree.

Magnetic and fluxgate compasses can be utilized. The magnetic variation or declination must be known for the area, as well as the deviations for all headings. The compass can be compensated to minimize the deviation with heading. In addition, there will be local and unknown anomalies at the bottom which are well known to the land surveyor who sometimes uses a compass for bearings. (He guards against error by taking forward and reciprocal bearings from each occupied point of a traverse.)

Some device to accurately measure the actual motion over the bottom is required to obtain dead-reckoning navigation. Since submersibles generally operate at low speeds, the set of the current is an important factor in navigation. The direction and magnitude of the current can be estimated by observing the bottom while allowing the craft to drift with the current. This estimate can be utilized with the measured water speed and heading while underway. Unfortunately, even a good estimate is not

reliable, because time and terrain cause the currents to vary in both magnitude and direction. Dead-reckoning navigation definitely requires some device to accurately measure the actual motion of the craft over the bottom.

Speed relative to the bottom can be obtained by trailing a wheel on the end of a trolley attached to the underside of the submersible. Some tests aboard the Perry Cubmarine are reported by W. E. Hart and R. F. Busby[1]. Their readout was an odometer.

A small computer could combine headings and speed of advance to give a DR plot automatically.

During the 1963 THRESHER operations, one method which proved successful utilized a grid of plastic reference markers, laid a little over 58 feet apart and numbered from #1 at the south end to #131 at the north end. Each line of markers was approximately 750 feet apart in the east-west direction. Developed by the Hudson Laboratories, these markers consisted of colored plastic sheets, 17" x 21", each with an identifying letter and serial number painted on both sides. They were rolled and tied to 10-pound sash weights and dropped from the surface ship. The ship proceeded for the laying operation by using Decca purple and green lines to control the track. After all navigation data were reduced, Fig. 3 was prepared. It can be seen that neither the spacing nor the track is constant at the surface, and, of course, since each one took about an hour to reach the bottom, the effect of the variable and uncertain currents would be to distort the actual location on the bottom considerably from Fig. 3. However, these "fortune cookies" (so designated because they had to be unrolled before the message could be read -- and many of them failed to unroll) proved extremely useful in the THRESHER search to identify different sections of the THRESHER in terms of this grid line. A second set of plastic markers was laid for the 1964 operations because the fortune-cookie sightings were often too widely spaced in time. Both sets of plastic markers and debris showed up in the photographs obtained by cameras towed by surface ships in both 1963 and 1964 and resulting information was valuable in planning the operations of the TRIESTE and TRIESTE II. Some similar type of bottom marking might be advisable for other search problems.

INERTIAL NAVIGATION

Inertial navigation is progressing rapidly. The author knows of no system that is light enough for small submersibles and still has an accumulated error less than 20 feet over eight hours of operation. Systems are being developed that are becoming lighter and more accurate and perhaps these will be available in the near future. A reliable system would be valuable when the submersible is operating in very deep water far from both the surface and from the ocean's bottom.

OPTICAL BEACONS

Another navigation method that might be used is optical. A bright flashing strobe light might be seen 500 yards or more and serve as a beacon on the bottom. Flashes were observed at the surface at night in 1952 when strobe flash pictures were taken at a depth of 1500 feet for scattering layer studies. Research is being done at the Navy Electronics

Laboratory to measure the actual light-scattering and absorption properties in the water column at the bottom. Results of this study will permit an assessment of the value of such a light as an aid in position-fixing as well as the optimum placement of flood lights aboard the craft for direct observations.

ACOUSTIC METHODS

Acoustic methods offer the most hope for good navigation at the present time. There are several types.

One type involves three receivers aboard a surface ship, receiving signals from the submersible. Such a system was used successfully in 1962 at Japan when the MARCEL LE BIHAN tracked the French bathyscaph ARCHIMEDE. A second type of system is the more sophisticated 3-D acoustic tracking system developed by the University of Washington Applied Physics Laboratory, to track their unmanned research vehicle. The surface ship queries and receives replies from the transponder. It utilizes travel-time differences to three receiving hydrophones and applies corrections for roll, pitch, and yaw to compute the relative coordinates of the transponder to the ship. This method was adapted for use on surface ships for the THRESHER operations in 1963 and 1964. Fixed transponders were moored on the bottom and a mobile transponder installed on the submersible. The computer aboard the USNS MIZAR in 1964 automatically determined the coordinates of the TRIESTE relative to the bottomed transponder and relayed this information back to the bathyscaph by underwater sound telephone system.

It would not be feasible to have the 3-D receiving system on the submersible because the spacings between the three hydrophones would be too small for any precision. However, an adaptation is possible where the submersible queries two or more transponders simultaneously and then computes its relative position by travel-time differences. A small computer would be feasible for this job.

PROBLEMS OF LAYING TRANSPONDERS OR BEACONS

It sounds simple to place transponders or pingers on the bottom; but, in fact, it is very difficult to obtain any precision. A transponder string with an anchor and a buoy to support the transponders and/or pingers can be dropped from the surface ship as accurately as possible. This would give a reference point on the sea bottom from which submersible sonar equipment could determine bearing and direction. A second string dropped at another desirable point and distance from the first could establish a "line" for both submersible equipment and surface ships' sonar to triangulate on. Of course, even if the surface position of each drop is known to an accuracy within 1000 feet, each string may take an hour or more to reach the bottom and may be moved considerably by currents (generally unknown). The result, then, would be two or three reference strings on the bottom, with neither their separation distances nor the relative bearings known with certainty. The transponders can be queried by the surface ships with precision electronic position-fixing equipment and their relative position determined from many measurements. The strings may take as much as three hours to reach the bottom in very deep water, but, ideally, the currents will be very small for most of the downward journey. The ships

may be at sea a thousand miles or more from land and any available electromagnetic navigation aids may have absolute errors of a half a mile or more. This problem could be alleviated by having three surface ships keep position on each other as accurately as possible, and simultaneously drop three reference strings with the desired geometry. Operations could then be conducted relative to the transponder strings. The transponders and/or pingers should work with both the surface vessels and the submersible for successful operations.

SOME UNDERWATER ACOUSTICS

All transponders or pingers at the bottom will operate with the limitations imposed upon them by the physics of the problem. One of the problems to consider is how far to buoy the transponder or pinger above the bottom. Sound speed increases with pressure approximately 1.8 feet per second for every 100 feet of depth. This causes upward refraction that curves the sound beam upward and creates a shadow zone near the bottom, at ranges beyond that where the limiting ray becomes tangent to the bottom.

No signals from pingers or transponders can be received if the receiver of the submersible is in the shadow zone nor can sound from the submersible be received by the transponder. The higher the transponder or the submersible from the bottom, the greater the operating range. Generally, the submersible will operate within 15 feet of the bottom and the transponder can be buoyed to ride, say, 200 feet above the bottom. This gives a maximum possible usable range of 4400 yards. However, the beam patterns of the equipments must be considered. The vertical angle increases as the range decreases, and the vertical directivity of the submersible receiver can result in no signals being detected over self noise for all ranges less than some minimum useful range. The blankout range will be smaller, the closer the transponder is to the bottom.

On the other hand, if the transponder is too close to the bottom, it may have landed in a depression and become shielded and thus of no use to the bottomed submersible. Bottom topography information is necessary to make the best choice of distance above the bottom.

It is not always true that refraction will cause a shadow zone, because in some areas the steep thermal gradient near the bottom will cause strong downward refraction. Some of these gradients have been reported by R. Gerard, et al[3], for the Atlantic. So, in the design of the best transponder string we must include the requirement of good oceanographic information for the last 300 feet of depth.

Even when the submersible is operating near the bottom with a near-bottom pinger or transponder at a range where direct rays can arrive, difficulty may be encountered due to interference phenomena. The grazing angles of incidence will frequently be less than the critical angle and the acoustic pressure field will exhibit interference phenomena due to the combining of three kinds of rays. For grazing angles less than critical, there will be a direct ray, a bottom-reflected ray (with a change in phase at reflection that can approach 180°), and a ray that has been partially propagated along the boundary. For grazing angles greater than critical only the direct and bottom-reflected need be considered. The change of phase on reflection may be near zero or 180° depending on the type of bottom.

The actual effective sound speed at the bottom needs to be known for any precise navigation. Anomalies may exist. Research is underway to determine the best in-situ sound-speed equation at high pressures and to then determine any sound-speed anomalies and their causes.

Bottom reverberation can be a severe limiting factor in many cases. Measurements will be made of in situ bottom reverberation near grazing angles of incidence. A great deal of information is available near grazing angles in shallower waters over a large frequency range. If a search is to be made for small objects of small target strength, reverberation in some areas may mas the echo. Some areas have rocks and pebbles; some have manganese nodules scattered about. Other areas have a rough terrain and show many confusing, unwanted echoes. Optimistically, this is not all bad because some of these may serve as acoustic landmarks and definitely aid the navigation problem.

DIRECT RANGE AND BEARING FROM TRANSPONDERS OR PINGERS

Transponders may be queried by continuous-sweep FM sonar aboard the submersible. Each transponder will show on the screen as a blob, which will be wider than a 3-dB-down beam width and more extended in length than the range increment of each of the filters. This is necessarily so because the total range will, in general, be broken into only 40 to 60 increments and then there will be some response by adjacent filters. To get sharp beams generally requires high frequencies and this limits the range. The frequencies used range between 30 and 100 kc/s. The operating frequency design choice depends on what trade-offs one wants to make for sharpness of detail and range of operation.

A simple ping sonar can be used with a transponder. The time on the ping sonar can be measured quite accurately, which means the range can be fairly accurate if the sound speed is known. The azimuth uncertainty will be extended over 5 to 10 degrees or more because of the beam width of the receiver.

A system that will be used by the Navy Electronics Laboratory will transmit an omnidirectional ping. Transponders will respond at slightly different frequencies. The transponded signals will be received by an omnidirectional receiver and the ranges displayed on a recorder. Travel times can be determined to use for computing relative position. In addition, a lightweight receiver in a corner reflector will be utilized to determine the bearing of any one of the transponders with an accuracy of 5 degrees.

ACOUSTIC DOPPLER NAVIGATION

One very promising method is an acoustic bottom doppler navigation system. This can work well when the manned submersible is operating near the bottom but would probably vehicle-noise limited at mid-depths. At present, available equipments are not yet light enough for the very low payload of smaller manned submersibles as, for example, ALVIN, ASHERAH, and DEEPSTAR DS-4000. Bottom doppler navigational equipments similar to those developed by Raytheon or Loral Company will, I am sure, be utilized in the future. Such a system could operate with an

inertial navigation system, and could be updated by use of any transponder information, bottom reference points, or plastic markers.

CONCLUSIONS

The state of the art has developed rapidly and we are on the threshold of reliable bottom navigation by manned submersibles. We have come a long way since the first operational job with the THRESHER search only three years ago. It is significant that all methods of navigation must be exploited to successfully accomplish missions of the deep manned submersible.

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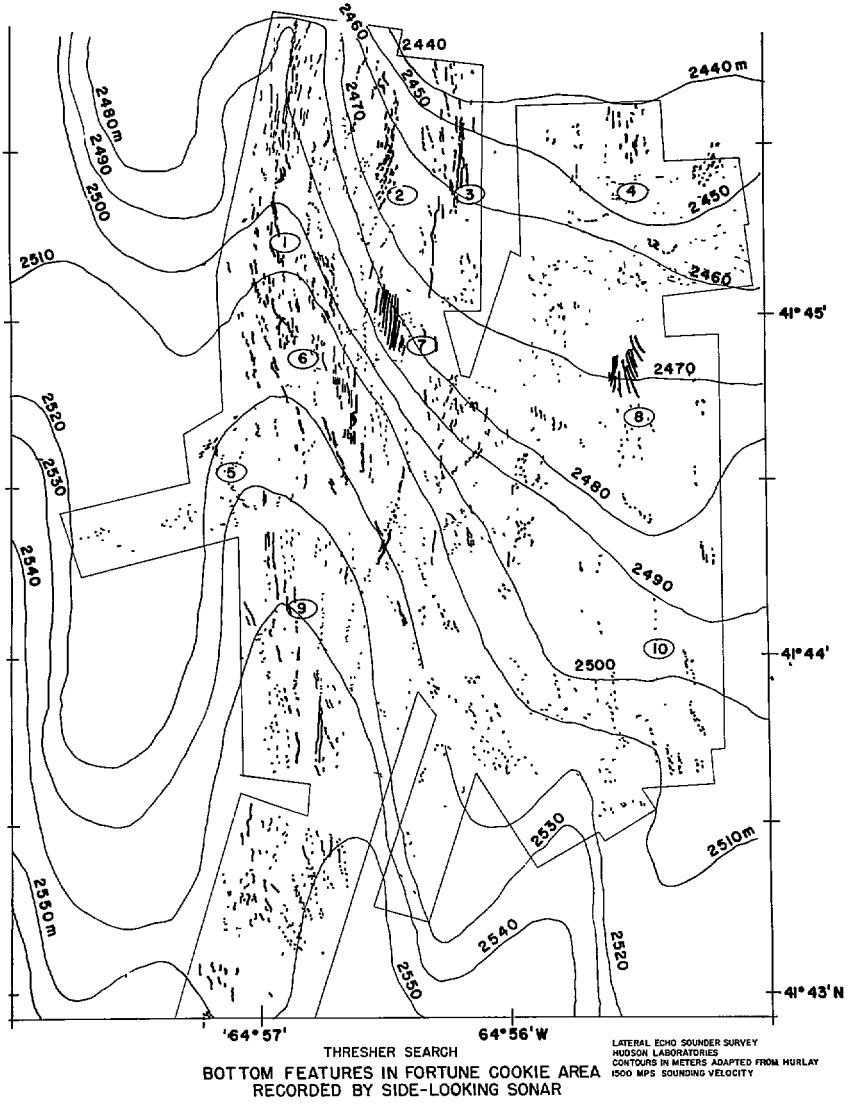

Fig. 1. Bottom features in fortune-cookie area (Fig. 7, ref. 2).

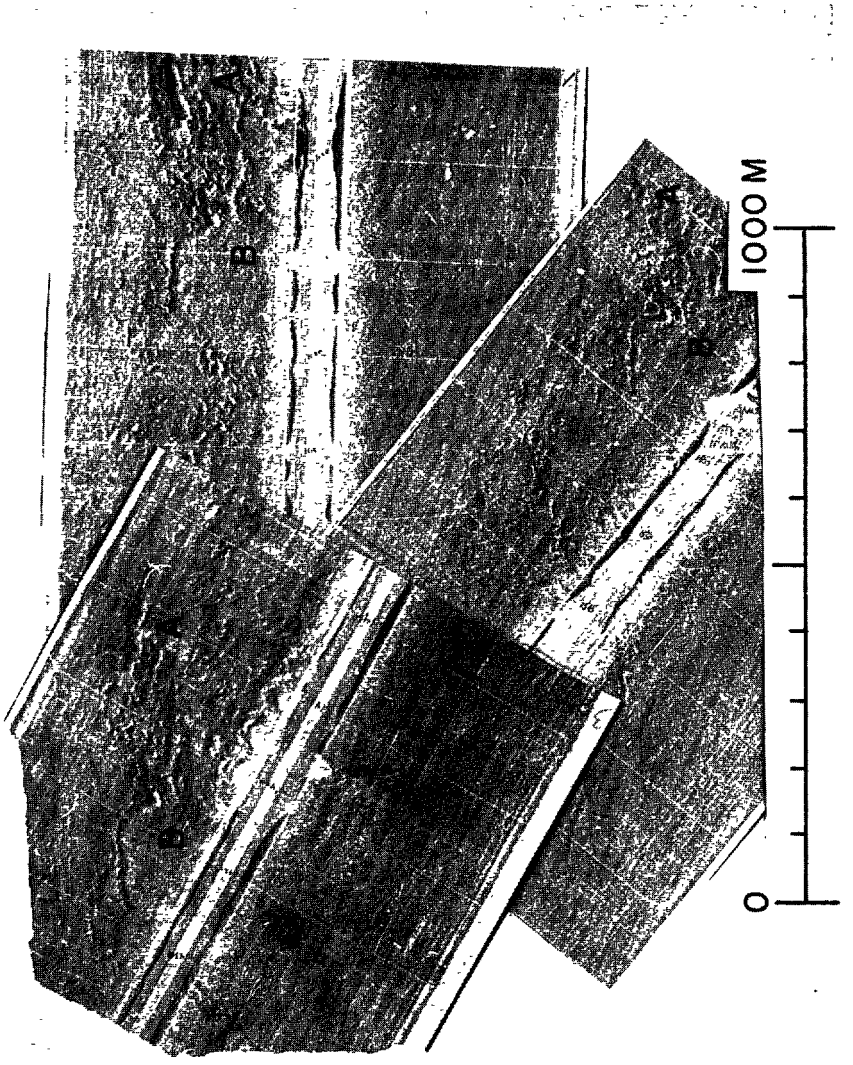

Fig. 2. Detailed bottom features from three crossings of a side-looking sonar (Fig. 5, ref. 2).

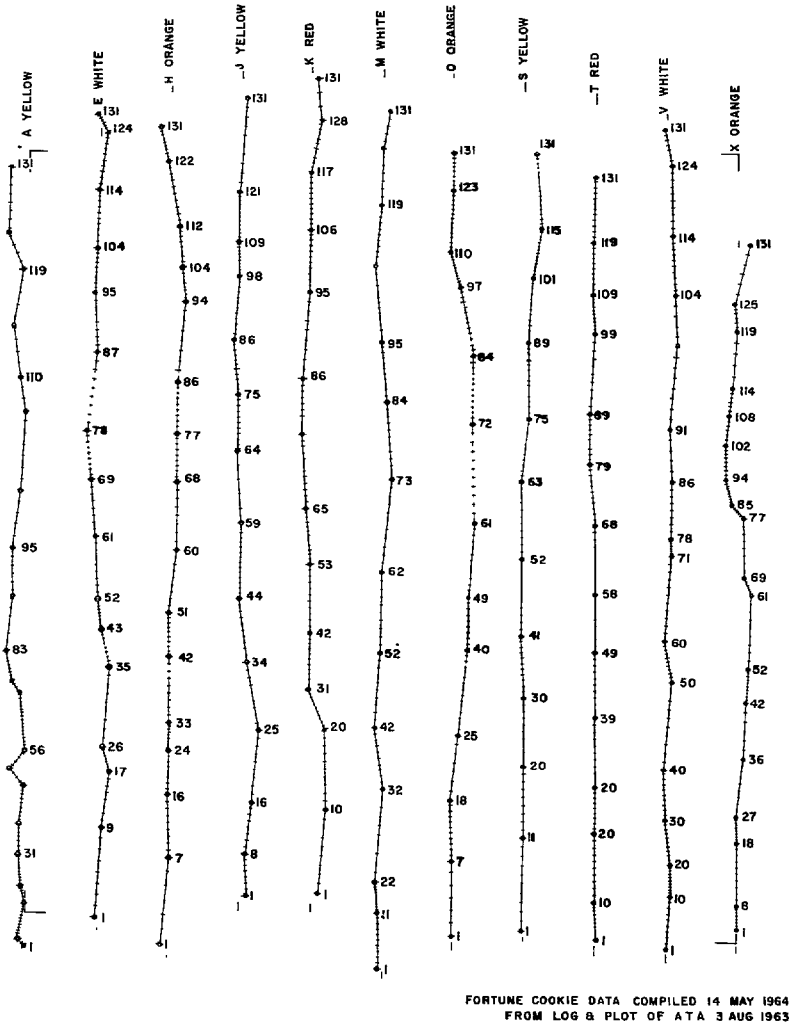

Fig. 3. Plastic marker reference grid as dropped from the surface.

DYNAMIC ANCHORING OF FLOATING VESSELS

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Abstract

Dynamic anchoring was first tried on the "Cuss I" on its initial drilling tests for the Mohole, but the first really successful dynamic positioning system was developed by Shell Oil Company on the coring rig "Eureka". The "Eureka" and the other operational dynamically positioned vessel "Caldrill I" have drilled core holes along the Atlantic, Pacific and Gulf coasts and have encountered a wide variety of weather and sea conditions. The "Terebel", a French built dynamically positioned vessel, has done preliminary testing in the Mediterranean. The operating experience of these vessels is discussed along with a description of this method of operation and limitations of these vessels. Some of the alternate methods of obtaining positioning information are discussed along with other methods of applying positioning power. The application of this most interesting development is seen to have a wide variety of applications as station keeping in our coastal waters and on the high seas becomes more and more important to our commercial industries and our military preparedness.

Dynamic anchoring is a method of automatically positioning a floating vessel without the use of anchors or anchor lines. As the name implies, a dynamic anchoring system utilizes constantly varying thrust producing means to hold a vessel in a fixed location on the water against the forces of wind, wave, and currents that tend to move it from the desired location.

Man has long desired the ability to position a floating vessel rapidly and in the extremely deep waters of the world without the use of large and awkwardly handled cables or chains and monstrous anchors. Even when using these time consuming anchors and cables, the water depth in which a vessel could be accurately held in position has been severely limited.

The first real attempt at dynamic positioning where accuracy of position was a critical factor was on the original "Cuss I" Mohole tests conducted between Guadalupe Island and the Mexican coast south of Los Angeles, California. During these tests, position was maintained by essentially manual control of four harbormaster units attached to the four corners of the "Cuss I" drilling vessel. An indication of position was obtained by radar and sonar signals from a ring of taut line buoys surrounding the drilling location. Although position was maintained sufficiently well to obtain the desired core information, the positioning accuracy was marginal as evidenced by the several drill pipe twist-offs.

The first really successful dynamically positioned vessel was the motor vessel "Eureka", Fig. 1, which is a one-bit coring vessel utilizing an APE (automatic positioning equipment) system developed by Shell Oil Co. This vessel which is 136 feet in length and has a beam of 36 feet was placed in operation in May 1961, and has been drilling core holes on the Gulf and West coasts ever since that time. This vessel has drilled core holes in 30 to 4500 feet of water, has held position in wind to 40 miles per hour and waves to 20 feet and has drilled as many as 14 core holes in

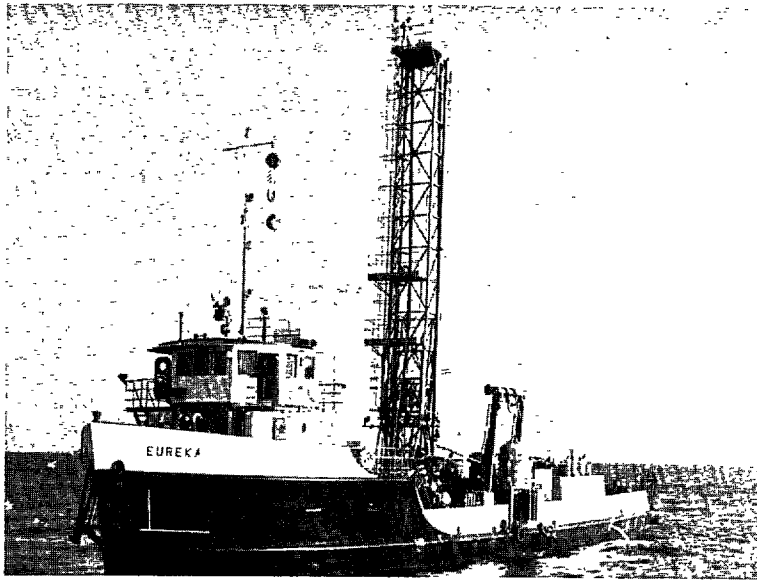


Fig. 1 Dynamically Positioned Coring Rig "Eureka"

a single day. The "Eureka" is equipped with two 200 hp propulsion drives located in the bow and stern of the vessel. At the present time, the "Eureka" is in the shipyard being jumboized by the insertion of an additional 26 foot mid-body. Additional AC power generating capacity and crew quarters are also being added.

In January 1964, the "Caldrill I", Fig. 2, owned by Caldrill Offshore Company of Ventura, California, was placed in operation as the second dynamically positioned vessel. This was the first vessel actually designed for floating well drilling operations to be equipped with an APE system. The "Caldrill I" is 176 feet long, 33 feet wide and is equipped with drilling equipment to permit drilling to approximately 6,000 feet with 4-1/2 inch drill pipe. This vessel was specifically designed to allow drilling, completion and workover operations while automatically positioned, as well as its use as a one-bit coring vessel. The "Caldrill I" has operated all along the Pacific coast, in the Atlantic off the coast of Florida, on the Grand Banks off Newfoundland and presently along the Gulf coast. Position has been maintained in 60 mile per hour winds and 25 foot seas. The "Caldrill" was also successful in drilling core holes with approximately 3 knot currents in the Gulf Stream off Florida.

Because of the reliability criteria required for drilling or workover operations on a live well, four propulsion units were used and two completely independent position sensing and computing systems were installed. Any two propulsion units can be used with either of the position sensing and computing systems, thus providing 100% back-up to the normal positioning equipment. Automatic switchover from one positioning system to the other was also provided. This equipment is almost instantaneous in operation when the vessel is operating in the automatic mode.

A third dynamically positioned vessel, "Le Terebel", was placed in limited operation by the French Petroleum Institute in December 1964. This vessel was a converted LCT 85 meters long and 12 meters wide and was equipped with two 300 hp propulsion units driven by diesel engines. The APE system on this vessel is essentially the same as on the "Eureka" and the "Caldrill I" though preliminary testing does not indicate as accurate position keeping capabilities. The French Petroleum Institute has been quite secretive about this vessel so no absolute performance data is available.

Automatic positioning equipment in its usual form consists of a Position Sensing System, a Computation System and a Propulsion System. These systems may vary widely and still accomplish the same results but all the systems in current use are quite similar.

The most common position sensing system is the taut wire system wherein a 1/8 to 3/16" steel cable with a 600 to 800 pound weight attached is hung over the side of the vessel and a constant tension system on board the vessel maintains a constant tension in this wire line of from 400 to 500 pounds. The change in angle of this wire line in two mutually perpendicular planes aligned with the bow-stern and port-starboard axis of the vessel then represents the change in position of the vessel with respect to the weight at the bottom of the ocean. The measurement of this change in angle is accomplished by a position transducer which has an output, Fig. 3, of approximately 100 mv per per cent displacement of the vessel where per cent displacement is defined as the horizontal movement H divided by the water depth D times 100%, Fig. 4. This is equivalent to the tangent of the angle the wire line makes with the vertical and is really more important than the actual horizontal displacement, since drill pipe stresses and other similar factors are effected by the magnitude of this angle rather than the actual horizontal distance. The position transducer has two independent outputs providing a positive DC voltage if the vessel moves aft or toward the port and negative DC output voltages if the vessel moves forward or toward the starboard. The weight on the

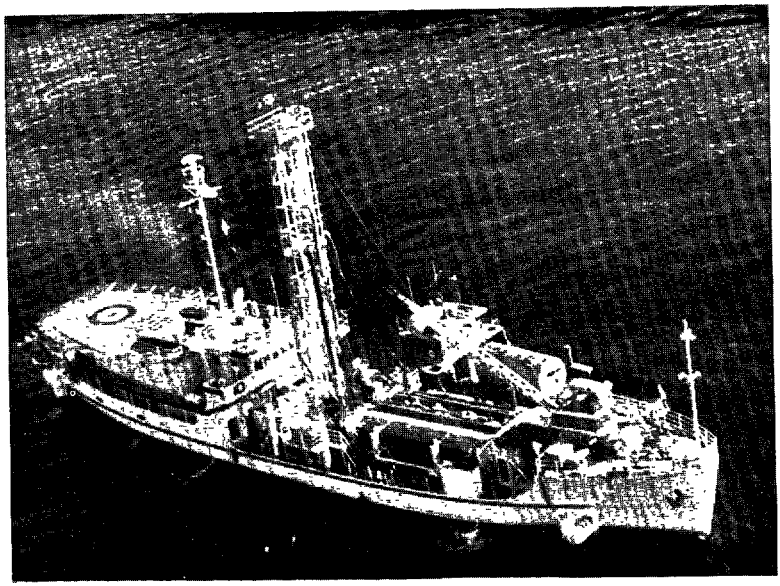
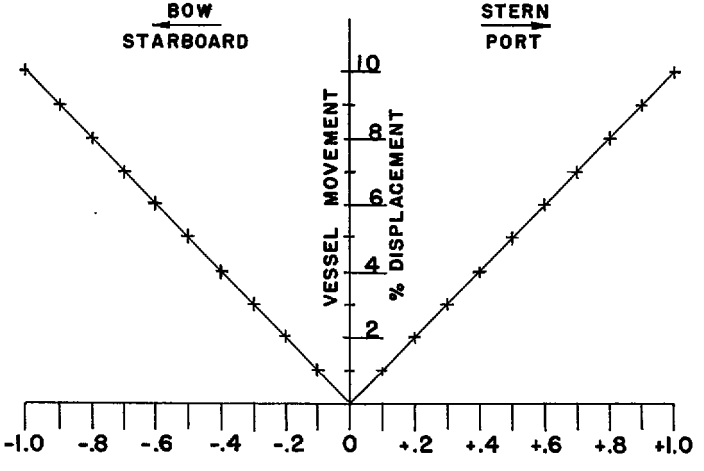


Fig. 2 Dynamically Positioned Drilling Rig
"Caldrill I"



D. C.

OUTPUT VOLTAGE

FIGURE 3

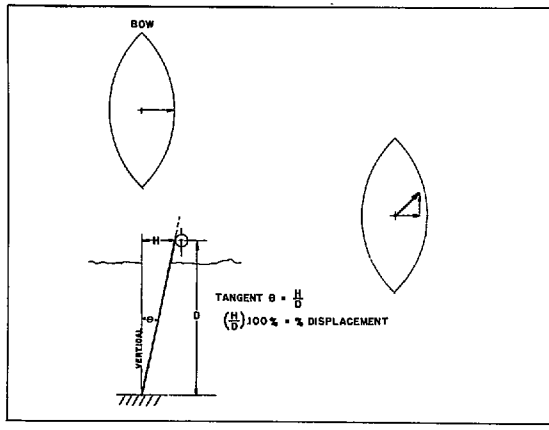


Fig. 4 Geometry of a Taut Wire System

bottom of the wire line usually consists of a block of concrete, an old railroad wheel or possibly old automobile blocks. Junk drill bits and other scrap have also been used and usually the cheaper the cost per pound the better. The most successful type of constant tension system, Fig. 5 and Fig. 6, has been found to consist of counterweights moving within a king post supporting the sheaves for the wire line. The use of a four part wire line supporting the counterweight allows increased freedom of movement (64 feet on the "Caldrill" and "Eureka") and yet keeps the weight moving slowly enough that acceleration forces may be neglected. No external power is required for the operation of this type of system except for hoisting or lowering to bottom and thus the efficiency is quite high and the operating problems greatly reduced. The remainder of this type of position sensing system consists of hydraulic rams to position the wire line at its operating location and a hydraulic winch to spool in the cable. The obvious advantages of this type of position sensing system are its simplicity and the fact that no active operating elements are located beneath the surface of the water, thus facilitating repairs or replacement of active elements if necessary. The ease and rapidity of setting up on location is also a major factor as well as the fact that no auxiliary service craft are required. The reliability, simplicity, economy and proven accuracy of this method of position sensing have made it the most widely used method in current use. Of course, other techniques such as sonar and radar reflections from submerged or taut line buoys and the use of accoustical signals from submerged transponders offer possible solutions to this problem. All of these systems have their limitations and apparent complexities but undoubtedly also have their place in certain position sensing applications. A considerable amount of study has gone into the action of a taut wire line in deep ocean use and a comprehensive computer program is available to predict taut wire performance. Generally speaking, it appears that position can be sensed accurately within one to two per cent of water depth with the taut wire system and if the current profile is known, correction can be made to give accuracies within one per cent of water depth. Since this accuracy is well within the allowable displacement of a drilling vessel from over the hole, this method of position sensing has become generally accepted in the drilling industry and many indicating and recording instruments are now in operation with very satisfactory results on numerous conventionally anchored floating drilling vessels throughout the world.

The computation system on a dynamically positioned vessel usually includes a position indicator to display the position of the vessel in polar form with respect to the desired location, a position recorder to record the vessel's movements with respect to time, and a computer to take the incoming longitudinal, lateral and heading error signals and compute the direction and magnitude of the thrust required from the propulsion units to hold the vessel on location or to bring it back on location. As discussed previously, error signals are obtained from the position sensing system as a result of longitudinal and/or lateral movements of the vessel. A heading error signal is obtained from the ship's gyro compass and each of these signals is put in its proper range by appropriate sensitivity, and range selection controls and associated amplifiers. Biasing signals are also inserted so that the operating point may be moved without the weight on bottom being moved and thus allow the vessel to operate with a predetermined angle on the wire line. After these error signals have been suitably scaled and biased, the computer solves the vector equations to arrive at resultant thrust magnitude and direction signals for both the bow and stern propulsion drive units. The computation system also includes circuitry to measure the rate of change of error or the speed of movement of the vessel in all directions and a corresponding increase is made in output signals to the propulsion drives to correct for the anticipated movements of the vessel based on the first derivative of the vessel's movement. This anticipatory sense of the computer allows it to provide much more accurate control and greatly increases its speed of response.

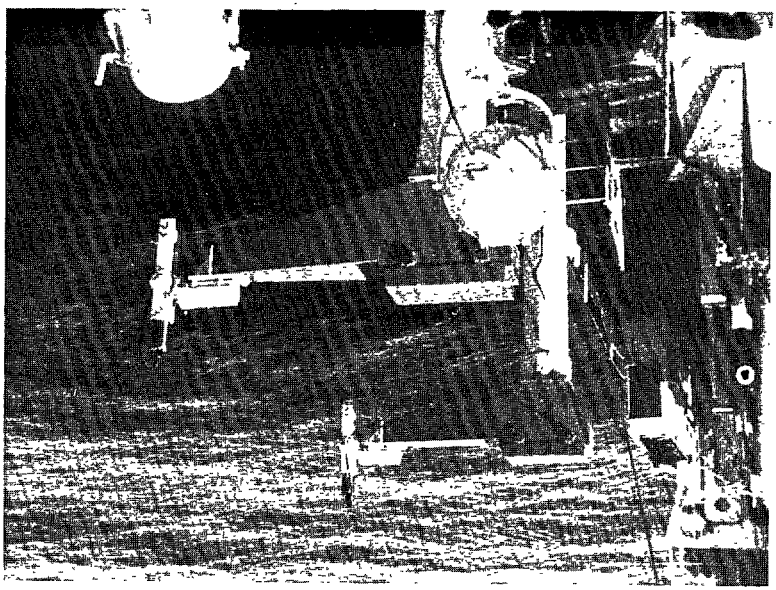


Fig. 5 Dual Position Sensing System on "Caldrill I"

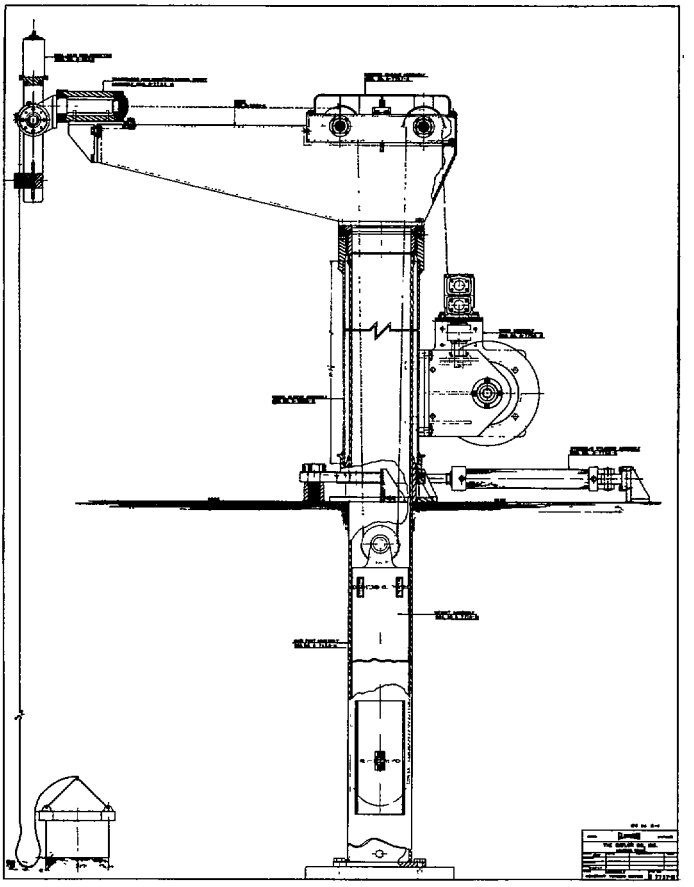


Fig. 6 Assembly of Counterweight Type
Constant Tension System

The computer also contains an integrating system or in effect a memory which constantly averages the error in position over a period of time and correspondingly changes the output signals to the propulsion drive units to correct for sustained errors in one direction. This part of the computer system makes it possible for the vessel to remain exactly over the hole while still providing maximum thrust on the propulsion drives, thus a constant wind or current from one direction will be automatically compensated for by the computer. With this control it is not necessary that the vessel be widely displaced from its desired location in order for the propulsion drive to develop the power required to hold against a constant force.

The computer is constantly being fed with varying signals representing the error in the lateral and longitudinal directions as well as an error in heading. Computation is being made constantly with these error signals and a constantly changing output is introduced to the propulsion drive units. This output is in the form of the voltage representing thrust magnitude and switch closures representing thrust direction. These signals cause the propulsion drive units to turn in a certain direction and provide the required thrust magnitude. This thrust direction and magnitude is constantly changing to keep the vessel on position, thus the term dynamic positioning.

An important aspect of the computation system is the introduction of a longitudinal anti-oscillation bias of opposite polarity to the bow and stern channels so that as the longitudinal error changes from plus to minus and vice versa, the propulsion drive units do not change directions 180° but rather, one simply increases its thrust and the other decreases its thrust an appropriate amount. The effect of this bias is clearly seen in Fig. 7 which shows the typical vector diagrams solved by the computer for various situations. The computation system also includes the various controls located in the control console, Fig. 8, to permit manual operation of any of the propulsion drives and numerous indicators to indicate thrust magnitude and direction and other variables. The computer system is made as reliable and fool proof as possible by the use of all solid state circuitry and modular plug-in construction. With reliability such an important factor in most positioning applications, the computation system is no candidate for cost cutting techniques. The best of computers is usually not good enough.

The propulsion drive system consists of the motors to turn the screws and adjust the azimuth, as well as associated circuitry and equipment to permit starting and stopping the motors, and control of the thrust magnitude and direction as calculated by the computer. On the "Caldrill" and the "Eureka", the main propulsion power, Fig. 9, is supplied by squirrel cage induction motors and thrust variation is obtained by means of oil cooled eddy current couplings. Controllers located with the motor starting equipment, Fig. 10, respond to the computer thrust magnitude signals and energize the eddy current coupling with a DC voltage proportional to required thrust. Motor current is monitored and fed back through a compensation circuit until the thrust equals the desired amount. On "Le Terebel", a diesel engine's speed is controlled by the computer thrust signal and feed-back circuitry is not used. Thrust direction on the "Caldrill" and the "Eureka" is controlled by a reversible electric motor and a servo feedback system assures that the direction is maintained as nearly as possible to the computed value. The thrust direction can be changed approximately 10 degrees per second and this appears to be about optimum for control in shallow -- 100 - 1,000 ft. -- water. Higher thrust direction speed changes have been tried and found unsatisfactory. The actual propulsion units on all operating APE systems are right angle drive units; however, this by no means suggests that this is the only usable solution or even the best solution. It simply means that this was the most practical solution at

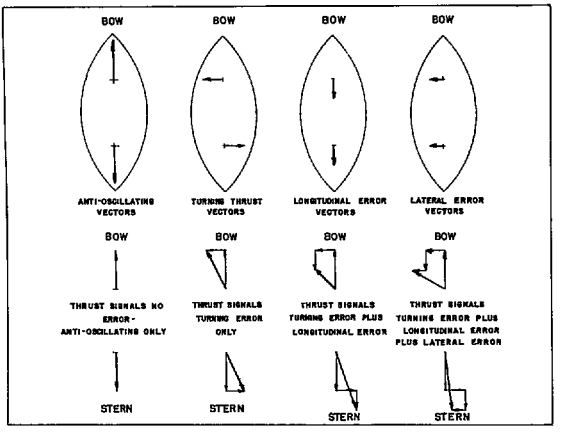


Fig. 7 Vector Diagrams for Position Keeping

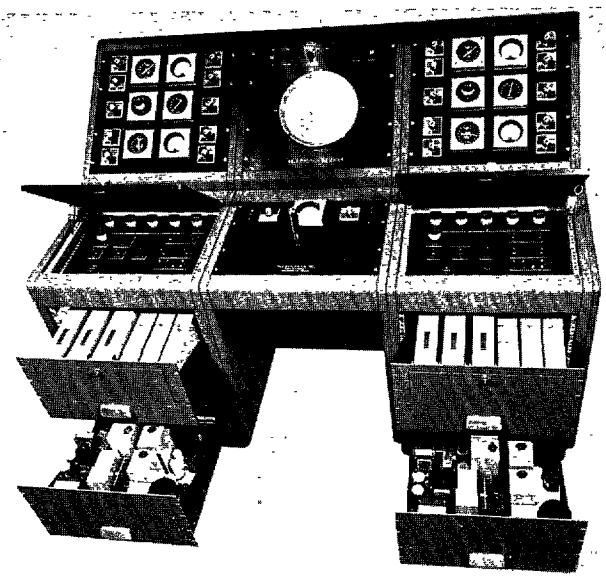


Fig. 8 Control Console on "Caldrill I"

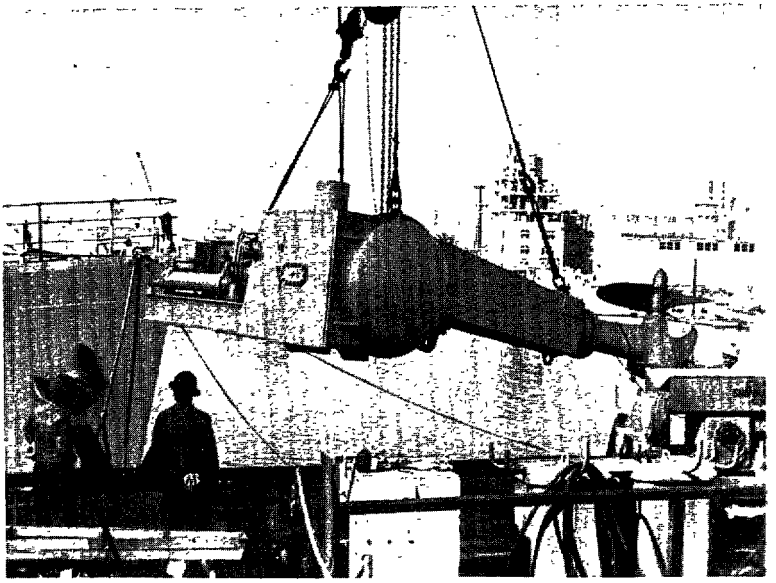


Fig. 9 Propulsion Drive Unit on "Caldrill I"

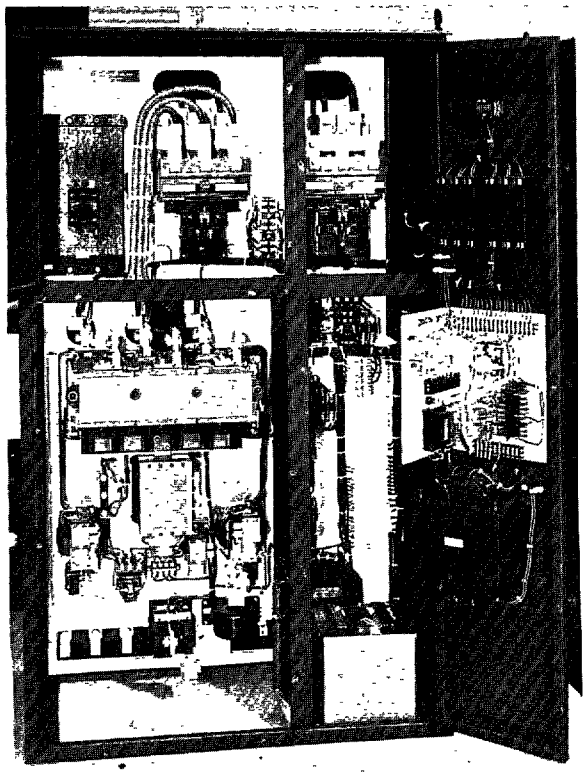


Fig. 10 Propulsion Drive Motor Starter & Coupling Control Console

the time for these particular units. Many other types of propulsion drive units have been investigated including DC motor drives, variable voltage AC drives, and cycloidal propeller drives. Each of these systems has significant advantages and undoubtedly each will find its place in the dynamic positioning picture of the future.

We have seen the beginning of a new technology in vessel positioning and can only dream of the many possible applications of this technology to our industrial and military requirements. As we move forward in our unending efforts to "Exploit the Oceans" for the good of man, I believe dynamic anchoring will play an ever increasing role.

ROLE OF GOVERNMENT IN OCEAN FISHERIES EXPLOITATION -- AN INDUSTRY VIEW

Lowell Wakefield, President

Wakefield Fisheries, Port Wakefield, Alaska

Abstract

No attempt will be made this afternoon at broad review of the subject assigned me. Rather, I will describe in some detail two federal activities which interfered rather beneficially with the conduct of our business. I have reference to the survey of unutilized bottom fish and crab resources in the Gulf of Alaska and in the Eastern Bering Sea conducted by the Bureau of Commercial Fisheries in 1940 and 1941 and to the agreements reached in 1964 and 1965 between the United States, the Soviet Union and Japan regarding the harvest of King crabs off the Alaska Coast. A discussion of these two projects will illustrate my thinking on the proper role of government in ocean fisheries exploitation. I want to make it clear that these are personal views. I represent no group or organization. I will nevertheless also comment on what I regard as industry's proper attitude towards what it views as government's responsibilities in this field.

THE BEGINNINGS

Thirty years ago there was no U. S. crab industry worth mentioning on the West coast or in Alaska. Plants in Petersburg, Wrangell and Cordova canned a few cases of Dungeness each year. A few hardy souls had tried to locate King crabs, but most of us in Alaska had never heard of or seen one. Total U. S. Crab meat consumption was a paltry ten Million pounds of canned, almost all brought in from Japan, and about eight million pounds of fresh, mostly from Blue crabs here on the East coast and from the Gulf states.

Today the U. S. is not only the biggest market, but leads the world in crab meat production. Alaska alone produced over thirty million pounds last year, more than our two biggest competitors, Russia and Japan, combined, and we have hopes the resource will sustain double the present level of fishing. Crabs are now number two in Alaska's biggest industry, fishing, and their harvest is revitalizing the whole economy of the state. Alaska's historic complaint against the fishing industry has been that we brought the cannery crews and fishermen North in the spring, harvested the salmon, the codfish, the halibut and the herring, then took the people, the pack and the money South in the fall. In ninety years we built almost nothing of permanence; few homes, schools, roads, towns. A cannery, a dock and a watchman to check the padlocks were our legacy. Crab fishing, however, goes on all twelve months of the year, peaking in the winter. Only local labor and resident fishermen make sense. Fishing towns and villages on the Gulf of Alaska coast and out the Aleutian chain have come alive. When our firm rented space to start processing crabs in the halibut cold storage at Sand Point fourteen years ago, the population was fifty seven. Two months ago we hosted a plane load of state and federal offi-

cials, including Governor Egan, Senator Gruening and Congressman Rivers, come to sit down with us in the assembly room of the Sand Point school and plan for more housing, better community facilities, for a village already grown 700 per cent.

WHO TO BLAME?

Fixing responsibility for this sorry state of affairs is difficult. Some people even blame me, and the charge is seldom denied, for it seems to help sales of our particular brand of merchandise. The truth is that many people, many circumstances and much luck have been involved. The most significant single factor, in my opinion, is the two-year investigation of the crab resources off the Alaska coast conducted by the U. S. Fish and Wildlife Service just before World War II.

In 1930 a Japanese cannery ship with a fleet of small fishing boats showed up off our Pribilof Islands. By 1935 there were seven in the Eastern Bering Sea, concentrated just north of the Alaska Peninsula in the outer reaches of Bristol Bay. The red salmon runs there are still one of the most valuable fish harvests on either coast of North America, and most of us believed the Japanese were out there to intercept our fish. Tempers flared. One rugged individualist, Captain John Shields of the codfish schooner Sophie Christiansen, telegraphed for guns and ammunition to arm his dorymen. The anguished cries were heard here in Washington. Secretary of State Hull made strong protest. The Japanese ships withdrew.

In the course of the excitement it was learned the Japanese were not fishing our s almon. They were canning something we didn't even know was there, King crabs. It seemed obvious that an Alaska resource which supported seven fleets employing over two thousand fishermen and cannery workers might afford opportunity for domestic industry, especially since the product was destined for export to the United States. President Roosevelt became interested and Congress appropriated sums totaling $125,000 to investigate the King Crab resource of Alaska. The Fish and Wildlife Service chartered a small cannery ship, the 396-ton Tandelayo, and the Dorothy, a 93 foot schooner built in New England in 1903, and equipped with sideset trawl gear. They worked the summer of 1940 in Pavlov Bay on the South side of the Alaska Peninsula and in Alitak Bay on Kodiak Island. In both places, the Dorothy managed to catch enough for the technologists to perfect canning techniques for a product as good as or superior to the canned crab being imported. That part of the project was then terminated to concentrate on a broad survey to define the limits of King crab distribution, to attempt to indicate where they concentrated in quantity, and to develop better fishing methods. The following spring the Dorothy was joined by the Locks, a 58 foot antique Puget Sound dragger and the Champion, a small herring seiner built in the 20's. Aboard each boat was it's regular commercial fishing crew of seven, a gear technologist, a marine biologist. Quarters were cramped, primitive forecastles with none of the amenities.

FANTASTIC COVERAGE

In the next seven months those boats turned in one of the most outstanding exploratory fishing surveys in history. They fished with tangle nets, with trawls, with crab pots.

They fished Southeastern Alaska, Prince William Sound, Kodiak, the Aleutians, the Bering sea; thousands upon thousands of miles of rugged coastline, hundred of thousands of square miles of fishing banks. They counted and measured and analyzed. They told us where the King crabs were, and also the other crabs, and the flounders and the perch and the Alaska pollock and the codfish. They missed a little on quantities available, for they couldn't tarry to work a school intensively as a commercial fisherman does, but had to move on. After twenty years, the fastest-growing fishery under the American flag, plus a great deal of additional research, has come up only with revalidation of their findings.

Without this modest research program the single most important industry to the economy of our new state of Alaska would likely never have come into being. What made government's effort so remarkably successful? I believe that (1) It was well planned. (2) It had good luck. The resource it sought was there. (3) It had very little money. The field work was all done by chartered commercial boats and crews. The results were directly translatable to industry terms. Love of money may or may not be the root of all evil, but lavish facilities can inhibit as easily as foster research activities. I have fished on the Champion. There is no comfortable place to lie down or sit and read a magazine. There is nothing you can do on her, but fish. If a single one of the lovely research vessels coming off the ways these days ever comes within 25 per cent of the research results per dollar achieved by the 1941 survey, I undertake to trundle Don McKernan in a wheel barrow from Interior to Harvey's and pay for his dinner. (4) Industry took advantage of the research work, and undertook the long expensive job of commercial development.

There is a lot of talk about government's responsibility to industry. There is little talk about industry's responsibility to government, or even to itself. In the late summer of 1941, Ira Gabrielson, then director of the Fish and Wildlife Service, overnighted at Port Wakefield, where I was superintendent of the herring saltery and meal plant. We talked of the very interesting findings of the King crab survey and Dr. Gabrielson pointed out that if no one in industry did anything about it, the research money would have been wasted. I said, "Tell the boys to throw ashore here all the gear they are going to discard when the survey is completed, and we will see what we can do." During the next few years we experimented in a small way with fishing and canning, and also learned King crab meat could be frozen. Right after the war, Harry Guffey, who skippered the Locks on the survey, built a small, integrated factory trawler, and I a larger one - a 140 footer. Ellsworth Trafton, captain of the Dorothy, converted a surplus mine sweeper to the same use. We began working the crab grounds of the Eastern Bering Sea, and Alaska had a new industry.

A NEW THREAT

In 1964, this new industry was seriously threatened by the proliferation of Japanese and Russian fleets off the Alaska coast. Ours had become strictly a pot fishery, and gear conflict with the trawlers was inevitable. Nor is the foreign tangle net fishery for crabs compatible with our pots. The Japanese had re-entered the fishery in 1953, but on a modest scale with a single mother-ship fleet. They agreed to joint study of the resource and the few areas of direct conflict were adjusted

equitably.

In 1959 the Russians entered the fishery and were up to three big fleets in 1963. The Japanese countered with more fleets and higher quotas. In four years, the foreign catch of Alaska King Crabs jumped from two to nine million. We were in danger of being crowded off our own grounds. The Department of State first brought the Russians to Juneau to discuss gear conflict off Kodiak, got agreement that has almost eliminated crab pot losses in that area. Then we sat down here in Washington with the Japanese in the fall of 1964 to discuss limitation of their Alaska crab fishery. We came out of that meeting with a two-year agreement barring them from 99 percent of the grounds on which we depend, reducing their catch quotas, and subjecting them to a strict conservation regimen. Later that winter a similar session with the USSR produced a parallel agreement. Without question, these are a series of the most successful negotiations ever undertaken by the U. S. to protect one of its commercial ocean fisheries interests (or the interests of any of its other industries, for that matter). What was responsible for this remarkable success?

THE POOR FOLKS

Success in 1965 was born of the same ingredients as success in 1941. (1) Careful, long-range planning, coupled with lots of luck, put us in a strong bargaining position. In 1958, the law of the Sea Conference in Geneva adopted a convention on the continental shelf which assigned living organisms in constant contact with the sea bed to the adjacent coastal nation. Some years later, scientists of the Bureau of Commercial Fisheries assembled evidence that some of the crabs - King certainly, Dungeness probably, came within the definitions of the convention. Our good friend Bob Bartlett, senior United States Senator from the State of Alaska, put through a bill providing the mechanics of enforcement. (2) The anti-poverty campaign has not yet reached the offices in State and Interior handling international fishery matters. Our delegation chairman at all these sessions was B ill Herrington, ably backed by Don McKernan at the last two. With little budget and a skeleton staff, and a thousand other matters crying for attention, they worked nights and week-ends to hammer through to agreement with a sense of urgency affluence might dull. (3) The industry attempted to assist government in the discharge of its responsibilities. The presidents of the two largest companies in the field and the State of Alaska's Commissioner of Fish and Game sat through all the sessions as working members of the team, and instead of making cheap headlines back home about the bureaucrats selling out the American fisherman, they took the heat back home for the compromises necessary to get agreement.

Private sector and government sector are so intertwined today that one could talk all afternoon about government's responsibilities in ocean fishery development. I think my two illustrations demonstrate that our government is capable of discharging its responsibilities for research to foster new industry and protection of that industry once developed remarkably well, especially if industry will cooperate.

FISHERY SCIENCE AND THE PREDICTION OF COMMERCIAL FISH LANDINGS

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Van Camp Sea Food Company Division
Ralston Purina Company

ABSTRACT

The practical value of fishery science data is examined in relation to the prediction of commercial fish landings. Examples are taken from the shrimp and tuna fisheries of the United States and the anchovy fishery of Peru. A general discussion of forecasting techniques is given.

INTRODUCTION

Much of the justification used by Government, university, and industry scientists for funding ocean research is based on the premise that knowledge of the sea and its occupants is of practical value to military and commercial interests. Today, I would like to limit my discussion to that segment of ocean research which relates to fish and shellfish resources and to consider if there is value to industry in these studies.

Ten years ago it was generally felt among industry people that the results of fishery research were interesting, but seldom could one use the results of this research to solve specific management problems concerned with raw material availability. Fishery scientists readily admitted that their accomplishments in the area of predicting resource availability were minimal. The reasons for failure are clear:

1. There was a lack of current synoptic information on the physical properties of the air and ocean.

2. There was a lack of basic research into the life histories of the animals under consideration.

3. There was a lack of understanding and interest by fishery scientists in the application of their findings to the forecasting of fish landings.

4. There was a lack of clear communication of the existing information to industry people in a form that they could understand or use.

5. There was a lack of currency in the data that was transmitted to the fishing industry. Most studies that related to the prediction of fish supplies utilized historical information, and findings were published years later.

During the past ten years, we have made rapid advances in certain of these areas. The amount of money spent on ocean research related to fisheries has increased many fold. The results are encouraging. For example, synoptic charts of sea surface temperature are now available on a current basis for most areas of the Pacific Ocean.

Increased research budgets for the Bureau of Commercial Fisheries, international fishery commissions, and universities have resulted in substantial additions to our fund of basic knowledge of the life histories of the commercial species of major importance to the United States fishing industry. New resources have been discovered and are now being utilized by industry.

The communication of current and useful information to industry has greatly improved in recent years. The results of tuna research directed toward predicting seasonal availability of skipjack in Hawaii and albacore off the Pacific west coast are published regularly. Landings of shrimp by port, by species, and by size count are published daily by the New Orleans Market News Service. Catches of yellowfin and skipjack in the eastern Pacific area are published weekly by the Inter-American Tropical Tuna Commission.

There is still, however, only a modest interest among fishery research groups in the development of forecasting methods. This is to be expected and, in my opinion, the fishing industry should not rely on research people who are removed from the day-to-day activities of the industry to solve the problems of forecasting fish supplies for them. It must be a cumulative effort with each group contributing in their own area of competence and need. Here the sea food industry is lagging badly in its attention to this vital area.

When the Van Camp Sea Food Company Division decided three and a half years ago to test the theory of linking Government and industry studies in the forecasting of fish availability, I had little concept of the problems to be encountered or the methods to be used in solving these problems. Further, management at Van Camp had nothing more concrete than an educated hunch that efforts in this direction would be worthwhile.

Today, I would like to mention some of the results that have come from our attempts to benefit from the $150 million spent in the United States each year by federal and state agencies in marine research. First, we should examine the areas of knowledge useful to fish forecasting:

1. Knowledge of fishery science methods to permit interpretation and evaluation of the research work being done by Government and university groups

2. Special interest in the dynamics of fish populations

3. Understanding of oceanographic and meteorological data so that the effects of the environment on fish populations may be evaluated

4. Knowledge of fishing vessels and fishing methods

5. Interest in the economics of the operations of fishing vessels and of processing, distribution, and marketing of fishery products

6. Knowledge of statistical techniques and data reduction methods.

Secondly, we should ask what methods are useful in the forecasting of commercial fish landings. For illustrative purposes, it would be best to take a single fishery and to outline the full range of background studies, information needed, calculations, predictions, and evaluation of results. I will not do this as the results of our efforts are not public information. What I will do is to take examples from several fisheries to illustrate techniques.

As background, it is essential to assemble all the existing information on the fishery. This will permit evaluation of the state of scientific knowledge concerning the fishery. For the larger fisheries in the United States, such as shrimp and tuna, this background material is extensive. It permits a pinpointing of key areas to be considered and an opportunity to note the areas of weakness in the scientific information.

FISHERY EXAMPLES

Shrimp - The shrimp fisheries of the Gulf of Mexico have been studied intensively during the past ten years. Excellent statistical information on landings is available on a current basis. A historical study of supply-demand-price relationships in the United States reveals that the year-to-year fluctuations in the supply of shrimp from domestic sources are the key factors in determining trends in price of raw material. We also noted from the biological data that:

1. Fishing effort for the three major species--brown, white, and pink--in the Gulf of Mexico has reached a level where further increases in fishing effort have a minor effect on total landings

2. The major share of the landings are from the initial age group. Total stock mortality (from fishing and natural sources) is extremely high and the recruits to the fishery are cropped off as they enter the fishery

3. Fluctuations in year-class strength vary by a factor of two in pink shrimp, three in brown shrimp, and six in white shrimp. The fluctuations are related to environmental changes

With this basic knowledge concerning the importance that yearly fluctuations play in shrimp prices and the knowledge that these fluctuations are environmentally induced, we can narrow our area of investigation.

Because we are dealing with essentially the recruits each season, it is useful to examine several preseason indicators of year-class strength developed by the Bureau of Commercial Fisheries's scientists in the Galveston, Texas, laboratory. They have found that indices of abundance of brown shrimp at the postlarvae and juvenile stages of their life history provide clues to the success of the commercial fishery for adults.

Tuna - Albacore supplies are the most critical to the tuna industry as this is the only species which can supply white meat needs. Light meat tuna can be packed using yellowfin, skipjack, bluefin, bigeye, and albacore. Again, as in shrimp, there is an abundance of background scientific material. The most productive albacore fishery in the world is the north Pacific Ocean. Fish from this stock is harvested by pole and line on both sides of the north Pacific and by longline in the western and central north Pacific. Scientific studies by the California Department of Fish and Game, Oregon State Fish Commission, United States Bureau of Commercial Fisheries, and the Japanese Fishery Agency have shown that a common stock is being utilized.

Length frequencies indicate that a major share of the landings are from three year groups. These are the two and three year old fish on the United States side and the three and four year old fish on the Japanese side. Fluctuations in year-class strength vary by a factor of two to three. As these groups remain in the United States fishery for four years and in the Japanese fishery for five years, it is possible to use the measure of year-class strength of one year old fish to forecast the next year's two year old abundance, the two year old fish to forecast the next year's three year old abundance, and so on.

In addition to the basic abundance of each year class, it has been shown that water temperatures play an important role in the availability of the albacore to the fishery each year off California, Oregon, and Washington. The beginning and end of the season are related to sea surface temperature, and the development of the fishery off Oregon and Washington is particularly dependent on the northern extension of the warmer isotherms during August and September.

Knowledge of the basic abundance and availability of the albacore is, of course, valuable, but one must also estimate the prices to be paid during the season and the amount of fishing effort that will be attracted to the fishery. These latter two factors are of great importance. High prices and increased fishing effort can make a year of poor abundance one with average landings.

Peruvian fish meal - Knowledge of changes in availability of raw material to our fish meal plants in Peru is of great value. Six years of intensive study by the Instituto del Mar del Peru and F.A.O. research people have provided an excellent store of basic information on this anchovy resource.

Statistical studies indicate that a level of maximum equilibrium yield has been reached in this fishery. Landings peaked at 8.8 million metric tons in 1964 and have declined slightly since that time. At the present level of fishing intensity, fluctuations in catch are due largely, in my opinion, to changes in year-class strength. Years when the sea surface temperature has been colder than average during spawning season--July through September--have produced poor year groups while years of warm temperature anomalies during spawning have produced good year groups.

In recent years the fishery has been supported by only two groups: the recruits and the adults from the previous year's recruitment. The recruits

first appear in November and December (age six months) and by February and March are contributing a substantial tonnage to the catches. Careful monitoring of this new age group each year provides information of a useful predictive nature.

Environment also plays an important part in the availability of the anchovies to the fishing year. The El Nino condition which develops periodically off Peru seems to adversely affect availability during the July-October period.

It is obvious, then, that careful monitoring of sea surface temperature, year-class strength, and fishing effort can assist in the prediction of anchovy landings in Peru.

SOME SUGGESTIONS FOR FISH FORECASTING

1. Useful forecasts cannot be made from a desk position. Intimate knowledge of the operational aspects of a fishery is required.

2. Interpretation of data requires a mixture of science and art. Use computers for data reduction only as feel for the information is lost if machine methods are employed at the forecasting level.

3. Government reports provide a sound base, but it is almost always necessary to supplement these data with a private information network.

4. Only limited significance should be placed in daily news. There is generally too high a noise level in this type of data. Trends based on weekly or monthly summaries are more reliable.

5. Word of mouth information should be used with caution and then only if the source is firsthand and is known to be reliable.

6. Do not attempt to exceed the limitations imposed by the data. Some situations do not yield to the use of predictive methods.

SUMMARY

If industry actively evaluates Government research, supplements it with additional analytical work, and applies the results to assist in business decisions, then we can state with emphasis that ocean research programs have very great value to the sea food industry.

MINING INDUSTRY'S ROLE IN DEVELOPMENT OF UNDERSEA MINING

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ABSTRACT

A review is made of what the United States Government and others are doing to aid the mining industry in establishing an off-shore mining capability. This newly developed know-how combined with the development activities of private mining/oil/chemical companies will lead to an orderly establishment of off-shore mining operations. Some economic, technical and marketing aspects are reviewed to give a clearer picture of the attractiveness and pitfalls associated with ocean mining. Also, recommendations addressed to the public as well as private sectors are made to speed along this new opportunity.

INTRODUCTION

I think the time has arrived when the mining industry can look upon ocean mining with "cautious optimism". For those people who place great value on statistical figures, we can state that today, in the entire world, some 50 million dollars worth of mineral products are mined directly from the sea annually. Furthermore, based on facts already obvious today, total world ocean mining within 10 years will have over 250 million dollars in annual value. In 15 years, probably over 500 million dollars annually.

Whether or not you put weight on figures such as these is not too important. We feel that there are more tangible reasons for giving marine mineral mining a good hard look. Certain mining companies, such as those dealing with sulfur, and tin are already forced to look into the sea for their only logical large future sources. There are more mining companies, who for defensive reasons, must, if nothing more, have a good working knowledge of the competitive position of those marine minerals that would eventually enhance or destroy their businesses. In order to do a good job on that alone requires some rigorous effort.

There are other reasons as well. Consider the fact that international trade and more intense business competition in the years ahead will place a heavy burden on shipping material at low cost around the world and that means filling the voids in backhauls. In many cases this means looking into the ocean for minerals where nothing else exists on land along the trade routes.

And last but not least, we cannot overlook the value of marine minerals to underdeveloped nations as well as have-not nations to whom a marine mineral, whether high grade or marginal, can mean the difference of successful international trade or not.

So the mining industry, which for many years has been aware of its global interests, must now look at mineral recovery with a new twist: Can an ocean resource compete with a land source in the world market?

My purpose today will be to call your attention to the recent development in ocean mining which will aid the mining industry in evaluating this new potential and also offer some opinions, humble as they may be, that will aid in opening up this new potential to the American mining industry.

Let us begin by looking at our government's role in this whole picture. By a stroke of fate, the Thresher submarine tragedy made us painfully aware that our working capability in the ocean environment was very limited. Somewhat frightened by the fact that the Russians might salvage or photograph the wreckage before we would, the U. S. Navy about five years ago embarked on a rigorous technical campaign dealing with the ocean environment:

1) To eventually operate a submarine at all depths
2) To gather the facts of the ocean--its currents, temperatures, physical attributes, etc.
3) To detect foreign objects,their movements and cognizance
4) To survey our adjacent ocean bottoms (first the continental shelves and the deeps)
5) To properly maneuver, navigate and operate military systems in the ocean environment

A broad based technological effort such as this has many ramifications. The Navy has had to deal with biological, physiological, engineering and scientific groups to resolve the myriad of problems that confront us in mastering the military aspects of the ocean environment. Fortunately, these same technological advances can be applied to marine mineral technology.

We have been made painfully aware again, since the Thresher incident, that we have a long, long way to go before we can locate objects at sea, much less haul them up. We need not treat the nuclear device in the Mediterranean ocean nor the crash of a commercial jet in Lake Michigan in August, 1965, with too much detail to remind us of our national limitations.

But let us look at the positive side of the ledger. At my latest count there were some 17 agencies of the Federal Government that are actively engaged in developing technology to deal with the ocean environment. It would be tedious to list them all. What would be interesting would be to highlight the progress that has been made by these groups in the last few years.

The most glamorous, probably, has been the recent success of SEA-LAB II which proved that man can perform a number of physical and mental tasks under 200 feet of water for longer periods of time without too much discomfort. Next year this test will be extended to over 400 feet depth and I think it will be safe to predict that the United States will have the capability to successfully "man" the continental shelf up to the 600 foot depth level by 1970.

Secondly, the National Science Foundation has launched the Mohole project. This is destined to generate an immense amount of information on the geology of our earth as well as make considerable technology available to a number of industries, such as ours, on how to maintain heavy mobile equipment over a specified area at sea for great periods of time.

The Bureau of Mines, with its Marine Mineral Technology Center at Tiburon, California, in concert with our company International Minerals and Chemical Corporation and the Lockheed Aircraft Company, have developed coring and probing devices and simple air lifts in the past year which are helpful in evaluating ore bodies that lie on or near the continental shelf surface. Further plans call for more development in this same vein and the tools and methods will get more sophisticated as we go along.

The United States Geologic Survey, the Coast and Geodetic Survey as well as the Corps of Engineers, have over the past four years, put some effort into exploration for minerals on our continental shelves and have reported a number of mineral and natural resource discoveries that look interesting. More of such activities by these agencies is on the books.

The National Oceanographic Data Center in Washington today provides us with a reasonably good compilation of world-wide oceanographic data which is exchanged with all the nations of the world which generate or need their own data. This year, the NODC is now including geologic data with the core samples to be stored by the Smithsonian Institute.

The United States Civil Engineering lab at Port Hueneme, California and the Naval Electronic lab at San Diego, has also made many contributions to science and technology applicable to undersea mining in their work dealing with corrosion resistant materials, mechanics of materials studies, underwater communication and visual detection mechanisms, and stabilizing structures at great depths.

The newly formed Environmental Science Service Administration of the Department of Commerce has formulated ambitious plans in the Sea-Air Interface studies which will aid tremendously in understanding weather conditions at sea and also give us a better handle on environmental conditions in the open sea.

This list of highlights can go on, of course, but sufficient evidence indicates that Uncle Sam is beginning to make a rather sober appraisal of his newly "won" terrain. All the knowledge that is thus developed, short of that which is considered secret in the national interest, will be made available to industry.

This substantial beginning, on the part of the Federal Government, must now be married to private industry's effort to exploit the sea. What is holding it back?

Probably the greatest single reason that ocean mining has not taken a more aggressive path is that, to date, no major deposit of any real value has been found. The fifty million dollar market served by present and underwater mining ventures around the world are, for the most part, unique local deposits which serve local markets. The notable exceptions are tin and sulfur. As a matter of interest, it should be stated that recently some seven companies have bid over thirty-three million dollars for sulfur mineral leases in the Gulf of Mexico. This probably represents the largest single development effort to date in terms of money, for an undersea mineral deposit.

However, we feel that most of the other mining operations around the world are too marginal in economic return, especially if we consider the risks involved with the open sea.

But we are of the firm opinion that once a substantially rich deposit is found that the technology to exploit it will be readily developed. At least for the continental shelves. But unless such a large and rich deposit is found, ocean mining development will continue to move rather slowly and rely, for the most part, on the military fall-outs from anti-submarine warfare technology.

Another serious impediment to a more rapid ocean mining and exploitation effort is the legal aspect. Who owns the ore body that has been found? Most of the seashore states in the Union other than Oregon and Alaska have not established a firm law concerning mining leasing rights and the Federal Government also has failed to establish a policy of ore body ownership that is acceptable to exploration and mining risk takers. Fortunately for us, this whole subject will be treated in greater detail later this morning by a much more qualified individual.

The real essence of ocean mining success or failure, or if you prefer a more modern jargon, is it GO or NO GO, rest basically on simple economics. These are economics as they apply to the mining company on land just as equally as they do for ocean consideration. A case in point: A number of marginal copper mines have re-opened in thelast two years because the price of copper has risen from 28¢ to 42¢ per pound. By similar corollary, off-shore phosphate nodules near San Diego, California, are not being mined because phosphate from Florida and Idaho are being delivered at lower prices to California markets. There is not much mystery surrounding the technology of extracting these nodules from the ocean floor. It is straight forward economics on the final product that favors one resource location over another.

Ocean mining, however, has got some good things in its favor which do not necessarily hold for land locked resources. A substantial part of any major mining scheme are the costs associated with housing and services for the miners' community, the laying of railroad track, harbor facilities, trucking equipment and the like. These capital charges are usually compounded by the operating costs added to the production cost for moving goods from the mine site to the cargo carrier (specifically cargo ships).

Any ore body that is high enough in grade and found in more than 30 feet of water can avoid these considerable expenditures. In some cases, even shallower water, would permit the use of ocean going barges to short distance ports.

An off-shore mining scheme would also be re-usable and transferrable. This means a lot, should a mining operation be located in a politically unstable area. And how many mining companies wished they could move their expensive mine shafts after a mine has "played out"?!

Now let us set aside all these considerations and look at ocean mining development from an entirely different viewpoint. Those of us in management are always beset with those managerial problems that are straight-forward and those that are new, untested, or unknown. I am addressing myself now specifically to the risk-taking or the entrepreneural aspects of running a mining operation.
(Slide 1)
Let us look for a moment at the projected slide which shows how we see the ocean exploitation industries broken down. This is a matrix describing the service and extractive activities that completely blanket this "business arena".

There are nine basic industries (as we see it) now involved in ocean exploitation. These are the basic industries that produce products for commerce or perform the vital functions that are part and parcel of the ocean environment. These are industries listed across the top of the slide from left to right. I think they speak for themselves. Acting as crosscuts to these basic industries are the industries that provide the specialized services necessary to complement the primary ocean business activity.

On the left hand column, the HARDWARE cross-cut pertains to those companies that build the ships, the floating platforms, the instruments and the tools necessary for the basic operation of the industries listed across the top from left to right. In the SYSTEMS cross-cut, we are talking about companies that develop navigation systems communication networks, diving services and techniques, supply services and other similar activities. In the area of KNOW-HOW, we speak of those companies or individuals who have a specific knowledge to sell or supply. This would include patents, operations assistance and guidance, scientific services such as seismic interpretations and the like. It also includes the knowledge developed by institutions such as Scripps and Woods Hole pertaining to geologic finds or general oceanographic methods.

In PROPERTIES are those individuals or companies that deal in minerals leases, land ownership, harbors and even the financing for the purchase or use of these facilities. For the TRADING cross-cut we include all those commercial services that pertain to the trading function, such as selling the minerals, promotion, financing the trading itself and so on.

Now for the Mining industry, there are companies in existence today that perform these service functions for the ocean environment. They are available to the other basic industries as well.

Now in developing this particular theme with you, I offer the suggestion that future marine mining ventures will be born from any one of six directions: The basic mining industry itself or from any one of five service industries on the left. While this is being done now with ordinary land mining, I submit to you now that this procedure will work even more so with ocean mining.

I think the reason for this is rather apparent. The mere size of the ocean itself, being 2-1/2 times greater than our land surface, means that one company or even a few companies can not hope to cover this entire area by themselves. And I'm speaking now from both a geographical as well as a commercial standpoint. The concept staggers the imagination! ! ! Inputs to a major mining company for an off-shore opportunity must come from as many reliable sources as possible for proper assessment. Otherwise the costs would be astronomical. And I include inputs from the various governments as well as private business.

To put it even more candidly, there are a number of mining companies who now own leases for off-shore property. But they are waiting for someone to develop an economic mining system that can economically extract the ore body. There are some mining companies who are developing hardware for marine application and waiting for someone to approach them with an interesting underwater ore body discovery. And there are some mining companies who are assessing the economics of certain off-shore raw materials and are waiting for the right opportunity to present itself for commercialization.

A mining company is prone to move cautiously in this regard under any circumstance, because even if a good deposit is found, what chance still exists that the competition will find an even richer deposit somewhere else? This same problem exists with land deposits but there, a mining company, has a number of basic tools at its disposal to more critically assess that possibility. These tools are still lacking for ocean bottom resources.

We have some other thoughts on ocean mining that we would like to share with you. After much discussion with ourselves and others in the mining industry over the last few years on this subject, we get the impression that nobody seems to know how to grab a hold of this subject. Well, let's discuss it some more and look at its numerous parts. We are even willing to stick our necks out a bit to bring a point across.

Mathematics and Operations Research have played a vital role in the mining industry over the past ten years. I won't attempt to treat that subject other than to point out some work done by T. B. Nolan of the U. S. Geologic Survey and Allais of the French Geologic Survey.

Nolan showed that the distribution of mining value followed a Poisson Distribution. Or in simpler language, he indicated that in any given large mineralized zone, most of the mines have relatively small value, some have good values, and only a few mines produce immense value. Nolan's chart dealing with California, Arizona, Nevada and Utah dramatize this point rather well.

Allais did some unique mathematical interpretation on geological anamolies in the Sahara Desert and also observed that the distribution of these anamolies follow a Poisson distribution.
(Slide 2, Slide 3)
The next chart on the screen is still another example. Allais listed the mineralized wealth of many major areas of the globe in terms of dollar output per square kilometer. This collection of areas was extremely large. He only considered those geographical entities larger than 100,000 square kilometers and some larger than a million square kilometers. The smallest area was Malaysia and the largest, the entire Soviet Union.

Again, the same mathematical distribution pattern appeared. Well, what we would like to suggest, based on this bit of interesting information, is that some types of mathematical relationships exist for ocean bottom minerals.

We have already done some interesting work in the mathematical treatment of ocean mineral deposits and have found, with the aid of computers and data received from the National Oceanographic Data Center in Washington, as well as our own data, the oceanographic factors do inter-relate. We see the mathematical approach to finding ore bodies as a valuable tool and intend to do more as more and more information about the ocean environment becomes known.

As an interesting corollary to this subject of mineral productivity is the one of agricultural productivity. This too has special significance to our company since our basic business is the production of certain minerals for the soil to improve crop yield.
(Slide 4)
The percentage of the earth's surface that is available for agricultural purposes is small indeed and that portion that is truly high for the production for food is smaller yet. This awareness of the distribution of arable lands is essential to fostering a sound agriculture policy around the world, both from a business as well as political standpoint.
(Slide 5)
Another avenue for looking at the future of ocean mining is from the technology viewpoint. We have decided to dream about what is going to happen in the years ahead and offer this table for consideration. Now I don't doubt for a minute that there are many of you in the audience who will challenge some of this prognostication but we will stick our necks out anyway -- primarily to inspire those that now are total skeptics.

We can see that for the most part, underwater mining activities can be operated for a number of ore situations in 50 feet of water or thereabouts. The literature already cites a number of mining operations around the world, almost all of which are in 130 feet of water or less.

The newly developing submarines that will be able to take samples by coring as well as the new coring methods applied from surface ships will make us aware of mineralized areas in 300 to 600 feet of water by the 1970's. The chart indicates that the necessary technology to complement most of the mining opportunities will be ready by then. At least we like to think so.

There is another interesting attribute to recovering minerals from the ocean shelf; one that deserves the attention of any company which has interests in the field of ocean resource recovery. Our beaches in the United States, especially those on the Atlantic Shelf are being eaten away by wave action and other causes. Cities that lie on the shoreline find themselves limited for expansion because the ocean represents a great share of the city's periphery. Many of the great harbors of the world are being silted up and/or find themselves too shallow to handle the newer and immense cargo vessels now being built.

The point to be made is that near shore ocean mining opportunities very often can be joined with other commercial activities that can enhance the economic return of a mining venture. It can also reduce the business risk of such undertakings. In some cases, it can even be that the on-shore aspects of off-shore mining can be a more lucrative aspect of this business.

We can take this thought one step further and suggest that the technology essential to off-shore mining can be applied to non-mining problems such as harbor and channel maintenance, under-water construction, land reclamation, improving near shore navigation and so forth. These all represent interesting diversification avenues for those companies that find themselves interested or capable in off-shore mining.

No one here will deny what new and lucrative businesses have cropped up with the off-shore oil industry. We hereby imply that similar activities will grow from mining opportunities.

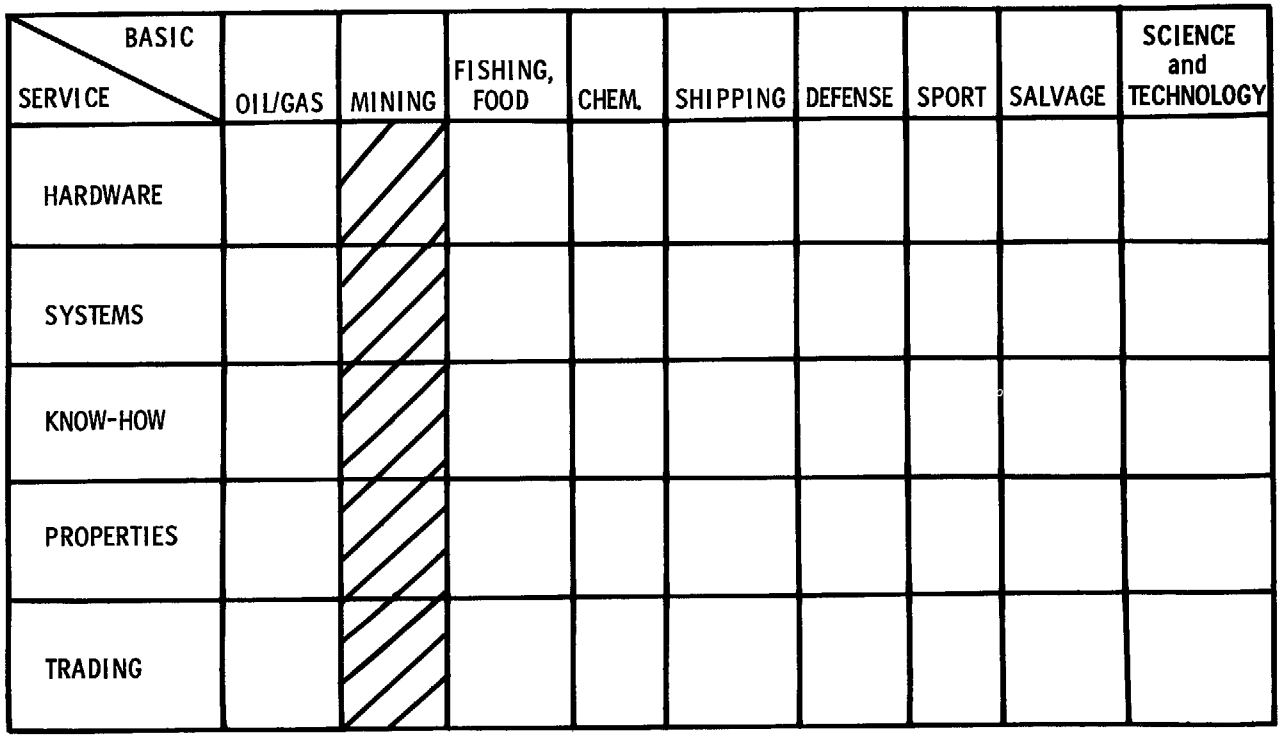
In closing, I would like to repeat my beginning thought: that ocean mining today should be viewed with "cautious optimism". The reasons why this new endeavor looks more and more attractive as the years progress is as follows:

1) It will be possible to develop certain mineral properties submerged under sea water and get them to market at competitive capital and operating costs.

2) The world's continental shelves alone represent an area of about 10 million square miles. This is a new continent worthy of development. Sufficient evidence exists to establish that a number of interesting minerals are there.
3) Because of certain political instabilities around the world, ocean mining opens up nearby resources heretofore locked in distant lands. It also permits plant and capital to be partially salvaged in case of economic and political difficulties.
4) It presents the opportunity for profits in spite of the obvious risks of working in the open sea.

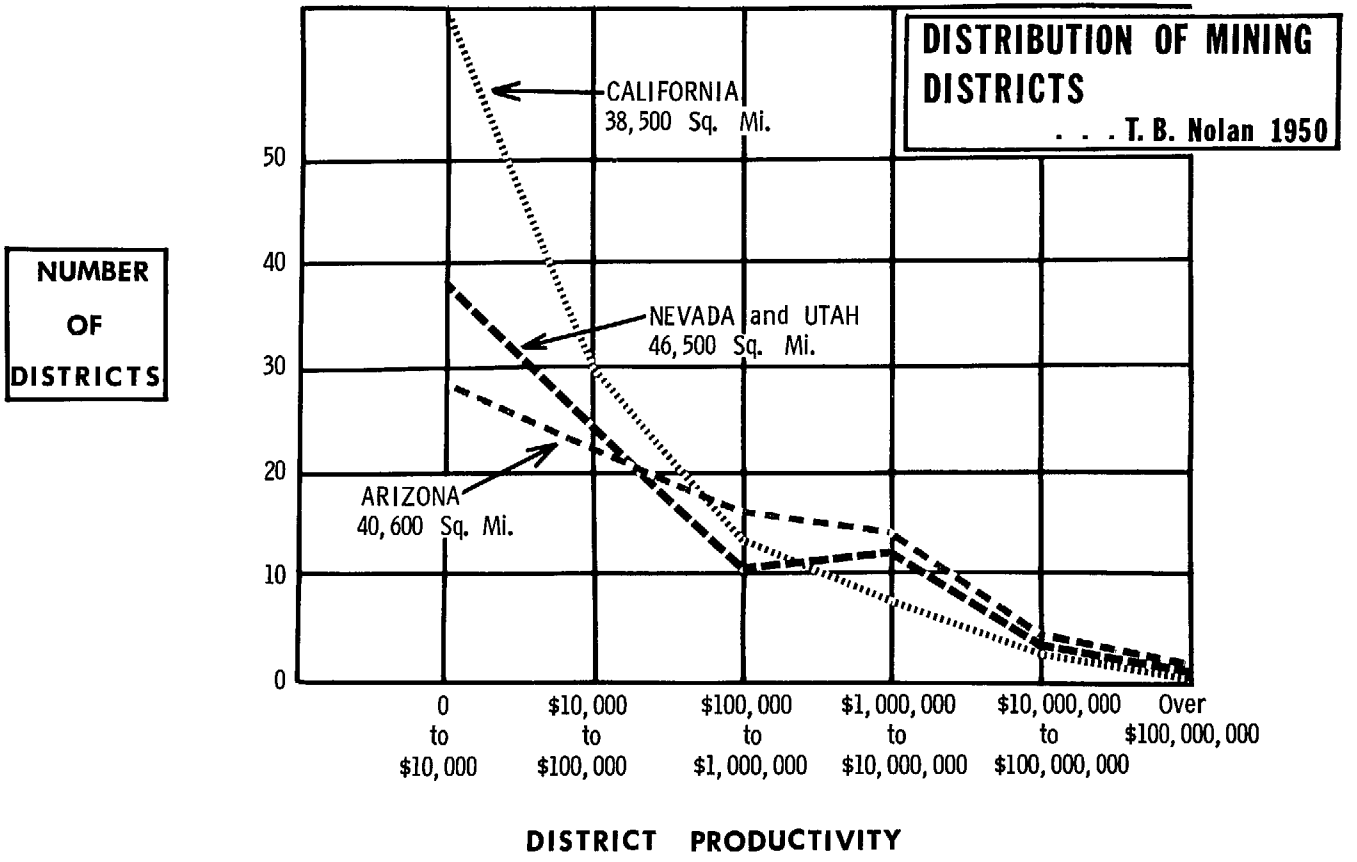
And last, but not least, we hear the words "vast", "rich", "unlimited" and so on used rather loosely while discussing ocean minerals. While we tend to be optimistic about the oceans resources, we must also be realistic enough to know that this is not the language of significance. Let's be realistic about approaching the mineral values of the ocean environment in relation to the cost to extract them. Using this cautious attitude, there seems little doubt that a potential is there and that the American mining industry can have a leading role to play in this relatively new opportunity.

Slide 1

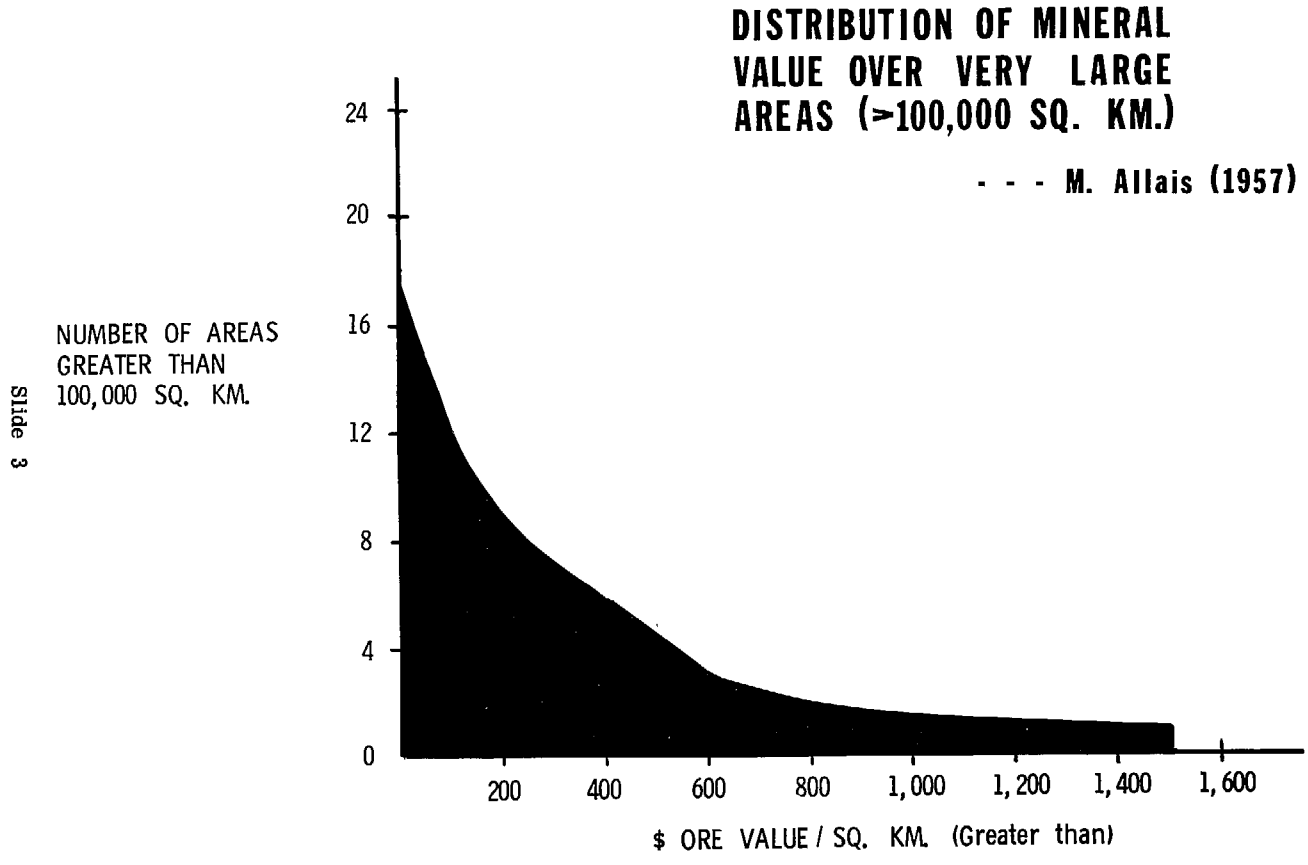


THE OCEAN EXPLOITATION INDUSTRIES

Slide 2


DISTRIBUTION OF MINING DISTRICTS
. . . T. B. Nolan 1950
NUMBER OF DISTRICTS
CALIFORNIA
38,500 Sq. Mi.
NEVADA and UTAH
46,500 Sq. Mi.
ARIZONA
40,600 Sq. Mi.
0
10
20
30
40
50
0 to $10,000
$10,000 to $100,000
$100,000 to $1,000,000
$1,000,000 to $10,000,000
$10,000,000 to $100,000,000
Over $100,000,000
DISTRICT PRODUCTIVITY

Slide 3


DISTRIBUTION OF MINERAL VALUE OVER VERY LARGE AREAS (>100,000 SQ. KM.)
- - - M. Allais (1957)
NUMBER OF AREAS GREATER THAN 100,000 SQ. KM.
24
20
16
12
8
4
0
200
400
600
800
1,000
1,200
1,400
1,600
$ ORE VALUE / SQ. KM. (Greater than)

Slide 4

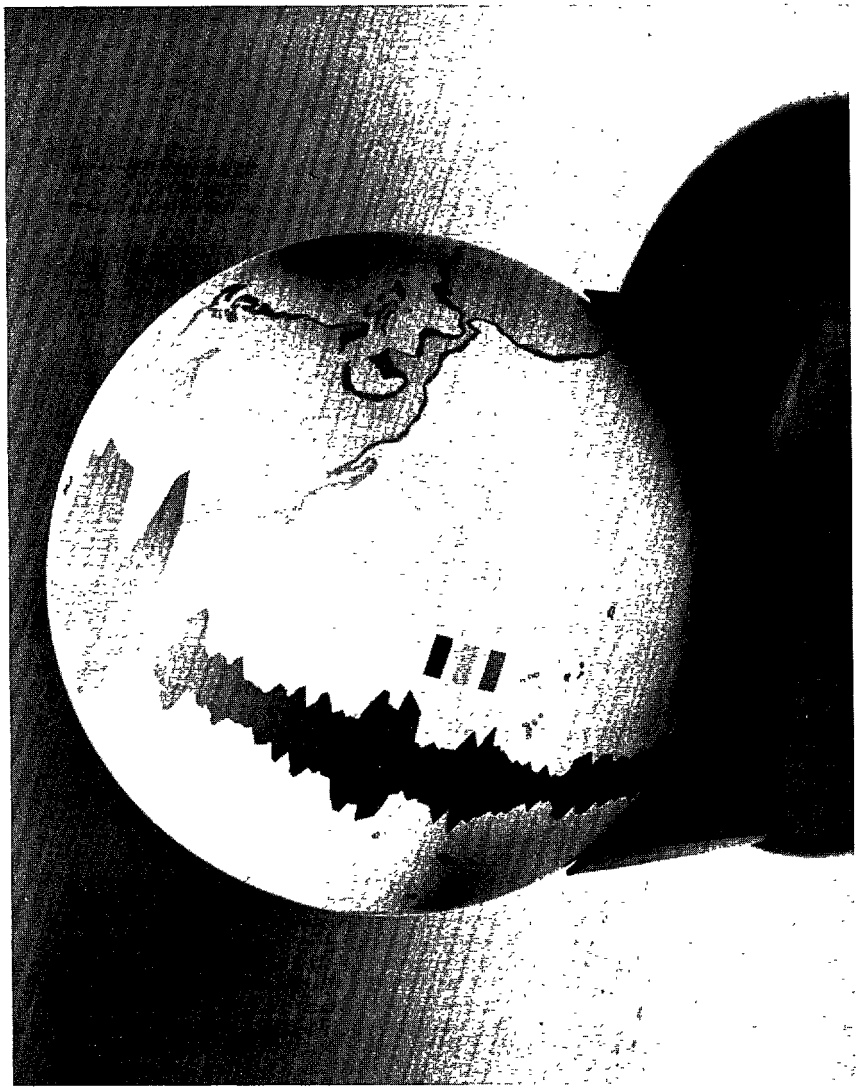
All present and all potential cropland would add up to under 10 Million Square Miles -

Translated into Acres this would be about 6 Billion - or only about One Acre per Person at the population level of the Year 2,000.

OCEAN MINING TECHNOLOGY TIME TABLE

	DEPTH OF WATER			
	50'	300'	600'	1000'
MINING USING AIR LIFT DEVICE	1960	1970	1975	1980
MOBILE MINER (OCEAN FLOOR)	1970	1972	1975	1980
BARGE DREDGE LIFT	1900	1970	-	-
STATIONARY MINING PLATFORM	1960	1970	1975	1980
BOYANT SUBMERSIBLE SYSTEM	-	1975	1977	1980
UNDERWATER OPEN PIT HARDROCK MINING	1975	1985	1995	2005
UNDERWATER "AERIAL" PHOTOGRAPHIC RECONNAISANCE	1960	1964	1970	1975
EXPLORATION SUBMARINE (CORER)	-	1968	1968	1968
UNDERWATER SITE DEVELOPMENT STATION	1970	1972	1975	1980
SOLUTION MINING (SULFUR, POTASH)	1961	1980	1985	2000
HARDROCK MINING (BELOW SHELF)	1900	1985	2000	2000
MINING SHAFT	1970	1980	2000	2000

Slide 5



Slide 6

THE GOVERNMENT'S PROGRAM FOR ENCOURAGING THE DEVELOPMENT OF A MARINE MINING INDUSTRY

By Walter R. Hibbard, Jr.

Abstract

Present emphasis in the Government's program for encouraging the development of an industry based on exploitation of marine minerals is determined by two principal factors - (1) the unavailability of the kind and quality of information required for sound economic evaluation of sea-bottom mineral deposits, and (2) the physical difficulty and high cost of obtaining such information. As knowledge and understanding of mineral deposits in their marine environment increases, program emphasis will shift to technologic problems of production. The job of finding and delineating sea-floor mineral deposits and developing the technology to produce from them, economically, the mineral raw materials the Nation needs is formidable. Its successful accomplishment will require that the combined capabilities of Federal and State agencies and the academic community be brought to bear in an aggressive partnership effort with private industry. The Government's marine minerals research program is considered to comprise three phases which are interrelated and more or less interdependent. These can be characterized by their objectives: (I) Marine Minerals Search and Exploration, (II) Marine Mineral Deposit Delineation, Evaluation and Development, and (III) Marine Minerals Production System Technology Development. Ultimately, as with dryland mineral resources, the bulk of the activity in all of these areas will be by industry. At the outset, however, the Government must contribute a substantial effort in all three phases.

In discussing with you "The Government's Program for Encouraging the Development of a Marine Mining Industry," I will be speaking primarily in terms of the Bureau of Mines activities with which I am most familiar. Other Federal agencies are, of course, also at work in this emerging field of technology--or at least in areas related to it--and, while I do not presume to speak for them, I shall describe briefly some of the efforts being made to coordinate parts of their operations with those of the Bureau and its industrial cooperators.

Those of us in science and engineering who have been working along the fringes of oceanography have long been intrigued with the great opportunities to be met in the sea. Having read and heard of the mineral wealth of the sea floor, we cannot help but look hopefully in the direction of this prize bounty. As world population increases and the corresponding needs for mineral raw materials grow, we are at last being compelled to turn to these new, unexplored regions, as a means of augmenting and expanding our domestic resource base. Now that we have begun to participate more fully in the National Oceanographic Program, we have come to learn what the pioneers in oceanography have known all along, namely, that opportunity is present but will be realized only after the challenges of a research development and testing program have been successfully met. By combining the talents of Government, industry, and the academic community, we believe technology can be sufficiently advanced to make marine mining practical enough economically to attract the large amounts of private risk capital that will be required for full exploitation.

The Bureau of Mines is helping to initiate these early stages of what we believe will eventually become a growth industry. We hope that marine mining will gradually expand into a major force in the international economy. We are, however, becoming increasingly aware of the questions that must be answered first.

Our program, currently being conducted cooperatively with three leading industrial firms, is still essentially in the embryo stage. The Bureau of Mines has a small operation at its Marine Minerals Technology Center, at Tiburon, California, where we are refurbishing and equipping as a research center the former Navy Net Depot. We have already had assistance from fellow member agencies of the Interagency Committee on Oceanography: a 65-foot Army T-boat; and a 165-foot reactivated Navy net tender, both of which have been modified and refitted for the specialized work that will be required as the program moves forward.

Mining on dryland is a costly and financially risky activity. This is so despite the fact that we are able to call on technology and engineering capability stemming from thousands of years of practical experience and engineering progress. In the marine environment, where we have as yet so little understanding of the complex environment and where we have virtually no mining experience, the risk is multipled many times. Research effort, it therefore seems to us, can reasonably be shared by industrial, academic, state, and federal entities--by all who have a concern in the future.

Our knowledge of marine mineral resources is limited but I'm sure we all are enthusiastic about developments in the recovery of shallow water minerals near shore. Recent efforts to develop gold production in Alaska's Norton Sound certainly have generated as much interest as the actual production of tin, iron ore, diamonds, aragonite, and construction minerals. If shallow water beach and stream placer deposits are abundant, then there is a basis for at least a small industry in the near future.

Interest has also been stimulated in the deeper water chemical precipitates. As you know, some areas of the Continental Shelf, such as offshore banks, are thought to be covered with phosphorite. Some of these deposits are reported as only a few hundred feet deep, and may eventually be fully explored and evaluated for their potential use as fertilizer material. I'm sure that all of us who are familiar with the literature have been made aware of the deposits of nodules containing manganese, nickel, copper, and iron, which have been found in non-depositional areas of the ocean and purportedly over two miles deep. They appear to be so abundant that they have sparked commercial inquiry in recent years. If the deeper marine mineral deposits are as plentiful as they appear to be, then the long range potential rewards certainly must be commensurate with the extensive research and development that must be undertaken.

Bringing a sea bottom mineral deposit into production will require the same sequence of basic steps as does developing a mine on dry land. First, obviously, a deposit has to be found--the discovery step. Next, the deposit must be explored to obtain data on extent and quality sufficient to make a market study and a preliminary economic judgment. Then, if this judgment is favorable, additional sampling and measurement must follow to develop the detailed knowledge required for sound evaluation in terms of technology and economics . . . . to define the physical and chemical characteristics of the ore body and to learn as much as possible about its environment. Only after successful completion of this step, called delineation, can design of the production system and development of the deposit for mining begin.

These three stages of mineral deposit development are obviously applicable to any mineral occurrence, whether on dryland, the ocean bottom, or the moon. If we look at the technologic requirements for marine mineral mining in terms of the objectives of these stages the pattern for the required marine mineral research program becomes apparent. The problems to be attacked will fall into one of three categories or phases - (I) Search and Exploration, (II) Delineation and Evaluation, and (III) Production System Design.

As far as the Department of the Interior is concerned, responsibility for research in phase I, Search and Exploration, rests with the Geological Survey. Both the Survey and the Bureau of Mines are concerned with the second phase, Delineation and Evaluation. Research related to the deposit of mineral production systems falls within the mission of the Bureau of Mines, as would the development of technology for processing the ores after their extraction.

Obviously the research in these three categories is interrelated and more or less interdependent, as are the corollary steps in the development and operation of a mine. They are considered as separate subprograms because of their relative priority with respect to time and their different requirements (and opportunities) for coordination and partnership operations with industry, the academic community, and other Government agencies.

Initial emphasis in the Bureau of Mines program for marine minerals is dictated by a very limited amount of definitive knowledge with respect to sea bottom mineral resources. Such information as we have is sketchy and qualitative, as might be expected because the bulk of the data were developed incidental to scientific investigations directed toward other aspects of the sea bottom. Only in the past decade has any effort at all been focused on marine minerals.

Not only is information on ocean floor mineral deposits sparse, but the tools and techniques for sampling in sufficient quantity and quality are not available. Only a thorough knowledge of the character of marine mineral deposits and the particular ocean environments in which they occur can support the sound economic judgments that must precede capital investment, without which a production operation cannot be established. But as yet, knowledge of these factors is required to define the specific technologic problems for which research must seek answers as the first step in developing commercially attractive marine mining systems.

The most urgent immediate need, then, is research and development on the problems delineating and evaluating marine mineral deposits. It is in this critically important area that most of the Bureau of Mines present effort is concentrated. The work falls into two principal categories: (1) Data Collection and Analysis and (2) Sampling Equipment and Methods.

In the first of these, liaison is being established and procedures developed for obtaining, from those of the oceanographic community who are generating it, available data on known and potentially mineralized areas. We are collecting much information as possible on those characteristics of marine mineral occurrences and their environment that will affect the design or limit the operation of a mining system, including data on mineral quality and distribution, water depth, weather, tides, local water circulation, sea bottom topography, and physical characteristics. All of these factors will be important in determining the physical requirements of the production technology. Assembly and analysis of adequate data for specific mineralized areas will provide the basis for defining the mining problem and for preliminary economic studies.

In this activity, the Bureau obviously must depend heavily on the Geological Survey and other Federal agencies such as the Environmental Sciences Service Administration, and the Navy as well as State agencies, universities, and private institutes engaged in oceanographic studies.

Work under one second category, development of equipment and techniques for sampling sea bottom mineral deposits, also will proceed much faster and more efficiently as a partnership venture. Here, industry already is a principal participant, and its participation can be expected to increase.

The Bureau has a long history of cooperating with industry in research that has proved both productive and mutually advantageous. We are confident that this practice will be as successful in building a foundation for commercial mining of the ocean as it has in previous dryland activities.

The present pattern for Bureau research in marine mineral sampling reflects the present state of the art and the fact that so little is known about marine mineral resources. Though we have not yet evaluated all available ocean bottom sampling devices, a preliminary review indicates their inadequacy for delineating certain types of marine mineral deposits in the detail and precision taken as a matter of course on dryland. I do not mean to say present tools are of no use at all. They are. But obtaining ocean bottom samples for scientific study and taking mineral deposit samples to determine the economics of a mineral production operation are two altogether different things. Indeed, it would be surprising if the tools already available were adequate since they were developed for other purposes.

Inadequate knowledge of marine mineral resources limits the present scope of the research on deposit delineation because obviously all of the problems cannot be defined until deposits have been identified.

Accordingly, because some of the same sampling tools required for deposit delineation will be useful in marine mineral exploration and because our sister agency, the Geological Survey, is responsible for the search and exploration phase of the Government's program, we have proposed the Bureau's work in developing sampling equipment be initiated in a joint project at the interface between the missions of our two agencies. In addition to the Survey, we have invited appropriate State agencies and industry to join us in a systematic effort to sample, in reconnaissance fashion, the most favorable areas on the continental shelves.

The work in many cases will follow up leads furnished by reconnaissance sampling already a matter of record, such as the Geological Survey Woods Hole study of the Atlantic Coast Continental shelf and slope. The program will locate and define, in a preliminary fashion, potentially economic sea bottom deposits in conjunction with the sampling research. This approach permits us to make our research effort do double duty. By testing and evaluating equipment on sampling campaigns planned by Survey and State geologists we not only will accomplish our objective but will add to the fund of marine mineral resource information necessary for guidance of our future work.

Cooperative arrangements for participation of industrial concerns in this project will differ somewhat from our usual practice because of the nature and broad scope of the work. Normally our cooperative research is concerned with specific technologic problems. Such research may concern a particular mineral deposit in which the cooperating group of companies has an interest, but the cooperative effort is designed to acquire knowledge

that will have wide application. In contrast, the research here is concerned with a relatively broad field of engineering, presently in the embryo stage, relating to mineral resources of which specific deposits have not yet been developed. Furthermore, one of the objectives is information on the resources themselves.

In the aggregate these differences probably account for the wide interest that we have found industry showing in the work. We are talking with a number of companies who have evinced an interest in joining the cooperative program that already is underway. Fortunately this is a program that can be open end. The size and duration of the effort need be limited only by the research requirements and the amount of funds and other resources we can bring to bear. Any strengthening of this effort will advance the beginning of commercial marine mineral production. We will therefore welcome proposals for additional participation.

As work on this project progresses and more information on marine mineral resources developed by the Geological Survey, industry and others working in the field becomes available, the shape of the Bureau of Mines marine minerals program will gradually evolve to conform to the usual Bureau pattern. It will be concerned with specific deposits that are typical with respect to a significant resource and specific engineering and technologic problems related to delineation, evaluation and exploitation of these deposits. Similarly, the opportunities, and the requirements, for industry participation can be expected to change.

Naturally we do not expect any one industrial concern, or even a group of companies, to contribute to or participate in all of the marine mining research we contemplate. A company's interest normally will be limited to those projects which may contribute to solutions for problems anticipated in its own future operations. In the aggregate, however, industrial interest and participation should cover almost as broad a spectrum as that of the Bureau. The growth will probably take place on a project-by-project basis, however, as has been the case in our other research programs, rather than by widening the area of inquiry of the sampling project to which our industry partnership is now confined. Industry participation in various future projects will no doubt vary as widely as it does in our other work, where it ranges all the way from the provision of company sampling data for trend analysis studies by Bureau engineers to the full financial support of Bureau research on a rock mechanics problem of mutual interest.

As I have already indicated, the development of sampling equipment constitutes only part of the research that will be required to solve the problems of marine mineral deposit delineation and evaluation. Though these problems cannot be defined in detail until more is learned about the resources and their environment, some areas where work will be necessary and productive are apparent now.

Determining the topography and physical character of the sea floor obviously will be a necessity. Some of the existing geophysical tools such as--density probes, underwater cameras, and manned submersibles, will be utilized and, with modification, doubtless can be made more useful for mineral deposit delineation. But the precision that will be required in making these determinations, and the necessary measurement of additional properties such as particle size, hardness, and strength, make it inevitable that new tools and instrumentation will have to be developed.

The character and properties of the superjacent water mass also will have to be determined in detail, because such factors as local patterns of water circulation and corrosiveness of sea water will be as important as the physical parameters of the deposit itself in designing and evaluating production equipment. Here again, though some of the tools we need are available they will, without doubt, need to be supplemented.

Even after the first generation of adequate tools and techniques has been developed for delineating marine mineral deposits, further research will be necessary because their application almost certainly will be slow and expensive. And unless the costs of this preliminary step in developing an ore deposit can be reduced to something approaching a reasonable figure they will form a major obstacle to early and orderly development of our marine mineral resources.

After a few deposits have been probed by sampling equipment and we know a little more about their physical characteristics and the nature of their environment, we can direct our research efforts toward the technology and economics of production. Our present activity in this area is limited to a comprehensive and detailed background study of available equipment that might be used in marine mineral production systems. We plan to collect, analyze, assemble, and publish everything we can obtain on the operating characteristics and limitations, both physical and economic, of dredges, offshore drilling equipment, floating work platforms, working submersibles, pumps and hydraulic slurry-transport systems.

The results of this study, when correlated with the physical parameters of both specific and typical marine mineral deposits, will permit reasonable economic judgments and also provide a sound basis for further research in the technology of marine mineral production. Until such an analysis can be made this latter phase of the research program cannot be planned in detail. Nevertheless, we can foresee the broad areas into which the work will fall.

Research leading to efficient methods for breaking sea-bottom ores will obviously have to be undertaken but the urgency of this problem cannot be determined now. It is probable that, for some time, attention will be directed principally to unconsolidated sediments. It is safe to assume, however, that some sea floor mineral deposits will be consolidated and sufficiently competent to require breaking or, if unconsolidated, will contain particles large enough to require fragmentation into sizes small enough to handle. Efficient economic fragmentation will probably be the most difficult obstacle to overcome in developing systems that may ultimately make possible the mining subbottom hard rock deposits, not accessible from shore by underground workings. Development work on sea-bottom-rock fragmentation will, of course, have to be preceded by basic studies of rock behavior in an ocean environment.

Another important element in any mining system, and one which will be critical to the economics of a marine system, is materials handling, or the gathering and transporting of minerals from the ocean floor. As with fragmentation, details of the research that must be done will become clear as work progresses in the exploration and delineation phases of the program.

The design of vessels to meet the special requirements of the mining situation is another important area for research and development. The Bureau of Mines does not have any active work in this area. We do intend

to develop some capability in the field however, in order to evaluate existing and newly developed equipment with respect to the requirements of mineral production systems and furnish specialized guidance to those already active in the design area. We propose to accomplish this by developing a close liaison with commercial shipbuilders, the Navy, and the others who have outstanding capability in ship design.

Requirements for research in mineral processing will become apparent as our fund of knowledge about marine mineral resources grows. In general, we plan to undertake such research as the need arises, and the initial studies are expected to differ little from those we now perform on minerals derived from dryland deposits. But, since it will be economically advantageous in many situations to do as much as possible of the processing at the mining site the factors of sea conditions and logistics will have to be considered. In these instances, equipment and processes will need to be piloted under simulated and actual sea conditions.

Research on the problems of waste disposal will be a major element of the program, since unwise dumping of the tailings, if not carefully planned, could quickly foul a mining operation. Furthermore, the compatibility of a marine mining operation with exploitation of the other resources of the sea, particularly the food resources, will depend principally on the effectiveness of the tailings-disposal system.

The results of research on near-shore-sediment movement and other oceanographic studies will be useful in attacking this problem. Hence, close coordination with research organizations working these fields will be required. Early liaison with those of the oceanographic community whose interests lie with food, recreational, and other resources of the sea will also be necessary.

The purpose of the Bureau's marine mining research program is to encourage and assist in the early development of a domestic, privately-owned-and-operated marine mining industry. Attention will be directed initially therefore to those minerals most likely to become commercially attractive first, such as the shallow water tin and precious metal placers, construction materials, phosphorite, and other industrial minerals.

We believe that the technology required to exploit our marine mineral resources will develop most rapidly if, within the framework of market demands, the effort starts at the shore and progresses outward. Such an approach can reduce the technologic risk and provide a sound basis of experience for the incremental advances in production technology that will be required as we move out to deeper water and into more difficult physical situations.

Ultimately the bulk of the Bureau's research in the marine minerals field will be concerned with the technology and economics of production. Right now, however, the state of the art and lack of adequate knowledge of the resources themselves make it necessary that most of our effort be devoted to acquiring the information that will enable us to define the mining problems.

And defining the problems is, in itself, a major task. The work will be difficult and costly, as will subsequent efforts to develop production technology. We are confident, however, that the partnership approach will yield solutions to these problems, on schedule and with minimum risk, and that the prize will be well worth the effort.

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LEGAL CLIMATE FOR UNDERSEAS MINING

Abstract

Elmer F. Bennett

The Public Land Law Review Commission, created in 1964, has been charged by Congress with making a study and recommendations concerning the disposition and restrictions on disposition of mineral resources in the Outer Continental Shelf. The sovereignty of the United States over the area appears well-established in international law, although certain ambiguities do exist and the United States has international obligations with respect to mineral operations in or over the continental shelf. Existing legislation and regulations do not make specific provision for underseas mining. There are at least seven basic elements to a favorable legal climate for industry participation in underseas mining: (1) certainty concerning sovereignty; (2) the right to develop minerals discovered; (3) adequate tenure and right to develop mineral reserves to offer reasonable opportunity for profit; (4) definite royalty obligations of reasonable magnitude; (5) certainty concerning relative obligations of the federal government and industry in complying with international law; (6) certainty concerning interruptions in the use of ports, territorial sea and internal waters; and (7) certainty concerning applicability of labor legislation and other domestic laws.

As you may know, I am presently serving on the staff of the Public Land Law Review Commission, a temporary agency created by Congress in 1964 to study and recommend any needed changes in the laws, rules and regulations governing the administration of the public lands of the United States. Since nearly everyone is aware of the activities of the Forest Service, the National Park Service and the Bureau of Land Management as they affect the daily lives of millions of people within our national borders, it may seem questionable whether a dry land lawyer like myself has a proper role on your program. Actually, Congress decided we did when it passed the legislation creating the Commission.

Most of you have some familiarity with the Outer Continental Shelf Act (67 Stat. 462, 43 U.S.C. Sec. 1331) which established a leasing system for minerals in the continental shelf beyond the areas ceded to the states by the Submerged Lands Act sometimes known as the Tidelands Act.

Section 10 of Public Law 88-606 (1964) charged the Public Land Law Review Commission with review and recommendation responsibility for "the disposition or restriction on disposition of the mineral resources in lands defined. . .as being under the control of the United States in the Outer Continental Shelf".

Thus it is clear that the Commission's dry land staff lawyers must get their feet wet in sea water and consider the complex field sometimes called the legal order of the oceans.

In addressing ourselves to the legal order applying to underseas mining we are attempting to find our way in what was almost entirely an uncharted wilderness before World War II. Fortunately, however, there are a few signposts which have been since erected because of the pioneering efforts of the oil industry. The immense values of underseas oil deposits have provided the necessary incentives for national governments to consider the problems inherent in bringing order and security to the exploitation of submarine mineral resources. Progress in resolving these problems is slow, but the stakes are so high both for industry and our nation that we cannot afford to make mistakes in law or policy that may well plague us for centuries to come.

The fact is that over two-thirds of the earth's surface is submerged, and over half is under 10,000 feet or more of water. As the world's population grows, we most certainly will devour at an increasing rate the minerals of the earth's land masses. In these circumstances it is readily seen that mankind may one day soon rely on submerged resources for a major part of life's mineral requirements.

Short-range policies in the international arena must be adopted with an eye on long-range needs as well, since what we do today as a nation will set a pattern for other nations to follow. And what we claim today as a nation we cannot deny to others tomorrow.

Perhaps the best example of the international effect of our national claims is the growth of the concept of the "outer continental shelf". By treaty in 1942 Venezuela and Great Britain each annexed one-half of the submarine area underlying the Gulf of Paria. Nevertheless, the primary impetus in formulating the concept came in 1945 when President Truman issued a proclamation declaring that the natural resources of the subsoil and seabed of the continental shelf contiguous to the United States were subject to the jurisdiction and control of this nation. By 1956 some twenty-five nations had claimed unilaterally varying degrees of exclusive rights to the exploitation of resources in submarine areas off their coasts. Within five years after President Truman's proclamation authoritative commentators were writing that customary international law included the principle that coastal nations have exclusive control over adjacent submarine areas.

International lawyers often speak of the exclusive and inclusive claims and interests of nations. At the risk of oversimplification let us define an exclusive claim as the asserted power of a nation to exclude other nations from use of or authority over

an area or specified activites. By the same token an inclusive claim is the assertion by a nation of the power to share with other nations equal use or authority over specified areas or activities.

Historically, the legal principles governing the vastnesses of the oceans have resulted from the interaction and conflict between the exclusive and inclusive claims of the nations of the earth. The great nations have recognized the oceans as common resources essential to commerce and communication. On the one hand, each has had vital interests in exclusive control over access to its coasts and natural resources of the adjacent sea upon which its people may be dependent. On the other hand, each has had so-called inclusive interests in free, nondiscriminatory use of and access to the oceans and their resources. Generally, the historic great powers have considered their interests in unrestricted access and use to outweigh their interests in excluding others from use and access, except where national security is endangered. Consequently, international law is generally said to favor and protect the principle of "freedom of the seas", and the recognized exceptions thereto have been relatively limited in scope, at least in times of peace.

For purposes of classifying the varying legal authority of coastal nations the seas have been divided into zones of control. Today these zones are classified as "internal waters", "territorial sea", "contiguous zones", and the "high seas". On the high seas a coastal nation can be said to have legal authority in time of peace only over vessels it registers and allows to fly its flag, with minor exceptions only, such as the right to suppress a pirate ship. As a ship approaches closer to a coastal nation that nation's authority increases until it reaches internal waters where the power of total exclusion is nearly absolute.

While these distinctions are important to underseas mining because of the necessity to use the oceans as highways and supply stations for mining operations, the principles involved are well-enough established so that industry can effectively measure those risks when contemplating investment. Today's uncertainties are primarily related to the use of the seabed and subsoil and the removal of the mineral resources themselves.

With respect to exploiting underseas mineral resources it is now clear that coastal nations have exclusive control over exploration and exploitation on the continental shelf, even when the area extends beyond their internal waters and their territorial seas. The principles inherent in this rule of international law were set forth in the Geneva Convention on the Continental Shelf, adopted by the United Nations Conference on the Law of the Sea, on April 29, 1958. I should add that at least thirty nations have ratified or acceded to this convention, including the United States, Soviet Russia and the United Kingdom, and it is now in effect.

I should make clear that the extent of the continental shelf over which coastal nations have exclusive sovereign control is not governed by geological criteria. Article I of the Continental Shelf Convention defines the shelf as extending beyond the territorial sea "to a depth of 200 metres or, beyond that limit, to where the depth of the superjacent waters admits of the exploitation of the natural resources of the said areas...."

Article II of the convention makes it equally plain that a coastal nation may exclude anyone from developing the resources of the shelf without its consent, and its legal rights to do so do not depend on occupation or proclamation. There are certain limiting provisions in the convention which should be noted:

(1) The legal status of the "superjacent waters as high seas, or that of the air space above those waters" is not affected. Article 3.

(2) The coastal nation may not impede the laying or maintenance of submarine cables or pipelines, except to the extent of "reasonable measures" for exploration and exploitation of the shelf resources. Article 4 .

(3) Exploration and development of shelf resources must not result in "any unjustifiable interference with navigation, fishing or the conservation of the living resources of the sea..." Article 5(1).

(4) Such activities must not result in "any interference with fundamental oceanographic or other scientific research carried out with the intention of open publication." Article 5(1). But the consent of the coastal nation must be obtained before undertaking such research. Article 5(8).

(5) While shelf installations and devices may be installed and 500-metre safety zones created around them, permanent means for warning of their presence must be maintained. Article 5(5). And they must not be established "where interference may be caused to the use of recognized sea lanes essential to international navigation." Article 5(6).

(6) The coastal nation is obligated to undertake in the safety zones "all appropriate measures for the protection of the living resources of the sea from harmful agents." Article 5(7).

Because of the tremendous investments involved industry must have assurance that certain interests will be protected in the event of successful mineral discovery.

The interests are essentially the same as those traditionally important in mineral operations. The differences are mainly in degree, but established legal methods are not necessarily adequate.

The Outer Continental Shelf Act makes specific provision for oil, gas and sulphur leases. That Act also authorizes the Secretary to grant leases on the basis of competitive bidding for the development of "any mineral", but the Act is silent as to the terms and conditions the Secretary may prescribe. (43 U.S.C. Sec. 1337). No detailed regulations have been issued by the Secretary to implement his authority. (43 C.F.R. Sec. 3382.1 et seq.) There can be little doubt that Congress had liquid resources in mind when the Outer Continental Shelf Act was enacted. Underseas mining operations for non-liquid minerals may present very different problems.

For example, mining operators undoubtedly need exclusive possession of mineral deposits to be worked, whether submerged or not. Ordinary police protection, however, would not be adequate in the case of submarine operations. Even the identification of predators might well prove impossible. To what extent will self-help be allowed in such situations? Even seemingly unlikely questions like this can prove very troublesome later. Fortunately, gatherings of experienced operating and professional people like this audience will stimulate solutions in advance of the problems, since our nation has the opportunity to legislate for submarine mining before technology has advanced to the point where submarine exploitation on a commercial scale is feasible.

Basic elements of a favorable legal climate must be developed before we can expect industry to undertake the risks of underseas mining.

The first of these basic elements, in my view, is certainty concerning what sovereign has the legal competence to authorize and regulate the mining of continental shelf minerals. As I indicated before, that seems clear enough, at least as long as operations are conducted at substantial distances from potential boundary claims of other coastal nations. In the absence of international agreement, or "special circumstances", Article 6 of the Convention on the Continental Shelf provides that shelf boundaries of coastal nations shall be determined as "equidistant from the nearest points of the baselines from which the breadth of the territorial sea" of each is measured. Of necessity this language incorporates the ambiguities of baseline determination under Articles 3 and 4 of the Convention on the Territorial Sea and the Contiguous Zone, a companion to the shelf convention now in effect among twenty-seven nations, including the United States. Suffice it to say for our purposes that anyone operating on the continental shelf in proximity to another nation does so at the risk of international complications unless a shelf boundary agreement

has been reached among the nations concerned.

Little will be done by industry to explore continental shelf areas unless assurance is given of the right to develop mineral resources discovered in the course of exploration. This is the second basic element of a favorable legal climate for underseas mining.

A third basic element is that industry must have sufficient tenure after discovery to provide an opportunity to recoup its investment with a reasonable opportunity for profit. This element necessarily implies the right to develop mineral reserves reasonably necessary for that purpose over time. Otherwise it is nonsense to talk about industry participation in shelf development. Because of the international obligations of the United States I mentioned previously, there are obviously serious questions connected with any suggestion that fee simple rights be conferred like those under our public land mining laws. On the other hand, millions of dollars have been invested by the oil industry on the continental shelf on the strength of leasehold estates. The real key must be certainty of rights and certainty of obligations, whether by lease or otherwise.

A fourth basic legal element, which has an economic root, is that payments for the right to exploit continental shelf minerals must be readily measurable and reasonably related to the risks and investment required in underseas mining. If the payment is indefinite or exorbitant in relation to these factors, industry can be expected to direct its efforts to more orthodox and less hazardous enterprises.

A fifth basic legal element is reasonable certainty with respect to industry's detailed responsibility to operate in conformity with the international obligations of the United States. For example, it is apparent from the pertinent conventions that the United States must not allow pollution of ocean water so as to endanger the living resources of the sea. Another typical question is whether an industrial operator must pay for the relocation of a submarine cable where that relocation is reasonably necessary or convenient for the purposes of mineral exploration. Also, what assurance will the operator be given that the government will require such relocation if necessary to the mineral operation. The Continental Shelf Convention prohibits "unjustifiable" interference with navigation, fishing and conservation of living resources of the sea. But what are the justifiable interferences that our government will allow? All this must be spelled out in arrangements between the government and industry, or industry participation may well prove to be only a pious hope.

A sixth element is that industry must have assurance of reasonable rights to the contiuous use of ports, the territorial sea and internal waters. If operations can be shut down for national defense reasons, for example, for how long and under what conditions can this be done?

A seventh element is that industry should have certainty concerning the applicability of our domestic laws. For example, to what extent will our maritime labor laws apply to underseas mining operations. To what extent will the laws of adjoining states be applicable to continental shelf mining. The utter dependence of underseas mining operations on port bases and water-borne supply calls for clear answers to these jurisdictional questions.

My catalog of basic legal elements of a legal climate that will encourage industry to enter into underseas mining is by no means comprehensive. But those I have mentioned are certain to enter into the business decisions involved in pioneering the way for maximum private development of our continental shelf resources.

As an individual privileged to serve on the staff of the Public Land Law Review Commission, I know that consideration will be given in our studies to the views and interests of all groups interested in the mineral and living resources of the continental shelf. Your suggestions for our studies will be most welcome and you are invited to contribute pertinent data and recommendations as well.

SOME ASPECTS OF WAVE FORECASTING ON THE PACIFIC COAST

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Abstract

The discussion is confined to wave forecasting on the Pacific Coast of the United States. Because of the large number of weather patterns that can exist over the Pacific Ocean, it follows that a given forecast site may be vulnerable to waves of many differing origins, several of which can occur simultaneously. Major weather patterns providing waves on the Pacific Coast and typical resulting waves are described. Major difficulties in providing reliable forecasts and requirements for improvement are outlined.

I. INTRODUCTION

To all who work in the marine environment, the value and utility of an accurate wave forecast is obvious. More often than not, the difference between success and failure is a knowledge of the sea and weather conditions which are likely to be faced during a given operation. Yet, in spite of its importance, wave prediction technology remained at a veritable standstill until the era of World War II when the importance of low wave conditions to successful amphibious landing operations was painfully realized.

Historically, wave prediction technology was placed on a reasonably firm footing by the pioneer work of Sverdrup in the U.S.(1942), and Suthons England (1945), who combined physical theory with available empirical data to provide working, fairly reliable, forecasts for military landings in the African, European, and Pacific World War II war theatres. These early efforts were followed by several revisions on the basic theme in the late 1940's and it was not until the early 1950's, more-or-less, that radically new and improved theories and techniques were proposed and developed by Longuet-Higgins, Cartwright, Pierson, Neumann, Darbyshire and other workers in the field. These latter theories now are well developed and form the basis for modern wave forecasting procedures.

It is clear, of course, that regardless of how refined or precise the wave forecast theory is, the fundamental requirement for a reliable wave forecast is an accurate weather forecast, since it is the winds themselves which produce the waves. In fact, once the weather forecast is made, the task of making the wave forecast is somewhat rote. The real problem, then, is to predict the space-time wind field. As will be discussed later, a good meteorological input is reasonably easy to provide where the data density is high, as is the case for the Atlantic and Gulf of Mexico areas. Conversely, where the data density is very low, as for the Pacific area, the task of predicting weather patterns often requires that the forecaster be scientist, swami, and gambler.

Aside from the military, non-military users of wave forecasting information are many. Reliable forecasts are invaluable to the offshore oil industry in everyday operations, as they are to harbor operations, dredging operations, fishing operations, shoreline development, marine construction, ship traffic, and recreational activities. In view of the pronounced trend towards the sea that is taking place throughout the country, it seems reasonable to expect that wave forecasting will find many more uses and demands in the future.

The purpose of the following presentation is to describe certain basic aspects of wave forecasting on the Pacific Coast of the United States and Canada. The discussion briefly outlines those meteorological conditions which are the important wave producers for the subject area, describes characteristics of these waves and their effects on various offshore operations, and finally, dwells upon some of the outstanding difficulties involved in providing wave and weather forecasts on the Pacific Coast. The art of making forecasts and the various theories involved therein are not discussed in this presentation, since they in themselves constitute lengthy treatises. Suffice it to state here that forecasting techniques used by most forecasters are composites of the more important theories, modified on the basis of field experience.

II. GENERAL WEATHER AND WAVE CLIMATOLOGY

In this section of the paper, a brief discussion of the major weather patterns which produce important waves is presented.

The mean atmospheric pressure and mean wind direction in the Eastern Pacific during January (winter) and July (summer) are presented in Figure 1. The position and intensity of the Pacific high pressure cell is of utmost importance in terms of storm activity on the Pacific Coast. This warm, subtropical high has a mean position a few hundred miles west of Southern California during January. Similarly the large relatively uniform mass of cold air which overlies the north polar area spreads southward during the winter. The southern most boundary of this polar air is termed the polar front. Along this front, extratropical cyclones or low pressure areas form and intensify as a result of the interaction between the cold polar air to the north and warm tropical air to the south. These extratropical cyclones represent by far the most important source of waves reaching the west coast during the winter, when, on frequent occasions, these storm systems move onshore between Northern California and British Columbia. Sometimes, particularly when cyclogenesis occurs in the far Eastern Pacific, these storms move as far south as Southern California.

In summer, the Pacific high shifts far to the northwest and intensifies markedly, and the storm track then shifts far to the north. Consequently, only relatively few storms move southward as far as Washington and Oregon. During this time of the year, the Pacific high becomes the dominant wave generator. Variations in size, intensity and position of this high pressure area can mean the difference between extremely high northwest seas or nearly calm conditions.

The problems for the forecaster in predicting the behavior of this high can be much more difficult, at times, than problems

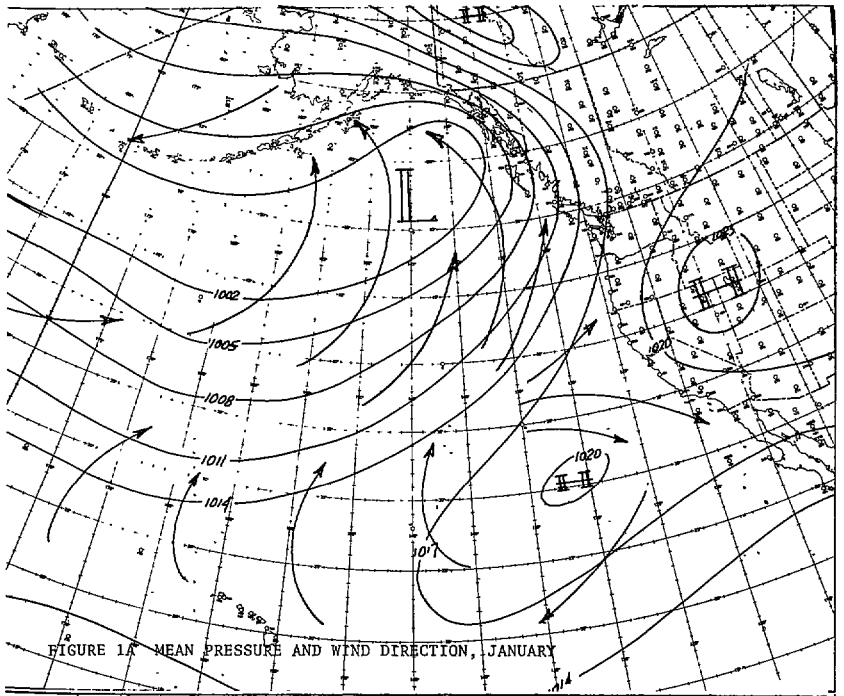


FIGURE 1A MEAN PRESSURE AND WIND DIRECTION, JANUARY

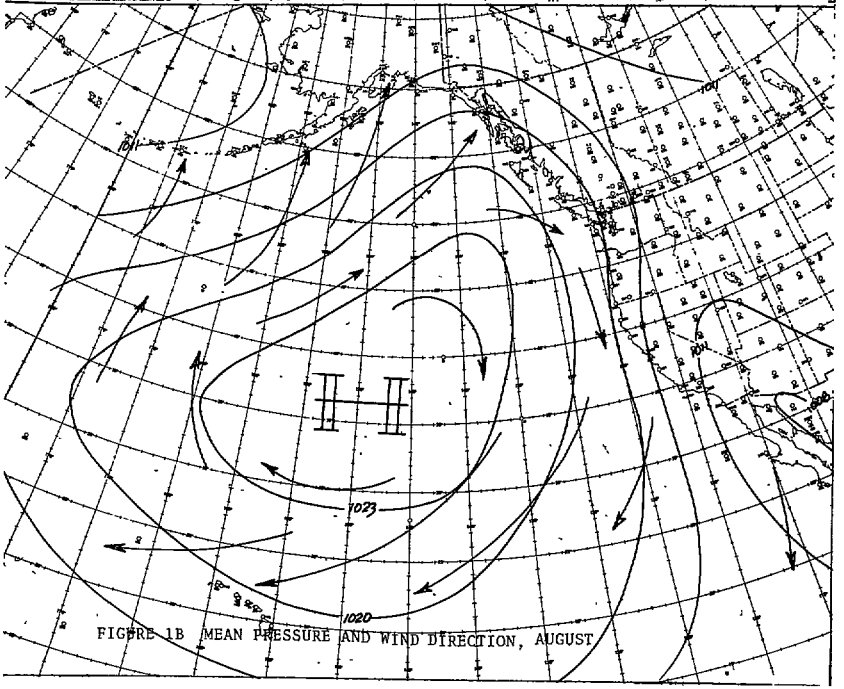


FIGURE 1B MEAN PRESSURE AND WIND DIRECTION, AUGUST

associated with the prediction of the extratropical cyclones and winter storms.

Speaking of the wave climate in broad scale terms, very gradual changes in wave characteristics occur in going southward along the U. S. Coast; the mean swell direction, for example, shifts from west-southwest off Northern Washington to west off Oregon, and to northwest off Central California; the frequency of high southerly seas generated by winter storms decreases southward, and the frequency of high northwest seas in the summer increases southward to about San Francisco. However, a very marked discontinuity in wave climate occurs along the California coast south of Point Conception (located at 34.5°North, 120.5°West). The area immediately north of Point Conception is, with local exceptions, fully exposed to swells generated by the Pacific storms and which approach the coast from directions between southwest and northwest. At Point Conception however, the coastline cuts sharply eastward, affording protection against swells arriving from angles of greater than 285°. Further protection, particularly for the area southward from Los Angeles, is provided by the Santa Barbara Islands.

The wave situation often is reversed during the summer when southerly swells of moderate height hit the coast of Southern California. In most cases, these swells are generated by tropical storms originating off the coast of Central America and traveling northwestward off the Mexican Coast. Swells from these storms approach Southern California at angles of 160° to 180° and therefore have little effect on the coast north of Point Conception.

III. SPECIFIC WAVE PRODUCING SITUATIONS

The most important weather patterns with respect to the generation of high waves along the West Coast of the United States are discussed in the following paragraphs.

A. EXTRATROPICAL CYCLONE

1. Cyclogenesis near the Coast:

Very often, the most severe winter storms intensify rapidly in the immediate vicinity of the coast. This undoubtedly is the most serious problem the wave forecaster must face. He must be able to predict the intensity and movement of the storm. A mistake of only a few millibars in pressure, or a slight error in wind velocity may prove disastrous to the client, for very high seas develop in a relatively short period of time. Fifty knot winds, for example will produce 25 to 30 foot seas in only a nine hour duration.

A typical example of such a problematic weather pattern occurred last December. Referring to Figure 2, on December 26 at 0400 Pacific Standard Time a weakening low pressure center was located off the Washington coast. Winds in the vicinity of the Columbia River entrance were south 10 to 20 knots, and the swells were 8 to 10 feet from the west. A second weak low with a trailing polar front was located about 700 miles southwest of the first low. The position and strength of the high

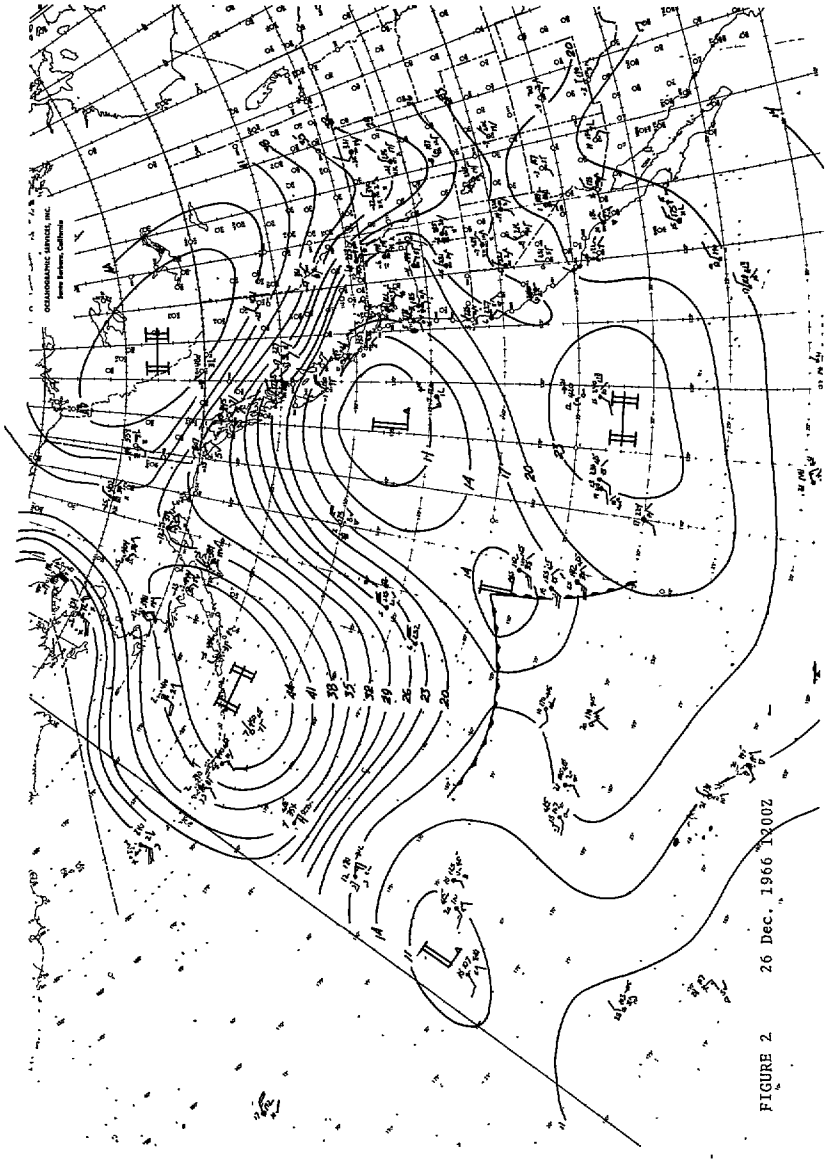


FIGURE 2 26 Dec. 1966 1200Z

over the Aleutians feeding very cold air southward indicated the possibility of a rapid intensification of this low. By late afternoon of the 26th, the low had moved east-northeast about 600 miles and the winds along the coast were beginning to increase. The map of 0400 Pacific Standard Time 27 December is shown in Figure 3. The low at this time is just off the Northern Oregon coast, having moved east-northeast at a speed of over 40 knots and having intensified 25 millibars in 24 hours. Maximum winds occurred about three hours later with southerly winds off the Columbia River reported as gusting to 120 miles per hour. Wave heights exceeding 50 feet were observed for many hours.

Owing to the very rapid movement of this particular storm, the winds in the cold air behind the front have not blown over a single stretch of ocean (fetch) long enough to generate significantly high waves. The forecast problem in this case is one of predicting the wind field (i.e., velocity, fetch, duration) preceding the front at the forecast site--in this case off the Oregon coast.

2. Cyclogenesis in mid-Pacific:

Another type of storm which presents a completely different problem for the Pacific Coast forecaster is illustrated in Figure 4. Here, a series of very intense storms has been developing north of the Hawaiian Islands and moving northeastward to the Gulf of Alaska. Two deep lows already are present with a third low just beginning to intensify near 25°North, 170°West. For a forecast point off Vancouver Island, the forecaster must consider three main wave generating areas: (a) SSE wind area preceding the occluded front off Vancouver Island; (b) SSW wind area behind this front; (c) SW wind area behind the warm front (near 145°West), which is predicted to move northeastward. Another most important factor to consider is the increasing southeast wind field preceding the latter front. Clearly, the resulting sea state is very complex, with wave directions ranging from southeast to southwest, periods ranging from 6 to 16 seconds, and heights from 25-40 feet.

The highest breakers along the Southern California coast are produced by storms of this type. Here, waves generated in the strong westerly wind fetch north of the Hawaiian Islands, travel eastward, reaching the coast in two to three days. Swells in deep water just off the coast normally range from 8 to 12 feet in height. Owing to the great decay distance, the period of these waves is quite long (14 to 16 seconds) whence shoaling factors are correspondingly high, and breakers of 15 feet or more occur at many Southern California locations. About once every two years this swell condition occurs simultaneously with exceptionally high astronomical tides; when this happens, considerable damage occurs to shoreline structures which have been built without due regard to the oceanographic environment (Figure 5).

One of the more severe storms on record, with respect to high westerly swells off Northern and Central California,

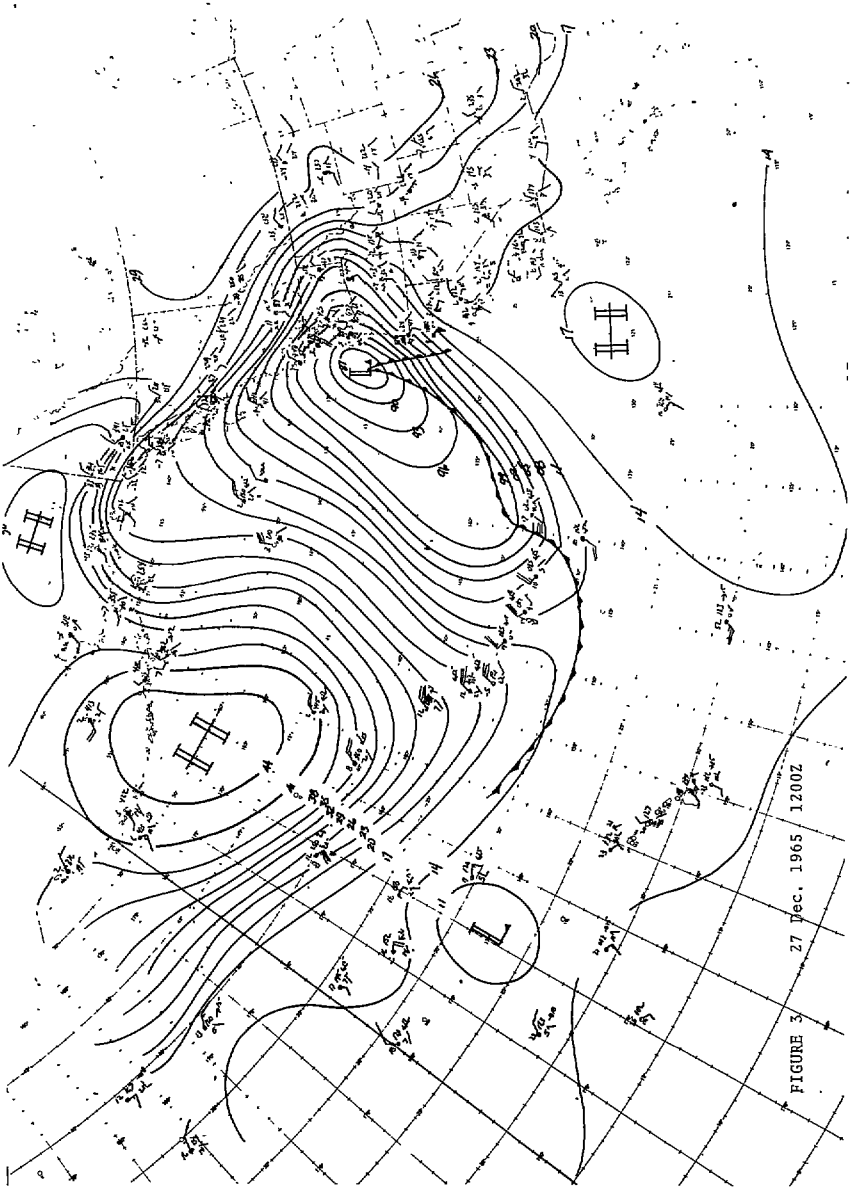


FIGURE 3 27 Dec. 1965 1200Z

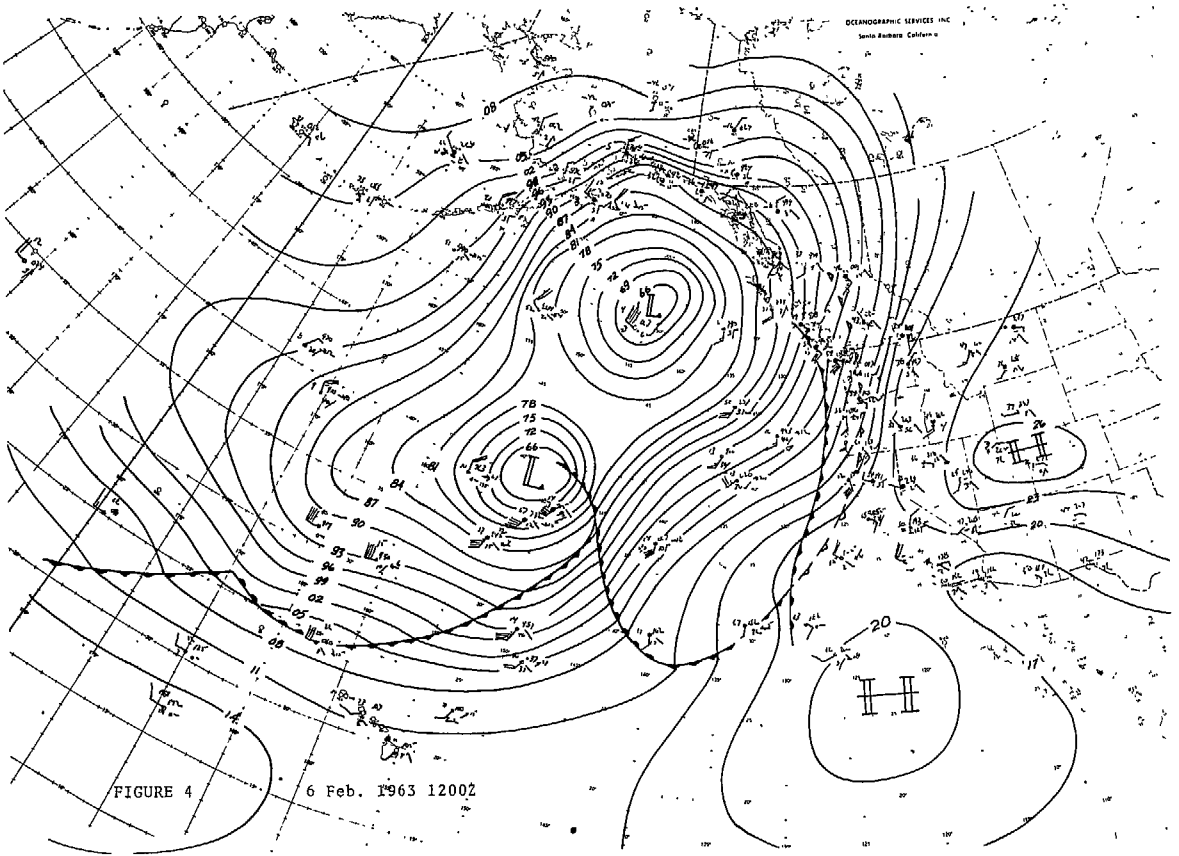


FIGURE 4 6 Feb. 1963 1200Z

FIGURE 5 STORM WAVES AT REDONDO BEACH
FEBRUARY 23, 1949

occurred during February 1960. This storm began to intensify north of the Hawaiian Islands on February 6, and is shown in Figure 6 at 1600 Pacific Standard Time February 8, the day preceding the highest waves. Note the exceptionally strong westerly wind fetch area between 125°West and 140°West. Normally, such intense storms as this will move into the Gulf of Alaska with the strong westerly winds remaining well off the coast. In this case, however, the westerly fetch area moved directly onto the California coast. The Coast Guard Cutter, U.S.S.Taney is shown in Figure 7, a few miles west of the Golden Gate on February 9. The 16-foot freeboard of this ship would indicate the hindcast significant wave height of 33 feet to be relatively accurate. These extreme wave conditions lasted for more than 24 hours. Again the necessity of an accurate weather forecast is evident, for had this storm moved to the northeast and remained 500 miles offshore, as is often the case, the wave heights along the coast would have been 15 feet.

B. PACIFIC ANTICYCLONE

Under certain conditions, very high seas are generated by strong north to northwest winds which develop on the east side of the Pacific high. This event is particularly common off California during spring and summer.

Because the dominant wave direction is very nearly parallel to the coast, however, severe waves, with local exceptions, occur only in deep water. There are two weather patterns which are of great importance in this regard: (1) Nevada Low; (2) California Thermal Trough.

(1) Nevada Low:

Frequently, particularly during spring, large cold air masses aloft move from Western Canada and Alaska south eastward into Utah, Nevada, and Arizona. Cyclogenesis occurs on the surface, with deep low pressure areas usually forming in the area of Southern Nevada. In coordination with the Pacific high which is located but a few hundred miles offshore, this low produces a very tight pressure gradient along the California coast. Winds are further intensified as the core of maximum winds in the jet stream moves south eastward around the low.

(2) California Thermal Trough:

During the summer, with intense heating occurring over the Mojave Desert and San Joaquin Valley of California, a thermal low pressure area develops which, depending upon its intensity, may extend northward from Southern to Northern California and sometimes into Oregon and Washington. The interplay between this trough and the Pacific high is of utmost importance in the forecasting of northwest waves. Frequently, for example, troughs in the upper air flow will move into California, and the sum effect is to shift the thermal trough eastward, producing very strong northwest winds (up to 60-70 miles per hour in spots) in the Point Conception area. Then,

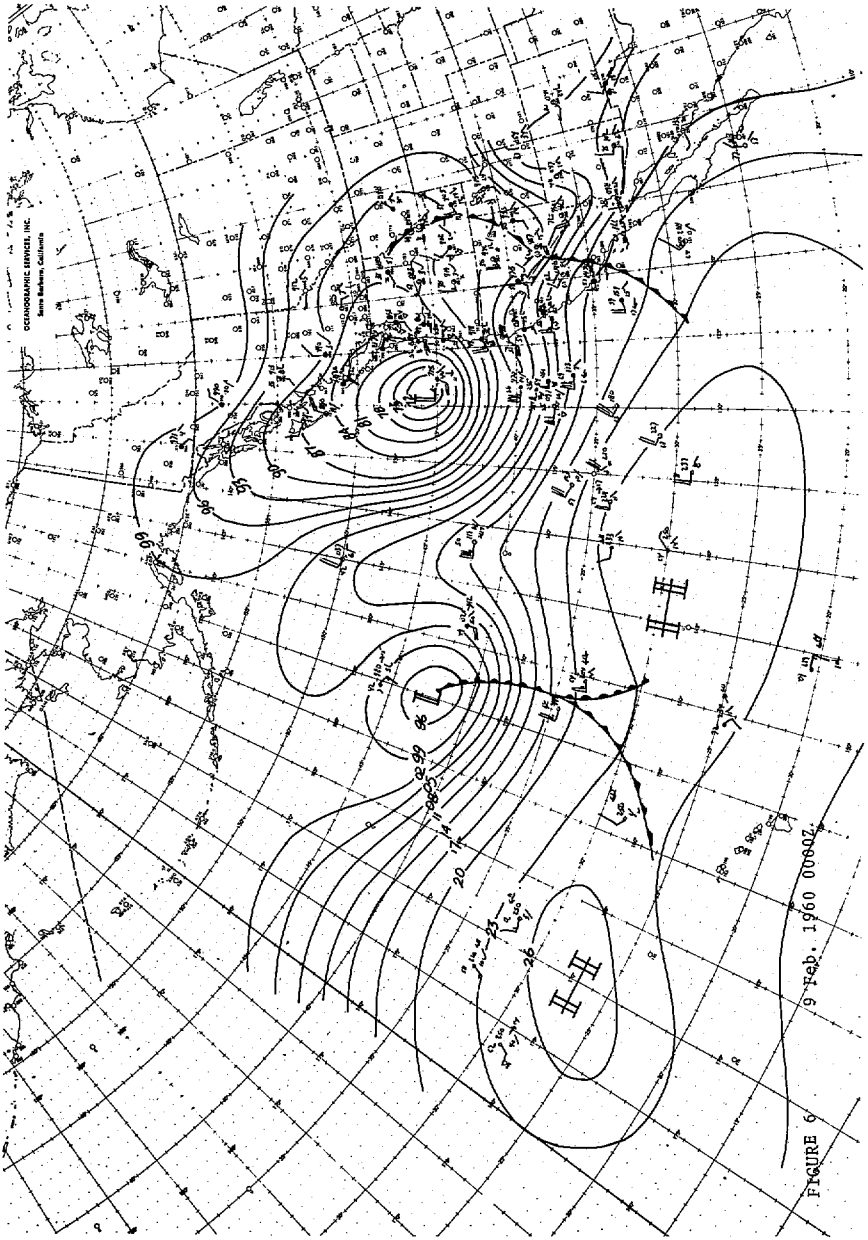

OCEANOGRAPHIC SERVICES, INC.
Santa Barbara, California
9 Feb. 1960 0000Z

FIGURE 6

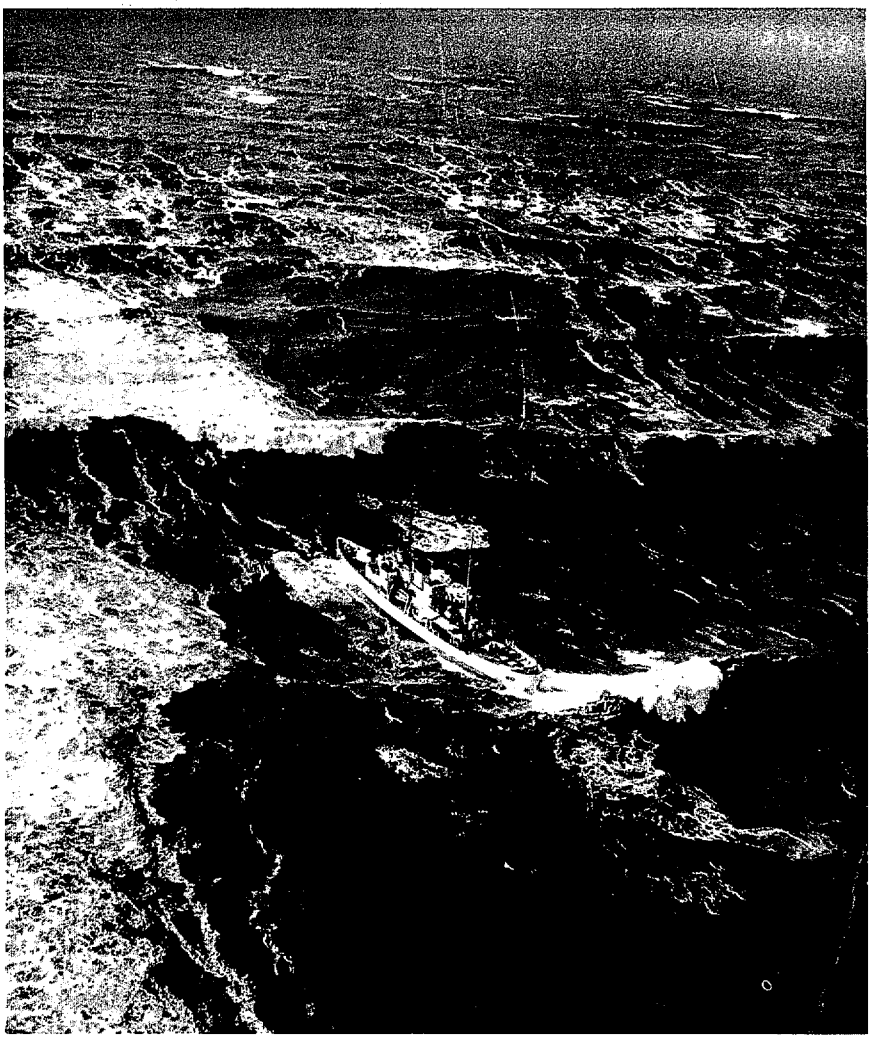


Figure 7

STORM WAVES OFF SAN FRANCISCO, Feb. 1960 (H_s= 33 ft)

as the thermal trough re-develops in the San Joaquin Valley, the strong northwest wind-field gradually shifts northward. An example of strong winds off the San Francisco Bay area shifting to Northern California is shown in Figure 8. Winds reported by a client located off Bodega Bay, latitude 38.25°North on the afternoon of September 20, 1964, were northwest 50 to 60 with gusts to 83 miles per hour. Seas were reported to be 22 to 32 feet. The following day, winds were down to northwest 10 to 20 miles per hour and the seas 10 to 12 feet. Although winds and seas of this magnitude do not occur often under thermal trough conditions, winds of 40 to 50 miles per hour and seas of 15 to 20 feet are quite frequent (several per year). This is a good example of the type of forecast which exists so often: a very subtle, difficult to detect change in the weather pattern, will result in vast differences in wave and wind predictions.

C. TROPICAL STORM WAVES IN SOUTHERN CALIFORNIA

From May to October, Southern California often experiences swells arriving from a bearing between south-southeast and south-southwest. These waves appear to have two sources: (1) Extratropical cyclones of the Southern Hemisphere; (2) Tropical cyclones moving along the west coast of Central America. Swells from the former are characterized by very low heights (usually less than 2 feet high in deep water) and long periods (16-20 seconds). Waves from tropical cyclones, however, though normally having a decay distance of 700 to 1200 miles, sometimes reach heights of 5 to 10 feet in deep water off Southern California. Periods range from 10 to 15 seconds. In recent years tropical storm waves occurred about 4 to 5 times per season.

Available records indicate that only three of these storms actually reached Southern California between 1895 and 1965. One of these, the hurricane of September 24/25, 1939, was of sufficient intensity to cause severe damage and considerable loss of life. This is, in fact, the most severe storm on which records are available for this area and has therefore been the subject of several investigations to determine design criteria for offshore structures. Due mostly to lack of offshore wind data, there is great divergence of opinion as to the actual wave height. However a significant height of 20 to 25 feet and period of 9 to 11 seconds appears reasonable (deep water).

This storm struck suddenly without warning, a situation which is not likely to recur, for satellite pictures now are of invaluable assistance in detecting these storms, and reconnaissance aircraft are dispatched once the storm is deemed a threat to the U. S. mainland.

D. LOCAL SEA AND SWELL CONDITIONS

A knowledge of local conditions, both with respect to weather and offshore topography is of extreme importance in wave forecasting. The Santa Barbara Channel, partially due to the east-west orientation of the coastline is an interesting study area of unusual local conditions. Three examples follow: two pertaining to local weather patterns, and one to offshore topography.

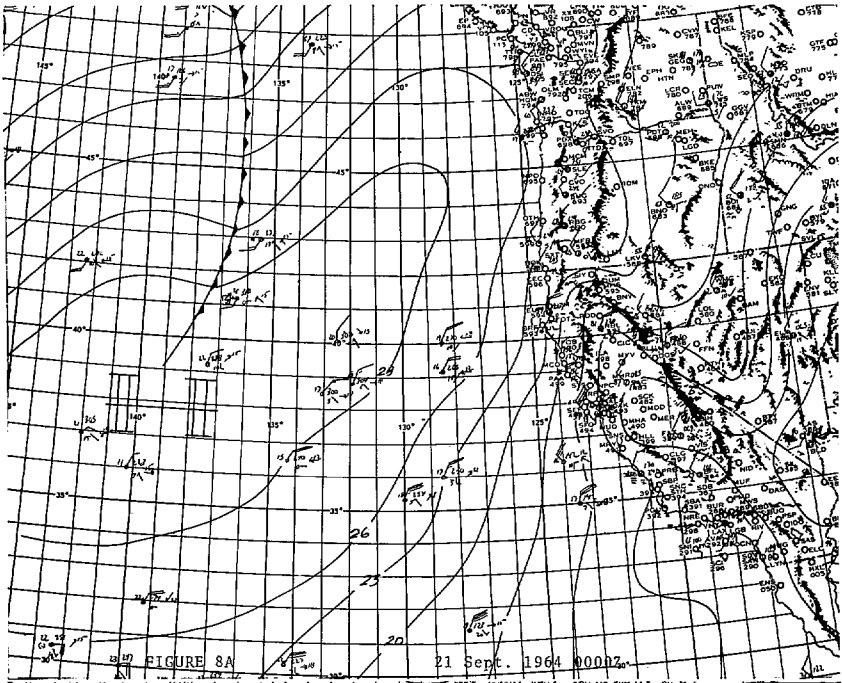


FIGURE 8A 21 Sept. 1964 0000Z

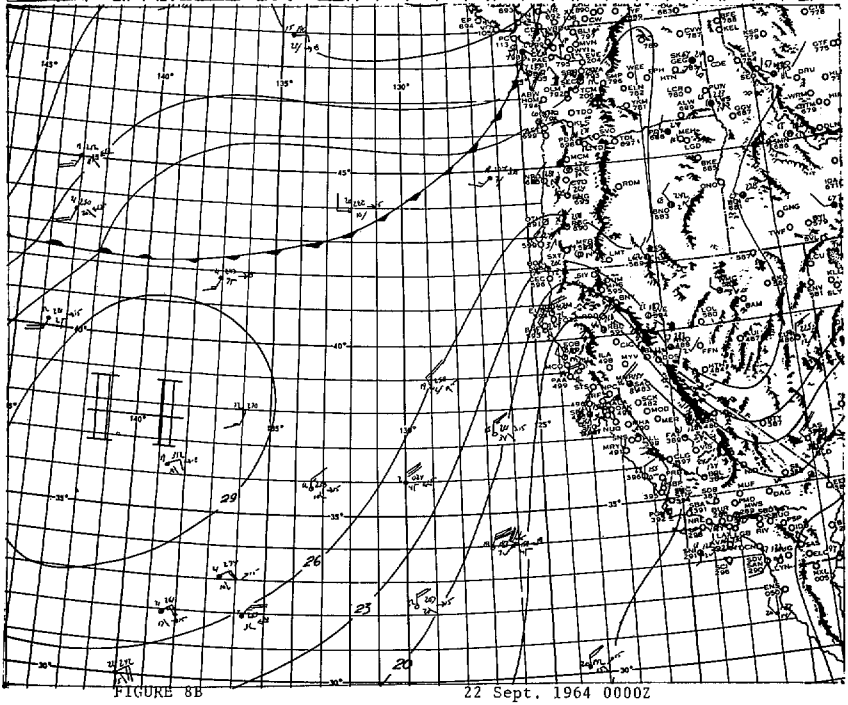


FIGURE 8B 22 Sept. 1964 0000Z

1. Northwest Winds off Point Conception:

Wave trains in a generating area exhibit a complex pattern of short-crested waves which contain components of considerable height traveling not only in the wind direction but also in directions at variance with the wind. When wave trains under a generating wind are interrupted by islands or headlands, as in this case, the variable direction of wave travel with respect to the generating wind becomes of prime importance. Consequently, the Santa Barbara coastline, though sheltered from northwest swell (being more unidirectional in nature), is exposed to northwest seas generated off Point Conception. Strong northwesterly winds in this area are common, and result from several different weather situations, the Nevada Low being one. Another example of a very local problem occurs under certain conditions when an upper trough is located just off the coast, rather than inland. In such cases, winds aloft blow from the southwest at heights above 5000 feet and blow from the northwest below 5000 feet. The relevant surface map shows high pressure offshore, with the usual eddy low circulation east of San Nicolas Island. Thickness differences for the 1000-850 millibar levels between Vandenburg Air Force Base and San Nicolas Island are 100 feet or more, with the shallower, dense layer lying to the north. As an example, a meso-scale surface analysis for 0700 Pacific Standard Time, August 21, 1961 is shown in Figure 9. For this situation, wind gusts up to 60 miles per hour were reported below the coastal canyons just east of Point Conception along with 8 to 10 foot swells in the lower channel. However, winds in the Santa Barbara area, just 30 miles to the east blew from the southeast to southwest at only 5 to 10 miles per hour. Winds and seas decreased rapidly once the upper trough moved inland.

2. Santa Ana Condition:

During the winter, strong high pressure areas frequently move southward from Canada into the Great Basin. Very cold air then spills to lower elevations, warming adiabatically and producing exceptionally strong northeasterly winds below the major coastal canyons of Southern California. The Santa Clara River Valley is particularly susceptible to such conditions, with northeast winds gusting to as much as 80 miles per hour upon entering the Santa Barbara Channel near Ventura. Because of angular dispersion in the wind and wave field, east-southeast waves then move up the channel and sometimes are as much as 8 to 10 feet in height in the Point Conception area. An example of this weather pattern is shown in Figure 10.

3. Wave Refraction at Ventura Harbor:

When a wave travels from deep into shallow water, a change in its height, length, and direction of travel occurs, because of bottom topography. A long-crested wave approaching a given shoreline at an angle is bent, or refracted, from its original direction because the inshore portion of the wave "feels" bottom first and travels at a lesser speed

FIGURE 9 21 Aug. 1961 1500Z

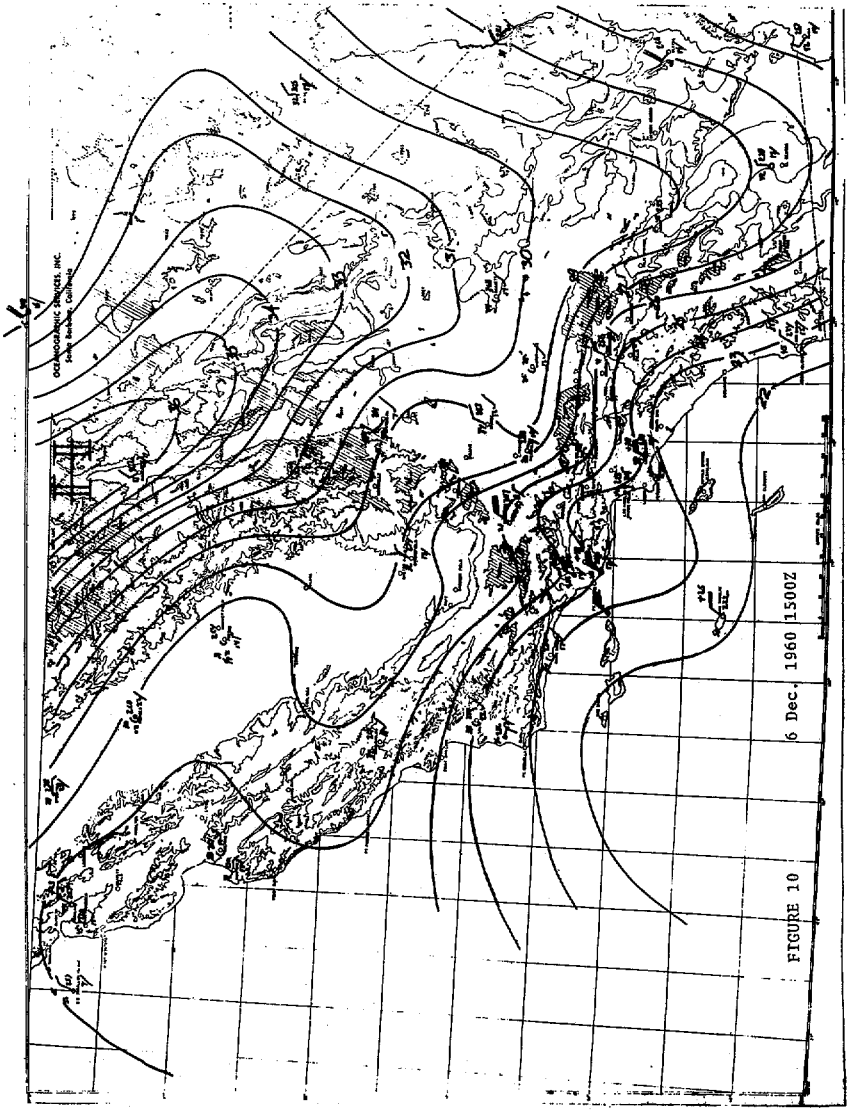


FIGURE 10

than does the deep water portion; this differential effect causes the wave crest to re-orient and become parallel (more or less) to the bottom contours. In the case of a submarine ridge, waves bend inward on either side of the ridge thus causing a focusing effect of wave energy; the opposite holds for a submarine canyon.

Such a submarine ridge exists immediately west of the Ventura Marina, in the middle of the Santa Barbara Channel coast. Here, waves approaching from the west to west-northwest, having periods of 12 seconds or more, converge in the immediate vicinity of the harbor entrance. On frequent occasions high breaking waves cover the entire entrance (many yachtsmen have been known to take up surfing), yet 1000 feet on either side, the waves are low.

IV. MAJOR PROBLEMS FACING THE PACIFIC COAST WAVE FORECASTER

Clearly, the ability to produce a good wave forecast is an art; it is based on technical skill and experience, but above all upon a reliable meteorological input and an ability to communicate with the user. This latter aspect is of paramount importance, meaning both message transmission in the usual context and content transmission in the sense of providing data for a given marine operation in a language that is clearly understood by the user. Thus, not only must the message be received by the client physically, but even more, it must be presented and interpreted correctly.

In general, communication problems are common to all forecasters, irrespective of location. That is, problems associated with phone systems, radio links, telegrams, etc. differ little between the Pacific, Atlantic, and Gulf Coasts of the United States. On the other hand, methods of presenting and interpreting wave forecasts are very closely related to the complexity of the wave climate; the more complex the wave climate, the more difficult the communication or interpretation. In this respect, the Pacific Coast forecast is unusually complicated, primarily due to the fact that at any given time, waves existing at a given location often are a composite of several wave trains--each with a distinctive direction, height and frequency spectrum. Specifically, it is not uncommon for three to five distinct effective wave generation areas to exist simultaneously in the eastern North Pacific. The interaction of these varied inputs on a given marine operation is not always obvious, let alone possible to forecast. Thus, adding several sets of wave energies and specifying the correct resultant for a moored drilling vessel that is highly sensitive to wave impulses from more than one direction, is not a simple matter. The problems in terms of resonance are obvious. Here, the forecaster must know each vessel's characteristics so that he can emphasize those wave conditions of main importance. In view of the large spectral ranges possible in the Pacific, the forecaster has a constant "filtering" task to perform.

Many marine operations are sensitive to multi-direction effects and many are not; many operations are endangered only when wave heights are very large and of sustained duration. Many shallow water operations such as inshore coring, and drilling, dredging, shoreline construction and small craft launching become susceptible to waves of relatively low deep water height and which in actuality were generated by large "off the map"

storms located several thousand miles away from the Pacific Coast, including the South Pacific Ocean, because of their shoaling enhancement. This is not to say that Pacific Coast wave conditions are mild; on the contrary, winter storms producing 30 to 40 foot high waves are as common off the Oregon-Washington coasts as are winter snow storms in the Midwest.

Above all, however, the fundamental problem facing the Pacific Coast wave forecaster is that of obtaining an adequate meteorological input upon which to make a wave forecast. In this respect the Pacific Ocean is a veritable Siberia in data coverage as compared with the North Atlantic and the Gulf of Mexico. When one compares the basic meteorological data input available for making forecasts in the three U. S. Coasts, he finds that the data density of the Pacific weather control regions normally is about one percent of the densities of the Atlantic and Gulf control regions. When severe storm conditions arise in the Gulf or the Atlantic, numerous special aircraft flights into the storm are made, and extra ship observations are procured as a matter of course; in the Pacific, on the other hand, if anything, ships and aircraft bypass severe storms or cyclogenesis areas, thus actually diminishing data density in time of need to the Pacific Coastal areas. In short, when the need for meteorological data is at its greatest, the data density in the Pacific goes from the ridiculous to the absurd.

As an illustration of the data density problem, Figures 2 and 3 show the weather pattern and data coverage for the "not-unusual" storm of December, 1965. As can be seen only four ship reports were available in an area outlining the storm between 34°North and 55°North and from the coast to 150°West. Of these four reports, one had its position incorrectly coded. Clearly, the task of accurately predicting the wave conditions produced on the Oregon-Washington coastal areas, by this storm, was, to say the least, most difficult.

The reasons for data density differences of the Pacific, Atlantic and Gulf regions are clear and logical. That is, the heavy meteorological station density in the weather control regions of the Atlantic and Gulf are consequences of natural storm tracks, population distribution, and ship traffic.

Under any circumstances, the task of providing truly accurate wave forecasts for locations along the Pacific Coast is made very difficult if not impossible by the lack of a reliable meteorological input. There is no simple cure to this problem since it is not likely that ship routes and seamanship practices will change materially in the next few decades, or that the density of ship traffic will increase very much. Probably the most reasonable solution to the data density problem involves the installation of weather buoys at the rate of one buoy per, say, five degree square throughout the Eastern Pacific. This is a task which will be both extremely expensive and difficult to conduct, and which, though justifiable, is not likely to be funded for some time to come. Satellite weather pick-up while interesting, is not likely to improve the picture for detailed forecasting.

DRILLING IN THE SEA FROM FLOATING PLATFORMS

By
N. E. Montgomery

Abstract

Credit for much of the early development of floating drilling goes back to the CUSS Group. This Group. composed of members of Continental, Union, Shell and Superior Oil Companies, was formed to study the application of offshore drilling for the West Coast. Using a converted Navy ship the Group in 1953 drilled several experimental wells while moored in sheltered waters. Since that time, many wells have been drilled throughout the world from floating rigs of various designs.

In 1962, Shell Oil Company drilled the first well from a floating platform with the well head and equipment location on the ocean floor in more than 250 feet of water. In 1964, Shell drilled in 574 feet of water off the West Coast using a floating semi-submersible rig.

This paper will describe in general the steps followed in drilling a well from a floating rig beginning with the moving on a location through the abandonment. Brief discussions are offered on the selection and application of the equipment necessary for drilling as well as the problem of stability, maintaining the rig on location and the requirements for specially trained personnel. Weather is perhaps the single most important factor opposing the success of floating drilling. Its effect on the operations conducted on the West Coast will be discussed.

It is concluded that the floating platform has been successfully employed as an effective means for the exploring of oil and gas in deep water throughout the world.

DEVELOPMENT OF FLOATING PLATFORM

The search for oil has lead man from the hills and plains, into the marshlands toward the sea and finally into the open waters throughout the world. Why this quest for oil in water depths too deep for divers and where such things as submarines and robots may become a standard member of the drilling crew? The answer is simple. The sea holds the greatest attraction to the oil man for continuing the search for oil. It is estimated that more than 70% of the earth's surface is covered by water, but that 90% of the world's oil supply presently comes from the land.

In the early 1930s marine drilling was born when the oil derricks and drilling equipment were added to barges and floated into the bayous and marshlands of Louisiana and Texas. Once on location in about 6 feet of water the barges were sunk to set on bottom and drilling proceeded. It was not until 1938 that the first producing well was drilled in the waters off the Louisiana coast. Since that time many offshore leases have been drilled both in state and federal waters, in the Gulf of Mexico and off the Pacific Coast as well as in many other parts of the world. Rigs used to drill these leases have varied in design and increased in size. Today it is estimated that more than 125 mobile and floating rigs are operating in waters throughout the world as well as some 90 tenders and platform rigs.

In 1948 a four party group of oil companies was formed in California to conduct offshore exploration including the study of offshore drilling techniques. The combine, called the CUSS group, was composed of the Continental, Union, Superior and Shell oil companies. This group, as well as other operators, had actively engaged in recovering core sampled from the ocean floor by means of jet and drop dart sampling devices. In 1953 the first conventional rotary drilling rig was mounted on a small ship called the "Submarex" and floating drilling was born.

The Submarex, shown in Figure 1, was a 173 foot long x 23 foot beam former navy patrol boat which was converted for use as a drilling ship, with its mast mounted over the side. The next four years, from 1953 to 1957 saw several floating rigs in service both in the waters off Southern California and in the Gulf. Most of these rigs were either converted barges, tankers or former navy landing crafts. In 1956 the CUSS group built the CUSS I. This vessel, a converted YFNB barge, was 260 feet long and 48 feet across the beam. A 98 foot derrick was mounted in the center of the ship and drilling was conducted through an opening extending through the hull which somehow became known as the "moon-pool". This arrangement gave greater stability than the rigs with the derricks mounted "over-the-side".

In 1961 the CUSS I was selected to drill the first test holes for the Mohole Project sponsored by the National Science Foundation. The rig was outfitted with four - 250 H.P. "Harbormaster" outboard motors for positioning and successfully cored in 11,672 feet of water off the coast of Guadalupe Island. This is the deepest water to date that any rig has operated in, however, wellhead equipment was not used and the system lacked the capability of re-entering the well once the drill string was pulled. The rig also holds the record for having drilled in waters of 632 feet, the deepest yet while using conventional wellhead equipment located on the ocean floor.

During the years from 1955 to 1960, oil and equipment companies were busy developing techniques and equipment for drilling and completing wells in water depths of up to 1000 feet. In 1960 Shell completed perhaps the first oil well in the world with all the well control equipment, wellhead and christmas tree placed on the sea floor without the use of divers.

Concurrent with equipment and technique development, investigations were conducted to determine the best design for a floating drilling vessel. It was concluded that while the ship-shape hull rigs were quite stable in protected waters, on areas wherein the direction of the seas was fixed, more or less, they would be less effective in waters wherein direction of seas shifted rapidly such as the open seas of the Pacific and the Gulf. After much investigation and model testing, the use of a semi-submersible rig was decided upon. Such a design appeared to offer the lease average resistance to wind, wave and current as these forces rotated about the rig. A number of these rigs, like the Bluewater No. 1, (Figure 2) were already in operation in the Gulf, where they were being used to drill while sitting on bottom in water depths of up to 90 feet. The merits of modifying one of the existing mobile rigs were considered and weighed against the cost and time delay of constructing a floating rig of a Shell design. It was decided to convert the Blue Water No. 1 rig, in conjunction with Blue Water Drilling Corporation, to become the first floating drilling platform.

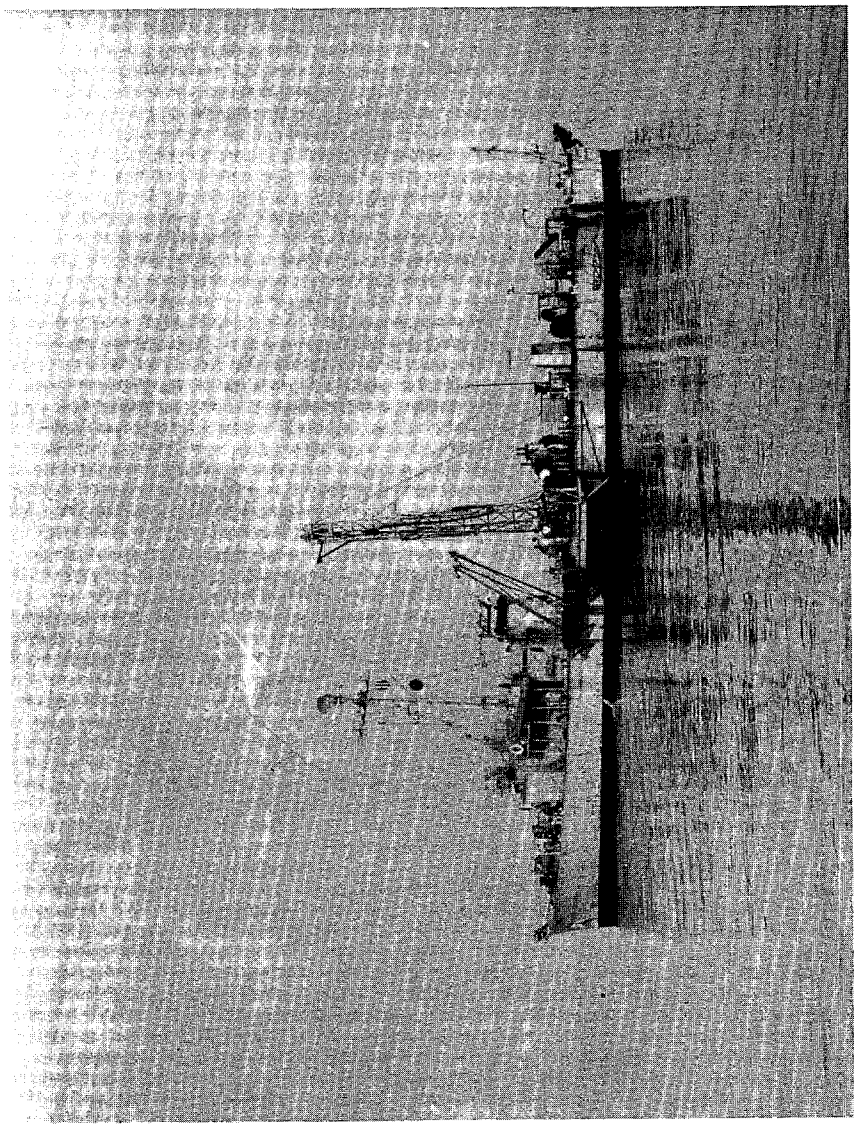


Figure 1

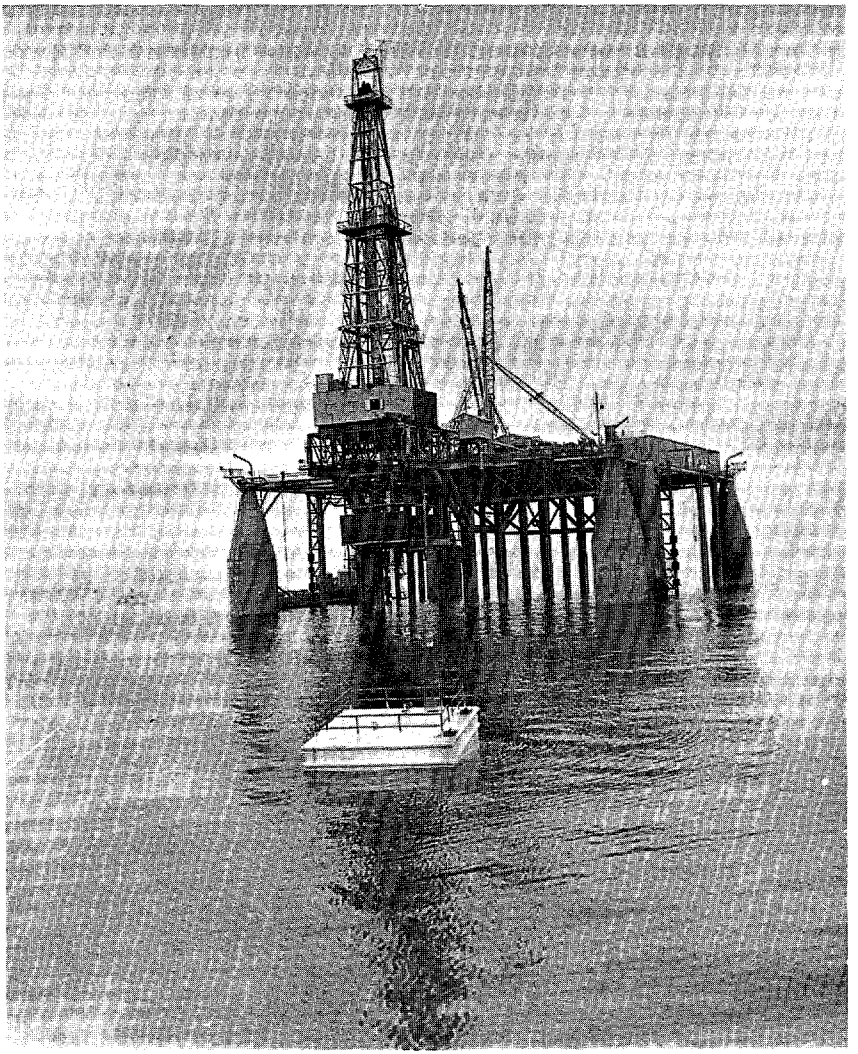


Figure 2

Two of the factors which influenced this decision were the federal lease sales of 1960 and 1962. Leases in water depth of from 240 to 300 feet in the Gulf of Mexico had been obtained by Shell in 1960. With another federal sale scheduled for March of 1962, Shell decided to evaluate these leases using a converted rig rather than building a new rig in order to save time and money. The conversion cost about $1.5 million and included the addition of automatic ballasting controls, an eight line mooring system and special handling equipment which would be needed in running the underwater equipment. The first well drilled from a floating platform was spudded in January, 1962.

It was only a matter of time before the industry would be pushing into deeper and deeper waters. Whether or not the successful demonstration by Shell of the capability to drill floating in waters of almost 300 feet had any influence on this timing, it is hard to say, but at the March, 1962, federal lease sale off Louisiana and Texas, some 1,958,000 acres were leased to 30 different oil companies. Of this total about 820,000 acres lie in 100 - 200 feet of water, 213,800 acres lie in 200 - 300 feet of water and some 37,000 acres were located in waters of 300 - 600 feet deep. All of these leases had a 5 year primary term in which to establish production. Since there were only six bottom supported rigs in existence that could drill in more than 100 feet of water, there followed a sudden surge in the construction and conversion of rigs for use as floaters. At the time of the March, 1962, lease sale there were only 12 floating drilling rigs of any type existing in the world. At the present time there are approximately 50 floating rigs of various designs, either available or under construction throughout the world.

At the first federal lease sale ever held on the Pacific Coast in May of 1963, 58 tracts containing 312,974 acres were sold to only 4 oil companies at a cost of $12,807,837. Of these 58 tracts Shell Oil Company obtained 49 containing roughly 267,000 acres, at a cost of $11,440,000. Figure 3 shows the location of the federal leases obtained in 1963 along the California coast.

In the fall of that same year Shell used the CUSS I to drill a well in 240 feet of water off Point Reyes, California near San Francisco. Because of the severe weather conditions that exist at Point Reyes, the CUSS I was replaced by a larger rig, the GLOMAR II and the well was successfully completed. However, severe storms continued to hamper the operations and the attempts to drill the second well were unsuccessful and operations were suspended in January, 1964.

Earlier in 1963, in anticipation of such weather, and future sales off Oregon and Washington where the weather was expected to be worse, Shell had contracted with Blue Water Drilling Corporation for the construction of the Blue Water No. 2. This rig would be the first floating platform to be constructed and used on the West Coast; thus Shell's requirements for a large and relatively stable rig that could operate efficiently year round in the hostile weather and sea environment was expected to be fulfilled.

The Blue Water No. 2 rig (Figure 4) which is now owned by Santa Fe Drilling Company, was built by Kaiser Steel Company, Richmond, California. It was launched in July of 1964 and towed to location off Point Reyes, California, near the site of Shell's 1963 drilling ventures.

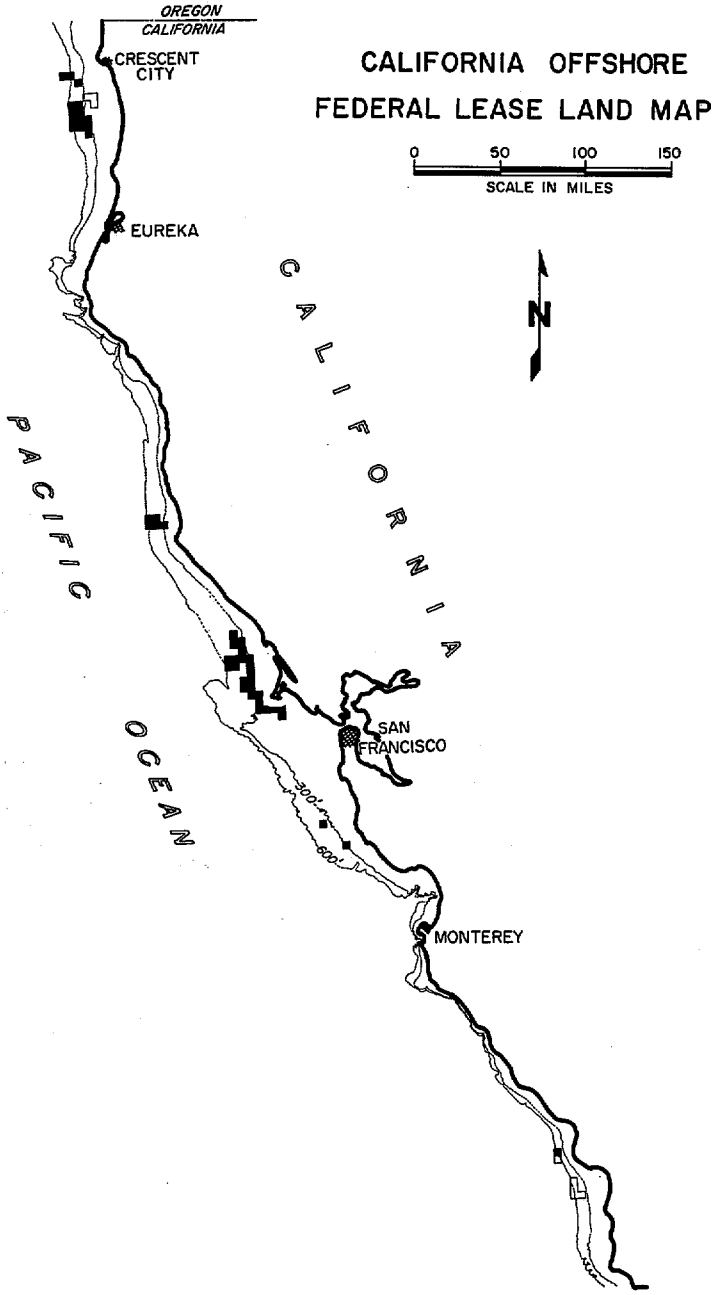
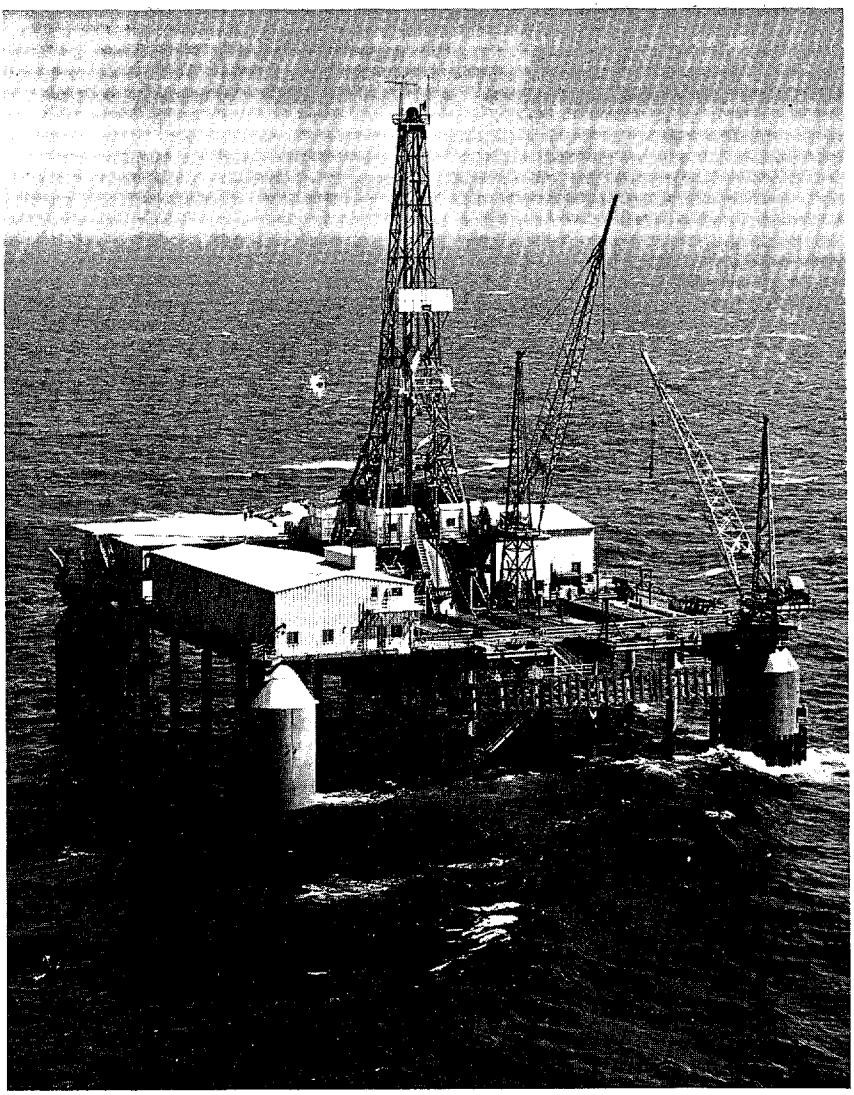

OREGON
CALIFORNIA
CRESCENT CITY
EUREKA
CALIFORNIA OFFSHORE
FEDERAL LEASE LAND MAP
0 50 100 150
SCALE IN MILES
N
CALIFORNIA
PACIFIC
OCEAN
SAN FRANCISCO
300'
600'
MONTEREY

Figure 3



BLUE WATER NO. 2
PT. REYES AREA

Figure 4

The rig, which has a displacement of 9,400 tons, is square, measuring 204 feet 8 inches outside the lower 14 foot diameter horizontal tubular hull. The main deck, located 68 feet 6 inches above the hull, is 188 feet x 188 feet with the 142 foot derrick mounted in the center. The main deck is supported by four 24 foot 8 inch diameter corner columns and twenty-five 42 inch diameter support columns. Living quarters provide facilities for 52 men.

Several special features were incorporated into the rig construction in anticipation of the drilling needs. A work deck, or spider deck, was located 47 feet below the drilling floor for use in handling and storage of the underwater equipment. A special building and handling facilities were added to house a robot which was to be used in the drilling operations. A counter-weight system capable of exerting 200,000 pounds of vertical force was installed to provide variable tensioning capabilities for supporting the marine conductor; and a marine control room was constructed to accommodate the automatic ballasting controls radar, and the many devices used in measuring and recording weather and the vessel's motion. The rig is equipped with an emergency general alarm system, necessary navigation lights, three 20-man inflatable life rafts, fire fighting gear, life jackets, Life rings and a hospital room.

Power for the rig is supplied by three General Motors, E.M.D. units which develop 4350 H.P. to drive 6 DC generators. These in turn furnish power to 9 motors at the various drilling equipment stations. AC power is furnished by two 625 KVA generators and one 150 KW, AC diesel generator for emergency use.

The first well, using the Blue Water No. 2 rig, was spudded on August 2, 1964, in 438 feet of water. Cost of this first well was $96 per foot compared to $300 per foot for the first well drilled nearby with the ship-shape vessel. Subsequent wells drilled in the general vicinity averaged about $60 per foot, some of which were drilled during the winter season of 1964-1965.

The rig was used to drill 10 wells off the California coast between August, 1964, and July, 1965. The maximum water depth was 574 feet near Crescent City, California. The deepest depth reached was approximately 10,600 feet.

In October of 1964 the first Federal lease sale off Oregon and Washington was held. The interest in leases was much higher from an industry viewpoint than what it had been off California in 1963, when only four companies were successful. The 101 leases were sold to 11 companies for a total of some $35,500,000. Of the total leases, 74 were located off Oregon and 27 off Washington and averaged about 5600 acres each. Water depths varied from 200 to 1300 feet, as shown in Figure 5.

In July, 1965, the Blue Water rig was moved from California to a location near Newport, Oregon, where two wells were drilled. The rig was later moved to a spot off the Oregon coast, south west of Astoria about 35 miles, in October, 1965. Here the rig remained throughout the winter and drilled only one hole between November, 1965, and March, 1966. Only two other wells have been drilled in the Federal waters of either Oregon or Washington by Standard Oil Company et al using the WODECO III. The rig worked throughout the summer and returned to California in October, 1965.

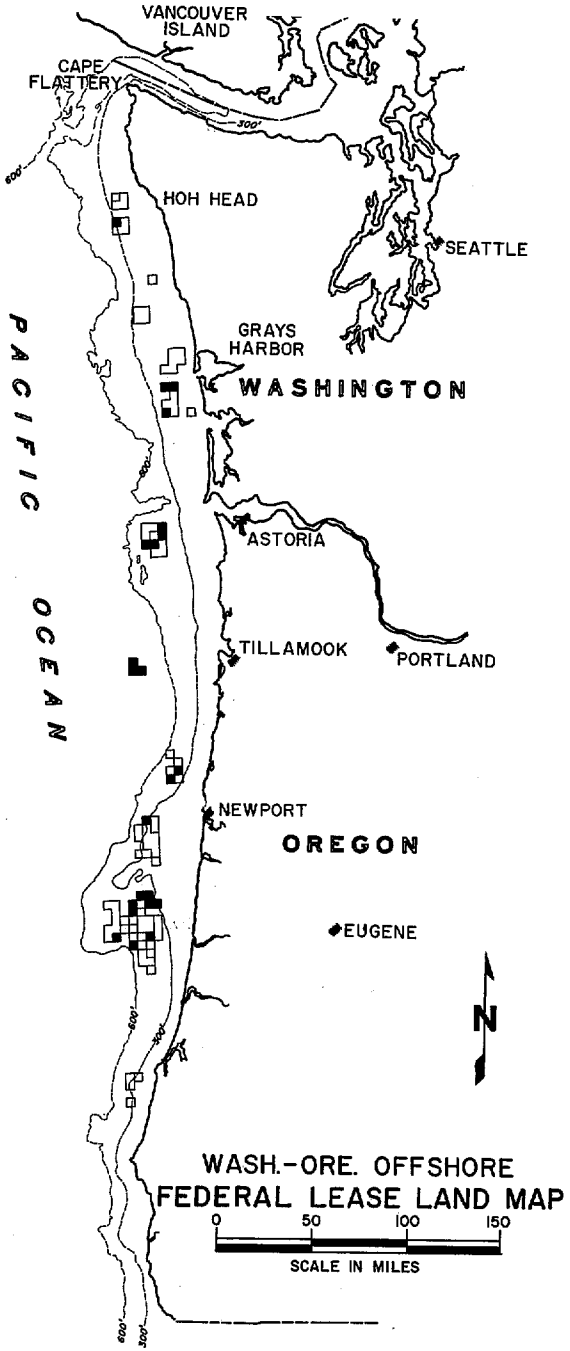

VANCOUVER ISLAND
CAPE FLATTERY
HOH HEAD
SEATTLE
GRAYS HARBOR
WASHINGTON
PACIFIC OCEAN
ASTORIA
TILLAMOOK
PORTLAND
NEWPORT
OREGON
EUGENE
N
WASH.-ORE. OFFSHORE
FEDERAL LEASE LAND MAP
0 50 100 150
SCALE IN MILES

Figure 5

OPERATIONS OF A FLOATING PLATFORM

To describe the operation from a floating rig, a brief discussion of the step by step procedure used in connection with the Blue Water No. 2 operations follows.

Moving and Positioning On Location

The rig is towed between locations by either three or four tugs. Generally, 3 tugs of about 1500 H.P. each are used for short moves and 4 tugs for long moves Average speed for all moves has been about 2 knots. To date, only 8.5% of the total time has been spent moving which also includes the weather down time during the move.

To position the rig at the desired location requires one of two methods; either by precalculated distances measured to a point of intersection using conventional visual survey instruments. Because of distances from shore, visibility, and prevailing weather conditions the rig has most often been positioned by use of electronic equipment, such as SHORAN. The accuracy of the method varies between 50 and 200 feet. The method provides continuous tracking of the rig and "instant plotting" of its position as well as the position of all anchors. Electronic gear is available both on the rig and the anchor handling boat. Once the rig is anchored, the position is checked using conventional equipment requiring a greater time-lapse between the observations and final results.

After the location is checked the rig is ballasted to drilling draft of about 38 feet and all eight of the 22,000 pound anchors are tested. Drilling operations can then begin.

Spudding

Once the rig is at drilling draft a measurement is made of the water depth. Next, 150 feet of 24" conductor pipe are attached to a pile joint and landing base for running. The pile joint is connected by way of the 13-3/8 casing head to the blow-out preventers. The assembly is tested and sufficient lengths of 16" non-buoyant marine conductor are then attached to the top of the B.O.P. stack and the entire system is lowered to within 20 feet of the ocean bottom. Hydraulic control of the B.O.P. stack is accomplished through a multiple conduit hose bundle attached to the marine conductor and extending between the stack and the rig.

The marine conductor is suspended on the spider deck below the drilling floor. The drilling string, usually consisting of a 12-1/4" bit and a 28" expandable hole opener, is run through the assembly and a 28" hole is drilled to about 250 feet below the ocean floor. When the hole is completed, the drill pipe is raised 150' leaving approximately 100 feet of pipe in contact with the hole. The lower portion of the drill pipe is hung off inside the marine conductor by means of a special landing sub and the upper portion removed. Additional lengths of marine conductor and the slip joint are then attached and the entire assembly lowered until the landing base rests on bottom. During this operation the proper amount of counterweights are attached to the slip-joint so as to provide proper tensioning to the system. Once the landing-base is on bottom the spudding string is removed and open ended drill pipe is run in to cement the conductor pipe.

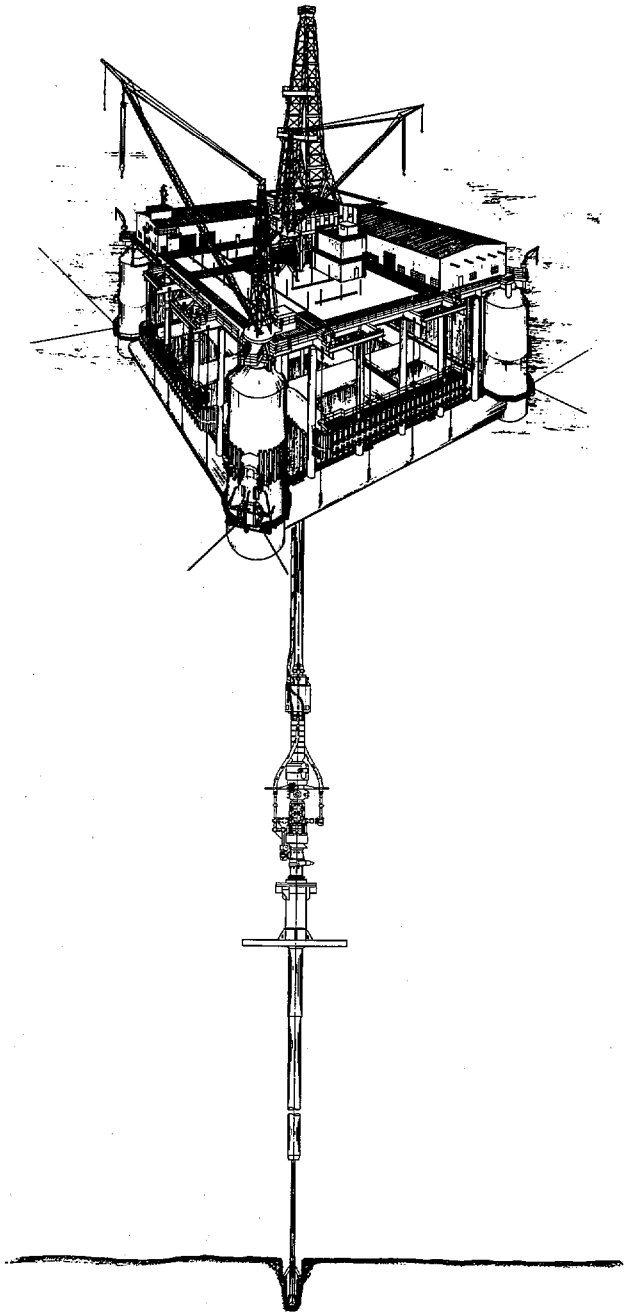


Figure 6

The kill and choke lines are run and subsequently tested together with the B.O.P.s. A 12-1/4" bit is then run to drill below the conductor pipe for setting surface casing (see Figure 7). This string usually consists of about 2,500 feet of 9-5/8" casing. The casing is made up to a hanger and run on drill pipe and seated below the B.O.P. inside the 13-3/8" casing head. The Robot can be used to lock the hanger in place or slips can be set if need be.

Shell's robot (shown in figures 8 and 9) is an integral part of the deepwater operation. The unit has two TV cameras, a sonar for locating equipment underwater, a gyro-compass for direction, and two electrically operated propellers for swimming.

A hydraulically operated socket wrench is also mounted on the unit for operating the various valves and lock screws mounted on the B.O.P. stack.

The casing running string is then pulled and open ended drill pipe is run to within 200 feet above the float shoe and the 9-5/8" casing cemented back to the ocean floor.

After the cement has set and the B.O.P. assembly has again been tested an 8-3/4" hole is drilled to total depth. If conditions warrant, either a 5-1/2" or 7" casing string could be run.

One feature of the system currently used by Shell on the Pacific Coast is that there are no guide lines between the rig and the equipment on the ocean floor. Once the landing base is landed, the kill and choke lines are guided into place by tracks along the marine conductor. A hydraulic hose bundle attached to the marine conductor operates the B.O.P. stack on bottom from controls located on the rig floor. Since all casing strings can be run inside the 16" marine conductor and the B.O.P. there is no need for guide lines. In the event it becomes necessary to view the wellhead, B.O.P., or marine conductor, the robot is used. It can swim freely and locate the assembly with the aid of its TV and sonar. A number of wells have been drilled without the robot making any such dives at all.

In cases of bad weather, the control valves on the well can be closed and the marine conductor can be released from the top of the B.O.P. stack to prevent damage to the equipment or the rig. To re-establish contact with the B.O.P. the robot is used, first to locate the stack, and then by use of the T.V. to afford the drilling personnel visual contact to re-attach the marine conductor to the stack. This operation has been successfully carried out numerous times in the waters off Oregon.

There is little to distinguish the normal routine drilling operations on a floating platform from that of any other platform. Round trips of the drill pipe to change bits are the same. Mud is circulated in the same manner and the B.O.P.s are operated in the usual way. When the total depth has been reached the well is logged using standard tools and after making necessary evaluations the well is abandoned.

Abandonment

In accordance with the U.S.G.S. requirements on the West Coast. the equipment must be removed to 3 feet below the ocean floor when the well is abandoned. In compliance with these

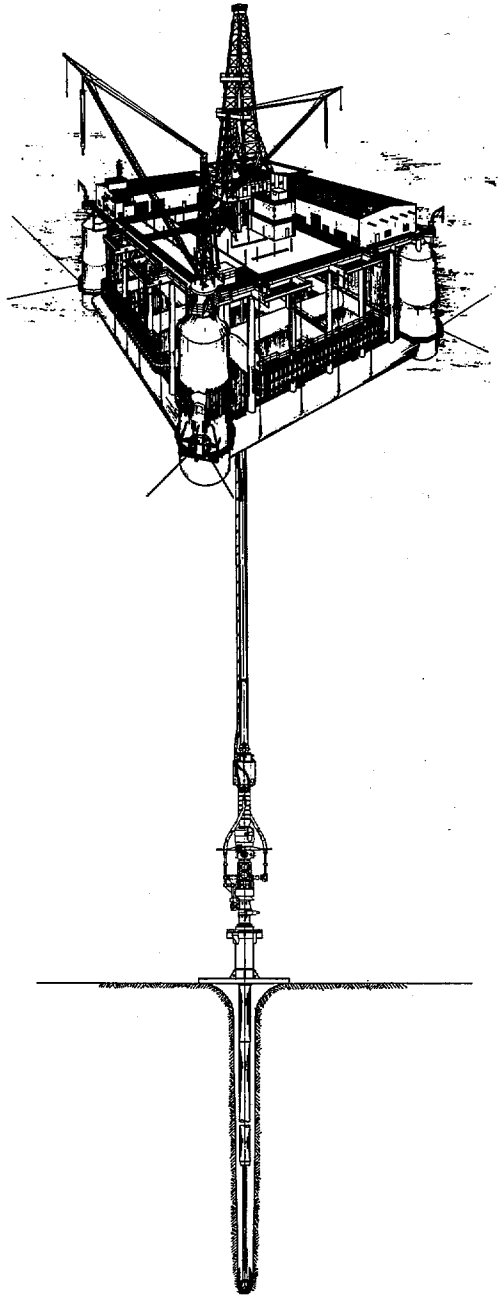


Figure 7

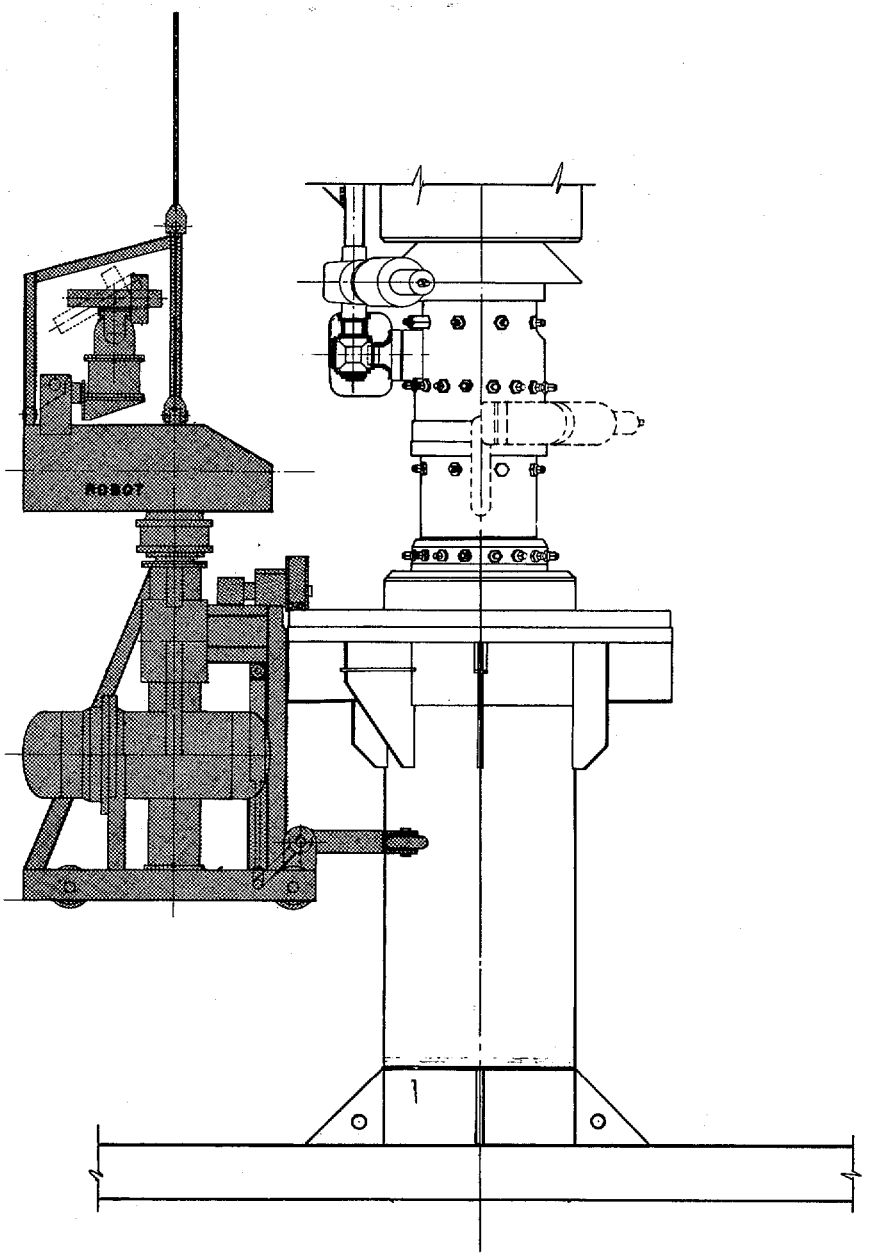


Figure 8

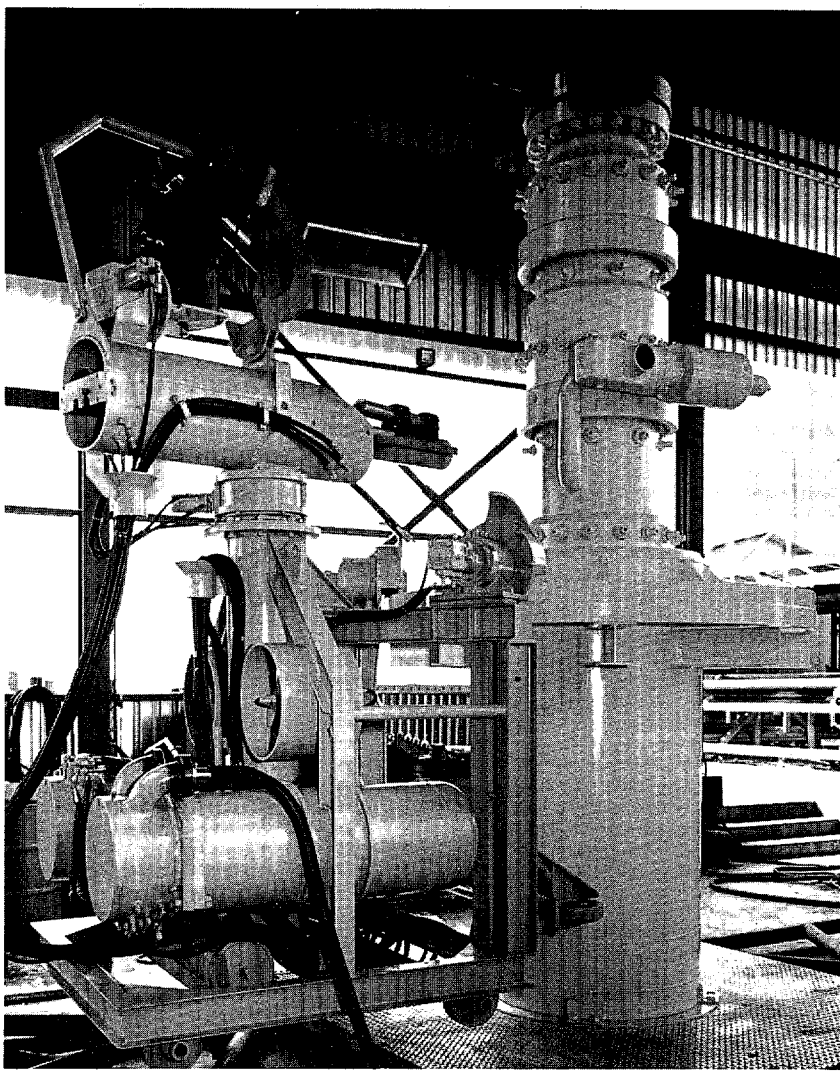


Figure 9

regulations the necessary cement plugs are set in the hole and all the casing strings are cut, using a mechanical cutter, at a depth of 20 feet below the ocean floor. Designed into the 24" pile joint is a shear joint which will separate at a total combined force of 600,000 pounds of pull and hydraulic pressure. The B.O.P. stack, wellhead and landing base are then retrieved leaving the location clear and the pipe removed to about 4 feet below the ocean floor. Once the equipment has all been retrieved, the rig is deballasted and the anchors retrieved to start towing to another location.

Performance

The rig has performed satisfactorily as expected. During the period from July, 1964, through March, 1966, the rig has drilled 13 wells, including one directional hole. Total down time due to weather during the period totalled 9.3%. A breakdown of the weather effect during moving and while anchored is shown in Figure 10. "At-anchor" down time due to weather has been only 7.9 per cent with most of this occurring on the last well in Oregon. High seas, strong unforecasted winds, and anchor problems on this well account for the delays. It is estimated that ship-shape vessels operating in this environment would have been shut down a substantially greater percentage of the time than the more stable rigs of the semi-submersible type. This conclusion has been reached after spending one winter in the Oregon waters. Much of the down time results in preparing for forecasted bad weather and recovering operations after the storms. The rig has conducted drilling operations in 25 foot seas, but since there is always the possibility of anchors slipping, precautions must be taken in this event to safeguard men and equipment. Thus, even though a large stable rig may not have the motion of a smaller rig or ship-shape vessel, it is subjected to large forces resulting from the wind, sea and current, and could still move off location. Furthermore, during periods of bad weather it is increasingly difficult to transport needed men and materials and safely unload them onto the rig. Figure 11 shows the actual winds and seas encountered while drilling off Astoria, Oregon, from the last of October, 1965, through the end of February, 1966. It is interesting to note that for a 72 day period between October 21 and December 31 the seas were 10 feet or greater approximately 52 days, or roughly 72% of the time.

Weather

Weather and its effect on the operations continues to be one of the most important obstacles confronting floating drilling. This is even more true in the Pacific northwest than in other areas such as the Gulf of Mexico. Most winter storms develop in the vicinity of the Gulf of Alaska and since there are few weather data reporting points available to the forecasters these storms are hard to track and difficult to forecast. In addition, the local topography of nearby mountain ranges often result in considerable variations in wind intensity. Such conditions have on numerous occasions resulted in winds exceeding hurricane force (75 mph) and on one occasion gusts of 105 mph were recorded on the rig while on the shore, some 35 miles away, the anemometer blew away at 120 mph.

Because such conditions can arise without much notice, a weather bill is furnished the operating personnel on board the rig. This bill outlines the necessary steps to be followed in case of such storms. Briefly, the bill provides that at any time

EFFECT OF WEATHER UPON BLUE WATER 2 OPERATIONS

	Location	Month Spudded	Moving - Hours			On Location - Hours		
			Total Hrs	W.O.W.*	% W.O.W.	Total	W.O.W.	% W.O.W.
1.	California	Aug. '64	48	0	0	1,600	16.8	1
2.	"	Oct. '64	262	157	60	648	16.8	2.6
3.	"	Nov. '64	43	0	0	305		0
4.	"	Dec. '64	168	76	45.6	624	48	7.7
5.	"	Jan. '65	84	32.6	39	636	120	18.8
6.	"	-	Sidetrack hole			259		0
7.	"	Feb. '65	72	12	17	403		0
8.	"	Mar. '65	107	11	10.3	2,245	91	4.0
9.	"	June '65	171	35-1/2	20.8	552	22.2	4
10.	"	July '65	41	0	0	481	0	0
11.	Oregon	Aug. '65	111	0	0	481	0	0
12.	"	Aug. '65	31	0	0	1,307	36	2.8
13.	"	Oct. '65	65.2	0	0	3,240	660	20.4
	Up to 3/8/66							
	TOTAL		1,203	324	27	12,781	1,011	7.9
	OVER-ALL % (Moving & on location)		13,984	1,335	9.5			

* W.O.W. = Waiting on Weather

FIGURE 10

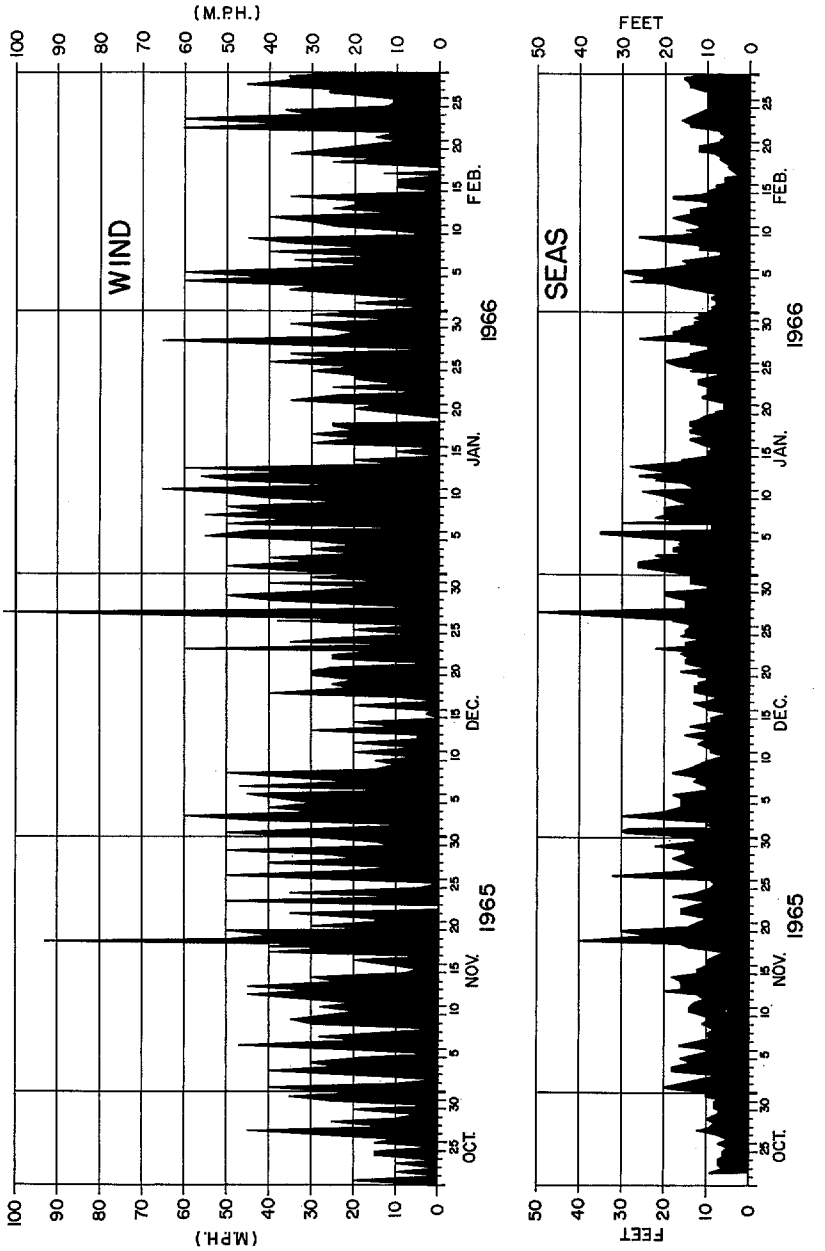

WIND & SEAS CONDITION
P 072
(M.P.H.)
WIND
(MPH.)
FEET
SEAS
FEET
OCT.
NOV.
DEC.
JAN.
FEB.
1965
1966

Figure 11

winds of 50 mph or greater are reached or forecasted, steps must be taken to be able to release the marine conductor from the B.O.P. stack. This usually entails setting plugs in the well and closing the B.O.P. blind rams. This action has been taken numerous times during the past winter.

On November 18, 1965, an unforecasted storm moved in over the area and because of localized conditions, winds of 93 mph were recorded. This storm resulted in the rig being moved off location and the marine conductor parted in two places. During the recovery period that followed several more storms reached the area. Figures 12 and 13 show the actual sea and wind conditions and the vessel motion that resulted from the storms of November 18, and December 27, 1965.

As already stated earlier, because of the unpredicted weather and its resulting effect on the operations, every consideration must be given to the weather in order to safeguard men and equipment.

Trained Personnel Required

The need for better trained and higher caliber personnel for floating drilling is becoming more and more evident. The roustabout, who not too long ago was engaged in unloading supplies and chipping paint, among other duties, now finds it necessary to pass tests in fire fighting, first aid, and survival. In some cases he must also be able to make and understand the stability calculations made on the rig.

The driller and his "roughnecks" must know and understand the working parts of everything he has run into the well. Once below the ocean waters it is hard to take another look or make some needed adjustment. They must also be constantly alert as to the effects the seas, weather or a particular operation will have on the rig, and must always be in communication with the barge supervisor on duty in the control room.

The supervisor of such operations must be the best available. He not only must be thoroughly familiar with the various aspects of floating drilling and the equipment, but must also be able to make necessary decisions to assure safe and trouble free operations. The personnel working in floating drilling operations must be the best trained the industry can supply.

Reasons For Floating Drilling

The application of floating drilling warrants consideration in many situations, such as the following:

1. In the deeper water depths throughout the world. Platforms are being designed for waters of 400 feet, however, their installation will cost between $4 to $10 million and can not be justified until production is assured.

2. In areas where bottom conditions will not support platform.

3. In areas where platforms will present either a navigational or aesthetic problem.

4. For conducting exploratory drilling in areas where time is a factor and water depths can vary from 100

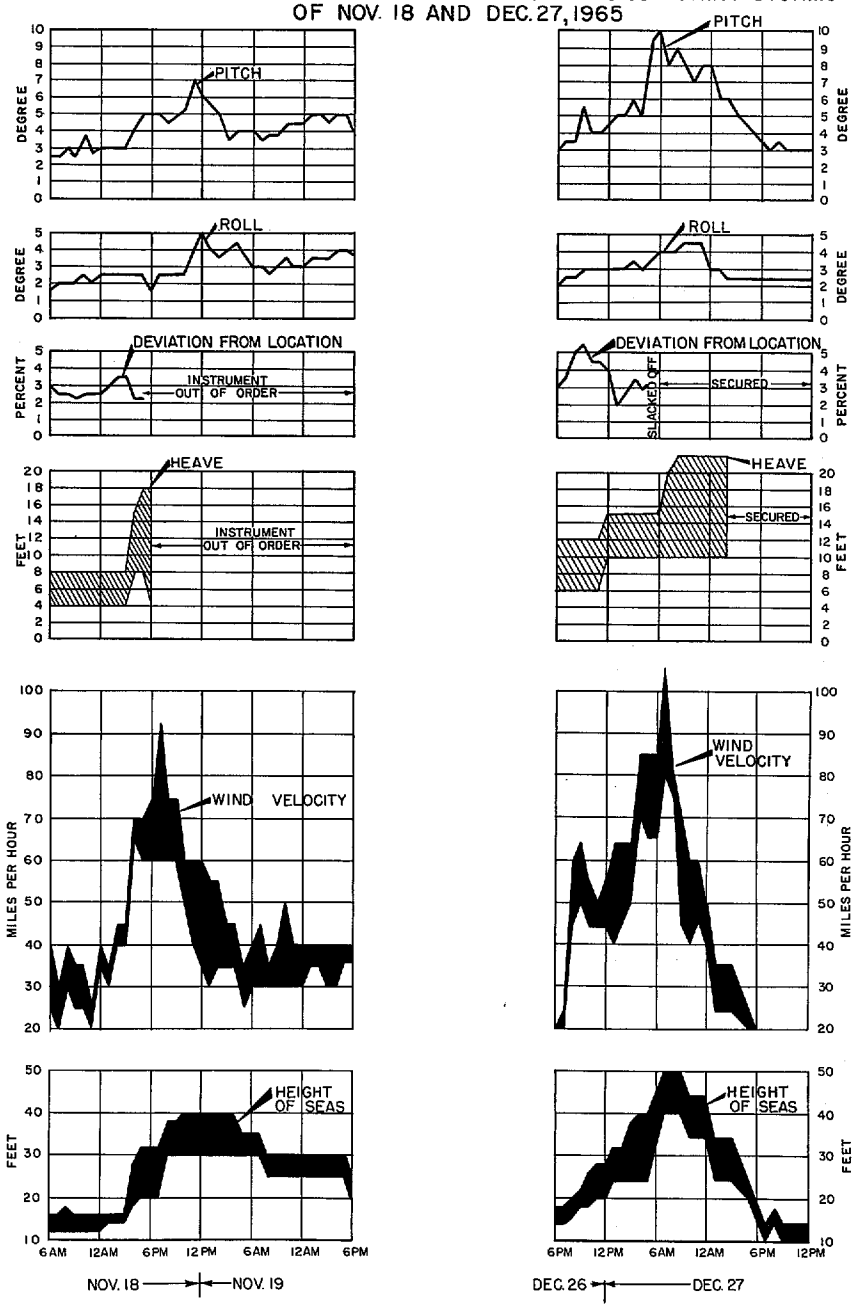

VESSEL MOVEMENT AND WIND AND SEA CONDITIONS DURING STORMS OF NOV. 18 AND DEC. 27, 1965
PITCH
DEGREE
ROLL
DEVIATION FROM LOCATION
PERCENT
INSTRUMENT OUT OF ORDER
SLACKED OFF
SECURED
HEAVE
FEET
WIND VELOCITY
MILES PER HOUR
HEIGHT OF SEAS
6AM 12AM 6PM 12PM 6AM 12AM 6PM
NOV. 18
NOV. 19
6PM 12PM 6AM 12AM 6PM 12PM
DEC. 26
DEC. 27

Figure 12

to 1300 feet such as along the Pacific Coast. One rig with its associated underwater drilling equipment is capable of covering this range.

Future

What the future will hold for the floating platform is hard to say. It can be expected that the next few years will see more and more of the wells completed on the ocean floor from the floating rigs. Such completions to date have been few, since rigs have been engaged primarily in programs to evaluate quickly the large number of leases for possible platform drilling development. As the waters become deeper these completions will be made on bottom. They will also be made without divers' assistance and such tools as robots, sonars, and TV equipment will become common place.

Most of the problems facing the floating driller today, namely, weather, anchoring and transportation will remain a concern regardless of water depth. However, one problem that becomes more serious as the water depth increases is that of designing a suitable marine conductor or a means of conducting the drilling fluids between the ocean floor and the rig.

Anchors and anchor lines will give way to dynamic positioning and rigs may even be placed on the ocean floor.

Conclusion

The science and technological development of drilling in deeper and deeper waters is presently in advance of our economic justifications for doing so. However, the development and experience necessary to make it economical can not wait to begin the day it is justified.

ACKNOWLEDGMENT

The author wishes to thank Shell Oil Company for permission to prepare and present this paper.

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The primary references for this paper were the many excellent articles which have appeared over the years in the Oil and Gas Journal and the Offshore magazine.

MARINE COMPLETION SYSTEMS

Leonard E. Williams
Cameron Iron Works, Inc.

Abstract

When the search for petroleum was first extended into the offshore areas, a conventional type rig with conventional equipment was used on a permanent platform, which in essence was a land operation on an artificial island.

The mobile bottom supported platforms and the floating structures (vessels or platforms) were developed for more versatility. Accompanying the development of these rigs was the development of the mudline suspension and the subsea systems. The mobile bottom supported platforms can use either a mudline suspension or a subsea system. The floating structure uses only the complete subsea system.

In the mudline suspension, the casing strings are landed with hangers at the mudline and the casing extended back to the surface where conventional blowout preventers and wellhead equipment are installed. The complete subsea system involves landing the casing strings at the mudline and installing the wellhead and blowout preventers on the ocean floor. Usually this is done by hydraulic connectors, but it can be done by divers. With either system, when the well is to be completed, a tree can be installed on the ocean floor or the casing extended back to a platform and a conventional tree installed.

DRILLING STRUCTURES

Depending on the environmental conditions, offshore drilling may be done from any one of five structures. They are:

1) the bottom supported rig, which is a platform or structure supported by the ocean floor during drilling operations.

2) the jack-up rig, which is a bottom supported rig, is mounted on a floating hull. The jack-up rig has movable legs that are raised for moving the rig, and lowered to the ocean floor to pick the rig up out of the water and support it during drilling operations.

3) the submersible rig is a bottom supported rig which is also mounted on a floating hull. The submersible hull is pumped dry for moving the rig, but is filled with water and sunk on the ocean floor for support during drilling operations.

The bottom supported rig, the jack-up rig, and the submersible rig utilize the mudline suspension system. In the mudline system the casing strings are landed and suspended with hangers at the mudline (ocean floor), and the casing is extended back to the surface where conventional blowout preventers and wellhead equipment are installed.

4) The semi-submersible rig -- a rig on a floating structure with a hull that can either be filled with water to set it on the ocean floor for support during drilling operations in shallow waters, or left dry with anchors to hold it in place during drilling operations in deeper waters.

5) the floating rig -- a rig on a vessel, barge, or floating structure that is not supported by the ocean floor and is held in place by anchors while drilling.

The second type of marine completion system is the subsea system. The semi-submersible rig generally uses the subsea system, and the floating structure

always uses it. The complete subsea system involves landing the casing strings on the ocean floor, and installing the wellhead and blowout preventers there also.

DRILLING OPERATIONS

The following discussion will cover drilling operations from a floating rig. The complete subsea completion system will be described, with a casing program of 30" x 20" x 13-3/8" x 9-5/8" x 7" used for illustration.

After moving on location, the first objective is to set the conductor pipe. The most common conductor pipe diameter is 30" ranging from 100 to 200 feet or more in length. There will be a casing head housing welded on the top and a guide base frame with guide posts mounted just below the casing head housing.

The conductor casing is set for the following reasons: to prevent consolidated surface formations from sluffing into the well bore; to provide a landing shoulder for the next housing to be run; and to attach the guide frame, which is used as a means of guiding and alignment over the well bore.

There are three methods of getting the conductor pipe down:

1) Jetting

2) Driving

3) Drilling a hole in the ocean floor and then lowering the conductor on drill pipe into the hole and cementing. When the hole is drilled for the 30" conductor, a guide template is lowered into position on drill pipe to guide the conductor pipe in place. The template has two cables extending back to the surface and serves as a temporary guide first for the drill string and then for the conductor.

A guide frame known as the Universal guide frame, is wrapped around the drill pipe just above the drill bit and guides the bit down along the guide cables to the ocean floor where a 36" hole is drilled. The Universal guide frame is retrieved on top of the bit. Next, the 30" conductor pipe is picked up and stood in the derrick in sections ranging from 50 to 60 feet. As the first section is lowered into the water, the Universal guide frame is wrapped around the 30" for guidance into the hole that has been drilled. Usually, one or two welds are required to make up the 30" into one section which is lowered to the second deck on drill pipe.

At this level the wellhead guide structure (Fig. 1) is attached to the 30", the guide lines installed to the posts of the wellhead guide structure, and the drill pipe is made up into the top of the 30". The 30" conductor is then partially lowered. When the 30" enters the guide template, the Universal guide frame is retrieved. Then the 30" is completely lowered and landed on the guide template. Cement is pumped down the drill pipe and displaced with water, spotting the cement on the outside of the 30" back to the surface. The drill pipe is then retrieved, as are the two temporary guide cables extending from the guide template.

A pin connector (Fig. 2) is sometimes used to latch onto the 30" conductor. This connector has a 20-3/4" bag type preventer on top to which is attached a ball joint and 24" riser system to the surface. The 20-3/4" preventer is used when drilling out through the 30" conductor. It is removed before running the 20" casing string.

A 26" diameter bit is made up on the drill pipe and guided down into the 30" by means of the Universal guide frame on top of the bit. In general practice, approximately 500-ft. of 26" hole is then drilled.

Next, preparations are made for running the 20" casing. The 20" is run and guided into the 30", again using the Universal guide frame as a stabbing means. When the 20" casing has entered the 30", the guide frame is retrieved by flexible lines and unhinged from around the casing. The 20" casing head is made up on the casing, a connector attached to the top of the head, and then the complete string picked up on drill pipe and lowered to the bottom. This 20" casing head lands on a shoulder in the top of the 30" with an annulus opening at the top for cement returns (Fig. 3). Cement is pumped down the drill pipe with returns coming back to the surface through the annulus by-pass provided. The connector is unlatched hydraulically and retrieved.

The 20-3/4" 2000 psi working pressure blowout preventer stack is picked up and run on drill pipe and hydraulically locked onto the 20-3/4" 2000 psi working pressure casing head housing. To test this connection, a mandrel type tester is landed at the taper in the casing head housing, the rams or a bag type preventer is closed around the drill pipe, and a pressure test is made on the connection. Next, a riser having a minimum bore of 21" is run and connected to the top of the blowout preventer stack by means of the connector shown in Figure 4.

A ball joint is located just above the connector which locks at the top of the blowout preventer stack. This ball joint provides flexibility at the bottom of the riser to allow for lateral changes in position of the drilling vessel, thus eliminating severe stress in the blowout preventer stack. This joint, shown in Figure 6, normally allows for 10 degrees deflection, 20 degrees included angle.

At the top of the riser, a slip joint is provided to compensate for rise and fall of the vessel.

A wear bushing (Fig. 7) is run and landed in the 20-3/4" casing head to prevent damage to the inside diameter of the casing head during drilling operation. A 17-1/2" hole is drilled to the required depth for running the next string, which will be 13-3/8" casing.

The wear bushing is retrieved on drill pipe and then preparations are made for running the 13-3/8" diameter casing string. The weight and length of this string is in proportion to the total depth of the well to be drilled. The 13-3/8" casing is run and a 13-5/8" casing head housing is made up on the last joint. A running tool is made up into the top of the casing head and lowered on 13-3/8" casing to a landing shoulder in the 20-3/4" casing head.

Another means which is commonly used to lower the casing head is a tool known as the Universal running tool. This tool is made up on drill pipe. Hydraulically operated dogs on the Universal running tool lock into the casing head, and the head is then lowered on drill pipe. The capability to use drill pipe for lowering the casing head is highly desirable where water depths are such that it would not be practical to carry on board surplus casing for lowering the head to the bottom.

In all instances it is common practice to run the 13-3/8" casing and head through the 20-3/4" blowout preventer stack. Two means have been used for cement returns:

1) When the 13-5/8" casing head seals into the 20-3/4" head, a hydraulically operated dump valve below the landing shoulder is opened to take returns.

2) In some instances there is no outlet in the 20-3/4" casing head; therefore, the 13-5/8" casing head housing has vertical slots on the outside diameter through which returns can be taken back to the surface. After the cement has been spotted, the running string is released and the area above the top of the 13-5/8" casing head is circulated clean.

The hydraulic connector is then released from the 20-3/4" casing head, and the riser and 20-3/4" blowout preventer stack is retrieved.

The next operation is to install the 13-5/8" bore blowout preventer stack (Fig. 5) and a 16" riser system. The 13-5/8" blowout preventer stack will usually consist of a guide frame which fits over the wellhead guide frame, an automatic connector on bottom, three to four ram type blowout preventers, a bag type preventer, and a short adapter on top for attaching the marine riser. The stack also has outlets for what are called the "choke and kill" lines. A fail-safe valve is clamped or flanged to these outlets. The fail-safe valve is hydraulically opened, but will close automatically in case hydraulic pressure is released. The riser consists of a connector or latching means on bottom, a ball joint and riser pipe back to the surface where a slip joint is tied back to the floating platform.

On the previous 21" riser and the 16" riser now run, guide arms with funnels can be provided for holding the choke and kill lines. These guide funnels provide a means by which the riser or the choke and kill lines can be pulled independently or guided back down. The hydraulic system for operating all of the components in the preventer stack is manifolded to a common point in the stack, and a hose bundle is run independently, locking onto this manifolding.

The preventer stack is lowered independently on drill pipe, and a pressure test is made on the connection before the pipe is pulled. It is common practice to run the choke and kill lines down with the preventer stack. The marine riser is then run independently and locked to the top of the stack.

A wear bushing is run on drill pipe and landed on a shoulder in the 13-5/8" casing head housing. A 12-1/4" inside diameter hole is drilled in preparation for running the 9-5/8" casing string. After this hole has been drilled, the wear bushing is retrieved on drill pipe and preparations are made for running the 9-5/8" casing. The 9-5/8" casing is run, and a casing hanger (Fig. 8) is made up on the string and then lowered either by casing or drill pipe. The casing hanger is landed on the shoulder in the 13-5/8" casing head housing. The 9-5/8" string is cemented, with returns taken through by-pass slots in the casing hanger. The running string is detached, and the hole is circulated clean above the casing hanger.

The packoff assembly is run on drill pipe and made up on the casing hanger body (Fig. 9). A seal on the packoff assembly is compressed, packing off the annulus by torqueing up on the drill pipe. The combination running and testing tool (Fig. 10) has a cup that seals off inside the casing hanger body. The drill pipe rams in the blowout preventer stack are closed around the drill pipe, pressure is applied through the choke and kill lines, and the annulus seal is tested to the required pressure. The lines are opened and the running and testing tool is retrieved.

The top preparation in this seal assembly has a landing shoulder for the next casing string.

A wear bushing is again run on drill pipe and landed in the top of the 9-5/8" casing hanger assembly. The hole is drilled for the 7" casing which will be the production casing string. The wear bushing is retrieved on drill pipe and preparations are made for running the 7" casing string. The casing is run and once again a casing hanger body with by-pass slots is made up on the string and lowered to the bottom by either casing or drill pipe, depending on water depth. (The drill pipe method again avoids carrying large amounts of surplus casing on board in deep water areas.) Returns are taken in the annulus and the same procedure is followed as in the 9-5/8" for circulating, running the packoff assembly, and testing.

If the 9-5/8" casing becomes stuck before the casing hanger is landed, the casing is then cemented in place and an emergency slip and seal assembly

(Fig. 11) is used to support and seal the casing in the wellhead. The stack-up will remain the same. The procedure for running the emergency slip and seal assembly is as follows:

1) If casing sticks before mandrel hanger is landed, cement casing.

2) Cut off casing above where hanger should be landed, and remove casing above cut.

3) Run a spear on drill pipe and grip the inside of the casing.

4) Using the same size casing as was cut off and a 10-ft. overshot at the bottom, run the emergency slip assembly down over the drill pipe and land it on the landing taper in the casing head.

5) Pull the desired tension on the casing with drill pipe and spear. Then release spear and retrieve.

6) By right-hand rotation, release running tool from slip assembly and retrieve tool.

7) Cut off casing a fixed distance above top of slip assembly and remove loose piece.

8) Run seal assembly, rotate to the right to energize seals, pressure test seals and retrieve running and testing tool.

The top of the 7" casing hanger seal assembly is prepared with a landing shoulder for the tubing hanger. When two or more tubing strings are to be run, it is necessary to orient the tubing hanger in reference to the wellhead guide frame so that the Christmas tree will be aligned with the seal pockets and the guide posts. This orientation is done by the following:

1) An orienting bushing is run on drill pipe.

2) The bushing is landed on top of the 7" hanger and seal assembly and rotated slowly to the right until the orienting dog snaps out into the orienting slot in the connector which is attached on the bottom of the blowout preventer stack. The drill pipe is then retrieved leaving the bushing in place. The inside preparation of this bushing is slotted so that when the tubing hanger is run, a key on the outside diameter of the hanger guides down the slot, thus automatically orienting the hanger in proper position with reference to the wellhead guide posts (Fig. 12). The tubing hanger has locking dogs for locking down in top of the 7" casing hanger assembly.

The riser and blowout preventer stack (Fig. 13) are then retrieved. The design of this subsea system allows the following option to be exercised at this point:

1) capping the well at this stage (Fig. 14) and waiting for future development and planning. If the decision is made to put the well into production at a later date, the cap can be removed, the casing extended back to the surface, and completion carried out on the platform.

2) continuing with preparations for subsea completion, which call for installing the production tree on the ocean floor.

THE PRODUCTION TREE

The Production Tree consists of a connector, two block valves, manifold spool, tree cap, and flowline connector (Fig. 15). The tree valve assembly includes a "wye" outlet spool with wing valves on which flowline loops are attached from the tree valve to the flowline connector.

The Production Tree is attached to the wellhead with a hydraulic collet connector that functions in principle like a standard wellhead connector. Guide arms on the connector give the tree its initial alignment as it is lowered into position and final alignment is obtained as the tree comes down over the neck of the tubing hanger. The close fit between the connector inside diameter and the tubing hanger neck outside diameter straightens the tree before it lands. The tree orients when the tubing hanger key engages the orienting slot in the connector inside diameter.

The block tree valve (Fig. 16) contains a master valve unit, a wye outlets unit, and optionally, a swabbing valve unit. The tree valve may have either two or three vertical runs for a single completion well and at least three vertical runs for a dual completion.

The wye outlets unit incorporates either two or three flowlines, each having a wing valve. The flowlines with a five foot radius arc intersecting the vertical runs permit passage of tools (pumped through the flowline) into the tubing. Provisions are made in the wye outlets unit to land a deflector tool. This deflector diverts the "pump down" or tubing tools back into the flowlines when the tools are being retrieved.

The deflector is run into the tree valve through the vertical tubing string from the drilling platform. The deflector is oriented by and landed in a special seal sub between the wye unit and swabbing valve unit.

The master valve unit, swabbing valve unit, and wing valves are equipped with fail-safe operators.

The hydraulic lines to the valve operators may be ported internally within the tree valve units.

A test port sleeve valve is located at the lower flange in one of the vertical runs; usually the casing annulus run (if an annulus run is used). This valve, when open, will vent from the vertical run into the area sealed off by the connector when the tree is landed on the wellhead. It is used to test the seal made by the gasket and the seals on the lower end of the stab type seal subs. The tree is always landed with the test port sleeve valve open so fluid trapped in the bore of the connector when going over the wellhead may be exhausted. Immediately after the tree has been landed on the wellhead and the connector closed, a testing tool is run down the tubing and a high pressure test made to make sure the stabbing operation was successful. After the test has been completed, the sleeve valve is closed.

The manifold spool is a spool mounted on top of the block tree valve. The lower face of the manifold spool connects the tubing runs and hydraulic operating system from the valve body to the manifold spool through a series of seal subs and is bolted or clamped to the valve body. The top face of the manifold spool contains stab type seal sub pockets for making the connection from the tree running connector to the tree. The upper end has a clamp hub and preparations for the installation of the tree cap. An orienting type guide post is mounted on the side to facilitate orienting and latching the running connector for reentry to the well.

Technically speaking, the manifold spool could be eliminated, and the preparation for attaching the connector incorporated in the top face of the block tree valve. The spool is used to allow replacing of the stab sub pockets without changing the block tree valve. It also allows the selection of a variety of hydraulic operating systems with the same basic block tree valve.

If individual solid block master and swab valves are to be used, a wye outlet spool is bolted or clamped between the two block tree valves. The wye type outlets are made with a radius for passage of "pump down" tools from the flowline to the tubing bore. When a wye spool is used, the deflector tools are installed in the spool just above the wye outlet.

The flowline loops are pipe sections running from the wing valve outlets on the production tree to the flowline connector. As mentioned earlier, they are made with a large radius in order to pass the "pump down" tools.

The flowline connector is used to make the connection between the flowlines and the underwater production tree (Fig. 17).

The tree hub section of the flowline connector is attached to the outer end of the flowline loops and is lowered into place with the production tree.

After the tree has been tested and the flowlines layed with the flowline hub in place, the seal assembly is lowered into position and the flowline hubs are clamped together, completing the underwater production tree assembly.

The tree cap is used to cover the top of the manifold spool, protecting the hub and seal sub ports after the tree running connector has been removed. The cap connects onto the manifold spool.

The cap is run and retrieved with a hydraulic running tool, using wireline retrievable darts.

THE FLOWLINE CONNECTOR

The flowline connector provides the necessary make and break joint between the Christmas tree flowline loops and the production flowlines. The Christmas tree and production flowlines can be run and retrieved independently with the final joint being made when both the tree and the flowlines are in position.

The remote hydraulic control lines, which operate the Christmas tree valves, run alongside the production flowlines and Christmas tree loops. The hydraulic control lines are connected at the same time that the Christmas tree loops and production flowlines are connected.

Because a hydraulically operated running and retrieving tool is used to make and break the connector, the lines can be joined or released before or after the tree is capped.

The construction of the Christmas tree loops provides the flexibility required when the tree hub is pulled toward the flowline hub to make the connection. A spring has been incorporated into the cartridge that supports the tree hub to insure that the two hubs are sufficiently clear of each other for landing and retrieving the clamp and seal assembly (Fig. 18).

All of the seal pockets in the hub are tapered, and for protection are recessed inside the hub faces.

Each hub has a groove on its outside diameter which receives the yokes of the running tool. Runners are attached to the flowline hub which lands on guide posts. This fixes the orientation of the sub pockets relative to the tree.

The tree hub lands on two plates welded to the guide frame and is automatically aligned when the weight of the running and retrieving tool is set down on the yoke groove.

Final alignment is obtained by a rocking action as the hubs meet the flat spacer portion of the guide and seal assembly.

The tapered seal subs do not slide into engagement and eliminate the need for a precise alignment of the hubs; they only engage when the hubs are in place.

The clamp assembly is like a standard clamp with the bottom half connected to a "U shaped" support and nut; the top half is connected to a stem threaded into

the nut. Turning the stem to the right tightens the clamp. Turning the nut to the right unlocks the clamp.

The top half of the clamp has ears, which run in slots cut in the "U shaped" support. Two support arms welded to the seal assembly also run in these slots, thus both halves of the clamp are centralized and supported during the running and retrieving operations.

The test port allows a pressure test between the outside diameter of the gaskets and control line seal subs.

Drill pipe adapters fitted with spring loaded keys are used to tighten or unlock the clamp.

The clamp is tightened by using the drill pipe locking adapter, which engages one of the slots in the stem with its spring loaded key. Using the drill pipe to turn the stem to the right tightens the clamp. A spring loaded nut stop key, mounted on the running tool frame engages a slot in the nut to keep the nut from turning.

Hydraulic operating cylinders are connected to two yokes. When the running tool is landed, the yokes fit over the grooves on the hubs so that the hubs can be hydraulically pulled together or pushed apart.

When the yokes are opened up, pickup bars engage slots in the support arms welded to the guide and seal assembly.

The procedure for running the flowline connector is as follows:

1) Open the clamp.

2) Make up a joint of drill pipe in the running tool.

3) Connect three (3) hydraulic hoses to the running tool.

4) Pick up the running tool and pressure the closing hose (#1) to close the tool.

5) Set the running tool over the clamp and seal assembly, and pressure the opening hose (#2) to open the tool. When the tool is open, it holds the clamp and seal assembly.

6) Put the running tool guide funnels around the two flowline guide cables extending from the guide structure.

7) When the running tool lands on the flowline and tree hubs, pressure the closing hose (#1) to draw the flowline and tree hubs together.

8) Hold the closing pressure, and turn the drill pipe running string to the right to tighten the clamp. Bleed off closing pressure.

9) Test by pressuring through the test port hose (#3).

10) Release test pressure and retrieve the running tool assembly by pulling straight up.

The procedure for removing the flowline connector is as follows:

1) Remove the clamp locking adapter and nut stop from running tool, and install the clamp unlocking adapter and stem stop.

2) Make up a joint of drill pipe in the running tool.

3) Connect two (2) hydraulic lines to the running tool opening and closing ports.

4) Pick up the running tool and pressure the closing hose.

5) Put the running tool guide funnels around the two flowline guide cables extending from the guide structure.

6) Remove the spider and lower the tool on the drill pipe.

7) When the running tool lands on the flowline and tree hubs, pressure the closing hose.

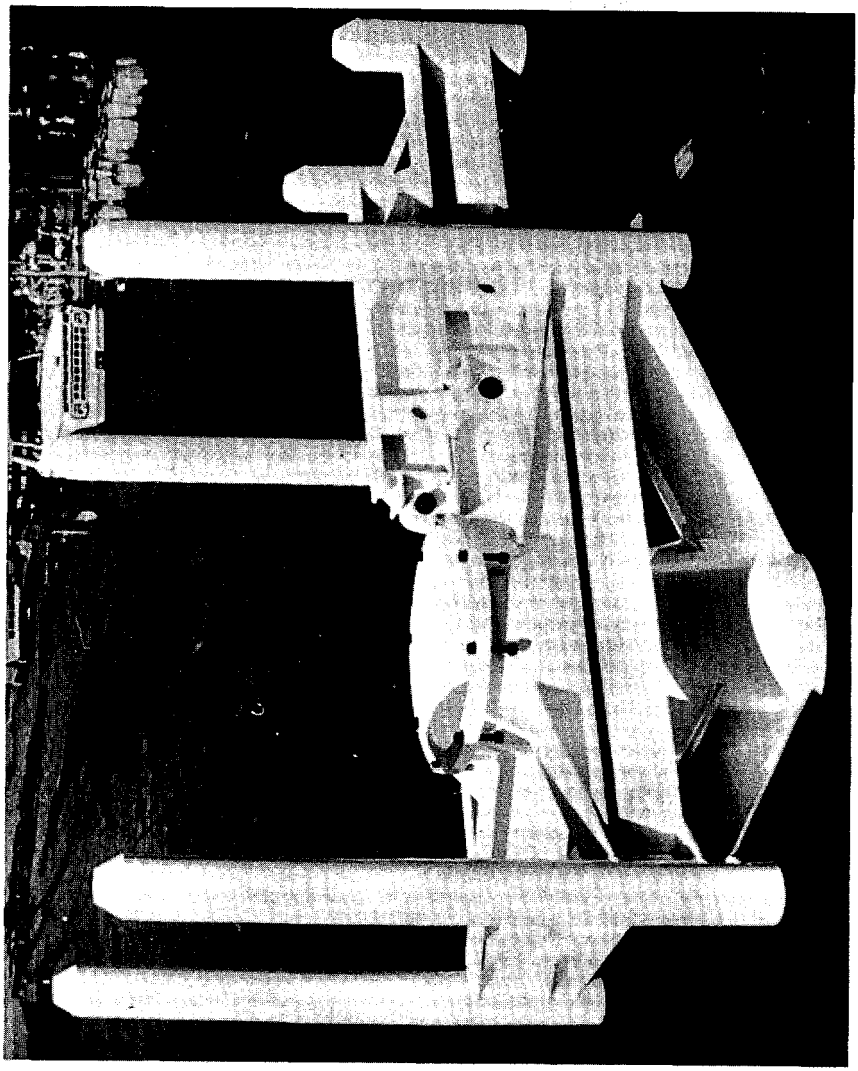
8) Turn the drill pipe running string to the right to unlock the clamp.

9) Release closing hose pressure, and pressure the opening hose to part the flowline and tree hubs. When the running tool is open, it holds the clamp and seal assembly.

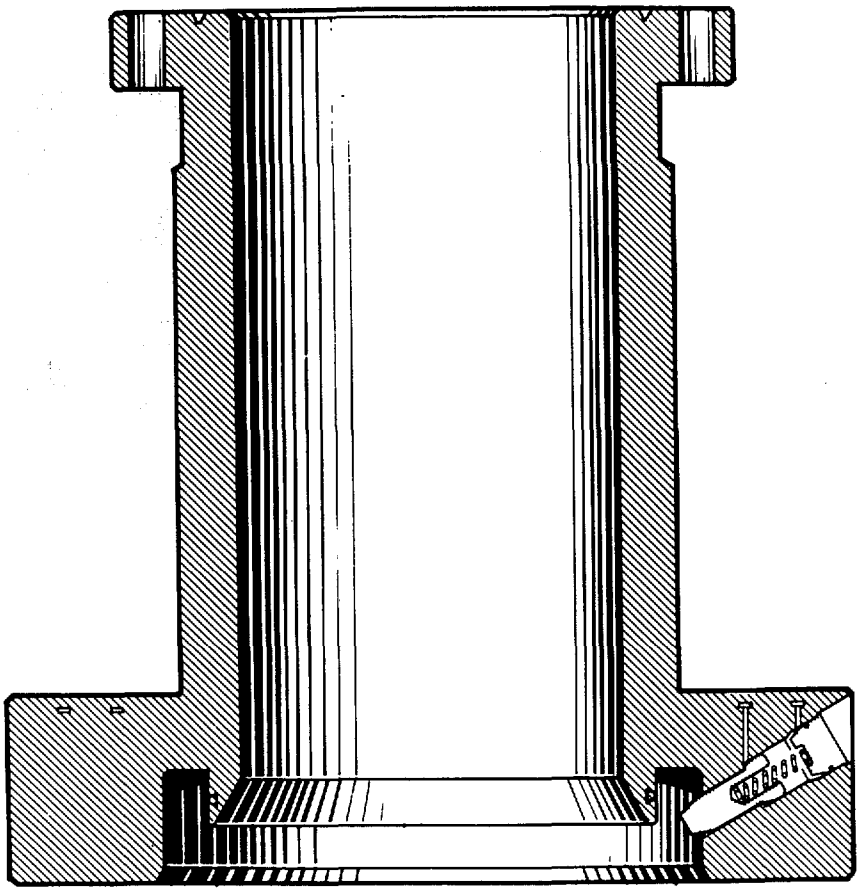
10) Release pressure and remove running tool and clamp and seal assembly by pulling straight up.

With drilling equipment now proven, the engineering search is centered on undersea production equipment. As rigs go into ever deeper water, greater demands will be put upon such subsea mechanisms as Christmas tree valves and flowline connectors.

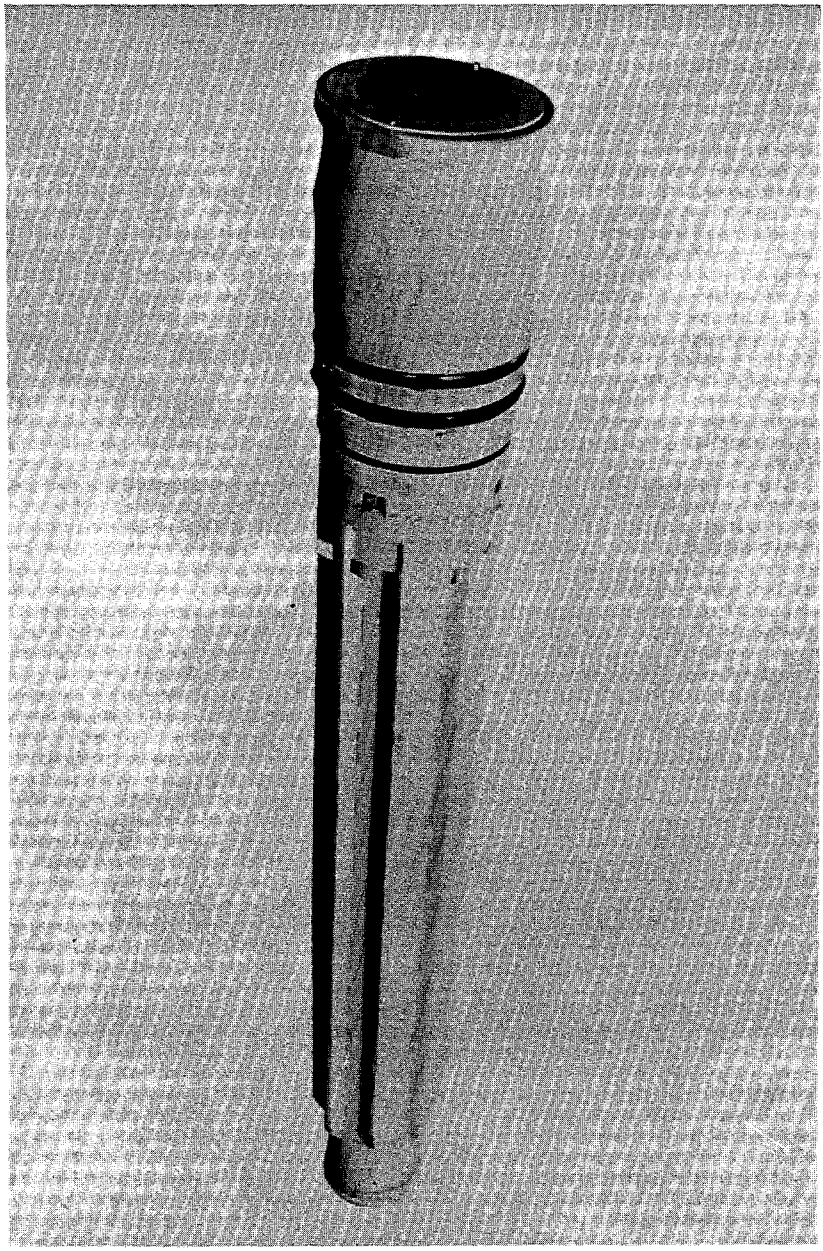
Successful subsea mechanisms for oil well completions have been developed and are now being used -- as was shown in this discussion. It is a surety, however, that continued engineering effort will result in still finer and more versatile equipment for the industry.



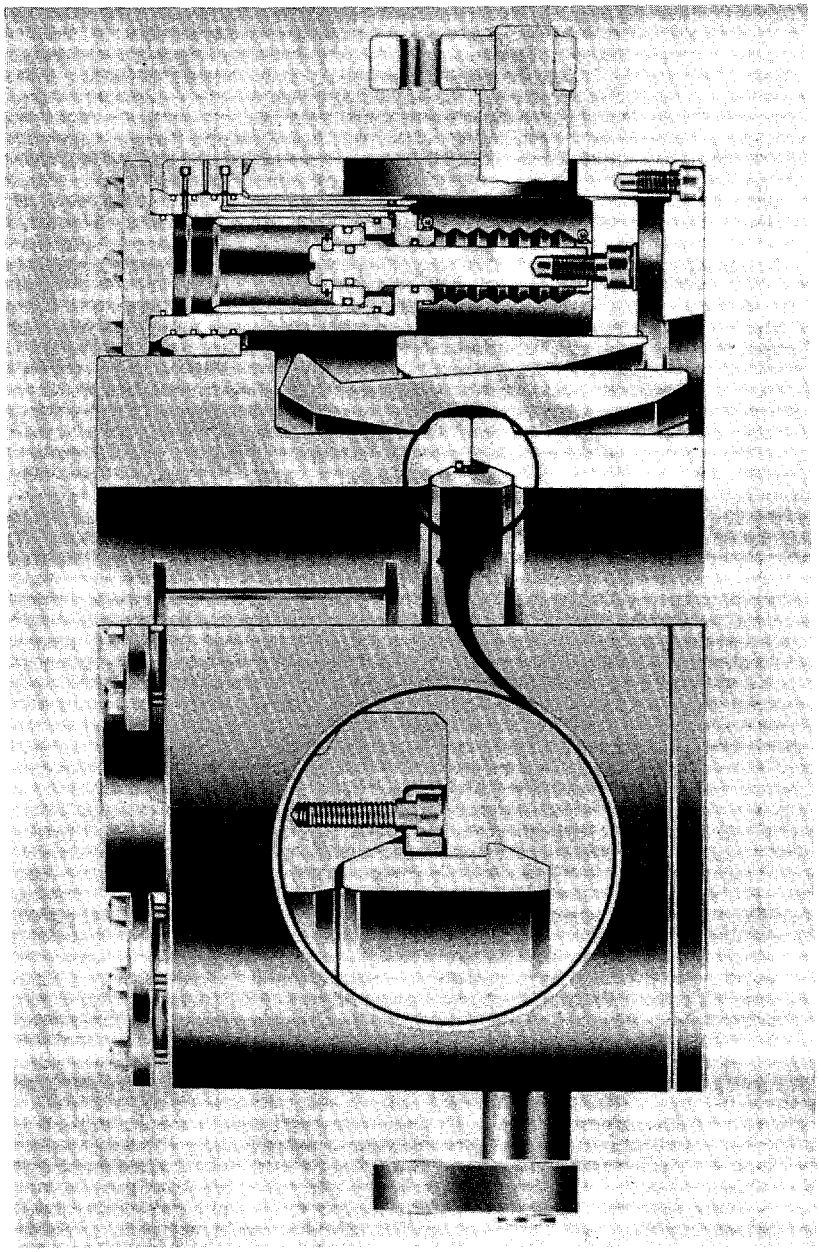
WELLHEAD GUIDE STRUCTURE
FIGURE 1



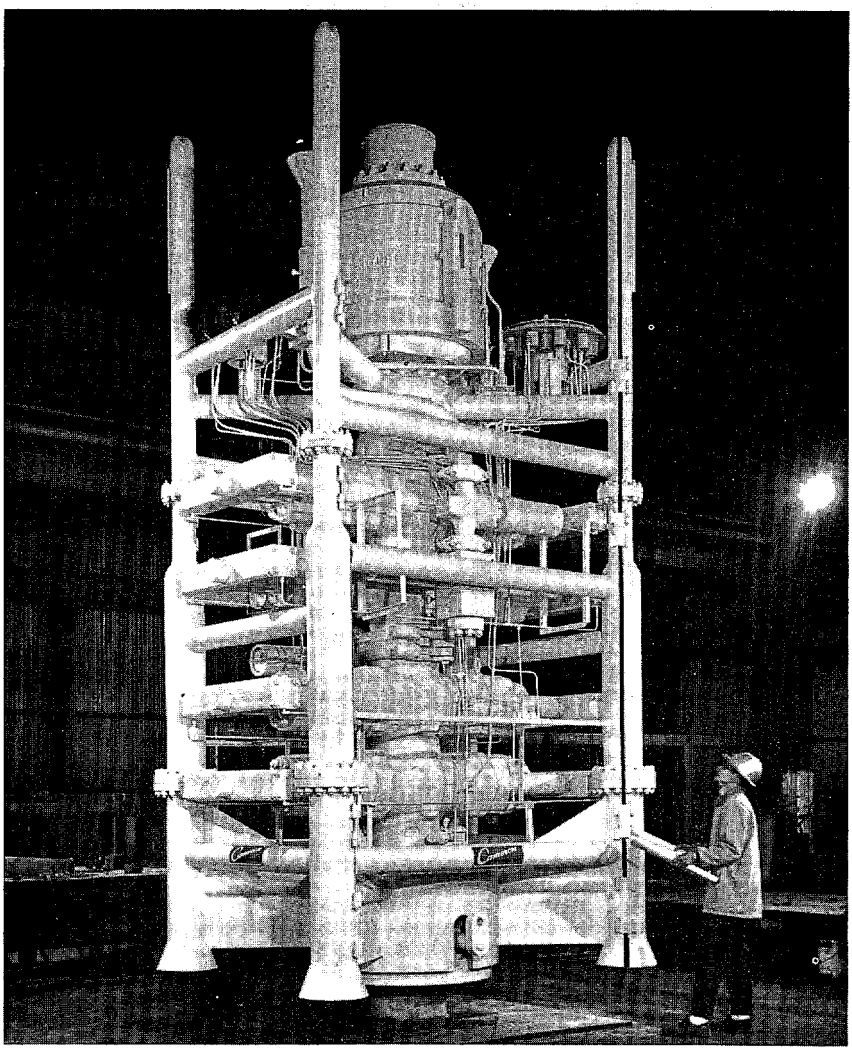
PIN CONNECTOR
FIGURE 2



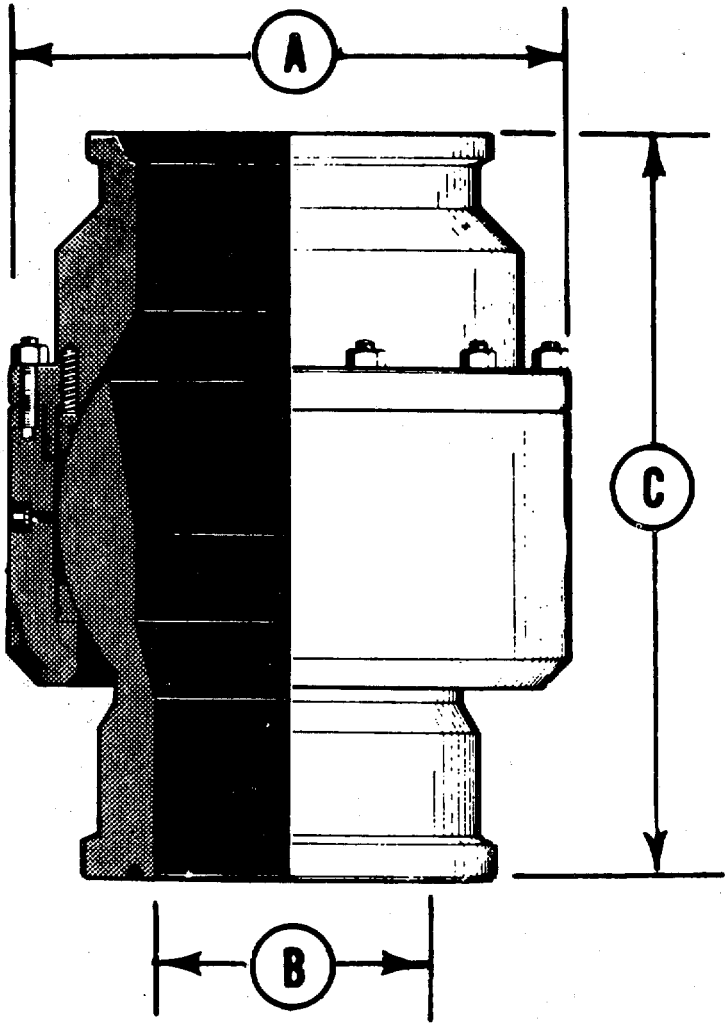
CASING HEAD HOUSING
FIGURE 3



COLLET CONNECTOR
FIGURE 4

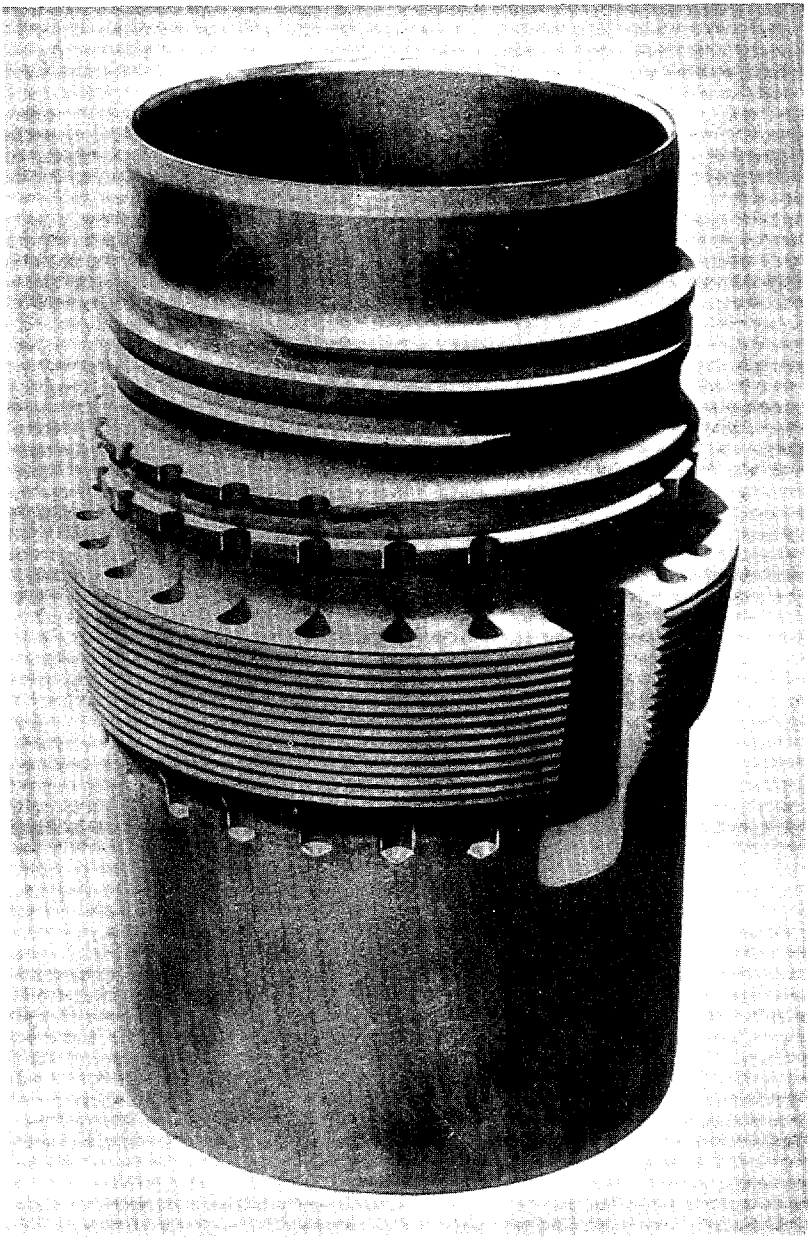


13-5/8 5000 PSI W.P.
BLOWOUT PREVENTER STACK
FIGURE 5

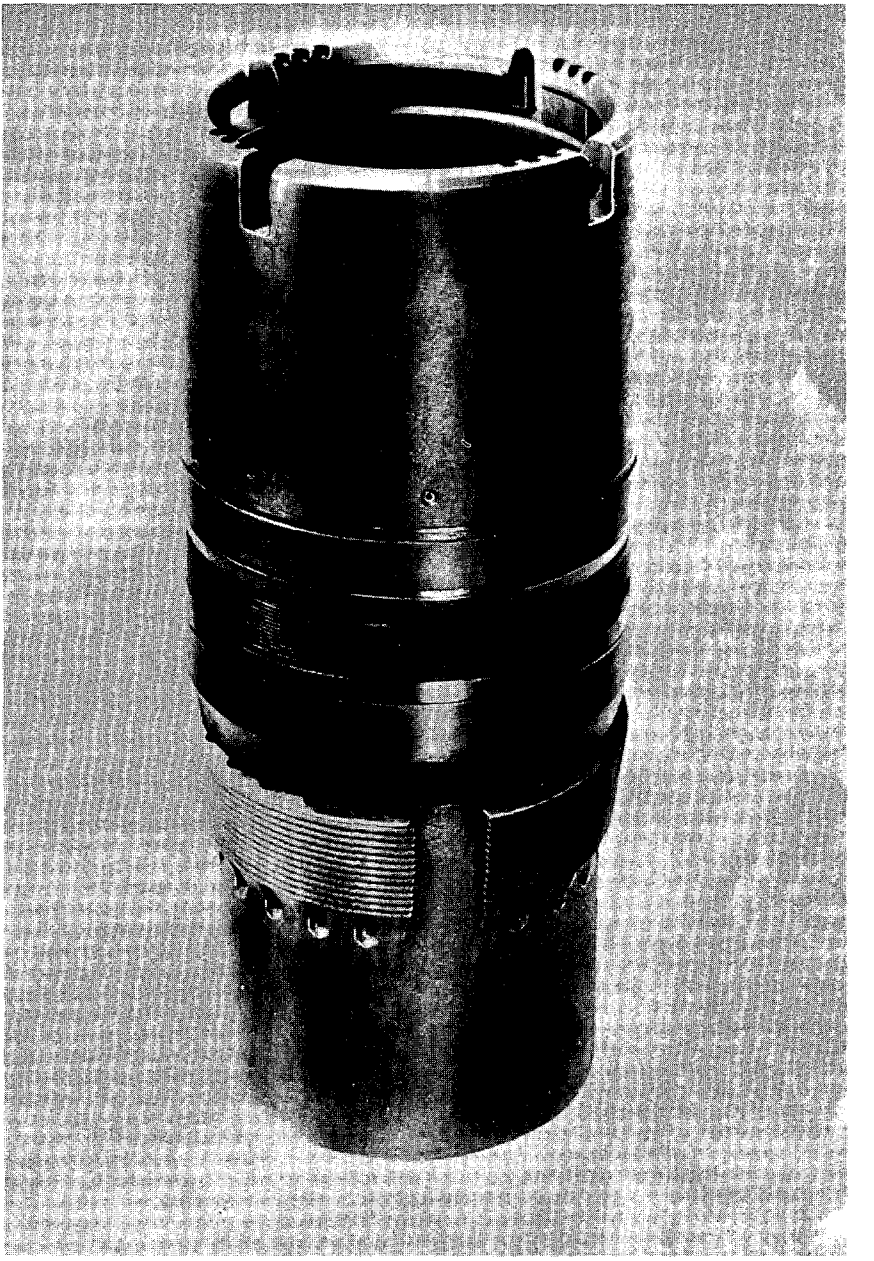


BALL JOINT
FIGURE 6

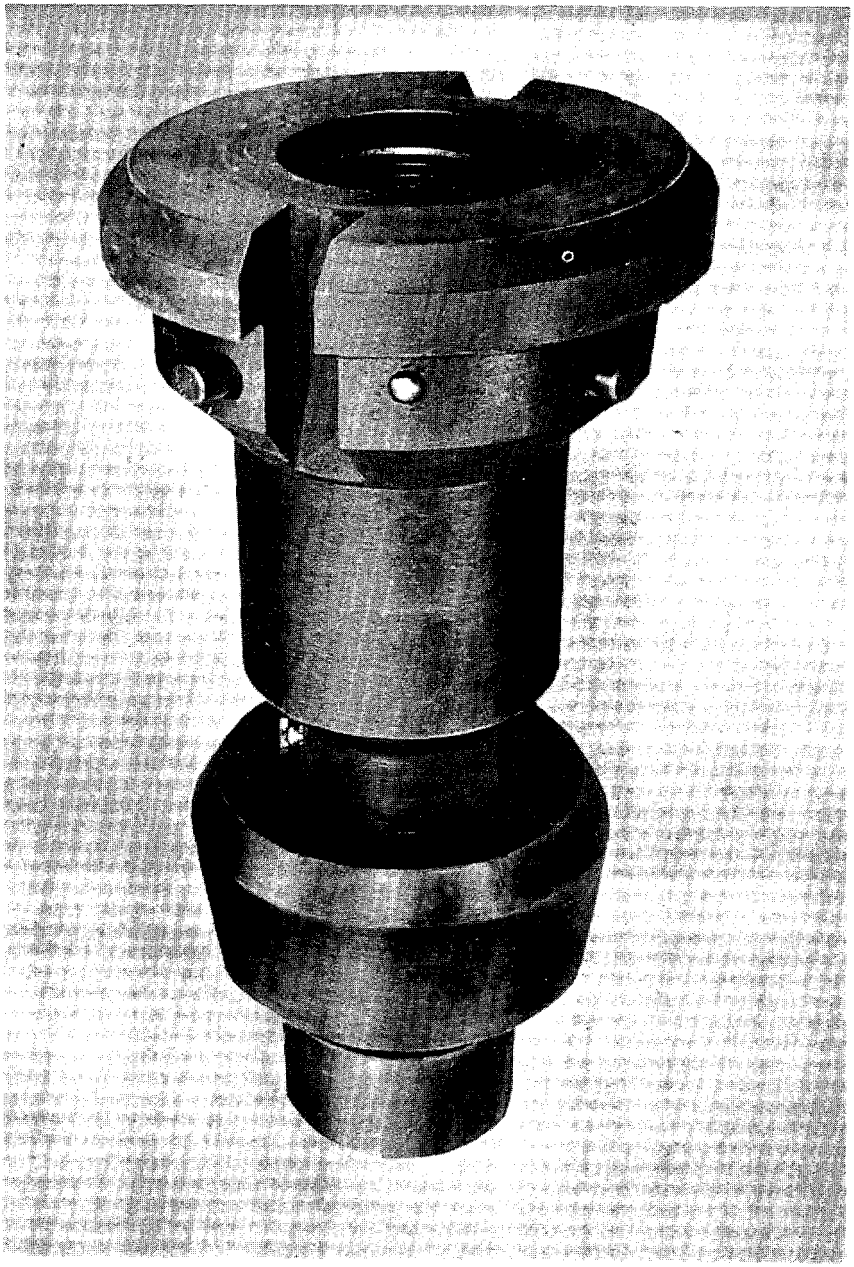
WEAR BUSHING
FIGURE 7



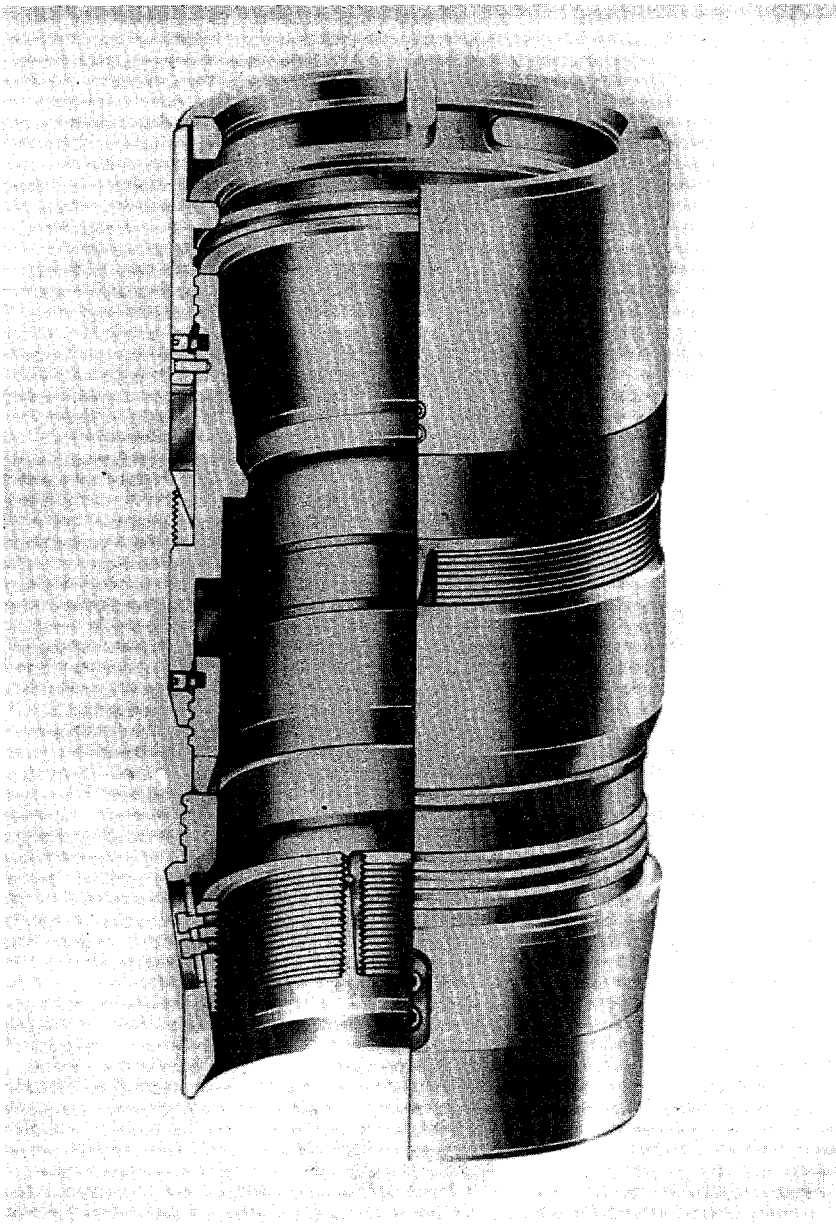
CASING HANGER BODY
FIGURE 8



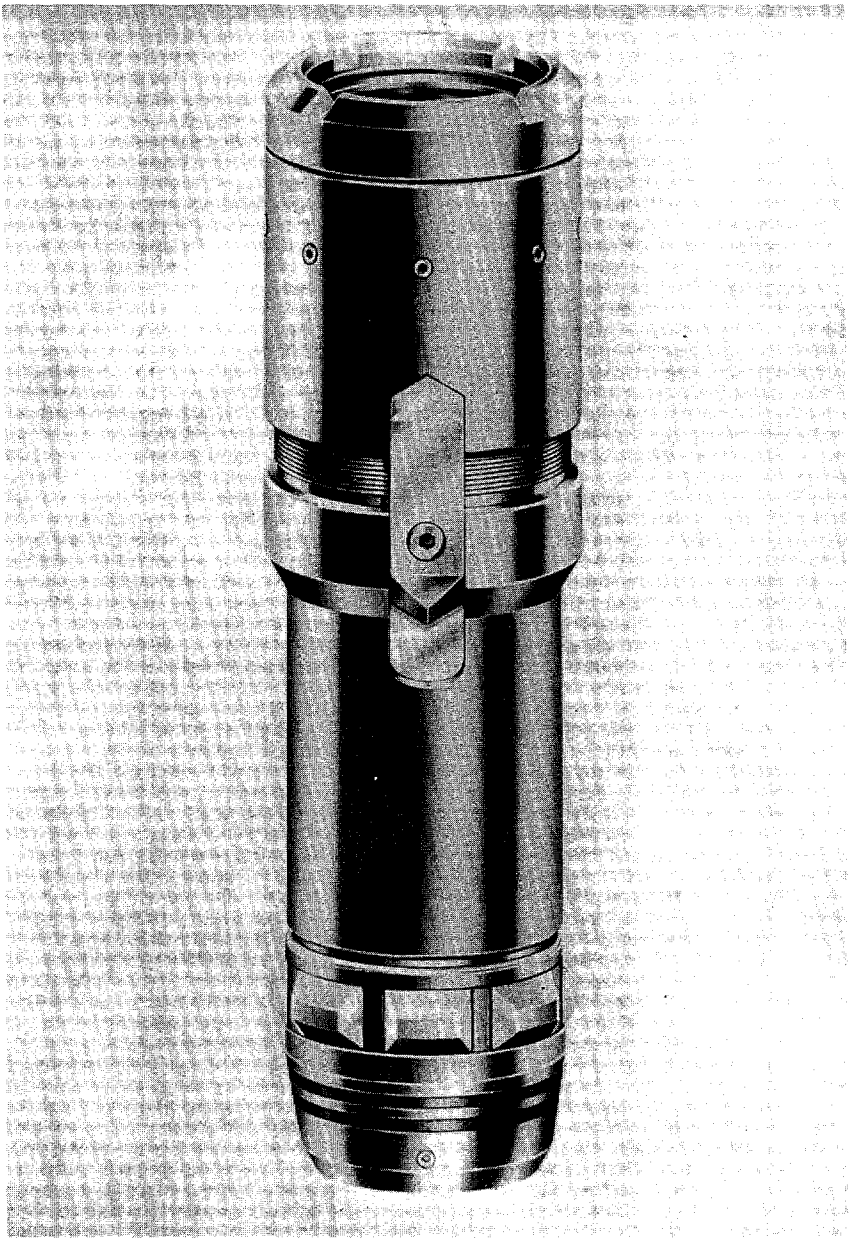
SEAL ASSEMBLY ON HANGER BODY
FIGURE 9



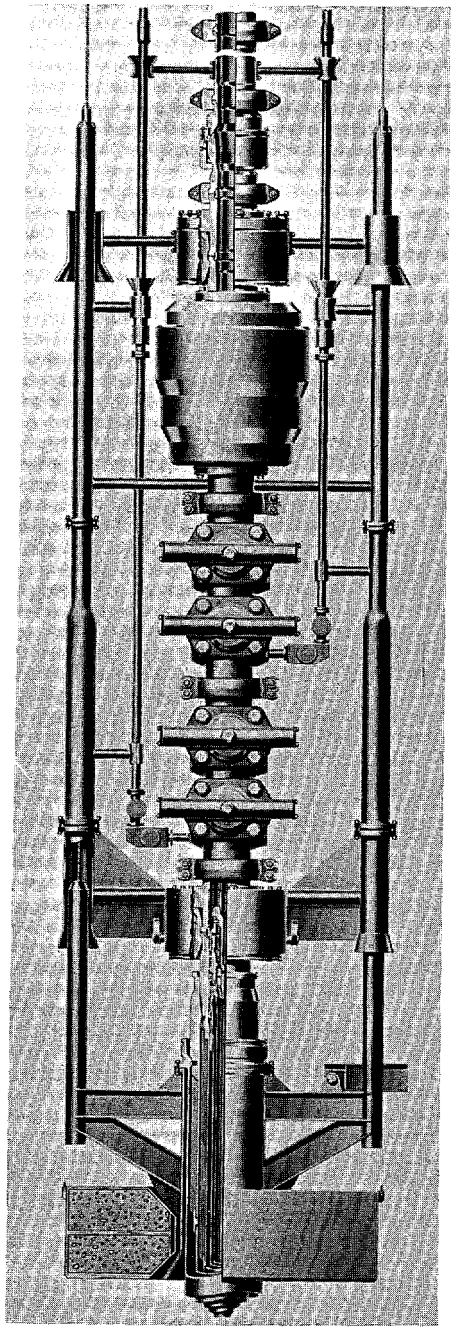
SEAL ASSEMBLY RUNNING AND TESTING TOOL
FIGURE 10



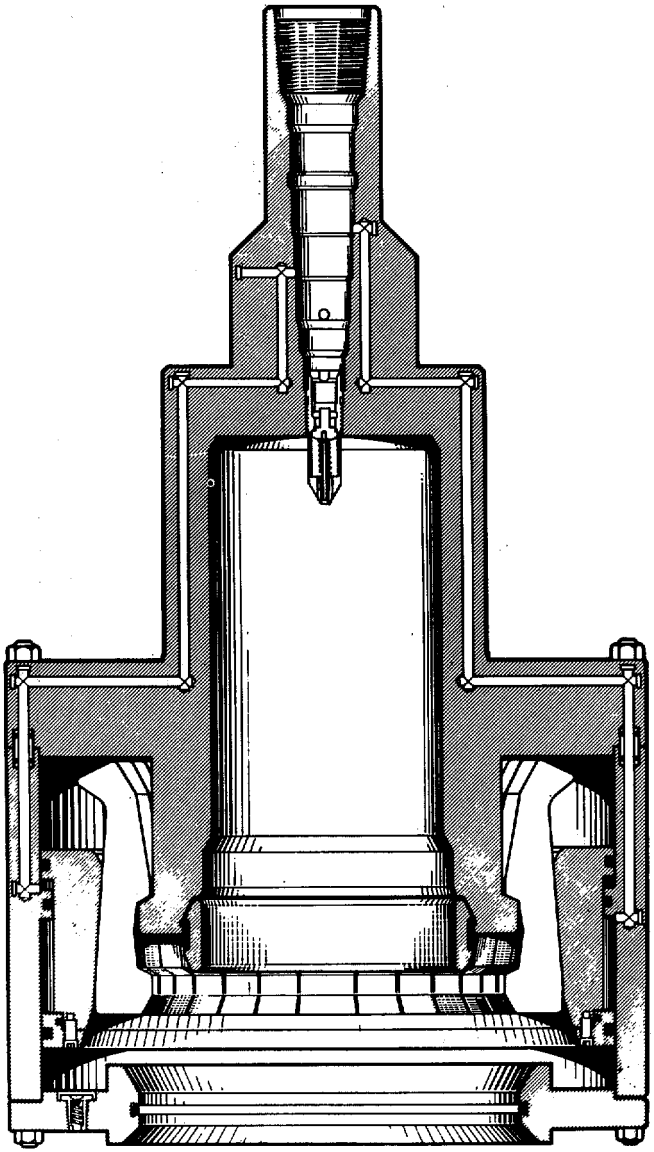
EMERGENCY SLIP AND SEAL ASSEMBLY
FOR CASING
FIGURE 11



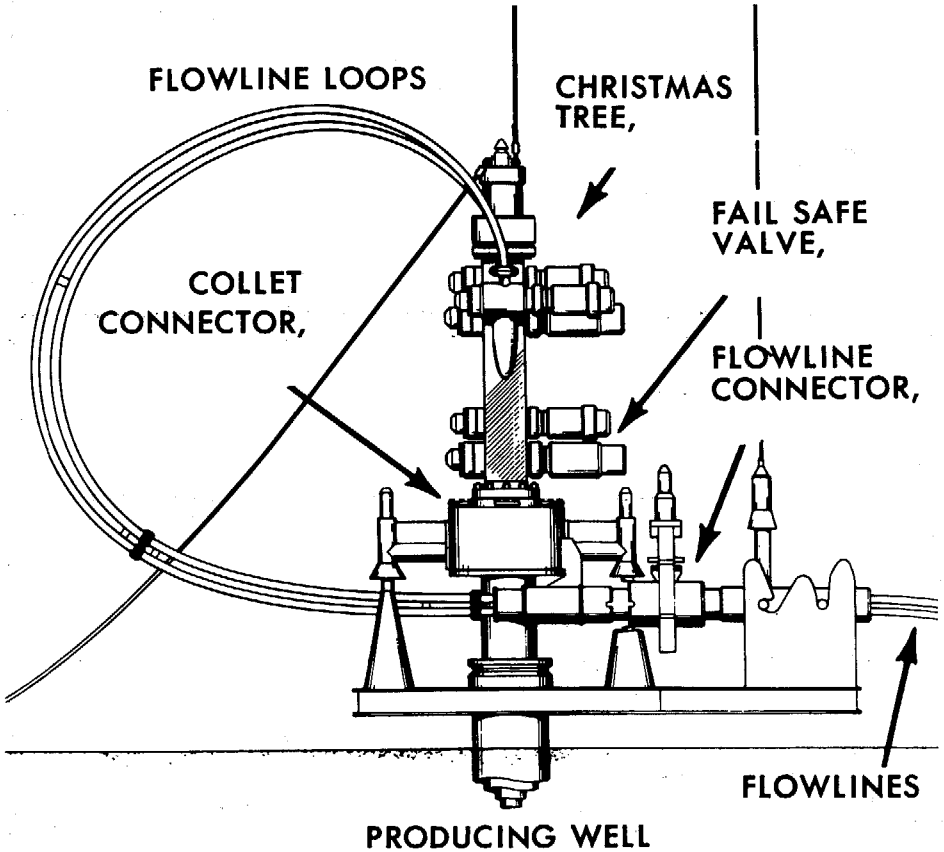
TUBING HANGER
FIGURE 12



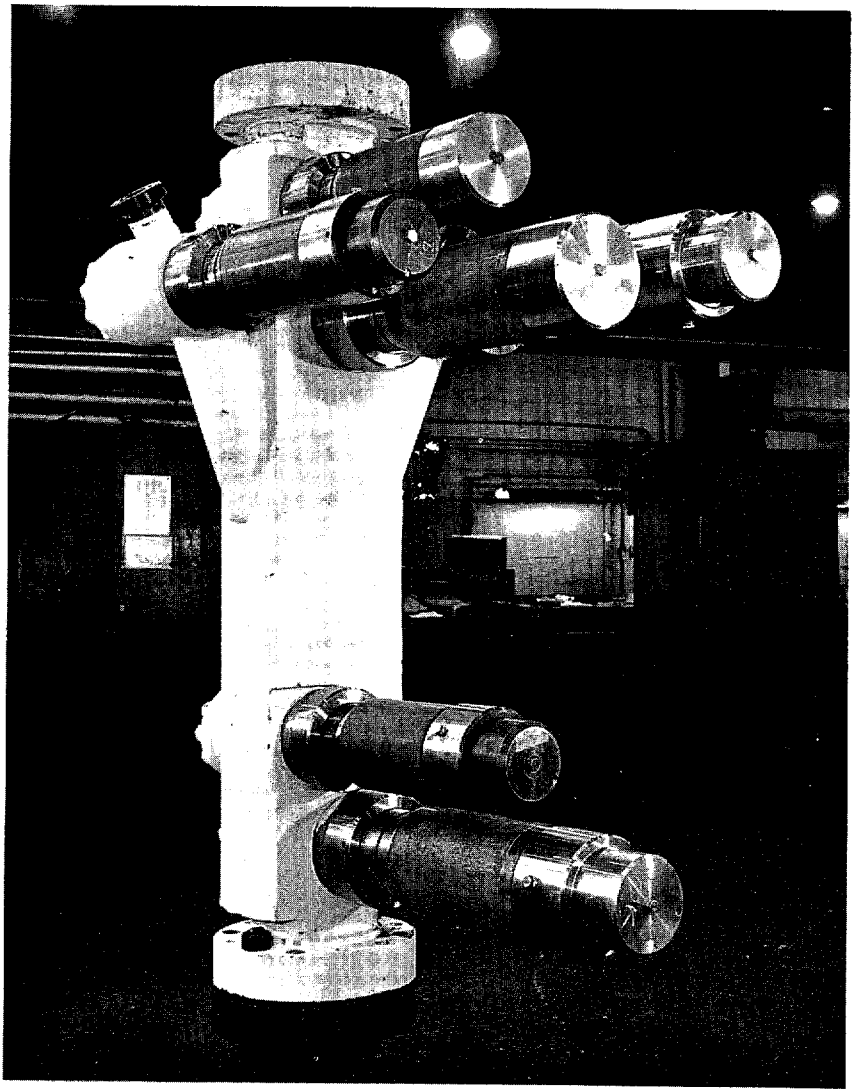
DRILLING STACK-UP
FIGURE 13



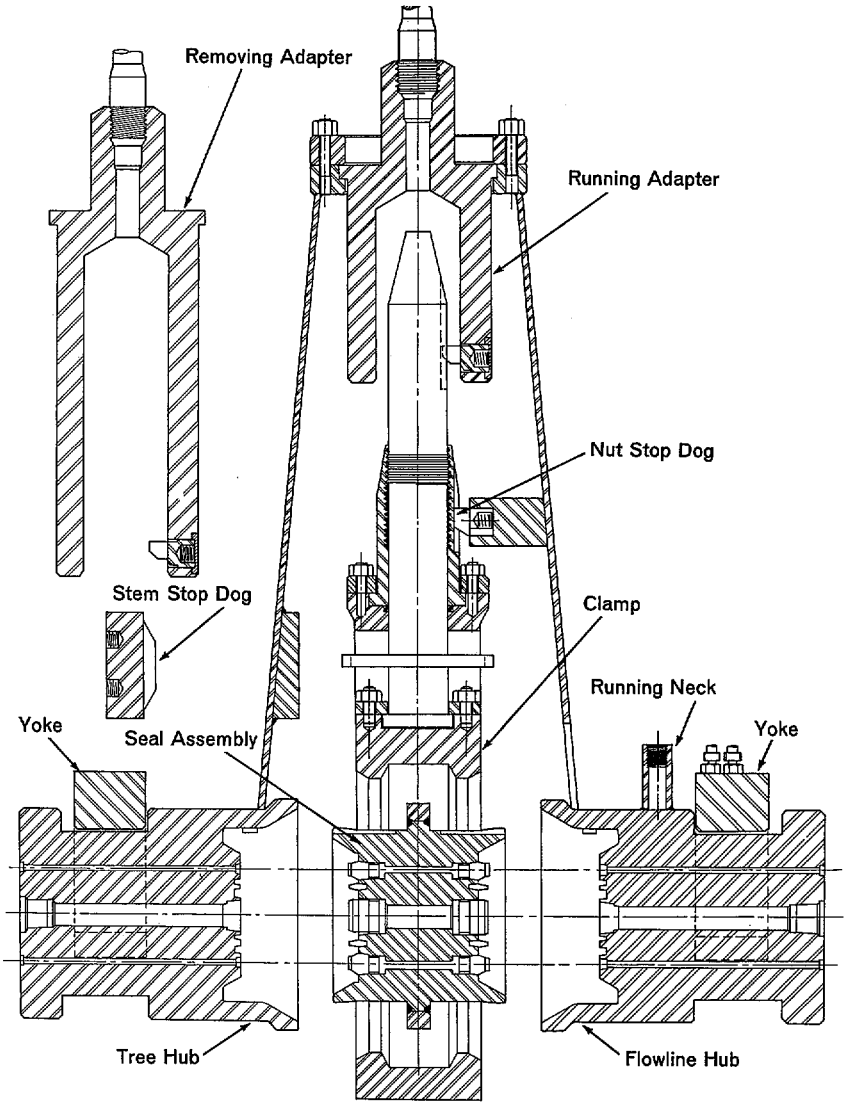
HYDRAULIC CAPPING PLUG
FIGURE 14



PRODUCING WELL
FIGURE 15



BLOCK TREE VALVE
FIGURE 16



FLOWLINE CONNECTOR—READY TO ACTUATE

FIGURE 17

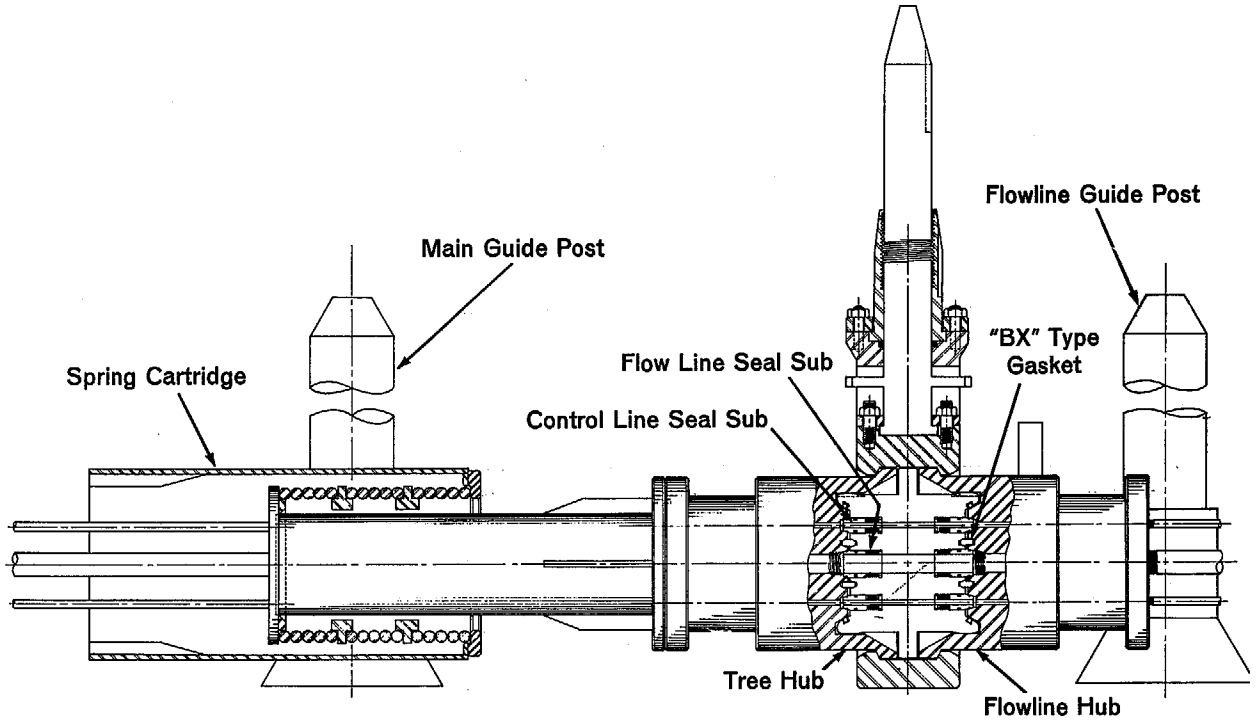


FIGURE 18
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FLOWLINE CONNECTOR—WITH RUNNING FRAME REMOVED

TELEMANIPULATOR SYSTEMS

FOR

DEEP-SEA OPERATIONS

by

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Abstract

"Telemanipulator Systems" (TMS) is suggested as a generic term for systems to accomplish manual tasks at or near the sea floor. All such systems provide man with mechanical aids and protective structures appropriate to the environment and the task.

Divers using power tools are telemanipulator systems; so are manned submersibles equipped with external manipulators. Fully-remote (telechiric) systems may be considered to be a class of TMS.

The three classes of TMS are complementary and arise from a common technology.

Examples of telechiric systems now in use are presented, and guiding principles to aid in the selection of TMS for specific situations are outlined. The application of TMS to realistic sea-floor oil-field situations is illustrated.

Introduction

Operations on the sea-floor are gradually superseding operations from the surface of the sea for many scientific, military, and economic activities. The oceanographic scientist can often study the flora and fauna, the geology, the chemistry, or the physics of the ocean more effectively from a base located on the sea-floor than from the classical oceanographic vessel. Some aspects of the Navy's task of protecting our country from enemy submarines can logically be done by means of bottom-mounted equipment. As the oil industry moves toward deeper water, a trend toward installing part or all of their production facilities on bottom becomes apparent. Freedom from troubles associated with weather motivates this move; as an unexpected bonus, one usually finds it less expensive to install a production facility on the bottom in very deep water than to build a stationary platform extending above the surface.

The "deep-sea operations" of the title are those associated with installing, operating, and maintaining sea-floor facilities and installations. The operations involved are in large part independent of the nature and purpose of the facility; things must be lifted, pushed, turned, and joined. All of the opera-

tions of construction and maintenance labor must be preformed in the hostile environment of the sea.

The term "telemanipulator systems" or TMS is proposed as a generic term for systems to accomplish deep-sea operations as just defined. All of these systems are manned. They differ in the location of the man and in the complexity of the power operated mechanical aids and sensory assists which he is provided.

The simplest possible telemanipulator system is a diver with hand and/or power operated tools. The most complex is a fully remote, mobile system with manipulators and TV's. Small submarines equipped with external manipulators are telemanipulator systems, as are remote-controlled earth-moving machines for site preparation.

A special kind of TMS is the "robot" or fully-remote manipulator. The distinguishing feature of these systems is the complete physical separation between the operator and the work; his only connection is by an electrical communication link. These systems may be referred to as "telechiric", from the Greek words meaning "distant hand".

Telechiric systems must not be confused with automatic systems (these also are sometimes called "robots"). Telechiric systems are manned; automatic systems are not. Semi-automatic systems are fairly common, in which the operations are pre-determined but an operator can control the timing of each.

Armed with these definitions, let us look at a few examples of TMS. Telechiric systems will be emphasized, since they are neither common nor familiar. After discussing the examples, we will look at some of the operations which TMS will be required to perform, and at the way in which the complex TMS which will be required to fully develop the deep ocean's resources may evolve. Finally, the pros and cons of each of the three types of TMS will be noted as an aid to the system engineer.

Examples of TMS

There are three basic categories of TMS:

power tools and aids for divers
external manipulating and/or sensing systems for DRV's
telechiric systems

The simplest TMS are power-operated aids for divers, such as wrenches or drills to aid in manual tasks and such as wet-subs to give the diver improved mobility.

Some of the diver's power tools can also be used by manipulator-equipped submersibles. Figure 1 is a familiar example of a DRV (Deep Research Vehicle); you all recognize Alvin, typical of the several research and work submarines now operational. The hull and propulsion system provide a base on which to mount the "arm"; the maneuverability of the hull is an integral part of the manipulating capability of the vessel. External TV may be used to augment vision through the portholes; sonar is helpful in dark or dirty water. These things taken together, the hull and propulsion, the "arm", and the TV and sonar constitute a TMS in which the man is encap-

sulated in a protective shell.

Telechiric systems come in many shapes and sizes. The earliest underwater example of a telechiric system in the RUM, built at Scripps in 1959. Figure 2 shows this vehicle on the beach. RUM (Remote Underwater Manipulator) is a bottom-crawling vehicle equipped with a general-purpose "arm" and with four fixed TV cameras. The operator is at a control console in a trailer on the beach; the cable is five miles long. RUM is obviously limited to hard sea-floor regions and to simple tasks such as placing instruments on the sea-floor. Experience with RUM verified the soundness of the concept, and the need for much more engineering development of components.

Figure 3 is a photograph taken in 1961 of a telechiric system to complete oil wells on the sea-floor without requiring intervention by divers. The well-head and the manipulator were designed as a system, to minimize the total cost. Since there will be many well-heads and few manipulators, the well-head was made as simple as possible and the manipulator as complex as necessary.

The operation of the system is shown in Figure 4 (a drawing, since photography of large-scale scenes in deep water is very difficult). The manipulator is suspended from a surface vessel, lowered to proper depth and guided to the well-head by the operator. Two marine screws maneuver the unit; sonar, television, a gyrocompass, and a hydrophone provide him with sensory data. After the remote unit is landed on the track on the well-head, hydraulic cylinders move a torque wrench vertically, azimuthally, and radially to engage with any one of a number of screws which hold the well-head sections together. This system will work in water up to 1000 ft. deep.

The man who operates the system is in a cabin in the interior of the support vessel on the surface. The safety and comfort of the operator, the ease of changing shifts, and the accessibility of the control desk to supervisory and personnel are advantages in this (or any other) telechiric system.

This telechiric well-completion system has been in fairly continuous use on the West Coast since 1961. It has been re-built a number of times, but the original concept is retained. The term "robot" sometimes applied to this system is a misnomer; this is a manned system and has no pre-determined programs or computers associated with it. It is better regarded as a very complex tool whose user may be several hundred feet away from the work site.

A telechiric system for recovery of experimental torpedoes is shown in Figure 5. Called "CURV" (Cable-controlled Underwater Research Vehicle), the remote unit is mobile in three dimensions and equipped with a grasping device matched to the torpedo to be recovered. TV and sonar are used to locate the target. After the grasping device is attached to the target, it is ejected from CURV and the target hoisted aboard by a separate line. CURV can work to 2000 ft. and recover payloads to one ton. Developed and used by NOTS-Pasadena, CURV has been successfully recovering torpedoes for some years.

A telechiric system without a cable has been developed at the Applied Physics Laboratory at the University of Washington, Seattle, Washington. Figure 6 shows this carrier for scientific instruments, which is commanded

to dive, turn, stop, start, and surface by coded sonar pulses.

In future, much more versatile telechiric systems will be needed than the special-purpose machines just described. The successful operation of the present generation of telechiric machines in spite of limited budgets, unskilled operators, and other practical problems demonstrates that the concept of a remote tool is a reasonable one that can be reduced to practice by straight-forward engineering; and that the tools can be operated by non-scientific skilled personnel.

The future telechiric system may look something like Figure 7, which is an artist's concept of a general-purpose system with its operator controlling it from a small submarine. Such a system would do the same tasks that divers do in shallow water, with no inherent limitation as to depth or time on bottom. It would be supplemented by a fleet of other telechiric vehicles, some specialized to a specific task like the well-completion manipulator, and others designed for heavy work like an underwater remote-controlled bulldozer.

The question "Why not put a man inside?" is sometimes raised when systems like the one in Figure 7 are discussed. The question refers to the remote-controlled vehicle in the foreground, not to the inhabited vehicle in the background.

If a man were put inside the remote vehicle, it could no longer be made small, simple, and maneuverable. An openwork structure like CURV (Figure 5) would not be possible. A life-support system would have to be added; in fact, it would be a DRV, and not a system distinctly different in capability.

Why TMS?

The alternatives sometimes offered to telemanipulator systems are of two opposite kinds: the unaided diver, and the semi-automatic system controlled from the surface.

As oceanic enterprises go to deeper water, the utility of divers can only decrease. The current spectacular progress with mixed-gas diving has extended the practical limit at which a diver can do economically useful work to 300 ft. or more, and this figure is certain to increase. A large fraction of the continental shelf is already accessible to divers. Power-operated tools and devices can increase the productivity of a diver at any depth, by reducing the demands on his large muscles and using him primarily as a set-up man and observer. Diver power tools are a simple form of telemanipulator system; as divers go deeper, their ability to do muscular work decreases, and the value to them of telemanipulator systems increases.

Thus we see that the diver is not an alternative to a TMS at all; to the contrary, he is a user of them.

To examine the second alternative to TMS, the semi-automatic surface-controlled system, let us consider a simple, but completely typical example. Valves with handwheels are common in oil-fields, whether undersea or not; and the handwheel must be turned from time to time. Minor maintenance of the valve body must be accomplished on a pre-planned schedule.

If the water is not too deep, a diver can accomplish these tasks, aided perhaps by appropriate tools. The obvious alternative is to apply a hydraulic or electric motor to the valve, controlled from a shore point or a surface vessel, so that the valve can be opened or closed at will. Valves can be actuated in this fashion at any depth -- so one may well ask, "Why TMS?".

One reason is cost. Valve motors are expensive, and a typical oil production facility may have several hundred of them within a small area. Only one telemanipulator system is needed (as long as only one valve needs to be turned at a time) in the area; and quite a complex TMS can be built for the cost of a few valve motors and their associated control lines. Each case is different, of course, but very often the TMS offers a decisive advantage.

The second reason is maintenance. Any TMS is movable and can be brought to the surface for maintenance and repair. The valve motor, in contrast, is integrated into the valve; maintenance of the valve motor and the valve body must be performed on site, and a TMS is necessary to accomplish it.

The third reason arises from the inevitable malfunctions and accidents. Most valve actuators provide a manual over-ride to use in case of malfunctions; a TMS enables one to actuate the manual over-ride at the bottom of the ocean.

These three reasons apply to any more complex surface-controlled components; another example is the "diverless" well-heads now being offered by a number of manufacturers. A cost comparison may favor this type of well-head, depending on the number of wells in the field and the depth of water. But even if a "diverless" well-head is selected, TMS must be available for routine maintenance and for coping with the inevitable malfunctions. The problems of re-entering the well becomes simple if TMS are available.

Selection of TMS

Preliminary guidelines to aid in selection of a TMS for a particular situation can be stated. Some may disagree with these; and experience will certainly alter and refine them. Depth of water and task complexity are the principal criteria.

The three types of TMS, as one would expect, have fields of application which overlap but are distinguishable.

Divers with power tools

When the water is not too deep, these should always be selected. As water depth increases, the diver's muscular capability decreases and the complexity of tools that he can use with good economy increases. Tools can be small and simple or large and complex, depending on the task. For tasks requiring more than a few hours to complete, the divers should be provided with a supporting base to which they can return for rest periods while remaining under pressure. Several variations on the diving bell principal are in use to meet this need.

DRV's with external aids

A DRV can operate at much greater depth than a diver; its principal value is as a platform from which to make visual observations. A DRV is of necessity fairly large; it is difficult to make its life-support capsule less than 6 ft. OD. This large, un-maneuverable structure makes a rather unsatisfactory platform on which to mount a manipulator. The control systems for the vehicle and for the manipulator must be integrated if complex manipulatory tasks are to be performed. It may be unduly hazardous, both to the DRV and to the structure to bring the DRV very close to a fragile structure like an oil-well.

Performance and time-on-bottom of DRV's are limited by their on-board power. They are most economical for missions lasting a few hours. Surprisingly, divers in deep water are most economical for missions lasting several days, since the cost of travel to the site and the decompression penalty are almost independent of the time-on-bottom.

Telechiric systems

Sometimes called "remote-control systems", "robots", or "universal manipulators", these systems are best thought of as very complex tools operated by a man at a considerable distance from the work site. They are sometimes called "unmanned" in contrast with DRV's which are "manned". This is a misconception. Both systems are manned; the difference lies in the location of the man.

Telechiric systems are most valuable in very deep water, where divers or even DRV's cannot go. The occupation and development of the very deep ocean will be done by telechiric systems if it is done at all.

Even in shallow water, telechiric systems are valuable for hazardous work or work too heavy for an unaided diver. Telechiric systems are expensive today, since they are made one-at-a-time; but they are not inherently costly. As acceptance of remoted systems increases, it will be possible to reduce their cost and thus reduce the depth at which a telechiric system is more economical than a diver with power tools and support equipment.

The TV, sonar, and other sensors of a telechiric system are constantly available to supervisory and technical observers. Sometimes this feature is valuable, as contrasted with the need to depend on second-hand, delayed reports from DRV crews or from divers.

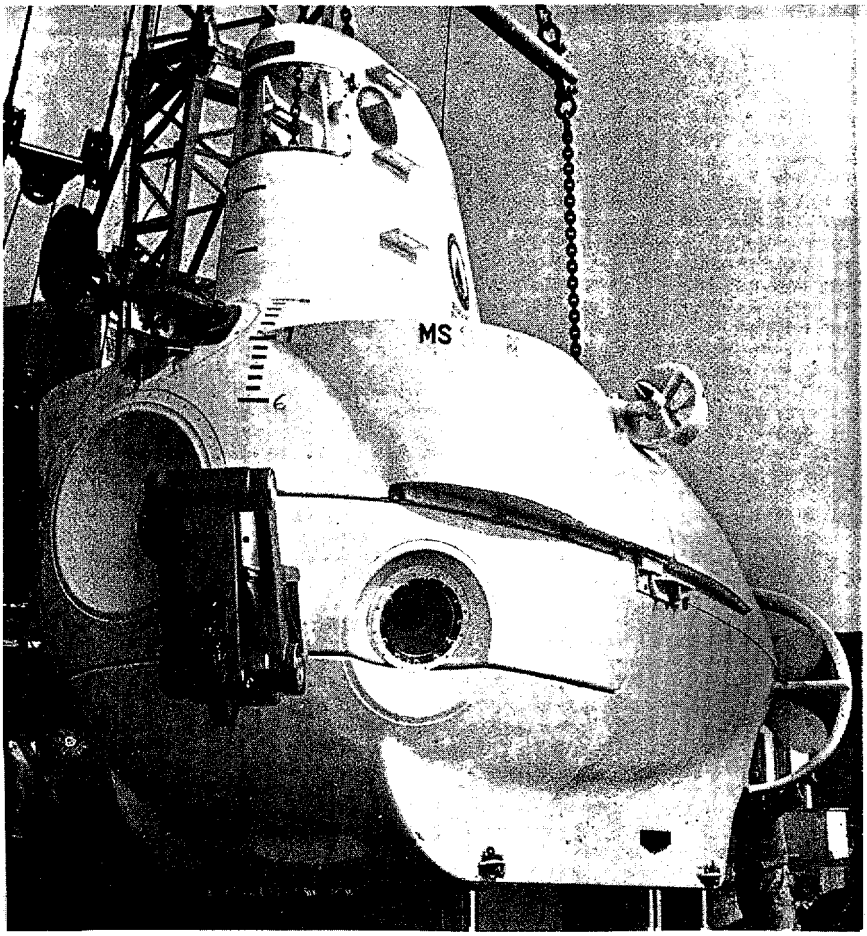
Conclusions

This paper will have served its purpose if the simple point that divers, DRV's and "robots" are complementary rather than competitive can be accepted.

A coherent engineering discipline is identified as one studies TMS. The performance of underwater tasks requires actuators and sensors. These may be used by divers, attached to the exterior of DRV's, or integrated into telechiric systems. This new, nameless discipline will probably become a major sub-classification of the equally new subject of ocean engineering.

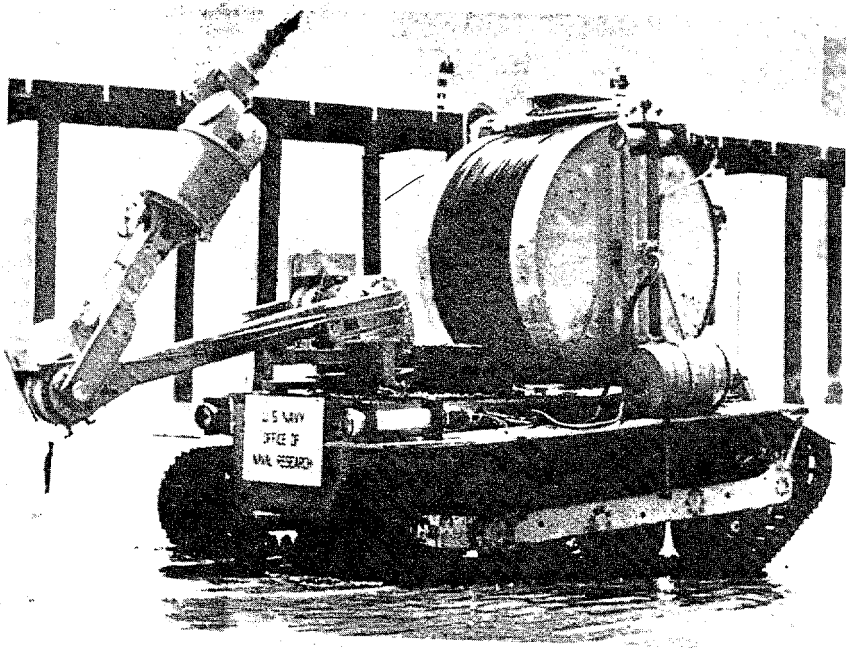
The designer of deeper-water systems must needs be well informed of the advantages and the disadvantages of each type of TMS, so his overall system will be economical.

The conclusion, then, is, "There is no one best way; but it can be done!".



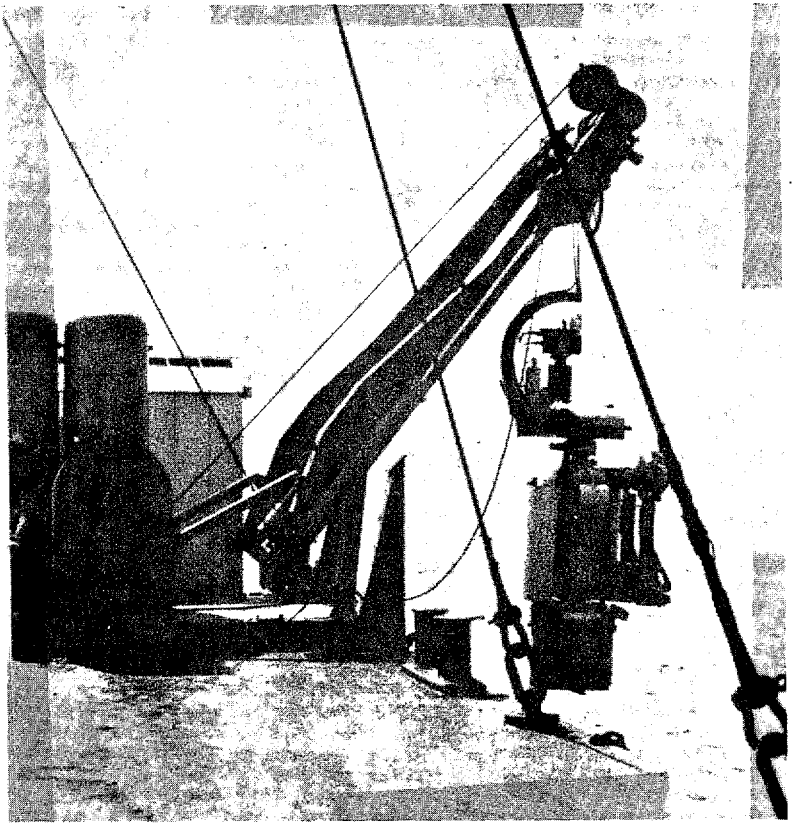
Alvin, a typical DRV with external manipulator

Figure 1



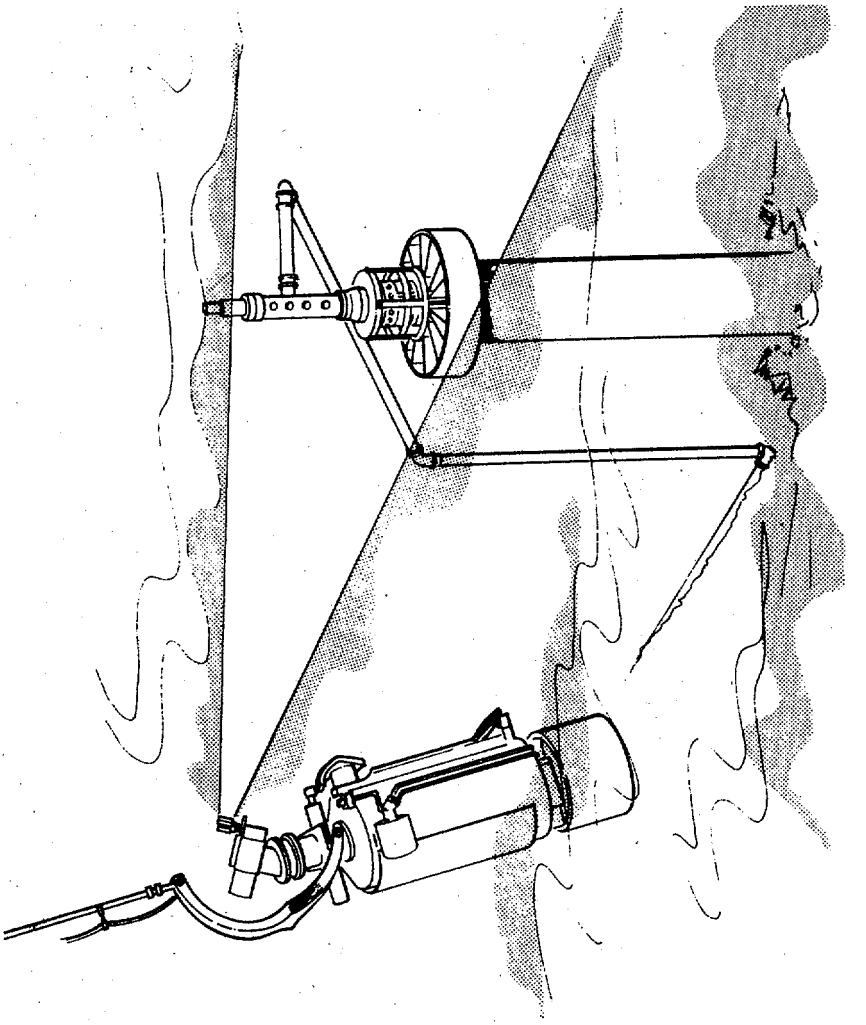
RUM, a bottom-crawling telechiric system

Figure 2



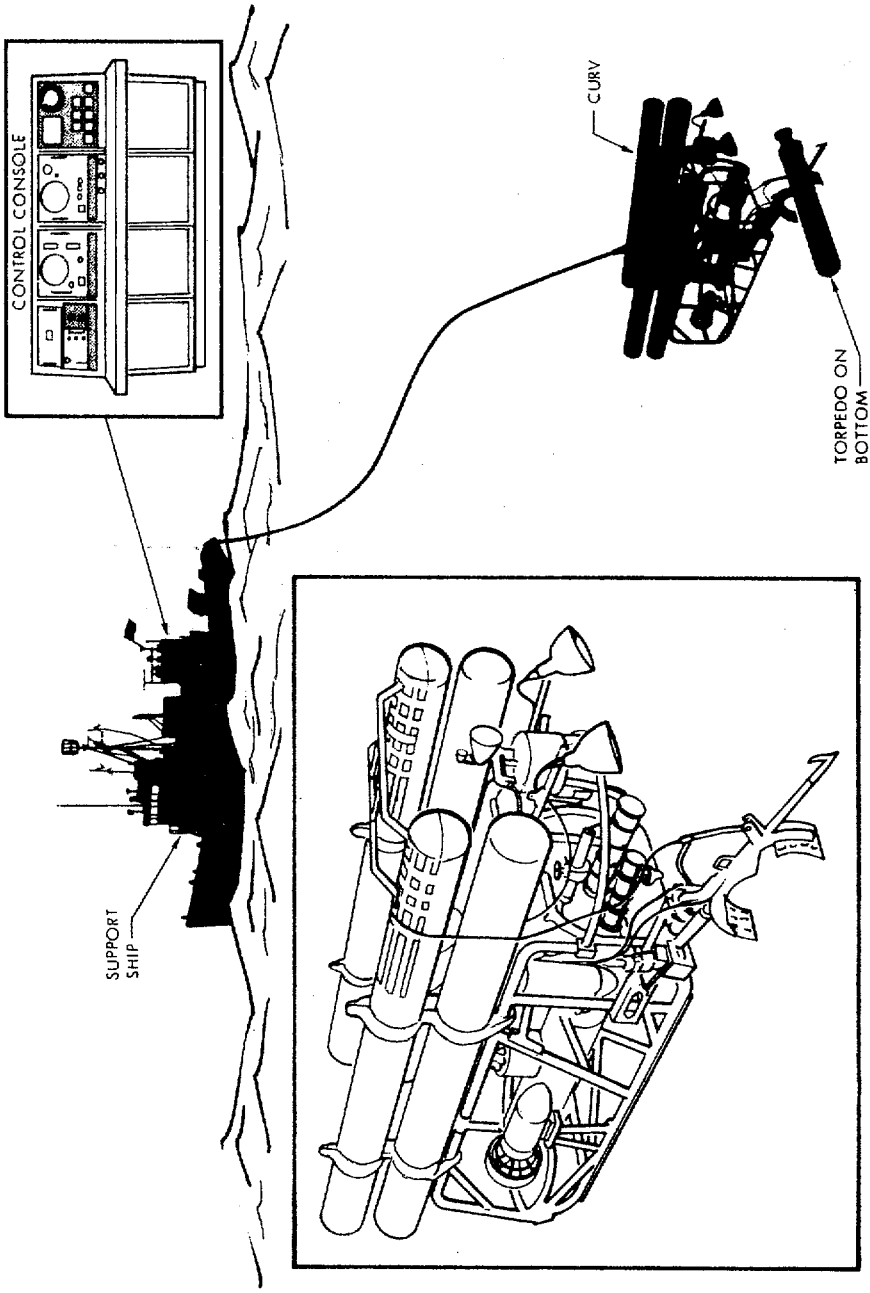
a telechiric well-completion system
operated by Shell Oil Co.

Figure 3



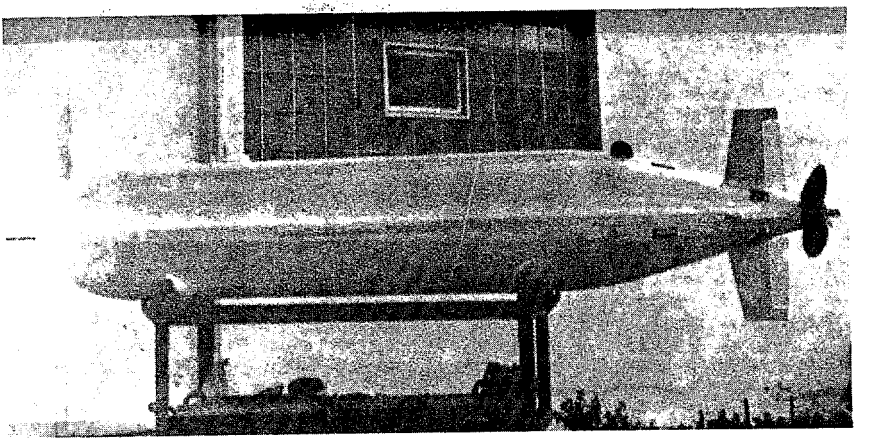
well-completion system in action

Figure 4



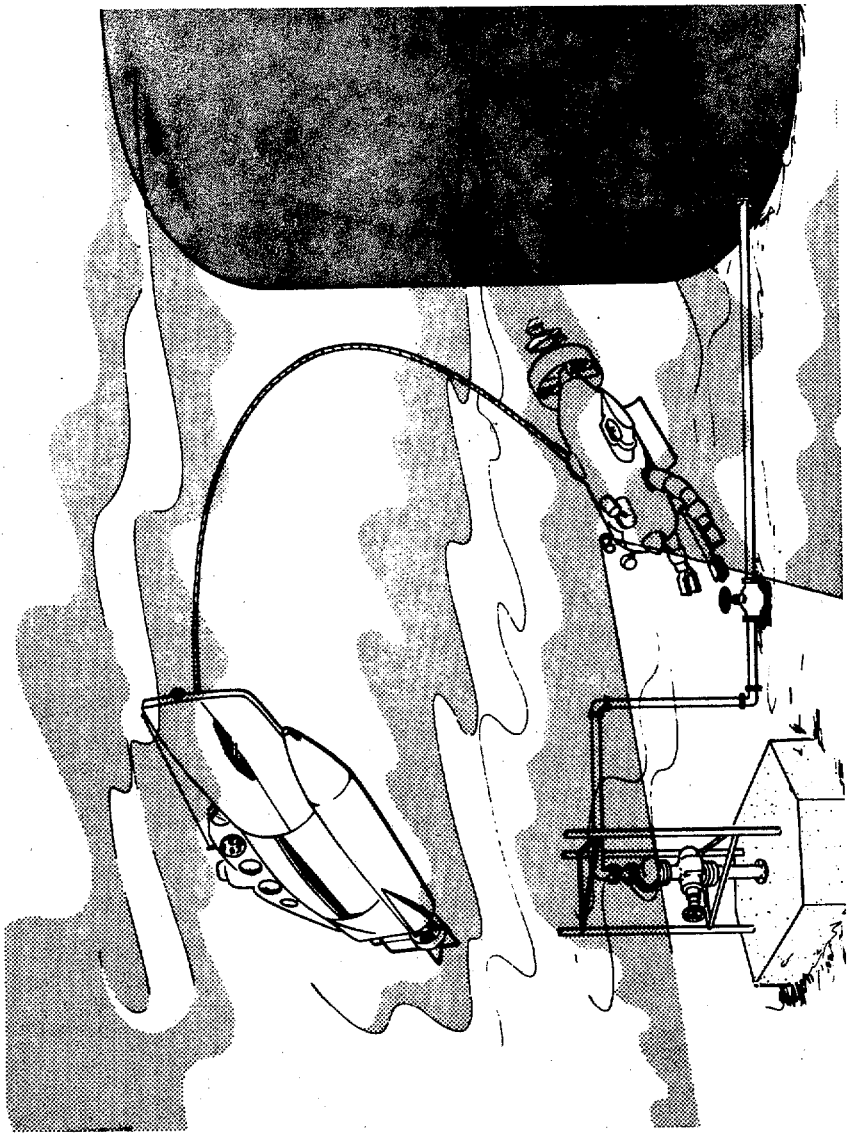
CURV, a telechiric object-recovery system

Figure 5



a sonar-commanded telechiric instrument carrier

Figure 6



Artist's concept of a future telemanipulator system at work in a sea-floor oil field

Figure 7

UNDERWATER PIPELINES

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Abstract

A review of present day technology for the design, construction and maintenance of underwater pipelines is presented. Typical pipeline projects both existing and planned are described which illustrate technical feasibility over conditions ranging from shallow and protected inland waters to deep and exposed offshore locations. Details of current pipelaying methods, various design aspects and maintenance problems are given in the paper.

INTRODUCTION

Pipelines are used extensively to transport gas and liquid hydrocarbons from well head to market. In recent years oil and gas production has moved into offshore areas thus bringing about an increased demand for underwater pipelines.

The technology of subsea pipelines is relatively new and each additional line built adds to our knowledge and confidence making it possible for new projects to move in the direction of deeper water, larger diameters, and longer lengths.

The purpose of this paper is to outline the present state-of-the-art of underwater pipelines including pipelaying methods and the principal design and maintenance aspects. In order to simplify discussion, pipelaying methods have been classified into four general categories: (1) Bottom Pull; (2) Flotation; (3) Reeled Pipe; and (4) Lay Barge. Details of each method along with illustrative projects are given below.

BOTTOM PULL METHOD

The pipe is fabricated onshore into one or more long sections, launched into the water, and then pulled along the bottom with a winch to its final position.

A special launchway is built consisting of a graded working area and dollies mounted on a track to handle the pipe. The pulling winch is located either at the far shore or on a barge firmly anchored into position. Space requirements at the launchway often are such that the line must be divided into a number of separate sections with the pull interrupted for tie-ins as required. Refer to Figure 1 for a diagram showing the method.

The length of the pull is limited by the power of the winch, the allowable pipe tension and the weight of the line. The weight in water can be reduced with pontoons, but too little negative buoyancy subjects the pipe to movement from currents and waves. The method is widely used for narrow water crossings and relatively short pipelines from the coast line to offshore facilities.

Selected projects illustrating the bottom pull method are:

1. Mackinac Straits[1]

In August 1953 two 20,000-foot, 20-inch lines were pulled on the bottom across Mackinac Straits in water depths up to 240 feet. The crossing located near where Lake Huron and Lake Michigan join is a vital link in the Lakehead Pipe Line Company 644-mile crude oil line from Superior, Wisconsin to Sarnia, Ontario.

Pontoons were attached to the pipe spaced at intervals to provide a negative buoyancy of approximately 6 pounds per lineal foot. All pipe in water depths up to 50 feet was laid in a ditch with no less than 15 feet of cover. In deeper water the pipe was not ditched.

Pulling was completed by a steam winch operated with a single drum which handled 1,250 feet of 2-inch cable for a single pull. Tension was maintained on the pipe with a 50-ton hold-back winch.

2. Kharg Island[2]

In 1960 19 miles of 30-inch concrete coated pipe was pulled on the bottom from Khargu Island to the mainland and then 3 miles from Khargu Island to Kharg Island in the Persian Gulf in water depths up to 160 feet. The crossing is part of a 99-mile pipeline installed by the Iranian Oil Exploration and Producing Company to carry crude oil to a sea loading terminal at Kharg Island.

A winch barge was used to pull the line from the launchway located on Khargu Island where the pipe was made up in 4,000-foot sections. A hold-back winch was used to maintain the correct tension.

The pull barge was kept on line with theodolites located on 86-foot towers.

FLOTATION METHOD

The pipe is fabricated at an onshore launchway into a number of long sections with pontoons attached for buoyancy. Each section is launched into the water and towed into position as a floating string. A tie-in barge holding one end of the previously laid section connects the arriving string. Pontoons are systematically released to lower the pipe to the bottom. The process is repeated as necessary until the line is complete. Refer to Figure 2 for a diagram showing the tie-in operation.

The flotation method overcomes the limitations of length inherent in the bottom pull method but is highly vulnerable in only moderate seas. The widest use of the method is for long lines in protected waters.

Selected illustrations of the flotation method are:

1. Corpus Christi Bay[3]

In 1956, 60,000 feet of 10-inch concrete coated line was laid across Corpus Christi Bay in water depths of about 15 feet. The pipeline transports natural gas from the Humble Oil and Refining Company's Flour Bluff gas supply south of Corpus Christi to the Reynolds Metals Company plants at LaQuinta, Texas.

Fifteen 4,000-foot sections were made up on a shore launchway with pontoons and towed into position across the bay. As each pipe section neared location, certain pontoons were released to allow it to rest lightly on the bottom. Tie-in welds were completed with an anchored "sideboom" barge that lined up the pipe and supported the ends of the two pipe sections.

2. Mediterranean Crossing[4]

Gaz de France plans a 100-mile, 9.6-inch pipeline across the Mediterranean from Mostaganem, Algeria to Cabo Palos lagoon in Spain in water depths up to 8,800 feet. The crossing would be a segment of a proposed 1,625 mile pipeline to transport natural gas from Hassi R'Mel in Algeria to Western Europe.

The pipe will be extremely high strength steel in the range of X-80 to X-95 with a wall thickness of 0.433 inch and screw type connections.

The line will be assembled on shore in 2.6 mile sections and towed out to sea with floats set to hold the pipe at a depth 45 feet below the surface. A tie-in vessel will connect the towed section and special breathing buoys shall give the pipe buoyancy when being lowered into the water.

The breathing buoys contain a bladder filled with air which slowly collapse with increased water depth thus gradually reducing buoyancy as the pipe sinks.

REELED PIPE METHOD

The pipe is fabricated into a continuous length and spooled onto a large diameter reel at some convenient location prior to installation. The line is laid by simply unspooling the pipe from a moving barge or vessel in much the same manner as a cable. Tension is used to limit the sag in the pipe while being laid, especially in deeper water. Refer to Figure 3 for a diagram showing the method.

Advantages are that the line can be tested in advance and then laid at rapid speeds. In current practice the method is limited to small diameter pipe and relatively short lengths that can be handled on a drum.

Selected projects illustrating the reeled pipe method are:

1. Operation Pluto[5]

During World War II twenty-one separate pipelines were laid across the English Channel to supply the Allied Armies in France with more than 1,000,000 gallons of petroleum products a day. The code name "Pluto" was coined from the initial letters of "Pipe Line Under the Ocean".

Two different systems were used: (1) Hais, a 3-inch lead cable armored with steel tape and wire and installed in the manner of a submarine telephone or power cable; and (2) Hamel, a 3-inch steel pipe coiled on drums and installed with a floating reel.

In August 1944 two Hais cables and two Hamel pipes were laid from the Isle of Wight to Cherbourg--a distance of 70 nautical miles--in water depths up to about 30 fathoms or 180 feet. After the Allied advance had pushed beyond the Calais area in France, eleven Hais cables and six Hamel pipes were laid from Dungeness to Boulogne--a distance of about 30 nautical miles.

2. West Delta Block 70 Field[6]

In 1964 the CATC Group installed one mile of 6-inch pipe between two platforms in the West Delta Block 70 Field in Offshore Louisiana. The pipe was coated with extruded polyethylene, reeled on a 40-foot drum and laid in a water depth of about 140 feet.

A specially designed reel barge was used with huge straightening rollers to take the bend out of the pipe before it slipped into the water. Laying speeds up to 100 feet per minute were recorded.

LAY BARGE METHOD

The pipe is fabricated on a barge specially designed and fitted with multiple welding stations set up to handle the pipe in an assembly line manner. The barge advances periodically and each joint progresses through the several stages of welding, radiography and coating and then into the water where it trails from the barge to the sea floor.

A ramp extending at a controlled angle from the barge almost to the bottom which is called a "stinger" is used in deep water to limit the sag in the pipe. A deep water lay barge is usually positioned by the use of a number of anchor lines. As the barge advances, tugs move the anchors forward one at a time. Since only a small amount of pipe can be stored on the lay barge, a continuous train of pipe barges is needed to maintain the operation. Refer to Figure 4 for a diagram of the method.

A typical deep water lay barge is shown in Figure 5 and the welding stations in Figure 6.

The advantages of the method are: (1) length is not a limiting factor; (2) large diameter pipe can be handled with modern barges; and (3) operations are possible in open seas and relatively deep water.

Selected projects illustrating the lay barge method are:

1. Eugene Island Block 126 Field[7]

In 1954-1955 Magnolia Petroleum Company installed 48 miles of 12-inch concrete coated line from the coast of Louisiana to Block 126 Field via Block 45 Field in the Eugene Island offshore area.

Pipe was installed with a shallow water lay barge between the shore line and Point Au Fer Reef in water depths from 0-8 feet. A deep water barge was used from the reef to Block 126 Field in water depths ranging from 8-36 feet.

All pipe was ditched to provide a minimum cover of 3 feet. In the vicinity of the shore line the pipeline was buried to a depth of 15 feet below mean low gulf level.

2. Red Snapper Pipe Line[8]

The Red Snapper Pipe Line Company has applied for an FPC certificate to install 285 miles of 30-inch line in Offshore Louisiana which would consist of a main header paralleling the coast 75 miles offshore in water depths from 110-150 feet and two widely separated shore lines to onshore terminals located in Vermillion and Terrebonne Parishes.

The line would transport gas and liquid hydrocarbons in two-phase flow from various fields in the offshore area. Spheres shall be inserted periodically to clear the line and keep the liquids moving smoothly.

Lateral lines from the producing fields to the main pipeline shall connect at five platforms located at intervals along the system and at intermediate underwater valve stubs installed during original construction.

It is anticipated that the bulk of the pipe shall be installed with a deep water lay barge.

PIPE BENDING STRESS

In the design of underwater pipelines, bending stress is frequently a controlling factor. Since steel pipe assumes the shape of an elastic curve, analysis can be made by ordinary beam theory methods.

A simple but very useful way to measure bending stress is in terms of pipe curvature. The maximum fiber stress is given by equation (1):

$$S = \frac{EC}{R} \qquad (1)$$

Where: S = maximum fiber stress, psi
R = radius of curvature, inches
E = modulus of elasticity, inches
C = distance from the neutral axis to the most remote fiber (1/2 outside diameter), inches

The bending radius and stress for various diameters of steel pipe are shown in Figure 7. Establishing a safe profile for the bottom pull method or the overbend at a lay barge are examples where the radius of curvature provides a good design criteria.

For some situations, however, it is not convenient to measure stress in terms of curvature. A simple illustration is a pipeline resting on the bottom with one end supported a certain distance above the sea floor as shown in Figure 8. The controlling conditions are the height and the slope at the raised end of the pipe.

An analysis of the unsupported pipe span in Figure 8 can be made from the differential equation for the elastic curve which is equation (2):

$$EI \frac{d^2y}{dx^2} = M \qquad (2)$$

Where: x = distance from the left end of the beam to any section, inches
y = vertical deflection, inches
M = bending moment in terms of x, inch-pounds
E = modulus of elasticity, psi
I = moment of inertia of the section of the beam in respect to the neutral axis, inches^4

General equations and their solutions for the bending moment at any point along the pipe are somewhat involved and thus beyond the scope of this paper. Satisfactory results, however, can be obtained in many cases by making simplifying assumptions.

PIPE COATINGS

Three kinds of pipe coating are normally considered for underwater pipelines: (1) protective; (2) internal; and (3) weight.

The protective coating is used in conjunction with a cathodic protection system to prevent external corrosion and is typically an asphaltic or coal tar material as used for onshore pipelines. An internal coating is considered for cases such as transporting a corrosive product or improving capacity by reducing the pipe roughness.

Weight coating frequently consists of a concrete sheath applied to bring the pipe up to a desired specific gravity. The weight of the pipe must be: (1) heavy enough to overcome buoyancy plus any drag or lift forces that might result from currents or storm action; and (2) light enough to avoid sinking in the soil.

In offshore areas wave action on the bottom decreases with increased water depth and is just perceptible at depths equal to about one half the wave length. Since hurricane wave lengths frequently exceed 1,000 feet, wave forces should be considered up to water depths of 500 feet.

Pipelines are frequently protected against currents and wave action by burial but in some cases additional weight coating or anchors might be preferred.

A pipe trenching barge utilizing high pressure jets is shown in Figure 9. After the pipe is laid on the sea floor the trenching barge pulls a sled over the pipeline which excavates a trench with high pressure jets. The pipe settles into the open ditch and is slowly backfilled by the action of the sea.

SOIL CONDITIONS

A survey of soil conditions along the route is standard procedure. Bearing problems are associated with plastic soils and according to Prandtl[9] the maximum load which can be supported is indicated by equation (3):

$$P_{max} = 5.14\ S \qquad (3)$$

Where: P_{max} = maximum load per unit area, pounds per foot^2 (angle of internal friction = 0)

S = shear strength, pounds per foot^2

It is customary to measure the undisturbed shear strength of the soil from cores taken along the route and then set the allowable bearing load by utilizing an appropriate safety factor. If the pipe is buried, it should be observed that the soil saturated with water, may have less effective buoyancy than pure water acting alone. The soil particles may bridge and support their own weight thereby leaving only the water in the voids to contribute to buoyancy.

Pipe flotation out of the backfill can also be a problem. Under certain conditions the soil and water may be agitated creating a fluid with a buoyancy somewhat greater than water.

MAINTENANCE

Due to the high cost of maintenance work on underwater pipelines, it is usually economic to install the most trouble-free system possible even at a somewhat higher capital cost.

A pipe failure normally means that heavy marine equipment is needed to (1) dig out the line for a considerable length; (2) cut the line underwater; (3) lift each end of the pipeline out of the water; (4) weld on a new section of pipe and flanges; and (5) make up the connecting flanges underwater with divers. Such a procedure invariably results in large expense and considerable down time for the pipeline.

Improved equipment and techniques are expected to be developed in the future, however, which should tend to reduce maintenance costs.

ACKNOWLEDGMENT

The author wishes to express his appreciation to Brown & Root, Inc., Houston, Texas, for furnishing photographs of pipelaying equipment used as illustrations in this paper.

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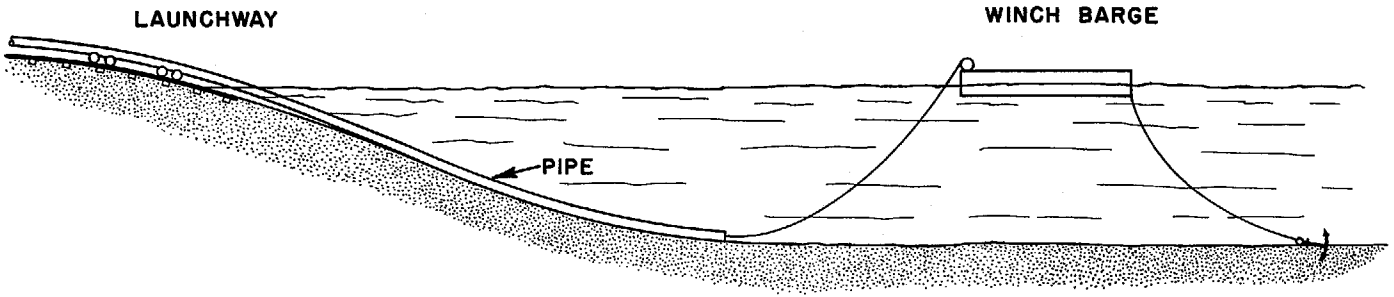


FIGURE 1

BOTTOM PULL METHOD

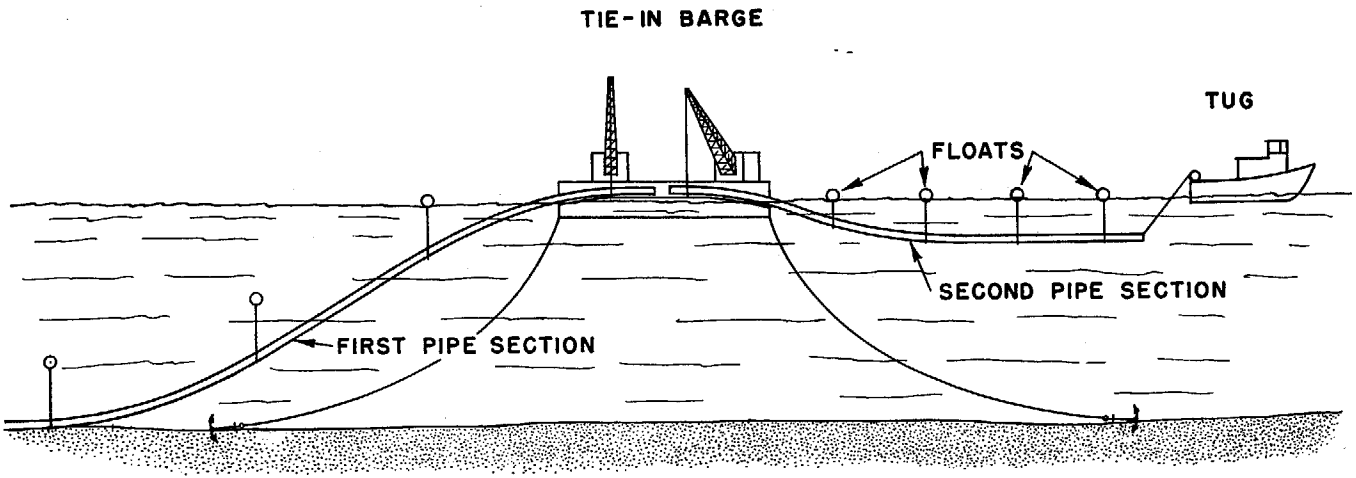


FIGURE 2

FLOTATION METHOD

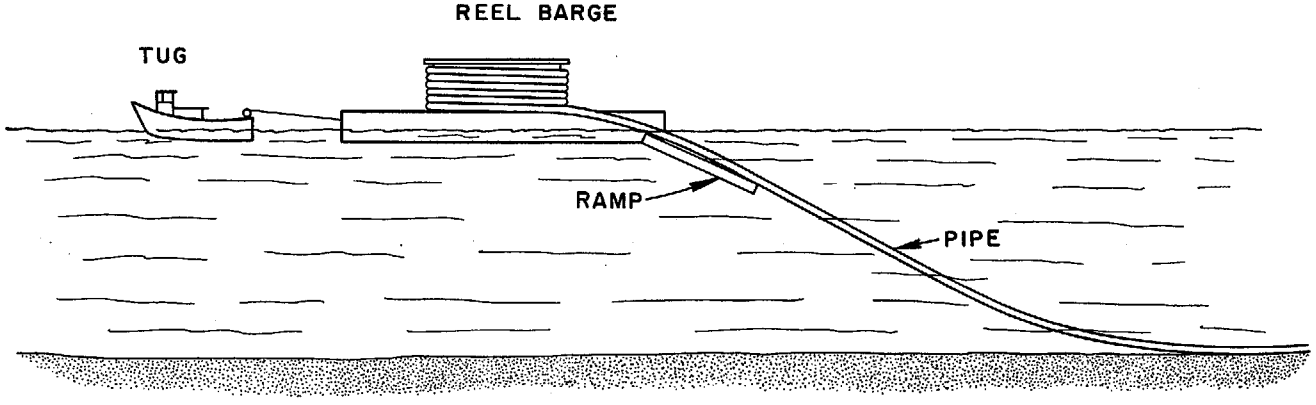


FIGURE 3

REELED PIPE METHOD

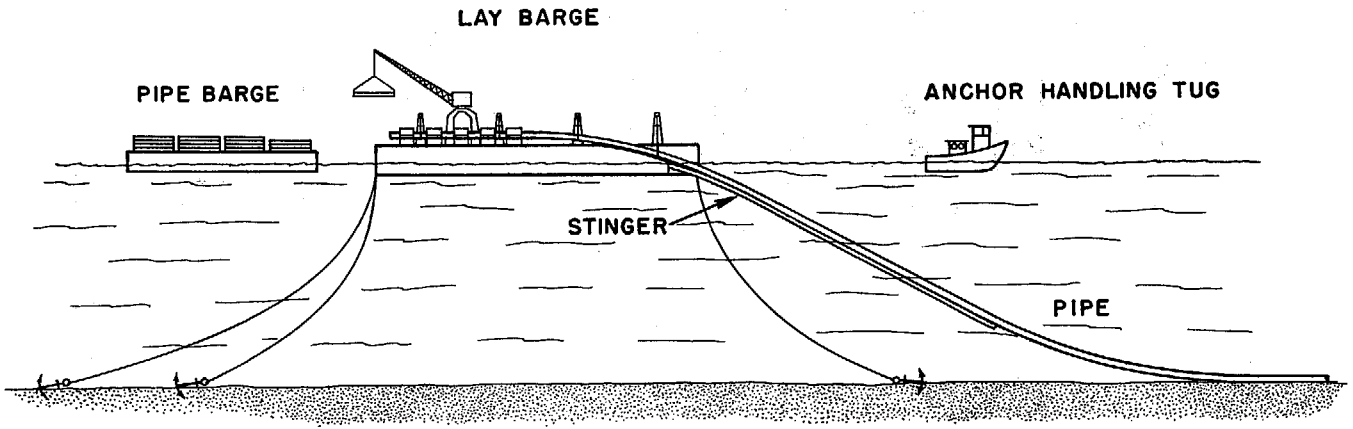


FIGURE 4

LAY BARGE METHOD

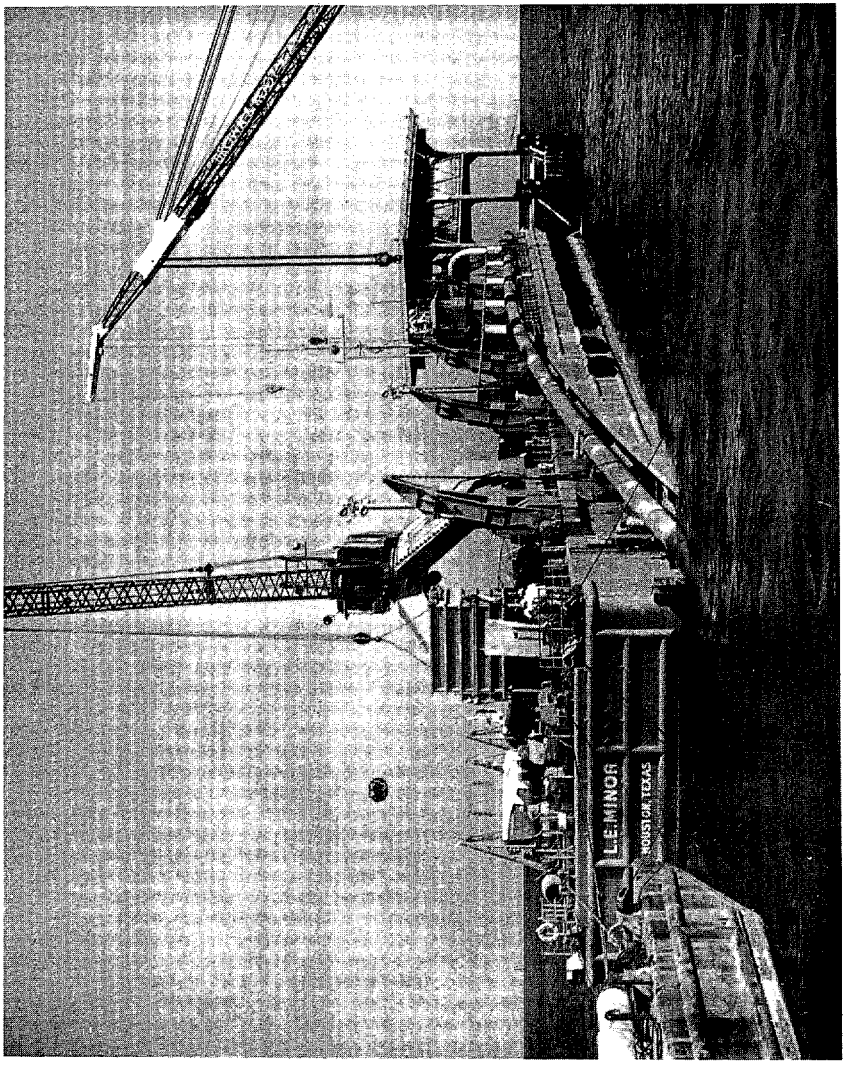


FIGURE 5
PIPE LAY BARGE

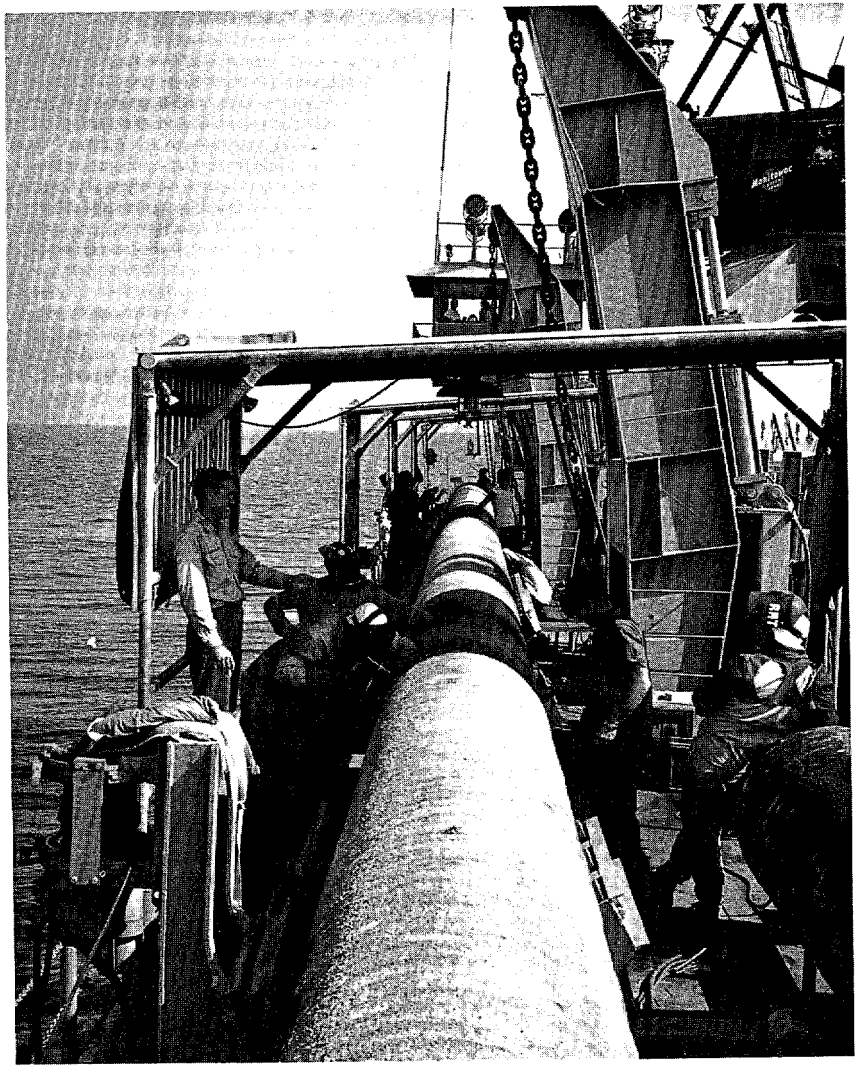
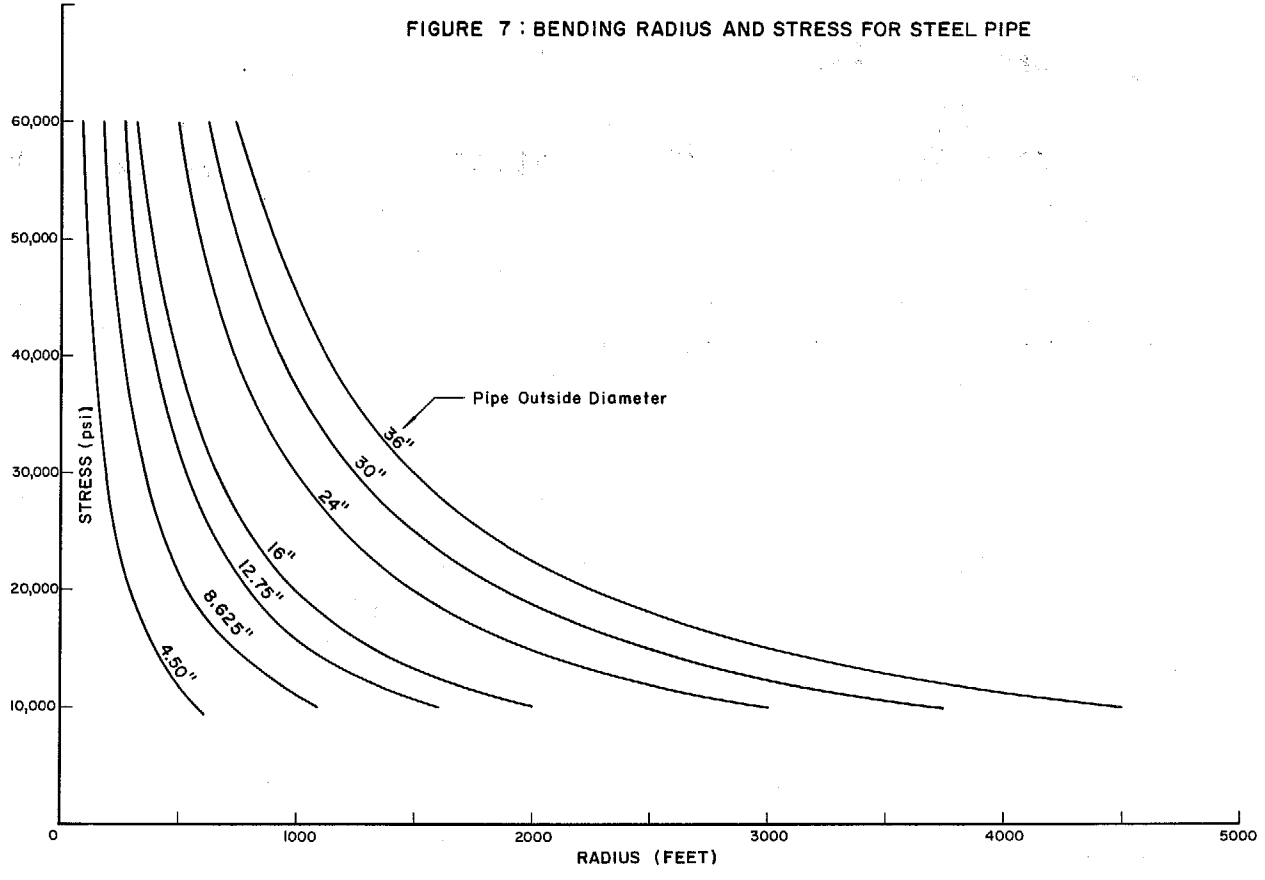


FIGURE 6
WELDING STATIONS ON LAY BARGE

FIGURE 7 : BENDING RADIUS AND STRESS FOR STEEL PIPE



V_A = Pipe reaction at point A, Pounds
V_B = Pipe reaction at point B, Pounds
w = Uniform load of pipe weight in water, Pounds per foot
Θ_B = Slope at point B, Radians
Y_B = Deflection at point B, Inches
L = Length of unsupported beam, Inches

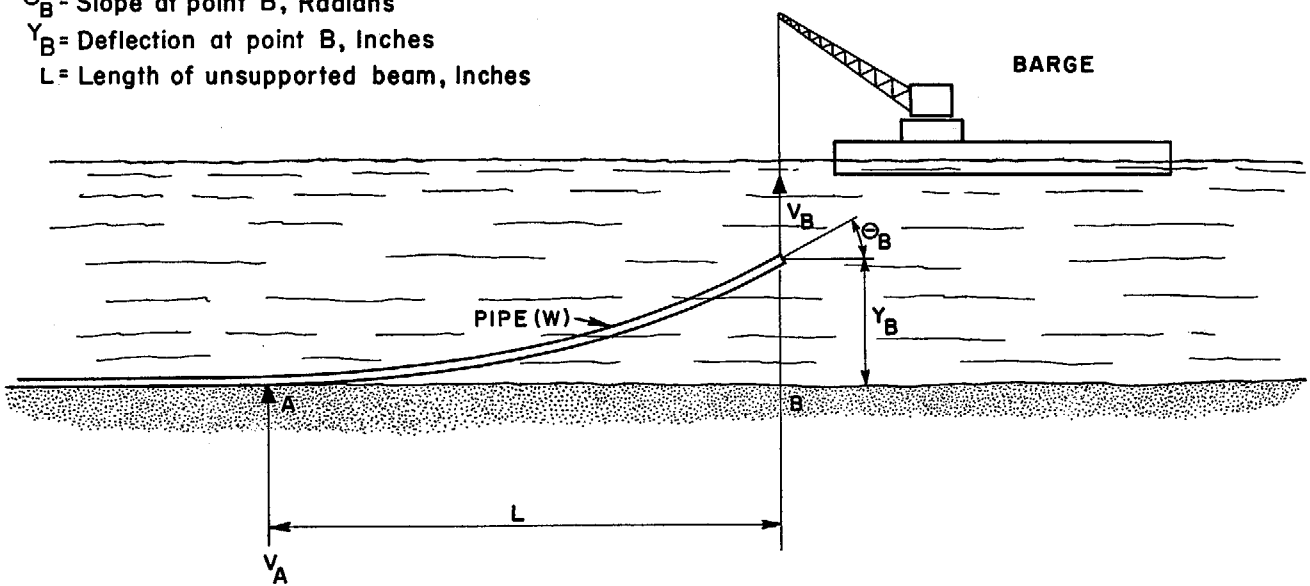


FIGURE 8

PIPE BENDING STRESS DIAGRAM

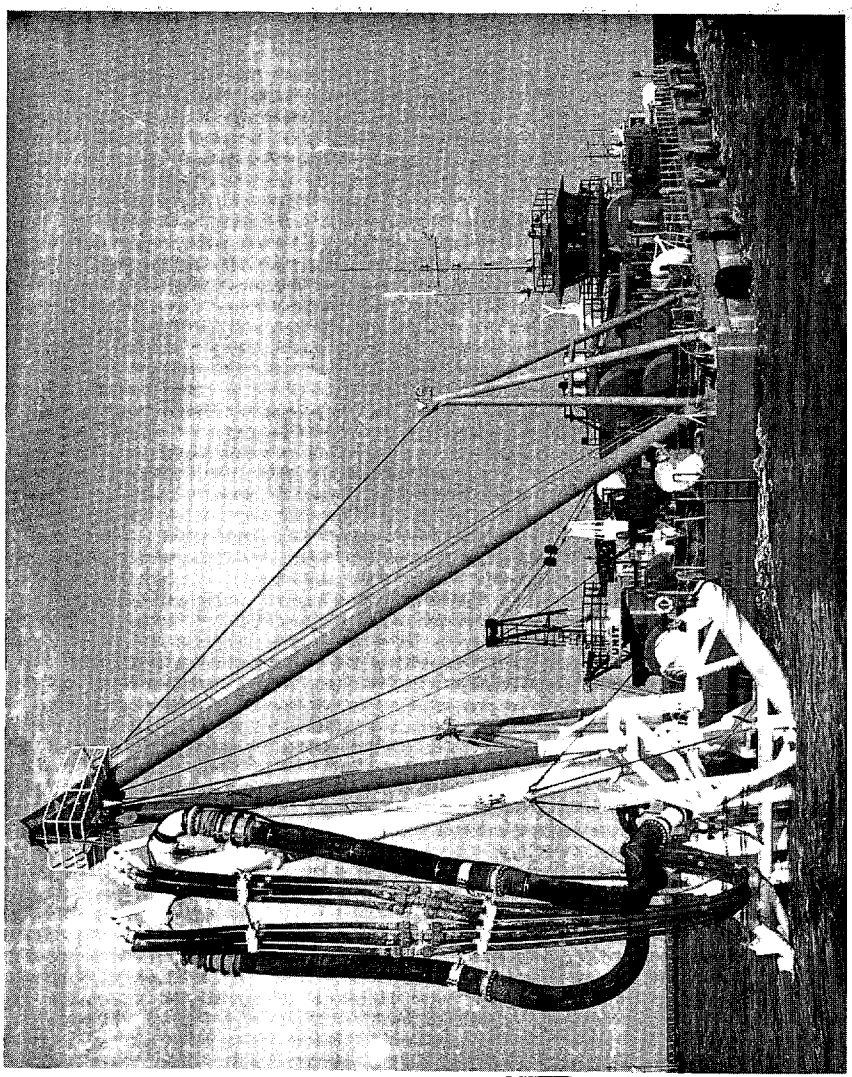


FIGURE 9

PIPE TRENCHING BARGE

OCEAN ENVIRONMENT AND FISH DISTRIBUTION AND ABUNDANCE

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Abstract

For U. S. fisheries to grow, they must become more efficient than those of other countries, as have most other industries, in order to overcome the high wage-price structure associated with our high standard of living. A major obstacle to efficient, systems-integrated fishery operations is the wide fluctuation in the abundance and distribution of fish, especially the pelagic schooling species which have the highest potential for providing increased catches. It is proposed that fish hunting time be reduced and flow of fish to port be smoothed by forecasting the time and place that concentrations of catchable fish will occur.

This requires (1) research to establish the environmental conditions conducive to fish concentrations, (2) research to determine the reaction of the ocean to the variations in the overlying atmosphere. For both (1) and (2) information is needed on ocean conditions, with time and space continuity, ocean-wide and down through the upper layer and well into the permanent thermocline. To provide this information an extensive ocean monitoring system is proposed to serve, along with the established weather monitoring system, the needs held in common by the military, the fisheries, the meteorologists, the physical oceanographers, the biological oceanographers, the radiologists and the pollution-control specialists.

INTRODUCTION

One of the marvels of these times is that the United States, with its high standard of living, has managed to keep its products competitive in the world market. One of the striking exceptions to this generality is the fishing industry. Ten years ago, 70 percent of the U. S. fishery supply came from domestic fish catch. In 1964 this had fallen to 38 percent. It probably is still lower now. We are a net importer of fishery products by a substantial margin.

There are a number of reasons for this. One of them, and I believe it to be a major one, is that the fishing industry, unlike most other American industries, does not lend itself to the American genius for applying technology and systems research and management, which produces goods at prices competitive with those of the rest of the world despite our higher costs of materials and manpower.

A large obstruction, if not the major one, to attainment of the modern systems type of operation at the fishing level is the variation in abundance, location and catchability of the fish. Too large a portion of time is spent hunting for fish, too little for catching them. On occasions when the fleet comes upon good fishing, its landings glut the market and there is either a price reaction or, sometimes, a failure of the market to handle the fish. Often the net effect on the fisherman is an income less

than his needs for keeping his vessel and gear in repair and replaced when worn out, and less than is needed to keep him and his sons in the fishery, while the higher income and greater security of shoreside employment offer a better life. The effect on the processor or the wholesaler is a highly irregular supply of domestically caught fish. Since frozen fish have become a common international commodity, he can offset these irregularities by imports. No doubt this, as well as price advantage, has been a powerful factor in making this country a large net importer of fishery products.

If this crude and overgeneralized statement is essentially correct, and if we wish to avoid slipping into further dependence on imports for our supply of fishery products, then it is logical to look into the causes of the irregularities in fish catch. If we can identify them and adopt measures to avoid them, or even make use of them, we will have a powerful tool for increasing the efficiency of fishing, processing and distributing our domestic catch. If we can fashion this tool and employ it successfully, we should greatly enhance the capability of our fisheries to compete with those of the rest of the world.

FISHERY FLUCTUATIONS

My thesis is that changes in the ocean environment cause major changes in fish distribution and abundance and thereby produce irregularities in fish catch. There are substantial differences in the amplitude of fluctuations in the catch of the various kinds of fish. In general the catch of bottom fishes like the cod, haddock, flounder, sole, halibut, etc., fluctuates less than the catch of most other types of fish. In contrast, the pelagic, near-surface swimming and schooling fishes fluctuate the most widely in abundance and especially in distribution. Among these are the tunas and tuna-like fishes, the mackerels and the herrings and many another. This type of fish never remains in the same ocean area in fishable concentrations for any length of time within the season or from year to year. It is this group of elusive fishes that affords the largest potential for production.

A few examples drawn from the historical record illustrate the year-to-year variation in catch of several kinds of these pelagic schooling fishes. Years of painstaking study have identified two general causes of variation in catch, quite apart from the variations in amount of fishing effort expended.

One of these is the variation in the over-all abundance of a species caused by year-to-year variation in the infant mortality. Seemingly regardless of the amount of spawning, some years many young survive through the larval and juvenile stages and grow to commercial size, and in other years very few survive. Figure 1, of the western Atlantic mackerel catch, shows variations which may be predominantly caused by such variations in infant survival.

During the 19th century the mackerel was one of the mainstays of the New England fishery, and a major food item. There was a barrel of salt mackerel along with the cracker barrel in almost every grocery and general store. Then in two years (1885-1886) there was a catastrophic decline in catch of about 90 percent. Great distress was caused in the

fishing ports, and salt mackerel became a minor food commodity. It remained so for 40 years. Then there was an upsurge in the middle 1920's. At that time I was studying the biology of the mackerel. In 1926 I found that the catch was composed almost entirely of two ages: 3-year-olds and 5-year-olds. The latter of course were spawned in 1921 and the former in 1923, and may be called the 1921 and 1923-class, respectively. In subsequent years I found the 1928, 1931 and 1933 classes to have been outstanding, whereas the survival from intervening spawnings was trivial. From the 10-year sample of age compositions in the catch, it was obvious that the infant mortality was nearly total in over half of the years. It appears probable, though we never can be sure, that variations in infant mortality were responsible for most of the year-to-year fluctuations in catch.

The other type of fluctuation is caused by variations in distribution. This changes the proportion of the fish population that comes within the range of the fishery. Fig. 2, of the catch of albacore tuna along the Pacific coast of the United States, most probably exemplifies variation in distribution rather than variation in over-all abundance. We did not know it at the time, but it has since been proved by mid-ocean fishing and by tagging that the albacore is distributed from one side of the Pacific to the other, and our coastal fishery catches them only in summer when warm water conditions usually prevail and the albacore approach near enough to the coast for the small boats to reach them. We now feel quite sure that what seemed to be nearly total disappearance between 1926 and 1938 was merely the failure of albacore to come far enough toward the coast for our fleet to reach them. The generally higher level of catch after 1940 than before 1926 probably is due to a combination of (1) an increased use of temperature information by the albacore fishermen, (2) a modest increase in the range of their boats, and (3) a spread of the fishing from southern California northward along the Oregon and Washington coasts.

Bluefin tuna, Fig. 3, is probably another example of this kind, though we know less about the migrations of this species. Like the albacore, this tuna appears along the American coast briefly during summer and fall. Most of the catch is taken off Lower California. The irregularities probably depend on how large a portion of the bluefin population approaches the coast and how close it comes. In any event, the catch fluctuates irregularly from less than one thousand tons to over ten thousand tons.

CHANGING OCEAN CONDITIONS

Most oceanographic information is confined to the average or supposedly typical ocean. We are now beginning to learn about changes in ocean conditions. In our laboratory at Stanford University, we /J. F. T. (Ted) Saur, L. E. (Larry) Eber and I/ analyzed the sea surface temperatures for 1956 and 1957 as collected by the Marine Weather arm of the Weather Bureau and archived at the National Weather Records Center, Asheville, N. C., for each month of 1956 and 1957. Figures 4 and 5, taken from U. S. Bureau of Commercial Fisheries Circular No. 134, give the analysis for June of each of these years. The difference between these Junes is given in Fig. 6. Most of the eastern Pacific and Tropical area was warmer in 1957 by varying amounts up to 4°C. (or 7°F.), whereas much of the western Pacific, and a tongue extending eastward in mid-latitudes, was colder by a similar amount. From perusal of the charts for the

other months of the year, it appears that this general feature of warmer water in the eastern Pacific and colder in the western Pacific developed early in the year and persisted through the rest of the year, though with many striking differences in detail.

To us, as warm-blooded animals, having a physiologically controlled internal temperature and further protected by clothing and shelter against a far wider daily and annual atmospheric temperature range, a change of 7 degrees may seem trivial. But to cold-blooded animals that live in the sea, this would be a very large change indeed. It has been aptly stated that cold-blooded aquatic animals are slaves to their environment. A variation of a very few degrees in temperature greatly affects their rate of metabolism, the amount of their activity, and the amount of food needed to sustain their activity. It is not very surprising that they have evolved habits, reactions, and migratory patterns which, in some species at least, tend to keep them in a relatively narrow range of temperature which, to each species, is nearly optimal. Each such species changes its location so as to stay within its optimal temperature range.

One such change, as from 1956 to 1957, and observed mainly in only one ocean condition, surface temperature, is not sufficient for drawing any conclusions between ocean conditions and infant mortality or between ocean conditions and the distribution of commercial-sized fish, although we know that in 1957 the distribution of a number of kinds of fish was quite different than in the immediately preceding years. Fish distribution can vary in three dimensions and fish certainly are sensitive to a number of conditions in addition to temperature. What is required at this stage of our ignorance are means for measuring the appropriate conditions in the three dimensions and their change with the fourth dimension, time, until we find out through a combination of at-sea observations and controlled experiments in the laboratory what the appropriate conditions are. Both the identification of appropriate conditions, and their measurement in the sea, are formidable and complex problems. I shall deal further, only with the problem of measuring ocean conditions as the one of most immediate interest to members of the Marine Technology Society and of most general concern to many other segments of the scientific, technological, and ocean engineering community.

What is needed, in my personal opinion, is information, with space and time continuity, on ocean conditions, such as temperature, salinity and probably other conditions of significance to biological activity, such as oxygen concentration, water clarity, etc., not only at the surface but also down through the mixed layer and well into the permanent thermocline. This means down to a depth of 600 meters (2000 feet) in much of the ocean and to 1000 meters (3300 feet) in a number of areas.

AN OCEAN MONITORING SYSTEM

Such data are also needed for other purposes. Through multiple contacts, I have become aware that the paucity of data also faces a number of ocean-oriented groups. To enumerate those groups that come readily to mind--(1) the meteorologists concerned with air-sea interactions, (2) the physical oceanographers concerned with processes causing variations in the sea, (3) the biological oceanographers interested in dynamic ecology of communities of ocean organisms, (4) the fishery-oceanographers

concerned with the dynamic ecology of seafood organisms, (5) the radiologists concerned with the diffusion of radionucleides in the sea, (6) the military scientists concerned with the acoustic channels in the ocean, and (7) the pollution scientists concerned with the near-shore and oceanic dispersion of pollutants.

All of these, I believe, have a common need for certain ocean information with some degree of continuity in time and space, though with some variation in the required degree of resolution in time and space and perhaps considerable variation in the required properties to be measured. This suggests a basic atmosphere-ocean monitoring system to serve as many of the needs held in common among the users as are practicable to serve in terms of the state of technology and of the procurable funding.

This leads me to envision a basic network consisting of:
1. The ships of opportunity presently cooperating in sending to the Weather Bureau 6-hourly marine weather reports, and provided with improved instrumentation for measuring near-surface sea temperatures;
2. Selected ships of opportunity equipped with expendable bathythermograph (XBT) systems to probe the sub-surface ocean, analogous to the already established radiosonde system for probing the upper atmosphere;
3. Automatic deep-anchored buoys, located in areas not traversed by steamer lanes, for measuring the customary atmospheric conditions plus a string of sensors measuring water properties at a number of levels down to at least 600 meters and deeper in some areas;
4. Existing tide stations, plus additional ones strategically located with reference to major ocean currents, and with certain of the tide gauge stations supplemented with weekly sub-surface observations in the adjacent ocean as was provided at many stations during IGY;
5. Airplane over-flights with infra red temperature sensors, and perhaps XBT capability, covering critical areas not otherwise monitored; and
6. Cloud cover charts assembled from satellite photographs.

For efficient deployment of these facilities, and for maximal return of information from the data they produce:
1. The design of such a network should be jointly determined by both the research users and the operator users;
2. The processing and communication of the information should be adaptable to users' needs; and
3. Quality control should be insured by the current study of the data--this being, in our experience, the most reliable insurance.

ANTICIPATED BENEFITS

With such a system in being, the way will be cleared for developing prediction capability. Of course, the information from the system alone will not be sufficient. In general, prediction of ocean conditions requires that the variable kinetic and thermal energy exchanges between the atmosphere and ocean be better measured and become more thoroughly understood, especially as to phase lags. For fishery prediction, the behavior of fishes toward environmental change must become better understood and quantified through laboratory experiments and through observations at sea. It can be expected that the atmosphere and ocean monitoring will serve to greatly accelerate the progress toward sufficient understanding of atmosphere-ocean relationships and fish and ocean environmental relationships.

It is to be expected also that the larger scale and larger amplitude changes in ocean conditions will be more readily predicted than the smaller and more transient effects. Similarly the larger and more extensive changes in fish abundance and distribution will be more readily observed and predicted than the very local and less pronounced changes. It may be envisioned that the eventual fishery forecasting system would consist of periodical medium and long-range general predictions of probable unseasonable abundances and locations of fish concentrations to guide the forward planning of fishermen and processors. Added to these would be more frequent, perhaps daily, advisories of current conditions on a real-time basis radioed to fishing vessels at sea to indicate which direction to sail with the best probability of encountering catchable concentrations of fish. Fishermen themselves may have advanced instrumentation aboard ship by which to further guide the deployment of their gear.

With these aids, together with technological improvement of fish catching devices, the era of week-long, month-long and year-long spells when the fleet cannot find the fish schools, or when they can find only a scattered few, should end. The flow of fish into landing ports should become steadier and the American genius for organizing efficient production systems will be able to play as large a part in keeping the domestic fishery competitive with the rest of the world, as it does now in many other industries.

That this is not an idle dream is proved by the experiences of the Bureau of Commercial Fisheries Tuna Resources Laboratory at La Jolla, California, in predicting, from April sea surface temperatures, when, where, and in what quantities the albacore will appear along our Pacific coast in summer. After several seasons of fair success, last summer the prediction went awry owing to a reversal between April and June in the seasonal warming trend, which retarded and diminished the early summer run. However, during the same summer the Laboratory also experimented with nearly daily radio advisories to the fleet. In one instance at least, and there may have been others, there was issued an advisory of suitable temperature conditions far north of the then area of fleet fishing. As a result, the fleet was led to an area of excellent fishing, days ahead of their normal occupation of this area. As a result, a significant tonnage was added to the season's catch. (Glenn Flittner, personal communication.)

Finally, it should be noted that the basic observation network and the attendant research here suggested as a tool for increasing the efficiency of fishing operations could also increase man's ability to select conservation measures appropriate for the wise use of fishery resources. Wide fluctuations in apparent abundance of fish can obscure trends imposed by overfishing; also, declines in catch from natural environmental causes, especially if prolonged, can be mistaken as evidence of overfishing. With the successful operation of the observation network, together with achievement of an understanding of the quantitative effects of environmental changes, it will become increasingly possible to "screen" out the noise of environmentally induced fluctuation and leave revealed the more fundamental trends related to the effect of fishing.

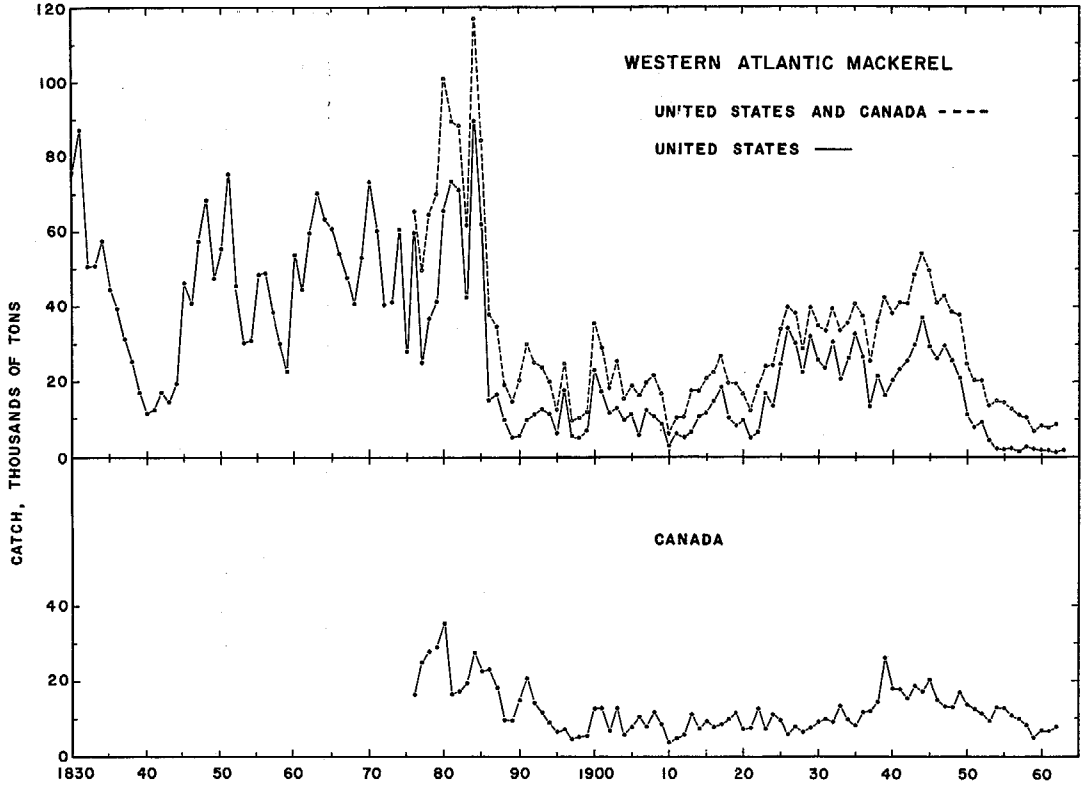

Fig. 1. Catch of mackerel along the Atlantic coast of the United States. Source: U. S. Bureau of Commercial Fisheries statistical reports.

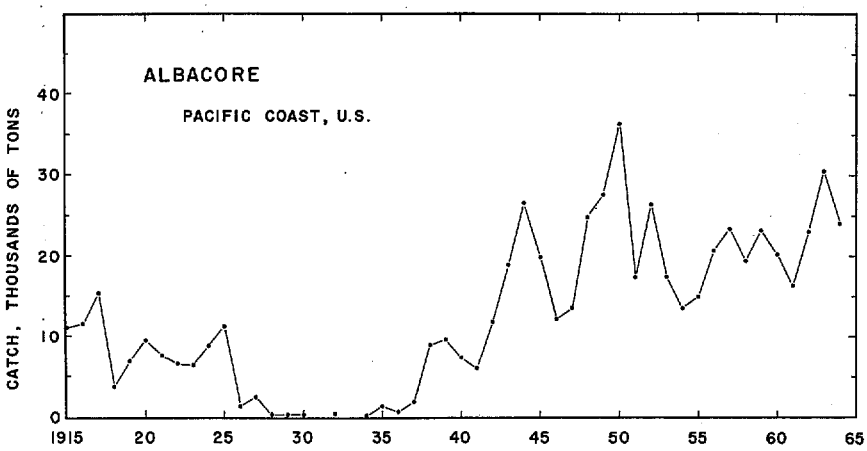

Fig. 2. Catch of albacore tuna off the west coast of the United States. Source: U. S. Bureau of Commercial Fisheries statistical reports.

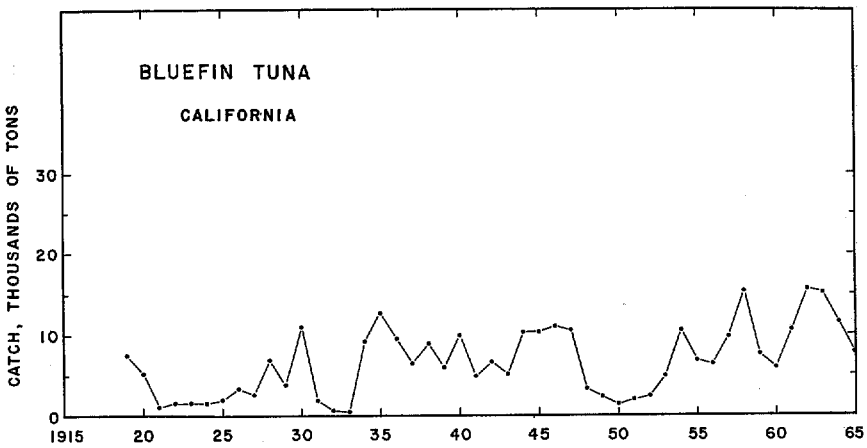

Fig. 3. Landings in California of bluefin tuna from waters off the west coast of North America. Source: U. S. Bureau of Commercial Fisheries statistical reports.

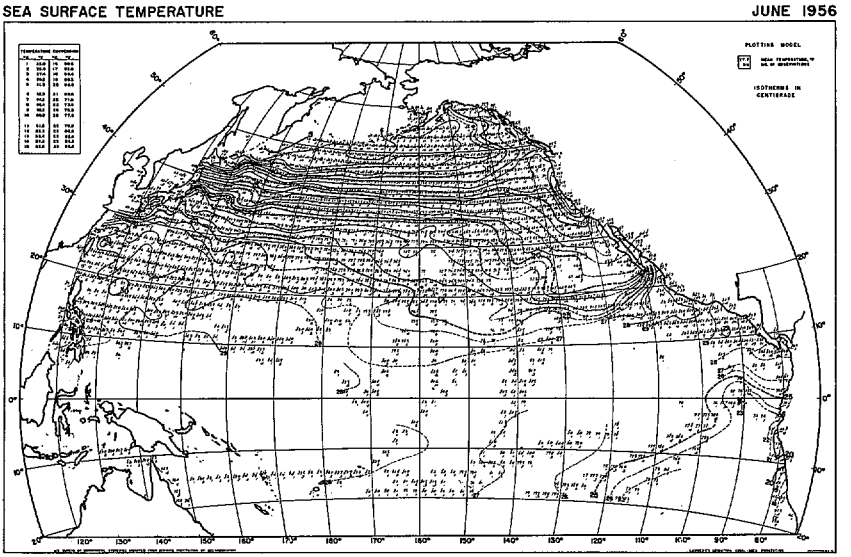

Fig. 4. Mean sea surface temperature (°C.) of the Pacific Ocean in June 1956. Reproduced with severe reduction from U. S. Bureau of Commercial Fisheries, Circular 134.

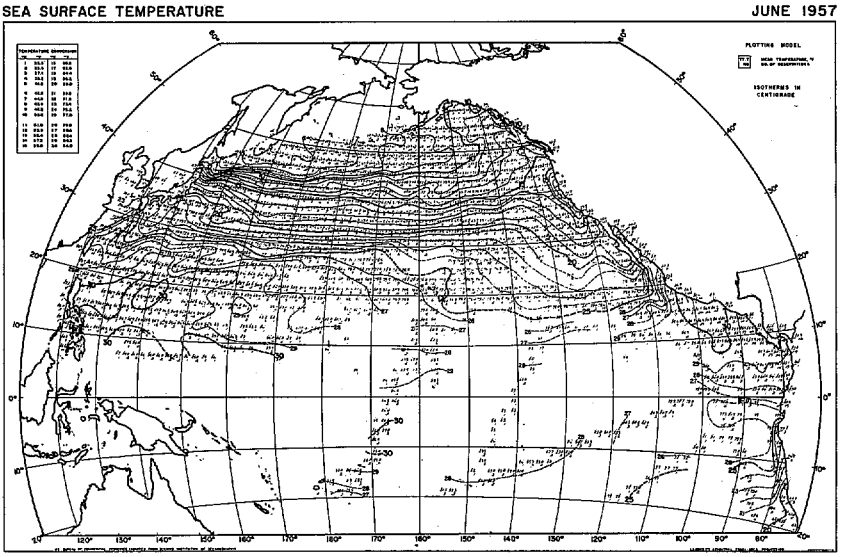

Fig. 5. Mean sea surface temperature (°C.) of the Pacific Ocean in June 1957. Reproduced with severe reduction from U. S. Bureau of Commercial Fisheries, Circular 134.

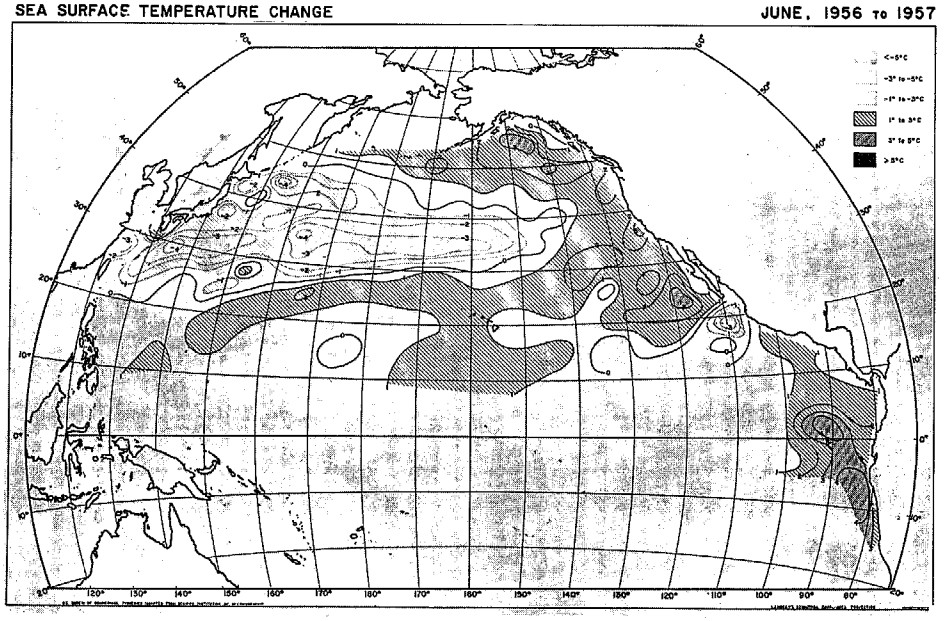

Fig. 6. Sea surface temperature difference (°C.) between June 1956 and June 1957. Negative values indicate areas colder in 1957 than in 1956.

METHODS OF SEARCH AND CAPTURE IN OCEAN FISHERIES

by

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ABSTRACT

Following a paper given last year at the Ocean Engineering Conference in Washington, D. C. on the application of engineering knowledge to improve fishing capabilities, the authors now review past and current trends in fishing practices. The main components in fishing activities are search and capture. Fish concentrations are located through knowledge gained from past experience and from communications with other vessels, visual search for fish, thermometric techniques and use of underwater sound (echo sounders). The latter method may be vertical or horizontal scanning from side to side. Four fishing methods account for more than 90 percent of the fishes harvested from the world's oceans. These methods are: seine or encircling nets; drift nets, gill nets, etc.; hooks and lines; and trawls. Since World War II, midwater trawls have been introduced to capture fish in the water column between the bottom and the surface. Acoustical links and telemetering through the towing wires provide accurate measures of the depth of the net. Fishing vessels are normally designed for a specific type of fishery although in recent years the trend is toward design of vessels which can operate a variety of gear. Developments which would make commercial fishing more efficient include control of the environment and effective methods of aggregating fish. Current trends are towards improving vessel designs, deck gear and further development of electronic equipment.

INTRODUCTION

During the Ocean Engineering Conference held in Washington, D. C., last year, we presented a paper reviewing the historical development of fishing gear research throughout the world. We pointed out the need for devising new and more effective systems for harvesting the protein in the ocean and implied that failure to satisfy this need would assuredly limit man's ability to extract the organic energy latent in the world's oceans.

Requisite to any formal program designed to improve ocean harvest systems is a thorough understanding of existing fishing methods. There prevails today many misconceptions of the characteristics of contemporary fishing technology, and the comment is often heard that fishing methods have not changed for centuries. Indeed, it can be argued that the basic techniques in today's fisheries were used in early Mediterranean cultures. There has been, however, an evolution in fishing patterns, fishing hardware, and vessels. In addition, adoption of electronic devices during the 20th Century has resulted in the development of rather sophisticated fisheries strategy, and today's major ocean fisheries scarcely resemble those of past centuries.

The purposes of this paper are to (1) describe search techniques and fishing gears used in ocean fisheries, (2) comment on fishing tactics, and (3) consider possible future developments in the harvest of ocean resources.

GROWTH OF OCEAN FISHERIES

Fishing can be considered one of man's earliest methods of food gathering and the harpoon, sinker, hook, and net were apparently used by cave dwellers of the Neolithic Era (Radcliffe, 1921). These are the fundamental devices used in today's fisheries. To the above methods the Greeks added rather complex fish trap systems in the Mediterranean. Changes in ocean fisheries following the fall of the Roman Empire are not well documented and it appears that fishing in the following centuries largely occurred in marginal seas and relatively close to shore until about the 19th Century. True ocean fisheries did not commence until the latter half of the 19th Century and the early part of this century. During this period steam and internal combustion engines were installed in vessels, thus providing reliable and controllable power sources which allowed fishermen to safely extend their operations seaward.

Although growth of ocean fisheries was slowed during World War II, the pace quickened in the decade following World War II, and ocean fisheries have since become an increasingly important factor in the world's total production of animal protein.

Perhaps some of the most significant developments in the evolution of ocean fisheries occurred in the post-World War II era. War had accelerated the development of electronic gadgetry for military purposes and yielded an array of reliable electronic devices which could be used for both navigation and fish detection. Indeed, it was during the post-World War II era, that fishermen found eyes to see in the dark and to search the waters below the vessel. In addition, electronic devices that allowed them to determine their position on the high seas quickly and accurately became available. These were giant steps forward in the utilization of ocean resources.

THE FISHING SYSTEM

Today the shipboard facet of marine fisheries can be broken down into two component activities: (1) search and (2) capture. Each activity requires a decision process with a subsequent operational performance, and the combination of decision and performance may be called "fishing tactics." In reviewing contemporary fishing methods, let us explore the search and capture phases of fishing separately and subsequently integrate them to reflect the tactics used in the more important fisheries.

Search techniques

Locating schools or concentrations of desirable species of fish is a prerequisite to any successful fishing activity. Fishermen sometimes rely almost entirely on empirical data in the search phase; that is, they may use past experience to guide them to areas and to select times for setting their nets, lines, traps, etc. In the larger ocean fisheries, however, fishermen rely on both empirical data and on communications flowing from other fishing vessels. This feed-back from vessels on the grounds may be completely informal or the result of formulated fleet or company plans. In the former, the skipper commonly uses the radiotelephone to discuss fishing success with other skippers. In such an instance the decision about where to fish may be made prior to leaving port or modified while enroute to the fishing grounds.

In fleet operations by large industrial firms or by Government, the fishing or scout vessels relay to a mothership or shore station information on the quantities and types of fish being caught. The information received is analyzed, and fleets deployed accordingly. This formal feed-back system provides relatively up-to-date information on the success of all vessels of a fleet and enables them to operate most effectively.

The informal feed-back technique is most common in the United States. Depending on the reports received from other fishermen, a U.S. skipper may set out to join a group of vessels on a particular ground or may decide to rely on past experiences and thus set a course for an area where other vessels are not operating. In such instances the fisherman, when arriving on the ground, may search for fish by using echo sounding devices or by applying other search techniques.

VISUAL SEARCH

Fishermen who use seines to catch surface fishes may determine the availability of fish by scanning the sea surface with binoculars. Fish breaking or disturbing the sea surface indicate the presence of schools. Fishermen may also rely on birds as indicators of fish schools, may search for feed in the water, or in some instances decide to fish when the water has a certain color. In large seine fisheries aircraft may search for fish, thus increasing the effective radius as well as the depth to which subsurface schools may be detected. At night, schools of fish may be detected by the phosphorescence which occurs when fish move through the water.

THERMOMETRIC TECHNIQUES

The distribution patterns of many commercially important fishes are seasonally and annually influenced by changing oceanographic conditions. Temperature, which is easily measured, is a convenient indicator of the possible presence or absence of some fishes. For example, one species of cod in the North Atlantic has been found in convergent zones with the greatest concentrations of fish occurring in a relatively narrow temperature band between $35^{\circ}F$ and $37^{\circ}F$. Haddock avoid areas with temperatures less than $41^{\circ}F$ and are not normally found at temperatures greater than $55^{\circ}F$. Many of the tunas also react seasonally to ocean temperature patterns, and along the west coast of the United States fishermen have long used thermometers when searching for albacore. Temperature, as such, is not a direct indicator of the presence of fish, but helps narrow down the search areas. When regions of "ideal" temperature have been located, search for the fish must still be made. Use of thermometric means to locate potential areas of fish concentrations is becoming increasingly important in world fisheries and will undoubtedly play an even greater role in fishery search strategy.

USE OF UNDERWATER SOUND

Underwater sound is probably the most universal technique for detecting fish in waters below the immediate surface of the ocean. Its use in fish

detection is almost entirely restricted to active "pinging" rather than passive techniques; that is, echo sounders are employed rather than hydrophones which detect noises produced by fish. Echo sounding may use the one-direction, vertical method or the horizontal echo-ranging or scanning method.

Vertical echo sounders are universally used by ocean trawlers to determine proper depths for fishing and to search for fish schools. Longline and some trawl vessels, however, may also use vertical sounders to detect feed in the water or to determine the characteristics of the bottom over which gear might be set. Vertical echo sounders now used by fishing vessels generally have sound frequencies between 20 and 50 kc and a maximum vertical range to about 500 fathoms. Most, however, on smaller craft, have somewhat more restrictive ranges (to about 200-300 fathoms).

Two methods are used to display the echoes from vertical sounders: (1) Graphic presentation on wet or dry strip charts, or (2) visual reproduction of the echo by means of a cathode ray tube.

More advanced sounders have a rather effective means to differentiate fish schools from the seabed. This system has a gating circuit that operates in response to signals above a certain amplitude. After the "gating minimum" is set to accept signal values only in excess of the strongest fish echo, but below the strength of the anticipated bottom echoes, the amplifier may be cut out for a short period of time (1/100 of a second) on receipt of the stronger signal. In a graph display of the echo traces made by an echo sounder using this technique, the bottom will be shown as a thin black line followed by a white gap, making it easy to distinguish fish traces occurring immediately above the seabed (Schärfe, 1959).

Horizontal scanners (sonar) are commonly used by vessels fishing pelagic species, particularly herrings, sardines, anchovies, and cod. The sounding principles are identical to those of the vertical sounder; however, the transducer is mounted beneath the vessel or alongside the vessel so that it may be rotated in the horizontal plane. Most of the scanning equipment on fishing vessels is fixed to search from the beam of the ship to the bow on either side of the vessel, thus providing a 180° search pattern. Models, however, are available which allow 360° search and a vertical tilt up to 90° thus allowing the equipment to function as a scanning device and a vertical echo sounder. Sound frequencies used are within the general range of 20 to 50 kc, although frequencies well over 100 kc are in use. The effective scanning distance depends largely on the model purchased and may vary from about 400 to 3,000 meters. The effective range, however, is dependent largely on sea conditions, and thermocline depth.

Three techniques of scanner search are used: Side-to-bow, side-to-side-and-back techniques, and side-to-side. (Vestnes, 1964).

In the side-to-bow method the operator directs the transducer to search 80 to 90° aft of the bow, and the transducer is set to move forward in short steps--for example, 5° . When the sonar is scanning directly ahead of the vessel, it is quickly turned to a position 80 to 90° aft of the bow on the other side, and a similar pattern followed (Fig. 1a).

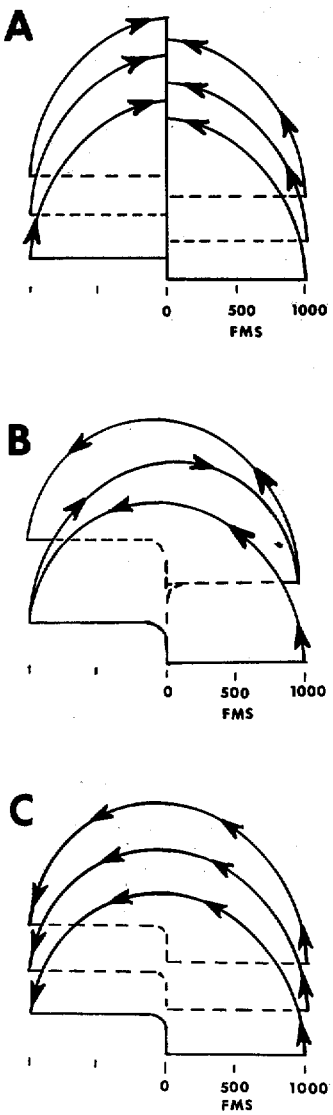


Figure 1. -- Sonar search techniques used in fishing operations.

(A) Side-to-bow method

(B) Side-to-side-and-back technique

(C) Side-to-side method

(More advanced sets employ automatic scanner rather than manual procedures.)

The side-to-side-and-back technique is perhaps self-explanatory in that it follows the side-to-side technique with the exception that at the end of the 180° scan, the instrument is not turned back to the side from which the search was begun. In this technique the operator merely scans back in the opposite direction (Fig. 1b).

In the side-to-side method the same pattern is followed except on reaching the bow the search pattern continues, working aft on the opposite side. When the transducer has scanned the 180° arc, it is quickly returned to the original starting position and the procedure is repeated (Fig. 1c).

After contact has been made with a school, the use of sonar depends on the species being fished and the fishing gear. When setting their gear, seiners commonly maintain contact with the school off one side of the bow and keep a certain distance from the periphery of the school. After contacting the school and determining its position, the midwater trawler may set the gear and then incline the transducer to a vertical position so that the depth of the school may be precisely determined and the depth of the trawl adjusted accordingly.

Fishing Gear

In this paper we cannot cover the myriad of ocean fishing methods, however, we shall briefly describe the major techniques. Four fishing methods account for more than 90 percent of the fishes harvested from the world's oceans. These methods are (1) seine or encircling nets; (2) drift nets, gill nets, trammel nets, tangle nets, etc. (3) hooks and lines; and (4) trawls.

SEINES OR CIRCLE NETS

An almost infinite variety of seines are used, depending on species sought and regional traditions or preferences of fishermen. The two most important circle nets used, however, are the purse seine and lampara. Both operate on the principle of encircling fish with a wall or fence of webbing, but differ in the manner of trapping and retrieving the fish.

The lampara seine consists of two long tapered wings of webbing (Fig. 2b) attached to a small central bag. Lampara seines may range up to 1,200 feet long from wing tip to wing tip. The top or upper edge of the net is equipped with a line (cork line) to which floats are attached so that the top of the net remains on the surface during fishing. A weighted lead line is secured to the lower edge of the net so this portion of the wall of net will sink, forming a fence 3 to 10 fathoms deep. Additional sections of webbing are normally secured to the forward lower edge of the bag and lower edges of the wing to form a shovel-like floor (apron), which prevents fish from escaping the net.

The lampara seine is normally set from the stern of the vessel by dropping a small skiff or buoy which is attached to one of the net wings. The net is payed out in a circle at some distance from the fish in the center. The maneuver is made in a manner to complete the circle at about the time all the webbing has been payed out. The wing which was attached to a float or skiff is then retrieved and hauling starts by pulling simultaneously on both wings. The wings are normally brought in over powered sheaves or rollers until the apron is brought alongside. When the apron has been retrieved, those fish that are in the net are completely entrapped and the remaining webbing can be brought in more slowly and the fish subsequently brailed aboard.

The purse seine (Fig. 2a) is a long ribbon or wall of webbing having floats on the top and rings and weights on the bottom. A line is threaded through the rings at the bottom of the net and is used to close off the net (pursing) after the fish have been encircled.

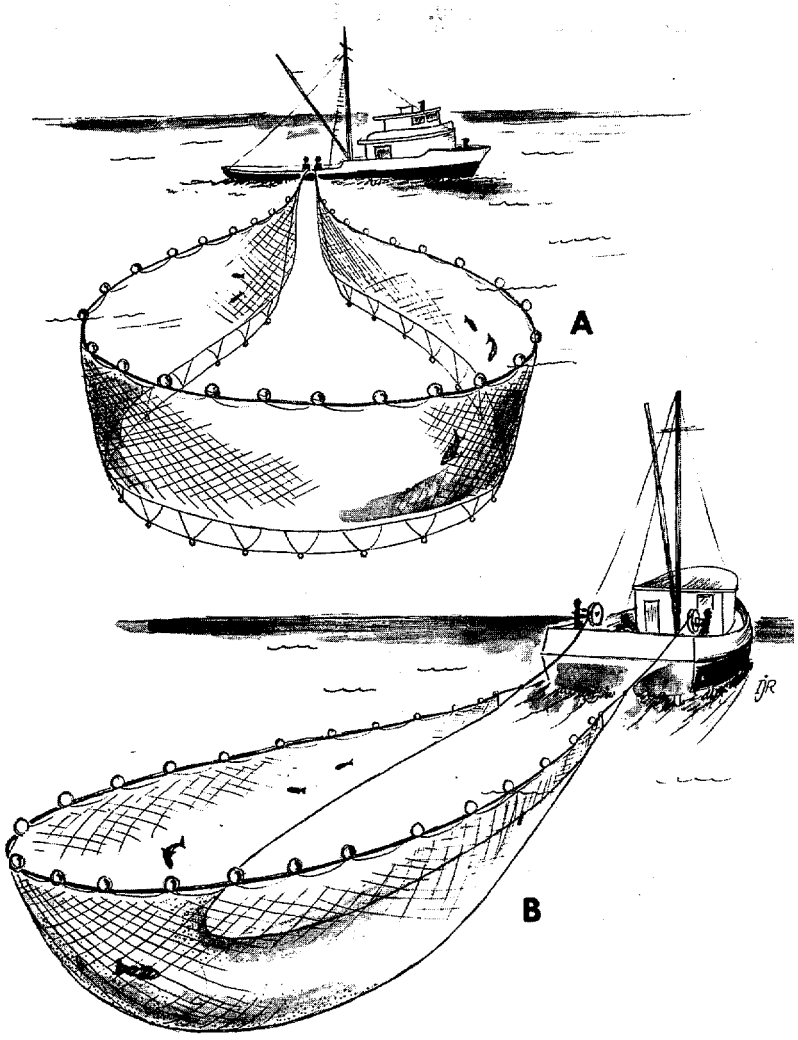


Figure 2 -- Round haul nets.

(A) purse seine

(B) Lampara

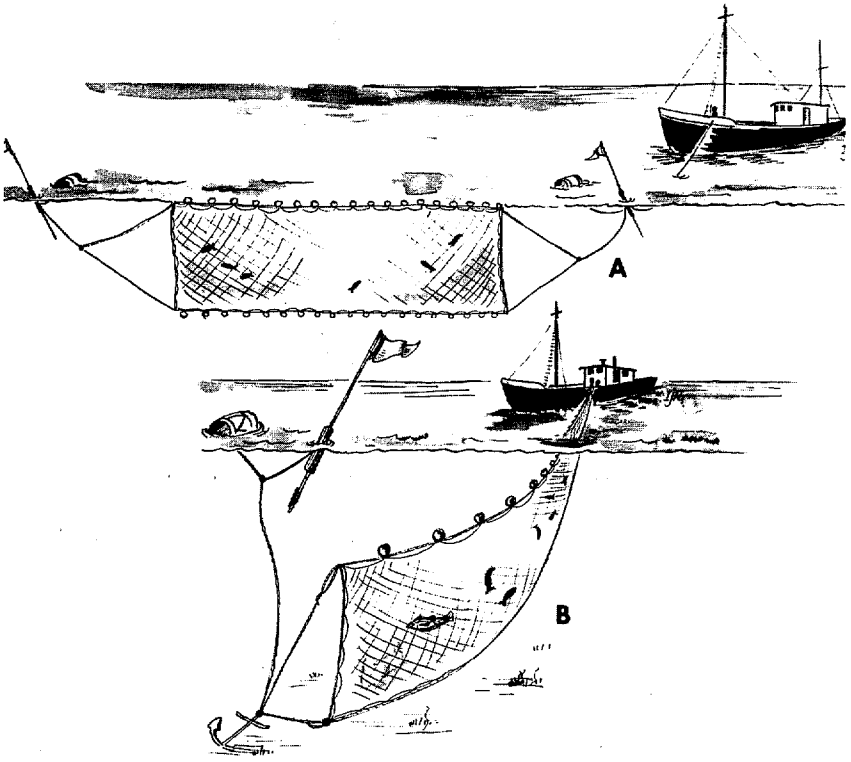


Figure 3. -- Driftnets

(A) Surface

(B) Sunken

Purse seines used by tuna vessels operating out of California are among the largest in the world. When fishing these seines may be three-quarters of a mile long and extend 200 feet below the surface. The nets may weigh 15 tons each and cost $60,000. About 6 tons of chain are used to weight the lower section of the nets and as many as 10,000 floats keep the float line on the surface.

A purse seine is normally set from the stern of the tuna vessel. To accomplish this, a seine skiff attached to one end of the net is dropped into the water with the net lead. The skiff has sufficient drag to start pulling the stacked webbing off the stern as the seine vessel proceeds in a near circular pattern at full throttle. After the seine vessel arrives back at the skiff, it retrieves the ends of the net originally set. Both ends are then secured, and the purse line is winched in until the rings are hoisted aboard, thus completely entrapping the fish. The net is then retrieved by hauling it over a hydraulic power block secured to the main boom. The seine skiff fends off the net from the larger vessel as the fish are brailed aboard.

DRIFT NETTING

Drift nets (gill nets, tangle nets, and trammel nets) are walls of webbing set out in a straight line. Drift nets may be used in turbid or muddy water during daylight; and in offshore regions, pelagic drift nets are commonly fished at night. Drift nets in the Japanese high-seas salmon fishery are 6.5 to 10.5 miles long.

The gear is normally shot over the stern of the vessel, and the net payed out in a straight line as the vessel runs ahead at almost full speed. If the gear is set at night, the ends of the net are marked with flag buoys and lights so that they can be clearly seen. In addition, radar buoys may be secured to the strings of gill nets. Larger vessels handling gear of this type normally haul the gear with a power roller rigged amidships or forward or haul the net with a powered sheave (Figs. 3a and b).

LINE FISHING

Large ocean-going fishing vessels use several line fishing techniques. The most common line method used by larger vessels is the so-called "longline." The longline consists of a main line to which a series of baited hooks are secured from droppers or gangions. The longline may be fished from a floating position (pelagic longline) (Fig. 4a), or anchored so as to fish on the bottom (ground long lines) (Fig. 4b).

Another line method is the pole and line fishing for tunas in the western Pacific and in the central Atlantic. This system requires a large number of men who stand in racks outboard from the vessel while they fish. The fish may be chummed to the side with bait, while the fishermen use lures or baited hooks to catch the tunas.

A third technique of line fishing which is still relatively common is trolling. Here a series of hooks or lures are towed from single lines which are fished off the stern and from poles rigged to extend outboard.

TRAWLING

The otter trawl is the most common system for harvesting species which live on or near the seabed. An otter trawl is a large sock-like net which is drawn over the bottom by cables from the fishing vessel. Otter boards or kite-like devices in front of the net keep the net open horizontally. The net is weighted on the groundline, and floats are placed on the headrope to provide the vertical opening necessary during fishing (Fig. 5). Some of the larger trawls used in ocean fisheries have groundlines of over 250 feet and the total length of the nets are over 280 feet.

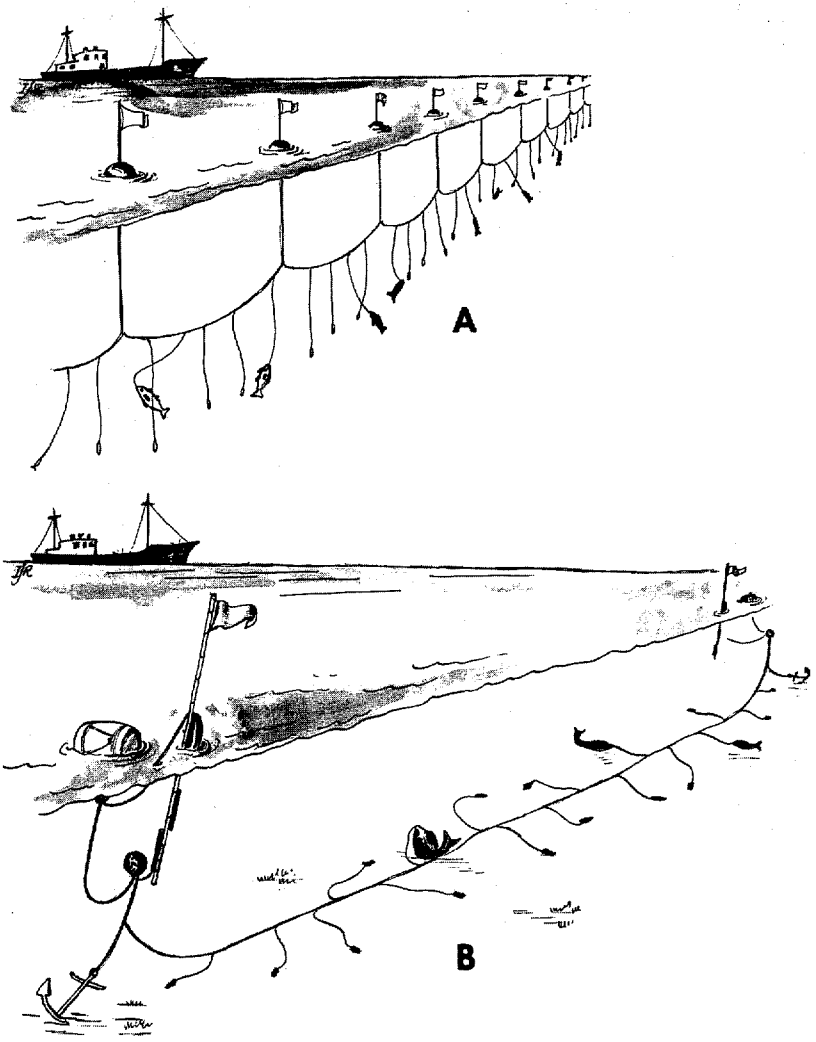


Figure 4. -- Line fishing methods.

(A) Pelagic longline

(B) Ground longlines

Large ocean trawlers are equipped with winches that carry up to 1,000 fathoms of 1-inch or greater diameter cable. The cables feed off the winches around several blocks to gallows frames (A-frames, davits, or stanchions) rigged on one side of the vessel (side trawling, figure 5a) or on either side of the stern (stern trawling, figure 5b). The otter doors, which may weigh over a ton each, are generally rectangular or oval in shape. The otter doors are rigged with a small bridle or attachment frames which are adjustable so that the front of the otter door will toe out or away from the axis of forward movement of the vessel. The bottoms of the otter doors have heavy steel shoes that ride on the ocean floor. The spreading power (ability of the otter doors to open the net in the horizontal plane) is a function of the lift it achieves moving through the water and the shearing force power provided by the frictional resistance of the otter door against the seabed.

The side trawler normally sets the net off the waist of the vessel while making an inward turn toward the side from which the net is being set. This allows the trawl to drift free of the stern. When adequate cable has been payed out, the two trawling warps are brought together and secured in a towing block near the stern of the side trawler. This allows the vessel to more effectively maneuver during fishing operations.

In stern trawling the winches are normally mounted to feed directly aft to the gallows frames or a gantry. The net is shot over the stern, and the towing warps are payed out rapidly while the vessel moves straight ahead at near full speed. When the gear is retrived the warps are pulled in until the otter boards arrive at the gallows frames. A by-pass system allows fishermen to free the doors so that the net, which is rigged to fish 30 to 60 fathoms behind the doors, can be hauled aboard.

SOME NEW FISHING DEVELOPMENTS

Types of fishing gear which evolved by the end of World War II allowed for relatively efficient harvesting of species inhabiting the areas near the surface of the sea or near the ocean seabed; however, between these two areas is a vast region in which man could not efficiently catch the available fishes. About the only means for harvesting the so-called midwater species were longlines or gill nets and neither gear was particularly effective in capturing most subsurface fish.

After the development of modern sonar and echo sounding equipment which provided information on the distribution and sizes of subsurface fish schools, gear technologists and scientists set out to design a midwater trawl. The development of an effective midwater trawl, which ostensibly seemed to be feasible by application of simple engineering principles, progressed quite slowly. The early midwater trawls did not seem to achieve the proper geometric shape during fishing, and methods of determining the operational depth of the net were unreliable. During early experiments the angle of departure of the towing cable was measured and simple trigonometric computations made to determine the net depth. This method provided only a poor estimate of how deep the net was operating and the error involved increased with depth of fishing.

Acoustical links and telemetering through the towing wires were soon used to provide more accurate measures of the depth of the net. The acoustical link systems that were developed, however, were continually plagued by pattern problems, and early telemetering devices that used electrical conducting towing cables were bedeviled with conductor breakage, corrosion, and difficulties in making terminations at the sensing units. These problems which handicapped the effective use of midwater trawls for over a decade now seem well on the way to being resolved. Commercial devices, both acoustical and wire telemetering, are now available to provide relatively accurate and reliable measures of the operational depth of midwater trawls. In addition, application of hydraulic principles in the design of midwater trawls has resulted in nets which assume more effective shapes during fishing. Midwater trawls

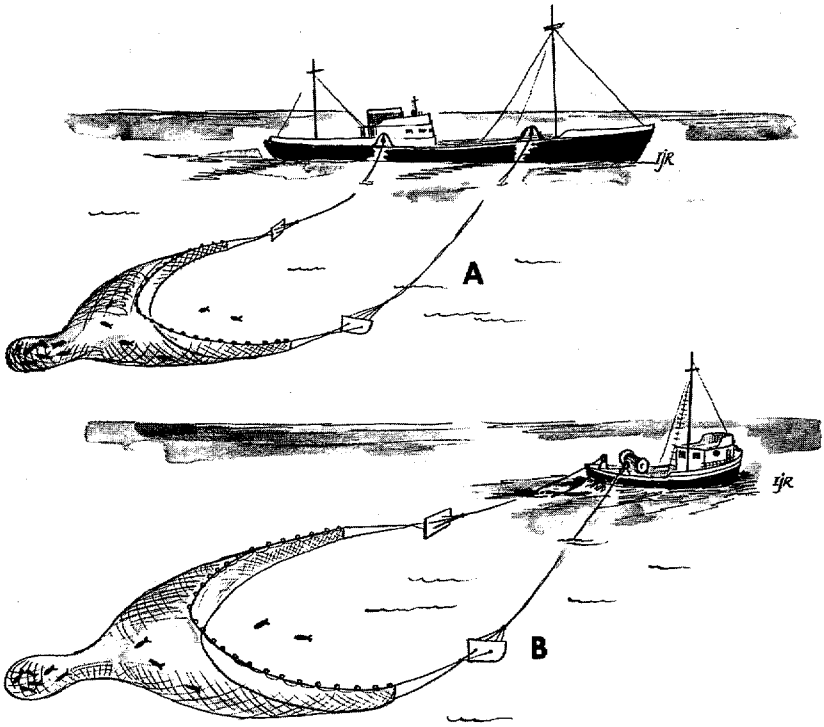


Figure 5. -- Trawling

(A) Side trawling method

(B) Stern trawling method

are now being used increasingly and could play a substantial role in future fisheries development.

A rather dramatic example of the effectiveness of midwater trawls has recently been demonstrated on the Pacific Coast of the United States. Several trawlers fishing for Pacific hake in the Puget Sound area have been equipped with midwater trawls and electro-telemetering systems. The average hourly catch of two vessels was 9.4 tons. The two vessels normally loaded up during 1-day's fishing, or after about three to five 40-minute tows. Bottom trawlers using standard otter trawl gear in the same area have fished for two days to catch as much hake as the midwater trawl vessels caught in one 40-minute tow.

Electrofishing, or the application of the principle of electrotaxis has been used on the east coast of the United States to assist in removing menhaden catches from purse seines, and recently bubble curtains have been used to guide herring into traps. The Soviets have developed a relatively efficient means of attracting some species of fish to lights attached to pump intakes. The fish are subsequently pumped aboard the vessels and no nets are used. These more exotic techniques, however, are responsible for capture of only a very small portion of the world's total fish catch.

Vessels

Fishing may be conducted from small open boats which use hand lines or small nets, or from large modern factory trawlers that harvest and process the catch aboard. Fishing vessels normally take the name of their fishing gear; that is, trawling = trawler, seine = seiner, longline = liner, and drift net = drifter. The vessels are, for the most part, designed to handle one or more of the four important fishing systems described above. There has been a trend, however, in recent years, toward designing vessels which have multipurpose capabilities; that is, vessels which can operate a variety of fishing gears effectively. It is not our purpose here to describe fishing vessels, but if the reader is interested he is referred to (Alverson 1961) and the two volumes on fishing vessels of the world Food and Agriculture Organization of the United Nations, (1955 and 1960).

Fishing Tactics

As previously noted, fishing tactics integrate the search and harvest phases of fishing. In a multi-species fishery such as trawling, the skipper will consider market demand for various species, and in some instances where limits are placed on the quantities of certain species that may be landed, he will take this into consideration in mapping the strategy for the coming cruise. He will also consider forecasts of weather, tides, and sea conditions that may affect fishing. Via radiotelephone he will have information on the success of trawlers on the fishing grounds. Thus, before leaving port a skipper may have set his sights on a certain fishing bank but enroute may modify his plans.

Upon arriving at the fishing grounds the skipper has a plan of operation. He will consult the sailing chart for that region and will note the number of drags he has made there previously. Snags or areas where the bottom is too rough to trawl will also be noted on the chart. Once in the area of the general fishing grounds, the skipper may key into a specific position by using his loran or Decca Navigator system. At the same time his echo-sounder will be charting the depth of the water as well as showing him any concentrations of fish over the seabed. When ready to set the net he will check the sea state, direction of the wave front, and wind velocity. If all factors seem favorable for fishing he will again determine his position. From the depth information conveyed by the echo-sounder, he will decide on the amount of cable to be payed out and will relay this information to the deck crew. The signal to set the net is then given and, after the doors have been secured to the towing warps, the vessel proceeds ahead at almost full speed while trawl cable is spooled off the winches. The cables themselves are

normally marked; e.g., every 25 fathoms, so the fisherman knows the amount of cable that has been shot.

When the proper amount of cable is out, the winches are dogged down and the vessel begins towing, normally at speeds of two to four knots. The cables are constantly checked during fishing to see if vibrations in the towing wire indicate that the gear is fouling on the bottom. During towing the vessel normally is steered to follow a particular depth contour or to maintain the depth within 1 or 2 fathoms. The direction, however, may depend on trawling conditions, and at times trawlers may fish over a somewhat wider depth range.

Trawlers tow from 1 to 3 hours; however, if the echo-sounder shows large amounts of fish, the duration of the tow may be shortened. When the net is retrieved, the master of the vessel will maneuver the vessel to minimize the effect of the sea on handling the net and unloading the fish from the codend.

As long as good catches are obtained, the trawler will remain on the same grounds; however, if the catches begin to dwindle, he will compare his results with those on other grounds, with the catches of other fishermen, and may set his course for another bank. Even if fishing is good, trawlers may be forced to leave the grounds if they have particular limits on certain species.

The problems of the seiner are somewhat similar to those of the trawler, for he must make a number of the same types of decisions ashore concerning the areas to be fished, weather and sea conditions.

After the seiner leaves port and heads for the fishing ground, he may receive more current information from other fishermen. Like trawlers, the seiner skipper listens to his radio to hear weather broadcasts and the talk of other skippers and may change his destination after leaving port. After arriving on the grounds the seiner must make a more concentrated search for fish than the trawler because blind sets of the seine are practically never productive. To detect fish he may use his echo-sounder or sonar or may make a visual search of the sea surface.

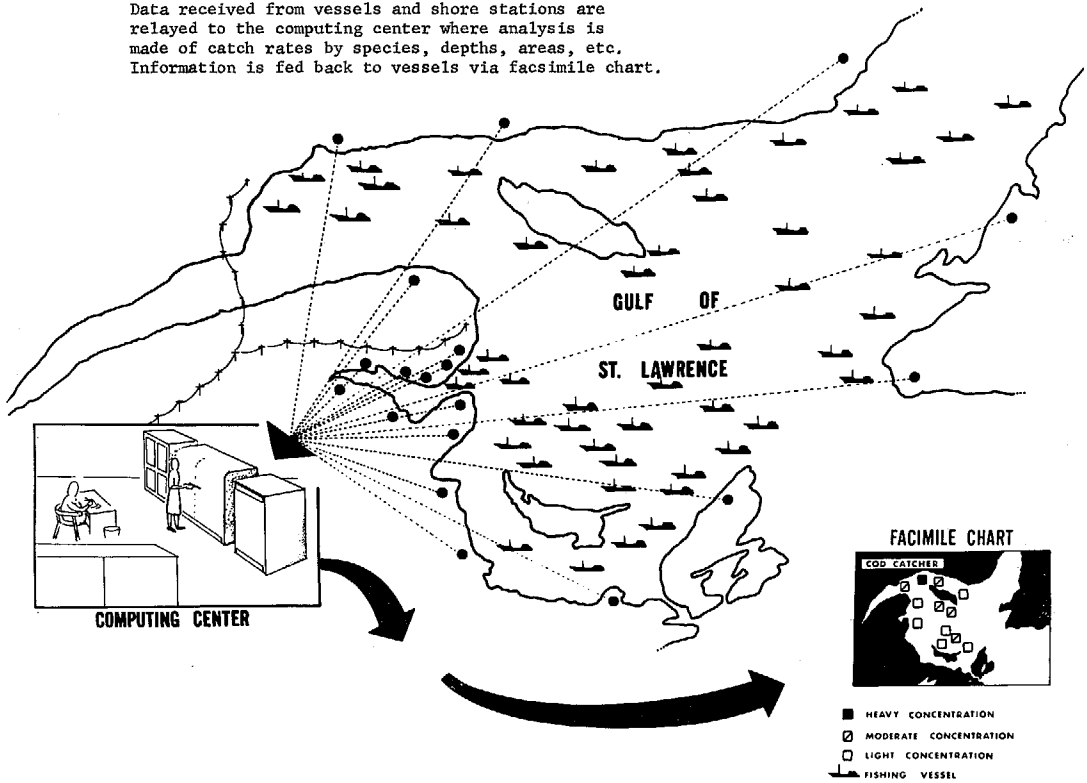
In tuna fisheries, once the fish have been sighted, a man in the crow's nest carefully looks at the school to determine the type of fish and size of school. The skipper will then maneuver the vessel alongside the school, keeping it off the port until he feels confident that the speed of the fish and their direction will allow suitable deployment of the net around the school. Often he circles the school several times before making the decision to set. If the tuna are traveling with a school of porpoise, he may wait until the fish lag behind the porpoise so that when he sets the seine he will minimize the catch of the unwanted mammal.

When setting the net, the skipper must decide just how long he can set the gear in a straight line ahead of the fish before turning (to the port) to encircle the school. This will depend on the behavior of the fish, the length of the net, and the length of the tow line. A normal set for tuna schools will have a "track line" in the water in the shape of a tear drop, but the net quickly forms a circle when pursing begins. During the pursing, a decision may be made to release the fish if the gear appears fouled or if the wrong species has been trapped. Once the fish have been brailed aboard and the net retrieved, the process of search and capture begins again. This continues until the vessel's holds are filled or the time absent from port requires the vessel's return.

FISHERY DEVELOPMENTS IN THE NEAR FUTURE

If one evaluates the methods in today's ocean fisheries, it is obvious that the hunting process is still represented--that is, search and kill. It is true we have come a long way in improvement of search techniques, and our fishing equipment and auxiliary equipment is more sophisticated than that

Figure 6. -- Fish forecasting system as visualized by simmons (1964).



used even several decades ago. Regardless, man still depends on the natural environment and on the biological characteristics of fishes to provide the concentrations necessary to harvest them in a profitable manner. He has not yet found how to control the environment, nor has he effective means for aggregating most fishes. His dependency on the environment and on the natural behavior patterns of fishes limits his ability to use effectively the living resources in the seas. This is particularly true in the open ocean where large amounts of organic energy may be available but are distributed widely.

Future further improvements will occur soon in two of the phases that currently control the output of the fisheries: search and capture. We can anticipate further improvements in echo-sounding devices (both vertical and scanning), and progress will continue in the design of the basic fishing gear used. In the next decade rapid progress will also take place in mechanization of deck equipment, and many of the fishing activities will be automated.

In the field of fishery strategy there will be a more formal exchange and use of information on fishing activities of vessels at sea and research vessels, and perhaps a more detailed analysis of the incoming catch data as related to the environmental features. The output from analysis of these data should allow fishermen to be more effective in planning and conducting their fishing strategy (see figure 6).

All of the above-mentioned developments are, however, refinements of existing techniques, and the real breakthrough in our ability to harvest the ocean must come as a result of acquiring knowledge in at least one of two basic areas: man must learn either to artificially aggregate fishes, or he must learn how to control the environment so that he can essentially control production and output of desired species.

Learning to herd or guide fishes will require much more information than is now available on how fishes behave toward stimuli and how their physiological processes are controlled by certain biological activities. If we can determine how fish detect their prey, such as by smell, sight, or sound, we might then use such knowledge advantagaously in attracting or aggregating fishes. This assumes, of course, that certain stimuli do elicit such desired responses in fish.

Control of the environment will perhaps be an even more difficult problem to solve and one which will have both biological and engineering difficulties. Scientists have proposed that artificial upwelling of high nutrient waters be created by transmitting heat to desired depths of the ocean and fencing off and farming certain areas of the ocean. For such a scheme it will be necessary to examine carefully both the biological and physical results that might follow. Manipulations of this type require thorough evaluations of the changes which will occur in the local environment.

Despite these difficulties, we should not overlook the fact that time may provide man with both the knowledge and the engineering ability to successfully aggregate fishes and farm offshore ocean areas.

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THE KIND OF OCEANOGRAPHIC INFORMATION OF DIRECT USE TO THE FISHERMEN

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American Tunaboat Association

Abstract

This paper represents a review of the experiences faced by the United States Tuna Fleet operating in the Eastern Tropical Pacific. Extensive oceanographic investigations have been conducted in the tuna fishery since the early 1950's. Tuna fishermen utilize oceanographic information and find it particularly helpful, especially as to sea temperature and thermocline topography data. Specific examples are represented in cases where the oceanographic information is of direct benefit to the fishermen. The author suggests that more oceanographic information concerning the enviornment of the tunas is required and points out that this information is of use to the fishermen only if it is properly and timely communicated by the scientist to the vessel at sea.

RESTRICTIONS ON THE SCOPE OF THIS PAPER

This paper represents a review of the experiences faced by the majority of the owners and operators of Tuna Vessels operating in the Eastern Tropical Pacific Ocean. Such vessels have occasionally fished for tuna in the Atlantic and South Pacific. The tuna fishery in the Eastern Tropical Pacific utilizes four fishing techniques: (1) Purse Seining, (2) Live Bait fishing, (3) Longline, and (4) Trolling. The fishing techniques used by the U.S. tuna vessels to catch the tropical tunas are purse seining and live bait, and of these two, purse seining is the primary technique. Trolling is used to catch Albacore tuna only. Therefore, this paper is limited in scope in that it will deal with the kind of oceanographic information of direct use to the U. S. Tuna Fleet operating from Southern California and Puerto Rico. And further, by the fact that it deals with the experiences of fishermen who utilize the purse seine and live bait fishing techniques.

GENERAL REMARKS

Oceanographic information directly benefits the tuna fishermen when it assists him in determining the availability of the tunas to his fishing gear; in determining the local distribution of the tunas within the fishing range, and when it helps him in determining the abundance of the tunas within the general fishery area.

OCEANOGRAPHIC INFORMATION AND THE TUNAS

A. Topographic Charts

From the belief by tuna fishermen that tunas are associated with the presence of feed, and that good feed conditions are associated with banks, islands and seamounts, representatives of the American Tunaboat Association made arrangements with the Scripps Institution of Oceanography and the U.S. Bureau of Commercial Fisheries for the preparation of bottom charts of certain sections of the Eastern Tropical Pacific. It was hoped at that time, in the middle 1950's, that these charts would be of value in increasing the productivity of the U.S. Tuna Fleet, and thereby contribute to the solution of problems caused by the competition generated by the Japanese Tuna Fleet. Unfortunately, the completeness and accuracy of these charts were affected by the requirements of National Security. Nevertheless, these charts are in general use by the Fleet and are of continuing value to the fishermen. Their value increased with the conversion of the baitboat fleet to purse seining. These charts have raised an unrestrained curiosity and a steady appetite for more topographic information.

Ever since hearing that the charts prepared by Scripps as originally drafted had more information than made available to the fishermen, and that the Department of Defense objected to the distribution of certain charts, our fishermen are convinced that somewhere, someplace, oceanographers have plotted seamounts and banks on charts dealing with the Eastern Tropical Pacific, that are not available to them for fishing purposes.

The desire of our fishermen for more information concerning the topography of the ocean floor is insatiable. Obviously, such type of oceanographic information is of direct benefit to the tuna fishermen.

B. Extent of Oceanographic Investigations In the Tuna Fishery

The extent to which oceanographic investigations have been directed towards the environment of the tunas was carefully and interstingly explained in a recent paper by M. Blackburn of the Institute of Marine Research, Scripps Institution of Oceanography, La Jolla, California. The title of this review, which I recommend for your reading is Oceanography and the Ecology of Tunas, printed in Oceanography, Marine Biology, Annual Review, 1965, 3, 299-322.

Blackburn points out that oceanographic research relating to tunas has been very fruitful in its contributions to pure oceanography. These investigations have been concerned primarily with an understanding of the distribution of tunas. As such, the oceanic properties of temperature, salinity, dissolved oxygen concentrations, transparency, phosphate-phosphorus concentrations, and other ecologically related properties of the ocean have been studied. In addition, investigations concerned with oceanic features and processes, such as surface currents, frontal systems, upwelling, thermocline topography have been conducted for the purpose of discovering their relationship to the distribution and abundance

of the tunas in the Eastern Pacific.

The concluding remarks by Dr. Blackburn concerning the distribution of tunas in relation to lower trophic levels are particularly relevant to this meeting. It is in this area that you will find acceptance by the fishermen. Acceptance, because it is generally believed by fishermen that oceanographic information in this area will help catch tuna. They believe that the availability and movement of tunas in the fishing range can be largely explained by the presence of food organisms that are available to the tunas. Blackburn states that this relationship needs more and harder work to substantiate than might be thought, and further, that essential estimates required in such work can only be developed by detailed local oceanographical knowledge. And, perhaps hopefully on my part, I discovered an indication from Blackburn that a joint venture of fisherman, oceanographer and biologist could make the job easier.

While on this topic of gathering oceanographic information from fishing vessels, let me point out the fact that our vessels are available to scientists. I do not know of any member of our Association who has refused a reasonable request from the U.S. Bureau of Commercial Fisheries, the Inter-American Tropical Tuna Commission or from the Scripps Institution of Oceanography.

EXAMPLES OF THE RELATIONSHIP BETWEEN OCEANOGRAPHIC INFORMATION AND FISHING SUCCESS

Complete and precise information regarding the limits of distribution of tunas by depth would be of direct use to the tuna fishermen. If the apparent vertical range of the tuna is from 0-150 meters, then the fishermen has a useful factor regarding the availability of the tunas to his fishing gear.

At the present time the fishery biologist is moving in the direction of determining the ability of tunas to live in the ocean environment under certain circumstances. At the present time, there exists two schools of thought on this subject. The first contends that the tunas have a short oxygen span, therefore, they must travel in water that has a high oxygen content. Thus, the vertical range of the tunas in any given ocean area will depend upon the oxygen content of the water. The other theory is that the tunas require a water that has a certain temperature gradient, thus they will always have a vertical range limited to the mixed layer above the thermocline, and that penetrations below the thermocline, if any, will be infrequent. Regardless, of what school of thought is correct, it is apparent that the answers needed by the fishermen must be founded upon oceanographic information. Further, it is clear that the availability of tuna is related to catch success, and thus far, catch success is closely related to the extremely important question of abundance of tunas in the Eastern Tropical Pacific. The model used by the Inter-American Tropical Tuna Commission in determining the maximum sustainable yield of tunas in the Eastern Pacific is founded upon catch success, that is, a formula that measures the effort exerted by the fleet in terms of

total catch and catch per standard days fishing.

THERMOCLINE TOPOGRAPHY

Recently, this question of the connection between thermocline topography and tuna fishing success was under study by the Bureau of Commercial Fisheries in San Diego, California. With the kind permission of their offices, the following information is provided:

Sample Used: 2,000 individual settings of purse seine nets on tuna schools in the Eastern Pacific.

Depth of Thermocline	Nature of the temperature Increase		Success of the Set
	Gradual	Sharp	
0-10 Fathoms	52%	64%	58%
Over 10 Fathoms	40%	46%	42%

When the thermocline is sharp and the depth of the thermocline is no greater than 10 fathoms, the fishing success experience is 64%. When the thermocline is sharp and the depth of the thermocline is greater than 10 fathoms, the success experience is 46%.

Since 1963, many vessels in the Tuna Fleet have adopted a practice of taking daily bathothermographs. More and more of the successful fishermen are developing thermocline information for use in their fishing operation. A more effective program of developing such information has been recently worked out by the American Tunaboat Association and the U.S. Bureau of Commercial Fisheries.

The use of thermocline data has affected industry and government judgments regarding the use of purse seine gear in tuna fishing in the Cental Pacific and other areas of the world's oceans. In this respect, therefore, oceanographic information regarding the distribution and nature of thermocline topography and its effect on the tunas is obviously important. I might add, that the Japanese longline tuna fishermen use thermocline information in determining the depth of his fishing gear. Special equipment has been developed by the Japanese specifically for use by their tuna fishermen in determining thermocline topography.

TEMPERATURE INFORMATION

Fishermen do rely upon water temperatures in making decisions for tunas within fishing areas. This is particularly true in the seasonal albacore fishery off the Pacific Coast. In the tropical tuna fishery, water temperature is important but not critical. In certain fishing areas, some fishermen constantly observe water temperatures. In others, fishermen ignore water temperatures and rely almost wholly on surface signs for

information regarding the presence of tunas.

Basically, there is no dispute on the value of temperature information in determining the limits of tuna distribution within the 300 million cubic miles of ocean, but some people do question the usefulness of water temperature in determining the varying pattern of distribution or availability of the tunas within those limits.

Since 1960, scientists at the U.S. Bureau of Commercial Fisheries Biological Laboratory, La Jolla, have been analyzing historical oceanographic, meterological and fishing records in an effort to understand variations in the availability of the albacore off the west coast of North America. "The ultimate objective of this analysis is the accurate prediction of the distribution and availability of albacore" tuna from year to year.

In connection with this work, these scientists provide monthly sea-surface temperature charts of the Eastern Pacific Ocean. They also issue 15 day temperature charts covering the area of the albacore fishery from April through October.

Since 1962, a radio reporting service was initiated by the BCF, San Diego, for the purpose of providing the exchange of sea temperature information between the Lab and the albacore fishermen. In 1965, these broadcasts were on a daily basis. In addition, a "coded" current 15 day analysis of the sea temperatures is broadcasted to the Albacore Fleet so that fishermen at sea can plot up their own temperature charts as soon as they are completed ashore.

The active participation of the albacore fishermen in this program is the best evidence of its success to date. It is also a remarkable example of how oceanographic information directly benefits the fishermen. It also indicates that there exists a relationship between the value of the information to the fisherman and how it is communicated to him. Unfortunately, the program initiated in the Albacore Fishery is not available in the Tropical Tuna Fishery. In Japan, there exists a program generally known as "Fax". My knowledge of "Fax" is extremely limited. I bring it to your attention, because it provides some evidence that oceanographic information to be effective to the fishermen must be properly and quickly communicated to him while he is on the fishing grounds. Essentially, "Fax" is a device where information is transmitted by a wirephoto machine from Japan to all vessels who have agreed to provide information to the transmitting station. The program was initiated by the Tokai University Fisheries Research Laboratory.

I visited the University in 1962, and have available for your inspection a Tuna Fishing Ground Condition Data Report for a portion of the Indian Ocean. I was deeply impressed by the techniques used by the Japanese to communicate useful oceanographic and fishing information to their fishermen. Perhaps,

a similar quid pro quo arrangement could be worked out by those who desire certain types of information from the U.S. fishing fleet. Certainly, such an arrangement would increase the effectiveness and safety of the U.S. fishing fleet and also provide additional oceanographic information.

Inquiries are still being directed on the Pacific Coast towards the question of whether there exists an oceanic property that determines the differences in abundance of tuna within the range of temperatures that limit tuna distribution. The need for more oceanographic information in this area is essential. As Blackburn points out, there have been very few attempts to depict distributions of ecologically related properties of ocean water on a world-wide or even on ocean-wide charts. And even these attempts cannot be depended upon to show fine details of any distributions. Such charts or information properly and timely communicated to fishermen would be invaluable. With regards to work dealing with the relationship of tuna distributions to coastal upwelling situations and fronts, much oceanographic work is required.

In essence, let me conclude by stating that more oceanographic information must be developed to be of direct use to the fishermen. In addition, there must also be a more effective method of transmitting this information in a way that will be intelligible and timely to the fishermen. At present, in the tuna fishery, the fishermen are being educated by the scientists, but not fast enough. The exchange of information between them is insufficient and improperly communicated. Perhaps, we can overcome these difficulties by following the Japanese example. In the U.S. Albacore Fishery, a fine start has been made, largely by the effort of a few scientists.

ENGINEERING NEEDS FOR FISHERY DEVELOPMENT

by

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ABSTRACT

Ocean engineering is examined from the viewpoint of the fishing industry. Fishery development must be considered in terms of overall industry needs and in terms of specific fishery units. Fishery Research can define problems in the industry and can conceptualize solutions with Engineering Technology support. Fishery Research is currently attempting to determine where Engineering Technology can be applied, and similarly Engineering Technology is attempting to enter into the field of fisheries through introduction of specialized equipment and concepts. Some of these concepts include artificial upwelling, manned and unmanned submarines, however, these have yet to be applied in commercial fishing. Problems to be solved for the commercial fisherman include ways to stop fast-moving schoolfish; means of concentrating scattered fish; means of locating subsurface fish more effectively; methods to repel sharks; how to induce feeding in hook and line fish; effective methods of monitoring trawl gear action; etc. The question arises, under present time and funding limitations, whether to pursue answers to these problems or attempt to improve conventional fishing. From the standpoint of the commercial fisherman, navigational aids such as radiotelephone, depth sounder, loran, radar and autopilot are fairly adequate. Of importance, but hard to define, is the expertise of the individual fishermen who often, with similar equipment, will achieve varying results.

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In a paper presented at the Ocean Science and Engineering Conference in Washington last year, Alverson and Schaefers (1965) gave a comprehensive review of the developmental trends in world fisheries and discussed the present concepts of the application of Ocean Engineering to improved and expanded fish harvest. The treatment was timely and thorough and another such resume here is needless. This paper will examine certain developmental aspects in greater detail and attempt to provide some perspective from the viewpoint of the fishing industry.

The above paper offered a basic definition of Ocean Engineering as: "The conception, design, development, and introduction to industry of better devices for harvesting the living resources of the sea". For discussion purposes this definition can be divided into two logical and more specific categories:

1. To improve vessels, equipment, gear, and tactics in existing fisheries, and
2. To devise means of making those species and stocks of commercial potential available to exploitation that would be otherwise left unharvested with the means at hand.

The great diversity of commercial fisheries is in every measure comparable to agriculture. (One of the previous papers described the wide variety of

vessels, gear, and methods that are employed in this harvest (Alverson and Schaefers, 1966)). But when we talk of fishery development it is also necessary to think of it both in terms of the broad programs that have wide application over many or all segments of the industry and in terms of the specific fishery units. The first usually encompasses wide spectra of political, social, economic, nutritional, and even promotional components. Within the individual fishery units, such as shrimp, hake, tuna, etc., we get a much clearer picture of specific technological requirements. But here again we must separate the components of handling and processing, storage, transport, and marketing from the basic production of raw material. There are, to be sure, varying degrees of integration of many of these components with fish production, but here the discussion will be limited as much as possible to the engineering needs in this restricted area of basic fishery production.

This limited aspect of fishery development has four essential ingredients; identification of problems, conception of solutions, experiment and trial, and finally profit. The general mechanics of the 3-way relationship between our Fishery Research, our massive Engineering Technology, and our Commercial Fisheries can also be defined although assigning responsibility is like separating a nail and a hammer and a carpenter. For functional results each must work with and respond as necessary to the others.

Fishery Research can define the problem by close association with Commercial Fisheries, and can conceptualize solutions with Engineering Technology support. Engineering Technology can test and develop with support from Fishery Research. Final application for profit by Commercial Fisheries needs the continuing support of Engineering Technology.

Since the end of World War II and particularly within the last decade a start towards unification of these increasingly diverse elements has occurred. Fishery Research is now attempting to determine where technological breakthroughs are needed and has at least started to provide conceptual guidance in specific problems. It is less prone to await each major engineering innovation with a faith that Commercial Fisheries can survive or thrive on a percentage of beneficial side effects as it has in the past. Its experts increasingly advise both the engineering industry on potential equipment markets and the fishermen on the potential value and application of the new equipment. Engineering Technology is taking a new look at Commercial Fisheries and is screening new instrumentation through Fishery Research for channels of potential commercial application. And Commercial Fisheries is showing signs of response to this more direct approach, although there would appear to be a frustrating lag in many instances of adoption and application.

The integration is in infancy--but it has tremendous growth potential. If fishery harvest by the United States is to climb above its present plateau, particularly in the face of burgeoning international competition, we must look to this partnership for the requisite developmental channels.

We can also ask what part of this directed effort should go towards bringing fish harvest to the stage scientists and economists can presently conceive to be the utlimate or ideal and what part should be devoted to the problems inherent in reaching the very next step on the developmental ladder.

Actually we have already developed a myriad of concepts for fisheries of the future. Fencing and farming the open oceans was proposed many years ago and much speculation has gone into how this could be accomplished and what could be produced. What kind of fencing? Physical, thermal, electronic, and sonic have been proposed. What could be produced and in what quantity? The picture is far from clear.

About 10 years ago it was suggested that through the use of atomic energy deep, cold, nutrient-laden waters could be warmed to create artificial upwelling. This method could be used to enrich large areas of impoverished oceanic surface waters. The resulting biological activity could be expected to yield a significant increase in available fishery crops. Or perhaps this could be further developed into an artificial aggregating device.

The application of manned and unmanned submarines was suggested and prophesied only a few years ago. However, the infancy of commercial submersibles has not yet provided clear concepts on suitability for fish production.

The functional and feasibility evaluations of these visionary and perhaps prophetic estimates of future fisheries are separated from the present, however, by wide technological gaps and many near-voids in the requisite oceanographic information and the biological and behavioral knowledge of the potential crop.

These far-reaching concepts have been far more interesting to the scientist and the technologist than they are to the fisherman. They provide an interesting contrast. Over the past 6 months the following question was informally asked of a variety of directly interested parties in the fishing industry: What new fishing gear or device would do the most to increase your catch rates or in any way improve your operation? The answers were as follows:

Captain of a tuna seiner

1. Some way to slow down or stop a fast-moving school
2. Some way to concentrate scattered fish

Aircraft tuna spotter

1. Some way to locate subsurface fish schools

Captain of a snapper schooner

1. Some way to repel sharks from the fishing area
2. Some way to induce feeding behavior of snapper

It could be noted here that the Gulf of Mexico red snapper fishery underwent a revolutionary change in productivity within the last 5 years by the simple means of introducing a new type of hook. By the late 1950's many considered this to be a dying fishery. This hook which had been in use in Japan for decades has almost doubled the catch per man/day and several new vessels have been added to the fleet within the last few years.

Captain of a shrimp trawler

1. Some way to monitor net and otter board behavior
2. Some way to repel sharks from the fishing gear
3. Some way to chase burrowed shrimp out of the substrate to permit round-the-clock operations

Captain of a menhaden seiner

1. Some way to move schools off the beach and out to fishable depths

Mackerel gillnet fisherman

1. Some way to repel sharks from the fishing area, or better still, to repel them from the gear

Perhaps the best way to describe these answers is that they are rather down-to-earth. They do tend to crystallize the alternatives to be faced in establishing priorities in this phase of Ocean Engineering. With the time and the funds that will be available, can we forge a new fishing technology? Or can we achieve productivity goals by devoting a major research effort to increasing the efficiency and effectiveness of the present operations. Both are needed. The latter for the obvious reason that regardless of problems of international competition, declining traditional fish stocks, or any of the many adversities that can and will enter the scene, our fisheries must maintain a profitable operation or they will disappear. The expanding effort and rapid technological advances of the competition assure us this assistance will be necessary. The former for the singular reason that many of the stocks and species that now provide the basis for the most optimistic hopes for future long-range expansion just cannot be harvested with the means at our disposal.

So, in very general terms, fraught with exceptions, we have two schools of thought. The first, loosely formulated at present but seemingly favored by many fishery scientists and research ocean engineers, is that the most rapid advances, the most notable progress, might well be achieved by conducting research that is designed to leap-frog the harvesting problems of today and the immediate future. The widely held predictions on the role of the seas in supplying vital nutritional elements to a rapidly expanding world population justify the urgency that is felt in moving fisheries in new directions of massive production. The second school, strongly held at the fisherman's level is that progress can best be achieved by solving and eliminating problems as they are presented. This is argued from the view that industry must sell what it develops and that commercial fisheries must need the product to provide the market; from the simple standpoint that both must stay in business.

In the above statements from fishermen we detect the absence of urgent need for navigational and communication improvement which might well have been the highest priority just 20 years ago. This evidences a significant developmental trend in the recent adoption of a standard electronic package consisting of radiotelephone, depth sounder, radar, loran, and autopilot. The importance of this package in present fisheries needs no further discussion here. It does show that the industry is highly receptive to developments having immediate bearing on production. It also shows that we are never without problems, that as the most urgent technological needs are met, others rise to occupy a position of urgency.

We can list selected examples illustrative of current thought and research in the major categories now considered to encompass future engineering needs. First, with respect to gear effectiveness and efficiency, we need a device that would provide continuous shipboard monitoring of gear performance. Bottom trawling, for example, can be compared to the operation of a complex engine without benefit of oil pressure, fuel, or temperature gauges, indeed without speed indicators or speed control. We are now studying the means to monitor such factors as bottom contact, speed over the bottom, spread and height of net opening, otter board attitude, load strain, and gear damage. If this package can be engineered to a functional shipboard unit we believe a new and useful tool can be added to trawling technology.

Second, with respect to improved technology in scouting, surveying, and monitoring the resource, the introduction of aircraft fish school spotting has played a major role in recent years to raise the productivity of many purse seine operations but has in turn challenged us to provide means to increase efficiency still further. There is an urgent need to devise some means of penetrating the air-sea interface to detect subsurface schools. The Bureau of Commercial Fisheries is presently conducting feasibility studies on the application of towed aerial platforms employing remote control television for scouting and survey. Also, the continuous monitoring

of selected environmental data will be required eventually as studies reveal those parameters associated with maximum availability. Temperature controlled pingers on bottom trawls would permit the gear to be positioned and held in the desired thermal levels. Moored, unmanned scanning buoys have been suggested to provide continuous radio monitoring of fish movements.

Third, with respect to control of animal behavior, we need means of selectively attracting, repelling, stunning, and regulating. This may well be our most promising area of harvesting study. Research in the application of electrical fields to behavior control has been both promising and frustrating. The problems of delivery of electrical impulse through sea water has brought numerous experiments to unsuccessful conclusions. Still, the responsiveness of marine animals to electricity has encouraged the development of an entirely new field of electrical fishing technology. In some areas commercial application is evidenced with promising results. In 1965, the USSR reportedly produced some 200,000 metric tons of anchovy, Pacific saury, and Atlantic sardines using lights to attract and concentrate and electrical fields to direct the fish schools to a fish pump. United States research efforts have been concerned with devising means of stunning fish in the path of the bottom trawl and to stimulating burrowed shrimp to leave the substrate and become available to standard trawling gear. Neither of these has reached the status of commercial application as yet.

And fourth, with respect to alteration to and control of the environment, we have reached little beyond the stage of pure speculation. Here we can only add that our experiences to date with man's alteration of the marine environment has created far more concern than encouragement. The acid test of new technology is, in the final analysis, quite simple. It must in some way pay for itself, its operation, its maintenance, and enhance the earnings and profits of the fishing enterprise. The best fishing vessel is not necessarily the one with the most and best equipment. It is the one that is equipped with everything that will yield the greatest long-term profit for the owners and crew.

This might partially explain an industry reluctance and reticence to move quickly down the many new trails being opened by industrial and technological developments. However, there is something else too. It falls in the category of one of our more poorly defined problems. Perhaps this example will be illustrative.

A modern trawler has reached the fishing grounds and is about to start fishing operations. The captain navigated to his position with LORAN, and oriented his vessel in respect to the rest of the fleet with RADAR. He has approached the grounds with a DEPTH RECORDER operating and has recognized familiar configurations of bottom contours he has fished for the past several seasons. Within a radius of 5 miles are five other trawlers of the same size, design, power, and equipment. He has just discussed the catch rates over the past few days with the other captains using RADIOTELEPHONE. The captains know each other well; discuss gear together; visit each other's vessels in port. As soon as any new gadget or tactic has been proven aboard one vessel it is quickly installed or adopted by the others. He is on the grounds on rather equal footing with his peers and the competition begins.

Twenty-four hours of round-the-clock trawling later we start getting a measure. Our captain has out-caught four of the other vessels but one has produced considerably more than our vessel. This is, more or less, the way it has gone all year. We have the high-liners, followed by the good producers, followed by the rest of the pack.

What is our captain doing during this 24-hour period with particular reference to out-fishing most of the fleet?

To all practical purposes he is practicing an art; demonstrating expertize, showing skill in diagnosis, judgment, ingenuity, and doing it competently. On the basis of experience and training he is correlating the physical capabilities of the vessel, gear, and equipment, with existing environmental conditions of weather, sea, and bottom, interpreting biological factors of schooling behavior as depicted on the variety of recorder and cathodic indicators at his disposal, evaluating these in terms of knowledge of response and escapement, and adjusting the fishing tactics accordingly.

Perhaps our greatest challenge will be to replace those individual qualities that provide maximum results with the tools at hand with some automated system. We can ask ourselves this question: Can this be accomplished now with modern engineering theory and technology? If this is possible, we have an undeniable justification to move quickly in attacking the problem. On the other hand, if this is now considered unfeasible, we have little choice but to recognize that the maximum benefits will accrue from directing our modern technology toward developing more practical tools to help the individual perform a highly individualistic craft.

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DEVELOPMENT OF LAW FOR OCEAN ACTIVITIES

By

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Abstract

All law--national or international, customary or written--is generated only by human interactions. From the remote and recent past we have inheirited a body of formulated rules governing ocean activities. These rules are found in the customary Law of the Sea, treaties, e.g., the four Conventions adopted by the United Nations Conference on the Law of the Sea (1958), the United States' Submerged Lands and Outer Continental Shelf Acts (1953) and other Federal and State statutes and common law. Although problems of application of the rules to specific situations will continuously arise, the presently existing rules are sufficient to provide a reasonable basis for the orderly conduct of ocean activity for the next few years. In the meantime the ocean activities industry as a whole, as well as Government, should begin to examine and study what should be the public policy and future law which would best serve the general and long term interests of the United States and its ocean activities industry.

INTRODUCTION

"Roll on, thou deep and dark blue ocean, roll!
Ten thousand fleets sweep over thee in vain;
Man marks the earth with ruin,--his control
Stops with the shore."

--Lord Byron

The beauty of Byron's lines lives on but their substantive truth is being eroded by modern technology. Man has entered an era in which his ever increasing ability to project his control beyond the shore has created a new triple interface of technology, economics and law.

A sometime complaint of businessmen hesitant to commit venture capital to a newly developing situation holding the prospect of profits is

that the law is uncertain. The purpose of this paper is to examine the validity of that complaint.

THE LAW DEVELOPMENT PROCESS

In law, as in any intellectual discipline, when one is faced with a novel situation resort must be had to the fundamentals of theory.

In September 1704 a sailer named Alexander Selkirk was marooned on a deserted island off the continental shelf of Chile and there he lived alone for five years until he was rescued. His adventures inspired sermons, essays, poems and the book Robinson Crusoe. Among the poems about his experience is one by Cowper which begins

"I am monarch of all I survey--
My right there is none to dispute;
From the centre all round to the sea,
I am lord of the fowl and the brute."

If Robinson Crusoe thought about his condition he might have realized that he was lord of nothing. He had no rights because there was no person against whom he could claim them. He had no duties because there was no person to whom he could owe them. He had no privileges because there was no one to dispute them.

This planetary island, Earth, is inhabited by people whose lives are affected by rules. The nature of the process by which rules of law are formulated is the same whether at the local, national or international level. Individual persons form groups which we call families, corporations, states or nations or by other names. Individual relationships continue but to these are added the relationships of the individual to the groups and of groups to groups. Any one grouping cuts through and across other groupings locally, nationally and internationally. The general problem is the resolving of conflicts of interest or desire, real or imagined, of individuals and groups. Conflicts are resolved by a process of social interaction consisting of the putting forth of a claim of right by an individual or group, a response by an affected individual or group and the ultimate working out of an area of reciprocal tolerence. A rule of law is simply the verbalization of a reciprocal tolerance of claim and response.

This process of continuous interaction of unilateral claim and response is nowhere better illustrated than in the uses of ocean space. The decision makers of particular states unilaterally assert diverse claims to the use of ocean space. These claims are appraised and responded to by the decision makers of other states who on other occasions are themselves claimants. When these decision makers accept by reciprocal tolerance each other's claims, the area of reciprocal tolerance is customary international law whether expressed in decisions of foreign offices, courts or legislatures. Or the area of reciprocal tolerance may be written into a treaty which is law for the parties.

The character of international society makes the growth of a new rule of international law a slow process. But as new claims are developed in ocean activity they will become accepted as law when the need is reciprocally felt. For this reason it is important that the United States develop new ocean activities and expand existing ones as rapidly as technology permits. It is only as a principal participant in ocean activity interactions that the United States can be a leader in the molding of new international law.

Our national law of ocean space is also the product of the process of continuous interaction of claim and response of the Federal government, the State governments, corporations and individuals regarding rights in the

use of ocean space but the more sophisticated nature of our national legal system tends to obscure the fact. Our national body of customary law (i.e. State and Federal common law) is administered by courts which perpetually reformulate and develop its principles in the light of the process of social interactions. Practices attractive to a group thinking of national security may not be attractive to an industry group concerned with developing and protecting an investment in ocean resources exploitation. Practices attractive to one industry group may be repugnant to another. If the area of reciprocal tolerance is worked out by negotiation and agreement of the groups concerned, we call it a contract. A contract is law for the parties. If the reciprocal tolerance is worked out by a court, we call it State or Federal common law. If it is worked out by a legislature, we call it a statute.

For an industry group to hold back from ocean activity waiting for the law to become more certain is self-defeating because becoming a participant in the process of interaction is the only way industry groups can become leaders in the molding of new law of ocean activity.

Moreover, to wait for certainty in the law, dealing as it does with social interactions, is to wait for the materialization of a chimera. It is the nature of all law--customary or written, national or international--not to be susceptible of exact or final formulation. When a body of customary law is administered by courts which perpetually reformulate and develop its rules, as in the case of our State and Federal common law, its uncertainty is so much reduced that it is no greater than the uncertainty which attaches to the interpretation of written law such as treaties and statutes. And every businessman who has been involved in antitrust law, for example, knows how uncertain the meaning of a statute can be. The principal difference between national and international law in the matter of obtaining certainty is that the clarifying influence of courts is only beginning to be felt in international law. The paucity of adjudicated decisions in the international area has only the effect of making it less possible to verbalize international law rules dogmatically than in the case of national law rules. The difference, however, between national and international law is not one of certainty versus uncertainty in formulation of rules; it is merely between a less and a greater degree of uncertainty in some situations.

Regarding the degree of uncertainty in the law for ocean activity, the fact is that we now have a body of rules of national and international law satisfactory for resolving most of the immediately foreseeable problems.

The customary international law of the sea has been evolving over a longer period than other branches of law. In 1958 a United Nations Conference on the Law of the Sea adopted four treaties, called Conventions, which reformulate in written rules much of the customary law and create new written rules. These four Conventions, supplemented by customary law, now form the basic framework of international law for ocean activity. They are:

(1) Convention on the Territorial Sea and the Contiguous Zone, in force from September 10, 1964 for 29 states, including the United States.

(2) Convention on the High Seas, in force from September 30, 1962 for 37 states, including the United States.

(3) Convention on Fishing and Conservation of the Living Resources of the High Seas, now ratified by 21 states, including the United States, and will come into force when ratified by 22 states. (In force March 20, 1966).

(4) Convention on the Continental Shelf, in force from June 10, 1964 for 32 states, including the United States.

It has been long established, in the words of the Supreme Court of the

United States, that

> "International law is part of our law, and must be ascertained and administered by the courts of justice of appropriate jurisdiction, as often as questions of right depending upon it are duly presented for their determination."

There are also federal statutes regarding ocean space exploitation (discussed below) which in part make some ocean activity the subject of the adjacent coastal States' law. Some interaction problems of State and federal jurisdiction remain to be clarified but they are no different in principle than those in other areas of State and federal relationships. If, however, the industry groups which may be affected desire to influence the nature of such clarification, they should begin to study and plan now.

OCEAN SPACE ZONES

The cardinal principle of the law of the sea is freedom of the seas but it has long been recognized that this principle is not appropriate for all ocean areas. Therefore, as a counterpart to the principle of freedom of the seas it has long been recognized that ocean areas adjacent to coasts must as a practical matter be considered as an appurtenance to the coastal state's sovereignty over its land territory.

The principle of national sovereignty in a marginal sea area gives rise to two problems: (1) What are the contents of this sovereignty? (2) What is the extent of the area over which it extends? These two problems may seem to be separate and distinct. In practice they cannot be separated because the more absolute the coastal state's authority, the greater is the interest of other states in a narrow width of such authority. Conversely, the wider the area of the coastal state's sovereign authority, the greater is the interest of other states in reducing the content of the coastal state's authority therein.

Over a long period the practice of states has evolved a pragmatic solution to this problem. Ocean space is divided into five zones in which the coastal state's authority becomes less and less absolute seaward until it becomes merged into the common right of all states to the freedom of the high seas. The five zones of ocean space recognized in customary international law and treaties are:

(1) Internal waters.

(2) Territorial sea.

(3) Continental shelf.

(4) Contiguous zone of high seas.

(5) High seas.

The problem, in general, of the contents of sovereign rights in these zones has been less controversial than the problem of delimiting their extent. Consequently the content or nature of sovereign rights in the zones has by now been reduced to formulated general rules whose uncertainty in intrepretation and application is no greater than the uncertainty which attaches to the intrepretation and application of our domestic common law and statutes.

The problem of delimiting the area of the ocean space zones has been more controversial in international relations and consequently remains somewhat

less settled, especially as to the width of the territorial sea.

INTERNAL WATERS AND TERRITORIAL SEA

The territory of a state extends beyond its land territory to certain ocean areas which form part of its domain as either internal waters or territorial sea. International law relating to these zones has been evolving for the past three centuries. Many controversial points were finally resolved in the Convention on the Territorial Sea and the Contiguous Zone.

There are certain ocean areas, such as harbors, bays, estuaries and canals, over which the coastal state exercises sovereignty in every respect identical with its rights over inland lakes and rivers. Such areas are called internal waters, as distinct from the territorial sea.

Article 1 of the Convention on the Territorial Sea and the Contiguous Zone says that "The sovereignty of a State extends, beyond its land territory and its internal waters, to a belt of sea adjacent to its coast, described as the territorial sea." The coastal state exercises in its territorial sea the same legislative, executive and judicial authority it exercises in its land territory. Hence the coastal state can exclude aliens and foreign ships from its territorial sea, except for the right of foreign ships to innocent passage.

The line between internal waters and the territorial sea is the low-water line following the sinuosities of the coast, except for bays and coasts fringed with islands. This line is called the normal baseline. Rules are formulated for the drawing of straight baselines in the case of bays and coasts fringed with islands.

The width of the territorial sea is one of the most controversial questions in contemproary international law. The rule of three nautical miles, which for more than a century and a half has been followed by the great sea powers, has never been universally accepted. In view of the large number of states now claiming a territorial sea of from four to twelve nautical miles and in view of the position of the over-whelming majority of the 73 coastal states represented at the United Nations Conferences on the Law of the Sea in 1958 and 1960 that no state is entitled to extend its territorial sea beyond twelve nautical miles, it would be difficult to defend the proposition that a state violates international law by extending its territorial sea to a width no greater than twelve nautical miles, at least as against other states claiming a similar width for themselves.

In the text of the Convention on the Territorial Sea and the Contiguous Zone the legal concepts of internal waters and territorial sea are expressly formulated only in terms of the water spaces involved, i.e. the water surface and the water column. However, under customary international law the sovereignty of the coastal state extends as well to the seabed and subsoil of internal waters and territorial sea.

Thus in all strata of admittedly internal waters space and territorial sea space international law governing the licensing of ocean activity has now been reduced to formulated general rules whose uncertainty in interpretation is no greater than the normal uncertainty which attaches to the interpretation and application of our domestic common law and statutes.

Within the United States the licensing and regulating of ocean activity in our internal waters and territorial sea is affected by the division of jurisdiction between the Federal Government and the States. The roiling of these waters by the "tidelands" litigation beginning in 1947 is well known. The turbidity was substantially reduced by the Congress in the Submerged Lands Act (1953) and recently by the Supreme Court.

The Supreme Court in the "tidelands" cases recognized and reaffirmed State control of internal waters space, subject to the ordinary Federal jurisdiction which exists in all State territory, e.g., as to navigation and commerce.

In the first "tidelands" case (1947) the Supreme Court held that the Federal Government has control of the seabed and subsoil of the territorial sea. But this was followed in 1948 by the Court's decision that the coastal States have power to regulate ocean activity in the water column and on the surface of the territorial sea. (Toomer v. Witsell, 334 US 385)

In the Submerged Lands Act Congress reaffirmed State control of internal waters and released to the States all rights to the lands beneath the territorial sea (3 mile limit or the State boundary in the Gulf of Mexico if more than 3 miles). Thus a State can grant its lessees exclusive rights in the land under the State's internal waters and adjacent territorial sea. The oil industry is the only one which has to date taken full advantage of this fact but others will doubtless do so as technological capabilities are developed.

The Submerged Lands Act did not provide a definition of internal waters or of the baseline between open stretches of internal waters and the territorial sea. This gap was recently filled by the Supreme Court's adoption for the purposes of the Act of the definitions used in the Convention on the Territorial Sea and the Contiguous Zone (U.S. v. Calif., 381 U.S. 139 (1965)).

THE CONTINENTAL SHELF

The geological continental shelf was not technologically exploitable, and therefore not the object of legal claims by states, until a recent time. The development of techniques for exploiting submerged land gave rise to claims by coastal states for extensive rights over the seabed. The growth of the legal concept of the continental shelf in the space of only sixteen years from its first assertion (1942) as a claim of right, to its acceptance as a rule of customary international law, confirmed and clarified by the Convention on the Continental Shelf (1958), is a remarkable illustration of the process of interaction of claim and response generating an area of reciprocal tolerance which is law.

A 1942 agreement between the United Kingdom and Venezuela dividing between them their claims in the land under the Gulf of Paria was followed in 1945 by the Truman Proclamation claiming United States' control of the natural resources of its continental shelf. By 1958 some 20 states had claimed rights over the continental shelf.

A number of Latin American states did not limit their claims to the subsoil and the seabed, but claimed sovereignty also over the superjacent waters, thereby interfering with the freedom of fishing in the high seas. Such claims were objected to by other states and the outcome of the 1958 United Nations Conference on the Law of the Sea leaves no doubt that they are unfounded in law.

Claims limited to the seabed and subsoil of the shelf were generally accepted, tacitly at least, by other states, so that it is arguable that a customary rule of international law developed on the basis of this practice. Such an argument was rendered largely moot by the adoption of the Convention on the Continental Shelf in 1958.

The continental shelf as a legal concept excludes the superjacent water and begins at the outer edge of the land under the territorial sea, extending in the words of the Convention "to a depth of 200 metres or, beyond that limit, to where the depth of the superjacent waters admits of

the exploitation of the natural resources" of the seabed and subsoil.

This definition of the outer limit of the continental shelf zone was recognized at the 1958 Conference as being uncertain but it was the best that could be agreed upon. It will doubtless have to be revised eventually but for the time being it seems to be a reasonably workable rule.

The depth limit of 200 metres was adopted simply because agreement could not be reached on any other apposite wording or figure. The exploitability limit was adopted to give flexibility and no apposite wording could be agreed upon.

The present definition is uncertain for two reasons:

(1) It does not furnish any criteria for determining that a particular depth admits of exploitation.

(2) As technological capabilities increase, a limit thus defined tends continuously to expand.

In applying the definition it must be remembered that the legal concept of the continental shelf owes its origin to the generally recognized need of giving the coastal state an exclusive right to exploitation of the resources reasonably related to it by geographical propinquity or contiguity.

The literal wording of the Convention on the Continental Shelf, Article 1, supports the view expressed by Mero that

> "Presumably also, the continental shelf can be extended by the coastal nation out over the edge of the geologic shelf, down the continental slope and on out over the deep ocean floor to whatever point a commercial minerals dredge can operate. Such an extension was probably not the intention of the Conference, but the wording of the articles of the Fourth Convention is so clear as to leave little room for maneuvering on this point."

However, Mero's statement states its own Achilles heel: "Such an extension was probably not the intention of the Conference...." The 1958 Conference did not envisage the magnitude of technological capabilities we now see as probable in deep ocean activities. The policies and interests that justify the allocation of shelf resources to the adjacent state are different from, and may not be pertinent to, allocation of the resources of the deep ocean floor.

Up to the time of the 1958 Conference the reciprocal tolerance of claims had not chrystalized into any rule affirmatively establishing the nature of the coastal state's rights over its continental shelf. However, a negative rule had emerged that the shelf having become an object of active interest to the coastal state with a view to the exploitation of its resources, the shelf could not be considered as either common to all states like the high seas or capable of being appropriated by the first occupier.

Thus the principal issue regarding the continental shelf in 1958 was the nature of the coastal state's rights. There were, broadly, two different approaches to this question. A group of predominantly Latin American states claimed the coastal state had complete sovereignty over the shelf and the superjacent water. A larger group of states rejected such claim and regarded the coastal state's rights as limited to those necessary for the exploration and exploitation of resources. The latter view prevailed.

The problem then became to find a verbal formula making clear that the rights conferred upon the coastal state included all rights necessary for and connected with exploration and exploitation of shelf resources without

in any way impairing the principle of the full freedom of the superjacent water and air space. The phrase "jurisdiction and control" over resources was rejected as too weak. The phrase "sovereignty" over resources was rejected as too strong. The phrase finally adopted was "sovereign rights".

Thus the language of Article 2(1): "The coastal state exercises over the continental shelf sovereign rights for the purpose of exploring it and exploiting its natural resources", creates the new legal concept that a state may have sovereign rights for certain purposes in respect of a certain area without having sovereignty over that area. The phrase "sovereign rights" was meant to carry the clear implication that rights of property in the natural resources of the shelf are vested in the coastal state and that ownership of such resources cannot pass to others except by way of express grant. The coastal state can grant concessions to private persons or it can exploit the resources through its own agencies. It can exercise with respect to all relevant matters legislative, executive and judicial action regarding any person, irrespective of nationality, engaged in resource exploitation, even if he operates from ships or floating installations in the high seas.

The Outer Continental Shelf Lands Act (1953) asserts the exclusive power of the United States over the resources of the seabed and subsoil of the continental shelf outside the boundaries of the States or the three mile limit. It adopts as Federal law for the area the law of the adjacent State to the extent not in conflict with other Federal law. Litigation "arising out of or in connection with " mineral operations is placed under the jurisdiction of the appropriate United States District Court. The Act further provides for the leasing of the seabed and subsoil by the Department of the Interior and for Coast Guard navigational control of the area.

It is normal for a new statute such as the Outer Continental Shelf Lands Act to raise a host of unsolved legal problems in a new area. Statutes must necessarily be couched in generalities. It is impossible to anticipate the permutations and combinations of fact situations which can and will arise in practice. The interpretation and application of the Act to concrete fact situations must be worked out by the parties and the courts in the interaction of claim and response. In the course of time experience will indicate the necessity for changes in the Act. This is the normal development process of law. Any one who refrains from participation in ocean activity effectively forefeits his ability to shape the meaning of the Act in practice.

HIGH SEAS AND CONTIGUOUS ZONE

The high sea is simply the ocean water area which does not fall within internal waters or territorial sea. The principle of freedom of the high seas means that the high seas are in law res communis, a thing common to all states, not capable of being subjected to sovereignty, in which every state has equal rights and duties.

Freedom of the high seas in regard to use means that each state has an equal right up to the edge of the territorial sea to navigate upon and to exploit the high seas. No preference or priority is recognized in favor of the nearest coastal state, or other group of states, except in case of fisheries.

Freedom of the high seas in regard to jurisdiction does not mean the high seas are subject to no jurisdiction. The right of jurisdiction, like the right of use, is vested in each state. But the right of jurisdiction, with limited exception, extends only to a state's own ships and nationals.

The contiguous zone is a zone of high seas contiguous to the territorial sea, within which the coastal state may exercise control to prevent and

punish infringement of its customs, fiscal, immigration and sanitary laws. The contiguous zone may not extend beyond twelve miles from the baseline from which the width of the territorial sea is measured. In other words, the recognition of a contiguous zone presupposes that the coastal state has extended its territorial sea less than twelve miles.

The seabed and subsoil of the high seas beyond the continental shelf is under customary international law res nullius, a thing of no one, over which sovereignty can be acquired by effective occupation. In view of current technological developments it appears entirely probable that the deep ocean seabed and subsoil can ultimately be effectively occupied. The traditional concept of occupation may have to undergo refinement, as it has in the past in connection with dry land masses which once were res nullius. The law will never be static as long as there is continued the interaction of claim and response.

THE FUTURE

There is now emerging the broad outlines of probable future technological capabilities: Expansion of present uses of ocean space such as fisheries and extraction of oil and gas. Harvesting of underseas crops, both fixed and migratory, at various levels and temperatures of submarine strata. Extraction of chemicals from sea water. Mining of ores from the seabed and subsoil. Human habitation in the sea.

These technological capabilities will présent, and are now presenting, the interaction process of law development with two broad catagories of problems.

The first problem might be called the legal techniques adaptation problem. The problem is to adapttoocean activity the legal rules and instruments of dry land activity. This problem may possibly be magnified in some minds through fear of what is felt to be the unknown. The way to solve this problem is to begin at the point where one finds oneself, size up the new situation, make tentative conclusions, plunge in and start doing, while continuously restudying one's tentative conclusions.

This is what the oil industry has done and is doing in off shore operations. For example, the off shore drilling contract is not fundamentally different in broad aspects from the on shore drilling contract. It requires an application of the same contract philosophy and technique; it too must be tailored to fit each individual situation and result to be reached. But the off shore contract becomes a more complex one because there are many more variables that have to be dealt with than in the on shore contract.

The other broad legal problem is where and how to draw the lines of accomodation among conflicting uses of ocean space, especially the accommodation of new uses with existing uses, e.g. navigation and fishing, and the employment of new techniques without undue derangement of other interests. The Convention on the Continental Shelf lays down only the broad guideline that exploitation of natural resources "must not result in any unjustifiable interference with" other uses. The application of this guideline in any given circumstances will require an assessment of the relative importance of the conflicting interests involved. In other words, the meaning of "unjustifiable interference" must be refined in the crucible of the interaction process.

We now have a body of formulated rules of national and international law sufficient to provide a reasonable basis for the solution of these problems of the orderly conduct of ocean activity for the next few years. In the course of time experience will solve some of the present problems, will indicate the need and nature of clarification of others and will disclose new problems. The lesson of centuries of legal history is that law

cannot be prefabricated in an abstract codification.

However it does not follow that nothing can or should be done now regarding development of future law of ocean activity. In the recent words of Dr. Wilbert M. Chapman,

> "What is wanted is an examination of what these new and old problems respecting the use of the sea are, and are likely to become; how they impinge upon the existing Law of the Sea; and what should be the public policy of the United States in respect of these problems, jointly and severally, which would best serve the general and long term interests of the U.S."

But if the ocean activities industry as a whole wishes to influence the shape of the future law under which it operates, it must band together now in some appropriate organization and begin to study and plan now, rather than leave the legal hydrosol solely to Government and the courts.

TOWARD A POLITICAL THEORY OF THE OCEAN

James W. Oswald

ABSTRACT

We must define the world ocean and analyze the soil in which political and social theories applicable to it may germinate.

The ocean is mutable. As both a land and water medium, it is likely that the water concept, which is international in disposition, and the land concept, which is national in orientation, will be mediated into a total operational concept. According to relative geographies, nations' concepts of the ocean differ.

Man's relationship with the environment will achieve a symbiotic character, and it will be a permanent relationship.

Ocean exploitation depends upon the development of a single technology. This technology is pushing the science. Comprehensive national policies for the creation of ocean science are lacking.

A contest is underway for the application of a public order to the ocean, in which the contestants are both nationally and use oriented.

The exploitation of the ocean environment presents a challenge for economic organization and effects the formation of foreign policies.

Finally, nations' are caught in paradox between their strategic interests and international social interests in organizing the ocean. The answer may lie within the concept of the balance of power. If it cannot be found there, the ocean will become a sphere of national competition.

INTRODUCTION

Traditionally, political and social theories have applied directly to men, their social formulations, and their institutions. From time to time, theorists of unusual insight, and I believe that last phrase disqualifies most geopoliticians, have described and discussed the influence of the geographic setting of human activities as constraining or determining factors upon the range of viable political, social, and personal choices available to men in society. More recently, attention is being directed toward the constraining, determining, and transcending properties of a society's technologic base.

Despite these "revisionist" tendencies in theorizing, a political or social theory developed specifically for an exotic environment and to take into account the technology the phrase "exotic environment" implies to a rarity; and it remains questionable whether such a theory can be evolved, given the questionable status of environmental studies, without its reverting to the basic theoretical presuppositions applicable to man in one of his more traditional environmental settings.

Two such attempts at the evolution of environmentally-oriented theory are presently under way, however tenuous they may be. Admittedly, these studies are peripheral, their focus being the operation of political and social utilities such as law, economy, and strategy rather than politics or the polity. These efforts apply to the popular medium of outer space and to the world ocean, variously known today as hydrospace, inner space, the seventh continent, and mare incognitum.

It should be mentioned as a caution that there is really no evidence that these two environments (the former of which may be described more aptly as the absence of an environment) are in any way related, except that they are both coming to light at roughly the same time and may come to share certain techniques for human use. This suggests that we be wary of publicists and postulators who seem to be falling from the heavens these days to make their maiden underwater voyage. It is important to note whether their first journeys in the sea are in tandem with their last in outer space and to judge accordingly.

The state of the literature regarding these two environments suggests that it is time we evolve comprehensive political and social theories regarding them. This paper will constitute a first generation attempt to politically define the world ocean and to analyze the soil in which these theories may germinate.

A POLITICAL DEFINITION

Although it would be superfluous in a meeting such as this to empirically describe the world ocean and its resources, a political definition is prerequisite to our discussion. Such a definition may apply to several of the environment's characteristics. The most obvious issues have to do with the degree of the ocean's mutability, whether it is principally a land or a water resource, and whether it serves a geographic function as a unifier or divider of land-based sovereignties.

Professors McDougal and Burke remark in "The Public Order of the Oceans" that "of all the elements in the social processes people, resources, and institutions - the most unchanging are the great immovable resources." This is physically unchallengable. Great investments and effort are required to even scar a physical resource. Still, one must wonder at the social accuracy of this assumption.

In practice, resources are adapted to human requirements, which change very little. The degree or amount of need ordinarily determines the extent of adaptation. Presently accepted demographic forecasts indicate that, lest the human population undergo severe calamity, the future degree of adaptation and use of geographic resources is likely to be very great. This is especially true of the world ocean which constitutes a "second source" to the "first source" of most essential land-based resources. What is today the epitome of a "natural" environment is likely to become noticeably artificial, in the strict sense; and although the mutations in the environment thus created probably will not consume the resource or significantly alter its configuration, they will certainly alter the social conception of it, whereas human needs and social and governmental formulas are likely to remain about as they are.

The question of whether the ocean is a land resource, a water resource, or both is central to all concepts of law and public order. Any technologist can tell you it is both, but he cannot tell you what it is likely to appear to be in the political context.

Man's penetration of the world ocean for his purposes has been so limited and has dealt so exclusively with the near-surface water component of the ocean that it was surprising to find the following definition at the beginning of the recent UNESCO IOC report, "Draft of a General Scientific Framework for World Ocean Study:" "Oceanography is the scientific study of that part of the earth which is covered with sea water." This is not only a radical departure from the standard definition; it may precurse an emerging vision of the world ocean not as water underlain by land but as land overlain by water. This is a vision our developing technology may thrust upon us.

Historically, attempts to apply legal prescriptions to the world ocean have involved a conscious distinction of that part of the ocean that is water from the underlying ocean bed. The legal distinctions made roughly correspond to the distinctions between the land surface and aerospace. Hence, the Geneva Convention of 1958 provided for certain nationalization of ocean bed resources on the continental shelves but, except in the territorial seas, internationalized resources in solution or mobile in the waters themselves.

The product and military technologies likely to be applied to the ocean in the next decade concern themselves with both types of resources. Fisheries technology, the extraction of minerals in solution, the conversion of sea to fresh water, and the generation of power from water are in the one category; the extraction of oil and gas and the dredging and mining of nodules and deposits in situ are in the other. The military uses of the ocean will certainly involve both the water and the ocean bed, although the ocean bed is of limited tactical significance today.

I have spoken of technologies, but this is a deception; for although they differ in application, they are unified in one technology that has to do with establishing the ability of man and/or his mechanical proxies to be located and perform work in the environment. The undersea work stations of the future could perform multiple functions. The same environmental conditions, the same engineering problems and equipment design constraints, and the same life support capabilities apply across the board. Where proximities of interests are great, diversified communities could be constructed to take from the ocean many of the resources men on the continent traditionally take from the land. If this is the case, the ocean as real estate will take on greater significance; and it will become increasingly difficult for the users of the ocean resources to regard the environment as two separate and distinct political and legal phenomena or to apply such a distinction to political problem solving. The prospects are strong for the water concept, which is international in disposition, and the land concept, which is national in orientation, being mediated into a total operational concept.

Finally, according to national relative geographies, traditional activities, and cultural predispositions, national definitions

of the ocean's strategic significance are certain to differ. In recent testimony before the Panel on Oceanography of the President's Science Advisors Committee, an industry spokesman remarked:

> We, an ocean-locked nation, must view the world ocean as a uniting feature of geography. But others, whose relative geography differs from our own, and whose political power and alliances are consolidated by land masses, will view that same ocean as a dividing feature, and, if they have done their homework, will seek to split the alliance system upon which the security of the free world rests by controlling the seas that unite the members of the various alliances.

Nations dedicated to open societies have an implied interest in the venerable doctrine of freedom of the seas. Nations committed to the maintenance of closed societies do not, and may be expected to apply ocean technology to effect a partial strategic isolation of nations that do.

MAN'S RELATIONSHIP TO THE OCEAN

Such political delineations of the world ocean do not qualify alone as bases for the formation of political or social theory. Such theory must be based on the activities of man in the sea, to which we must now turn our attention.

Man does not at present occupy the undersea to any great extent, but his activities in the ocean have achieved a high enough level of mutation to prompt the authors of the UNESCO ICO report to say that "man in his role as a geological agent is now affecting the chemistry of the oceans." Some of this is the product of the disposal of waste generated by land-based technologies, but some of it is unquestionably due to the processes of exploration and exploitation presently being undertaken by petroleum and related interests in the ocean itself.

Man as an active agent is now beginning to populate the ocean, if only for short periods, for the purpose of testing the unified and product technologies. These experimental efforts which have been largely successful are designed to result within a decade in the establishment of the continental shelf of work stations that will be manned on a full-time basis, although not by full-time personnel.

The questions for us to ask with regard this human relationship to an environment made accessible by technology are: Will the presence of man result in the creation of a symbiotic relationship? If so, is the symbiosis likely to involve a dependence of a permanent nature?

Philip Wagner in his study "The Human Use of the Earth" contends that man's interrelationship with his environment has traditionally resulted in the creation of artificiality in the environment. Wagner believes that the expansion of the artificial component of the habitat at the expense of the natural portion results in the enhancement of material well-being and in increases in human population. Furthermore, an order and proportion exist in the growth of artificial complexes, in that

human purposes and natural conditions interact to limit the development of the environment. This argument implies that there are natural limits to the stability of the artificial environments man creates and that these limits depend chiefly on the resource to consumer ratio.

Regional imbalances in population in relations to available natural resources have become a major social concern today, especially since regional political instabilities can disrupt world order. It is quite clear that, given a world economy and international public planning, there would be plenty of most resources to go around; that is, to supply what are believed politically to be social needs. This type of economy and planning are not in the offing in view of the proliferation of militant nationalisms. Therefore, we must approach the question of the human use of the world ocean from a nationally-oriented position. On this basis, serious shortages exist in units of protein required to sustain civilized societies. Raw materials to sustain increasing productivity are also subject to considerable national shortages. It must be noted, however, that these become shortages only in relation to two common national goals of emerging nations; specifically, the development of viable industrial societies with large labor forces where such societies do not at present exist and the establishment of national military establishments.

The national requirement for use of the ocean environment begins with the argument of need, the real or imagined shortage of land resources. The ocean is to be exploited to make up differences between available materials and those national planners say are required to achieve development or security. This suggests that Wagner's "order and proportion" are put out of kilter because of sovereign boundaries and that the ocean must be used in some instances to restore order, whether by direct exploitation on the part of the potential national user or by exploitation by a different state which will apply a portion of the benefits of exploitation in its own national interest as foreign aid.

However this is accomplished, the dependence of man on the ocean environment is implied as one method to achieve modern social goals. In consideration of the amount of total protein historically provided by fisheries products, this is not a revolutionary idea; but the degree and scope of requirements have been expanded to the limits of the promise of technologic competence. It seems clear that once man gets into the undersea as an active agent, he will not be able to get out of it without admitting the indiscretion of social ambitions and acceeding to static or declining standards. If human population continues to increase at a near geometric rate and should concepts of progress prevail, new resource bases in addition to the world ocean will require development. A permanent dependence of man on oceanic resources is a probable (12) to (7).

TECHNOLOGY AND SCIENCE

Before discussing the competition for the application of an order to the world ocean, it is necessary to define the nature of the technology with which we are faced and its status vis-a-vis ocean science.

I have suggested that we are talking not about technologies, but a technology with several applications. In other words, ocean technology is not product divisible. The basic engineering problem is getting man into the total environment to perform useful work and creating design concepts and configurations that will function in the environment. All the applied sciences of oceanography are pertinent to each product requirement, and many of the specific techniques for extension of the science as technology are the same for all applications. This means that several product applications could achieve feasibility simultaneously. Whether these applications are effected simultaneously is another matter. This will depend on the variables of land resources available in each instance, differing political and economic pressures to develop specific resources, and the ability of government or industry to fund or capitalize exploitation. For example, a brief review of these variable factors suggests that the petroleum technology will move more rapidly than that in dredging or mining. But the social effect of the feasibility of total resource recovery will be an across the board recognition of new levels of materials for human consumption to support human productivity. The resource base for the development and maintenance of industrial society and national security techniques will soar. The expectations thus induced may negate the constraints of the variables. In this negation, the dynamic factor is the goal of national industrialization to create viable standards of living and bases for effective national political organization. Technology serves this dynamic, and it is the duty of the state to make technology responsive to the polity.

It is also necessary to define the relationship of science and technology for the ocean environment. Again, from testimony before the PSAC Panel on Oceanography:

> Science should precede action, and presently I do not believe that it does...We (the United States) have long possessed a superior capability for improving the manufacturing,...but we have also borrowed much of our science and many of our prototype designs. This must not happen in the undersea.

This assessment is national in character, but it is universally applicable.

Explorers, industrialists, and strategists have chosen to pursue ocean technology in the absence of a comprehensive scientific program. Efforts on the parts of entrepreneurs to promote the mounting of a comprehensive scientific program through governmental action have failed so far. The public administration of a national ocean program has not resulted in the level of governmental organization that even approaches that accorded to outer space, partly as a result of the proliferation of industrial exploitive interests in the undersea. As a result of this imbalance in attention and funding, ocean technology is now pushing ocean science. If this continues, technologists will have to content themselves with operating hit and miss where high capital investments and major stakes of national security are involved. Significant breakthroughs will be achieved by accident and only imperfectly understood; and potentially great opportunities will be passed up unrecognized. The development of the

applied sciences of oceanography is required to ensure the safety of private capital investment and to permit the formulation of valid strategic concepts by allowing the technology to operate with reasonable assuredness that the problem solutions selected to industrial and security problems will work. As it is, the approach to the world ocean is in terms of problem solving. If, as Professors McDougal and Burke suggest, the goals of ocean activity are power, wealth, enlightenment, well-being, respect, skill, and solidarity, it should be clear that the present situation mitigates against the achievement of each of these goals, but especially against enlightenment. This is meaningful because, whereas the ocean is a spatial extension resource, it is also a thing to be known and understood. Man's working it without first understanding it could lead to a series of calamities detrimental to the national and industrial interest involved and to the future of the environment itself, making the symbiosis parasitic.

The organization of technological activity in the exploratory stage will determine in part the content of a political concept of the world ocean. Unfortunately, this organization is often more fortuitous than by design, and it can be seriously affected by international problem solving situations not concerned with the ocean. For example, should an oceanographic "Sputnik" be launched, it is certain that the national planners would give priority to military science and technology for the understanding and exploitation of the environment, thereby making the process of mediating non-military national and industrial interests somewhat academic.

THE CONTEST FOR A PUBLIC ORDER

Thus far, I have suggested certain qualities of the ocean environment. It is mutable, it is a land-water environment in which the land aspects are achieving increasing importance, and it is a unifying or isolating geopolitical phenomenon, depending on where you sit. Man's relationship to the environment is moving in the direction of a permanent dependency for purposes of national and social development goals. It is technologically oriented for problem-solving purposes. Comprehensive national policies for its exploration and exploitation are absent, except possibly in the Soviet Union and Japan.

What of the contest for the application of a public order? The contestants exist on two levels: according to national orientation and according to product or use orientation.

In a world which is strategically bipolar, it is questionable whether a workable public order, which implies international agreement, can precede the formulation of national policies on the part of the major national contestants for power, despite the frequently heard and sometimes convincing argument that the ocean as an environment must not be nationalized. Although the formulators and ratifiers of the Geneva Conventions of 1958 were able to speak from the points of view of their respective national interests, they were not able to speak against the background of national ocean policies. At that time, undersea technology was just beginning to be applied; and national policies would have been superfluous. The problem in the creation of international agreements for the application of order

is that the parties to such agreements at present must be nationally oriented rather than use oriented: this in the face of controversy over whether the state is the proper unit to explore and use the ocean. This agrument must come down to a decision between the conflicting values of strategy and other social gains. Clearly, since strategies in peacetime can no longer operate irrespective of each other, as Professor Burke points out in "Ocean Sciences, Technology, and the Future International Law of the Sea," agreements between nations can only be formed where strategic plans for employment of the environment are not in conflict. As a practical matter, those nations whose technologic capability permits the exploration and exploitation of the environment need not concern themselves with the desires of nations who cannot participate effectively in the mutation of the world ocean. Those nations technologically equipped for exploitation are almost members of one or the other major strategic coalitions. Neutrals need not apply. I will deal later with the question this alignment poses for foreign policy and for the formulation of an oceanic order. For the present, it is sufficient to say that the primacy of national interest in an age of coalition conflict cuts across the solutions of all non-strategic or semi-strategic problems of gain and use.

The contestants for the formulation of a public order according to product or use orientation are composed of private individuals, corporations, and special functions of national governments. Their disagreements may be aesthetic, legal, or scientific; but many of these disagreements are either partly strategic or expressed in strategic terms.

Functionally, these contestants are: the military establishment; the industrial establishments of fisheries, oil and gas, and mining; and the inevitable utopians and 19th century romantics.

The military establishment's argument is based on the strategic problems of achieving a viable national defense and rests upon freedom of the seas for friendly craft and denial of acc ss to a nation's land base to unfriendly craft when coercion is threatened. This was once a simple matter, solvable by the defense of the territorial seas. This is no longer the case. Missile firing submarines make possible the penetration by nuclear weapons of national territories at long range under conditions of concealment and high mobility. For this reason, the military is responsible for ocean-wide policing action even in peacetime, so long as a military threat from rocketry exists.

The claims of the military establishment extends from the research function to the final exploitive phases of the technology. Those responsible for national security insist that they should determine the character of a lion's share of government funded ocean research and have the benefits of some of it on a proprietary basis. The script reads that if we allow industrial users the benefits of sensitive scientific findings, these findings automatically become public property and, just as automatically, give aid to a national enemy.

The effect of the military position is to reduce access to the undersea to private individuals and industrial interests. It is likely, as Professors McDougal and Burke contend, that the

security of the participants is weakened as access to the sea is reduced. From a broad strategic point of view, the classification of scientific research may result in deprivations of proven resources detrimental to the national interest in time of conflict. This deprivation would take its toll not only on wartime production but on peacetime economy, in that it would force dangerous foreign commitments for import purposes, deny a source of economic growth, and act to limit labor market expansion. Science is of no military value until it is applied to a military device, which should be classified. To make a science subservient to the military component of national strategy alone is to obviate the total strategy.

The military establishment could press for the extension of territorial waters in time of peace, a closed issue Geneva made moot. Since, as McDougal and Burke point out, "modern technologies of destruction make all widths obsolete," this is a point of view that should not prevail.

The industrial establishments are interested in the development and exploitation of science and technology for profit. It is the industrial view that this is its natural and reasonable function in the society and that this function benefits society. This interest is often expressed in strategic terms. Two statements of an industry representative from PSAC testimony will illustrate:

> The whole superstructure of the Western Alliance and its Eastern allies rests now on foundations of geography and resource. The alliance is tied together by great bodies of water . . . And although the nations of the free world are in possession of all the machinery required for industrial production, these nations are not as rich in resources as they once were; and many are becoming resource poor in the face of productivity and the requisites of human survival. Our ability to explore, exploit, occupy, and defend the undersea is the major factor in this equation. To begin, we must decide once and for all that we are willing to make this task a national requirement of high priority.
>
> A doctrine of American policy toward the world ocean and its in-lying and under-lying bonanzas is as necessary today as were doctrines of commitment to hemispheric solidarity in the past. After all, the move into the ocean is in effect the enlarging of the American continent, and we must make it clear that the new continent will be guarded as jealously as the old.

Industry, like the military, wants government expenditure in ocean science, and on a rather imposing scale. The industrial rationale for this attitude is expressed in "A National Ocean Program," a report of the National Security Industrial Association's Ad Hoc Committee on Ocean Science and Technology:

> Under our economic system, much of the practical work (of ocean exploitation) will be done by industry. The division of markets has long been a characteristic of the American industrial

> complex. Even "big businesses," in the light of the job industry does for the society, are small spokes in the wheel of American development and production. To achieve freedom of industrial enterprise, we have wisely and deliberately sacrificed the "togetherness" that, despite its efficiency, lowers industrial incentive. This very spirit of competition has resulted in industry's dramatic research into human needs and problems. Upon occasion, this has required the development of whole new technologies, sometimes technologies so vast and complex that no one business interest could create them. Therefore, it has become tradition that when major problems of science and technology arise, problems outside have often turned to the federal government for action and coordination.

The "action and coordination" the report suggests is the expenditure on ocean science and specific exploratory projects of 12.5 billion dollars over a six year period, administered by an agency similar in structure to NACA.

The validity of the industrial approach lies in its call for a comprehensive national ocean program, which implies the establishment of a comprehensive policy toward the environment. Industry does not suggest that we shackle the science. Only specific aspects of the technology covered by patents or proprietary agreements would be excluded from the public domain, and none of these would be government funded.

The problem with this approach is that it requires the nation to insure, protect, and sometimes defend a capital investment in the undersea. Industry would feel safer about its investment programs in international waters were foreign competition eliminated by agreement, fiat, or threat of coercion. The Geneva Convention on the Continental Shelf has provided considerable protection for investments, but industry is not ultimately limited to on-shelf activities. The success of a technology for the continental shelves will goad the entrepreneurs to try for the deep ocean.

The problems of the fisheries industry are somewhat unique in that fisheries are granted national exclusivity only in the territorial sea before facing international competition. For the most part, ocean fisheries are not highly sophisticated industries in the United States. If they were to become big business, they would have less cause to fear international competition and more leverage to effect the partial retreat of foreign flag fishing vessels from waters near the U. S. coast.

The utopians and romantics are, for the most part, private individuals, some of whom are vested with legislative authority and others of whom have the limited support of a government. Several assertions are prominent among them, none of which constitute a total policy. Some want to use the world ocean and its new technology as a key to the economic conversion of defense industry to peaceful pursuits. Still others fear that uncultured technologists will harm the delicate balance of the

ocean and cause an environmental or resource calamity. Others want to make the ocean safe for the purveyers of popular culture.

In listing the contestants in the struggle to formulate a public order, I deliberately ommitted the growing community of social and political thinkers who do not want to extract anything from the environment themselves but who wish to set the tone for the policies that govern use.

Although there is some dissent, most legal and social writers in the United States see the inherent dangers in the nationalization and militarization of the environment. McDougal and Burke have postulated that "all peoples can benefit most from a public order of the oceans which secures for all the highest possible degree of shared access to ocean resources and of shared competence over ocean activities and, secondly, that a public order adequate to such ends can only be established and maintained by peoples' effective recognition and understanding of their common interests, with continuous reassessment in the context of the development and change characteristic of the contemporary world." These authors point out that historically, ocean law rejects "egocentric assertions of special interest in contravention of general community interest" and that in this sense, the resource is now internationalized. With the development of an undersea technology in a time of coalition crisis, this international character is endangered. Further, "not only does no agency exist for prescribing and applying policy, but no single state or group of states has the effective power to enforce policy without wholly uneconomic violence". Finally, the alternative to consensus is the exertion of naked power.

Representing no one national interest or user in an official sense, these writers state what they believe is in the social interest of all. The hard facts of national security and capital investment stand against them but this does not mean they are anything but correct in their prescription.

ECONOMIC ORGANIZATIONS

The contestants are in the ring; but before I proceed to the normative question of a public order, it is necessary that two additional matters be discussed: first, the problem of economic organization and second, the challenge of this environment and its developing technology to the formation of foreign policies.

Risk incentives will be the subject of the next paper. I shall not infringe on that territory, but I would like to suggest an economic postulate.

Wagner, in "The Human Use of the Earth," describes economic organization as "a means to exploit and compensate for uneven distribution of natural features in space and their variation in time." Planned economies which are minimally responsive to consumer demand and democratic pressures are able to apply this definition without constraints other than those inherent in the stability of the economy. Most of the economies of the Western Alliance are not. Demands for continually rising standards of living in these economies conflict with national strategic needs and are mediated to produce mutually disagreeable decisions. One of the tools used by capitalized economies

in both national and industrial planning is the standard of "cost effectiveness," with the emphasis on cost. Cost effectiveness techniques frequently result in a failure to develop second sources or alternate designs. Design and source decisions are usually made at the program definition stage or before design data is hard. The decisions are based on best guesses. This is not so in the Soviet Union, where several alternatives to achieve a resource or design goal are pursued simultaneously into the design and sometimes the production stages. This procedural distinction could provide a substantial edge to a planned economy in the exploitation of an environment via a new technology, since not all designs will function as hoped once they are placed in the ocean environment. I am suggesting that strategic aspects of technologies to develop unutilized environments should be exempted from the strict laws of cost effectiveness. Of course, this is sometimes done. No matter how little a program costs, there is nothing cost effective about outer space. The result of applying cost effective measurements to new environments in the face of threats to national security is the ultimate expenditure of more funds than would initially have been required; that is, their expenditure once the "Sputnik" has been launched.

FOREIGN POLICY FORMATION

Several aspects of foreign policy formation are connected with the development of a new environment. For present United States policy, we must consider the significance of technologic advancement to international prestige.

I have mentioned often the relationship of developing ocean technology to the maintenance of an open ocean compatible with the concept of open societies. Returning to our PSAC testimony, we find the following:

> In terms of the farthest reaching considerations, the question which stares at all those who toil in ocean technology is: Are the oceans to be part of the open society? Just as we built an empire of the seas for trade, will we build an empire of the undersea to bolster the geopolitical and resource bases of the free world? Perhaps a new "heartland" of geopolitics is involved.

Although heartland concepts seem irrelevant to an age when nuclear preparedness is a key to national security, this suggestion holds considerable validity. It says that resource recovery on a first-come, first-serve basis is the key to the maintenance of open seas in a situation where competition between nations is involved. It must be pointed out that, in its approach to the use of technology, the planned society may again hold a considerable edge, for the actual competition between the Soviet Union and the United States for the extraction of undersea resources and the establishment of work stations which bear the imprint of the flag is now a competition between a government on the one hand and corporations on the other. In the deep sea, where the prescriptions of the Geneva Convention do not grant exclusivity, the governmental installations are reasonably

certain of the national commitment to their defense on a no-loss basis; the corporate installations are not. This tends to reduce the amount of activity a corporation is willing to capitalize.

What I am suggesting is that deep sea exploitation is a foreign policy matter, as well as a domestic one. Governments are unused to treating environmental technologies as such, except for their military aspects.

Tables of strategic materials are frequently referred to in formulating and justifying area policies. Everyone is familiar with the somewhat tainted phrase, "oil diplomacy." Materiel considerations are not purely matters of national need, for although resource requirements a d projected requirements as opposed to proven resources are taken into consideration, purely international questions are also raised. A bipolar political arrangement dictates a rigid pattern of resource politics. In a world divided into competitive, non-intermeshed economic units and production capabilities, economic and industrial need are transcended. For this reason, balances of resources are considered, even when national need can be satisfied domestically. Prior to the introduction of offshore oil into resource tables, the Middle East contained over 60 per cent of the total proven crude reserves. Control of the region where these reserves were located constituted access to 80 per cent rather than 20 per cent of the world reserves for the Western Alliance after World War II. With the introduction of proven offshore reserves on the continental shelves, the ratio of Middle East to world oil decreased somewhat. If present predictions are correct, the development of deep sea petroleum deposits in international waters will reduce it much further. This may not alter the commitment to the Middle East but it would alter the reasons for the commitment. For example, American interests would become less strategic in character. The addition of major proven and recoverable resources across the board would challenge the basis for the present concepts of resource dependency and make parts of the world high in resource but low in political power less worthy of the present degree of commitment.

This seriously affects the less developed nations. Professor Burke remarks that as few will use the ocean, the diversity between developed and underdeveloped nations will be broadened when ocean technology is developed, as the dependency of powerful nations upon the underdeveloped states' natural resources will diminish. This would leave the underdeveloped nations for a time free to utilize natural resources for national purposes, only if nations technologically equipped either perform the work for them directly or export ocean technology as a matter of foreign aid. Our industry spokesman addressing PSAC makes the point:

> Of first importance is the coming struggle to impose one concept or another of society on the emerging nations of the world. They are bound, since the security of their power rests on their ability to feed and industrialize their people, to those proclaimers of concepts who will do the most material good for them. Throughout history, this has been the basis for the alignment of

> neutrals. The non-aligned become aligned when the material benefits of alignment force the issue. Hope for the perpetration of United States influence with emerging nations is based to a significant extent on the proposition of the superiority of American technology.

Simplistic as this may be in not assessing other componentes of the attitudes of less developed nations, it again points to the danger of developing an ocean technology after a national competitor has done so, and that was the purpose for which the statement was made. The development of each new environmentally oriented technology becomes a race under present international conditions.

Finally, a word about prestige. Prestige used to be measured in terms of diplomatic finesse, enlightenment of policy, and ability to coerce. The technological component of prestige is not new, but it has become accentuated in a time of rapid competitive development. "Sputniks" launch with them the national image and create fear in competing nations of loss of stature with other governments. The development of deep sea technologies, both industrial and military, by the Soviet Union in advance of similar Western development is now feared for this reason, among others. This is because achievement in technology seems to support the productive and administrative theses in terms of which a government is organized.

CONCLUSION

As I said in the beginning, this paper would not formulate a political theory but rather it would suggest certain definitions and guidelines. I will close with a postulate for the development of a notion of public order.

Who shall use the resource and under what constraints? We have seen that the historical constraint of international coalition policies affects the answer. We have seen that nuclear armaments affect the answer. We have seen that there is a competition for use on two levels, one a national level and the other, a product oriented level. We have seen that there is an argument regarding the nature of the environment itself which will only be resolved by actual use but which will probably result in a unified social concept of the environment. It is evident, as Professor Burke states, that "if understanding of the complexities of the ocean environment continue to be a critical component of the total strategy, it seems probable that the benefits, actual and potential, of new information about the ocean will be limited severely." Here, the nations of the world are faced with a great paradox: for whereas it is in the strategic interest of nations to lock up certain key underwater resources in a sovereign way, it is to their social advantage not to do so. Our discussion of international problems made it clear that, under present conditions, speed in the development of ocean technology is important. "Haste makes waste" is more than an old saw. A catastrophic misapplication of technology to the environment could occur in an attitude of rapid and total offense upon it. A review of technologic capabilities on a national basis makes it apparent that a very few nations, if they reach agreement on an ocean policy, could close the deep ocean environment to all others, forcing a reliance on the major powers for the

produce of ocean technology necessary to the eventual livelihood of all. Yet, the odds for violence, if such an agreement is not reached, seem overwhelming.

Perhaps, the answer lies within the ancient concept of the balance of power. The competing coalitions have presently arrived, in part by technological accident and in part by the design of the concept of mutual deterence, at a stage where a balance in capabilities exists. It was this balance that made the Nuclear Test Ban Treaty feasible. Although neither coalition is publicly committed to the concept of maintaining this balance, the East less than the West, the Test Ban Treaty set precedent for the institutionalization of certain aspects of the balance. Professor Burke has suggested that competing nations might end up by sharing some of their capabilities to mitigate against the collapse of this power structure. It is a hopeful suggestion and one that we would be negligent not to pursue. Its pursuit would involve the development and employment for strategic ends of considerable scientific and technological expertise, for competing national, as well as functional, interests foreclose against reasonable solutions being reached by those who are not intimate with the environment and the methods for its exploitation. Further, decision-making processes established by agreement must assure the application of expertise in the day-to-day process of decision making.

But, if the answer does not lie within the present balance of power, the world ocean, in all its mutability, will become a sphere of ruthless competition. Unfortunately, since that is a character it may very well assume, competing interests must be very well prepared. Under these conditions, any nation or user who does not develop his technology with deliberate speed will find the paradox between strategic and social benefits has become an academic relic.

It is often claimed that this sort of dilemma implies that environmental technology possesses a dynamic nature that leads the formulation of public policy. That is nonsense. The entrepreneurial and planning functions, combined with physical survival requirements, constitute the dynamic. When all is well, this is apparent. It is the failure of public policy to foresee the effects of technologic development and the feeling of lack of control that results that creates a mirage of technologic dynamism under condtions of ultimate competition. That such a mirage can now be seen is woeful testimony to the level of scientific and technical comprehension in the design-making process upon which the future of the ocean environment rests.

THE LAWS GOVERNING EXPLOITATION OF THE MINERALS BENEATH THE SEA

By

Northcutt Ely

This article is concerned with some of the current trends in the world's mineral legislation. I have selected, for this purpose, the most dynamic development now going on in this field of law, that relating to the minerals which are submerged by the waters of the world.

The question of what laws ought to govern the minerals beneath the sea is of critical interest right now for many reasons. Technological developments, particularly in the oil industry, have made the undersea mineral resources available for the first time on a large scale. Two greatest oil wells in the world are offshore, in the Persian (or Arabian) Gulf. The North Sea is the site of intense exploration activity. Certain seabed areas are carpeted with nodules containing concentrations of manganese or iron or phosphorites. The American Navy and the French, led by Cousteau, have proved that communities can be established and maintained at great depth for substantial periods of time. The loss of the submarine "Thresher" and its relocation at great depth by the Navy's deep-sea exploration vehicle, Trieste II, focused attention on the potentialities of these devices. There has been public discussion of undersea missile launching stations, bunkering stations, and submarine detection cables. Scientists and industrialists are attracted, two thousand at a time, to meetings to discuss how to exploit the undersea minerals. Project Mohole is expected to tell us what lies beneath the earth's crust at great ocean depths. The Senate has passed a bill to create the National Oceanographic Council to concern itself with international marine resources. Quite literally, we have just put one toe into the water.

It is known that the Russians are working on oil drilling techniques designed for great depths. We know that if missiles can be housed and fired from submerged submarines, then they can also be concealed, housed, and fired from beneath floating or fixed platforms of the types used for drilling. To bring this problem into abrupt focus, what can we do about it if Cuba licenses to the Russians the privilege of anchoring floating platforms in the Caribbean, purportedly to drill for oil?

We are dealing here with the third dimension of a very large and amorphous body of law, the international law of the sea. As subdivisions of this subject, we are concerned now with five classifications: (1) inland waters, (2) territorial waters, (3) the so-called contiguous zone, (4) the continental shelf, and (5) the high seas. These classifications are recognized in a set of four international conventions signed at Geneva in 1958. One covers the subjects of "The Territorial Sea and the Contiguous Zone," another "The High Seas," a third "The Continental Shelf." The fourth, on "Fishing and Conservation of the Living Resources of the High Seas," has not gone into effect and does not directly touch our subject.

Inland waters are those which are landward from a "base-line," fixed generally by reference to low-water marks on the coast. The method of locating this base-line has been a matter of historic controversy. The 1958 "Convention on the Territorial Sea

and the Contiguous Zone" says the normal base-line is the low-water line along the coast as marked on large scale maps officially recognized by the coastal state. But where the coast line is deeply indented or cut into, or if there is a fringe of islands along the coast,the method of straight base-lines joining appropriate points may be used, the base-line so drawn to follow the general direction of the coast. If a river flows directly into the sea, the base-line joins points on the low-tide line of its banks. If a bay lies within a single nation, the base-line, in general, is a line between its entrance points. There are exceptions, qualifications, and residual ambiguities, but, for our present purpose, the point is this: Landward of this line, the minerals beneath the rivers, harbors, bays, and other waters enclosed by the base-line, are wholly within the sovereign control of the coastal nation. I am putting to one side, for lack of time, discussion of the contest in this country between interests of the federal and state governments.

A nation's territorial sea, as distinguished from inland water, is a belt of sea to the seaward side of this same base-line. The nations of the world are not in agreement as to how wide this belt should be, and the 1958 conventions do not decide this. Our own country says three miles on the Atlantic and Pacific Coasts, but three marine leagues, something over nine miles, off portions of the coast of the Gulf of Mexico. Other countries say six, still others twelve; others, particularly in Latin America, would like to go much farther, primarily to control fishing. But article 24 of the convention I have cited does establish, in addition to this belt of territorial seas, what it calls a "contiguous zone," saying that it shall not extend beyond twelve miles from the base-line from which the breadth of the territorial sea is measured. I shall not stop to compare the differences between a coastal nation's powers--or, as the international lawyers say--its competence--to deal with matters on or in these two classifications of waters. They relate to such subjects as the right of innocent passage, exceptions to the State's police powers, and so on. Some have said that the convention is an invitation to all nations to extend their territorial water belt to this same twelve miles, but not all have done so. It is clear that, insofar as mineral resources are concerned, the coastal nation has full powers in the whole twelve-mile contiguous zone, as much as it does on dry land, because, as we will see in a moment, those powers over mineral resources extend much further to sea than the limits of this zone. Again, I will by-pass the contest between our federal and state governments over the minerals in the contiguous zone, and move into deeper waters.

The next step seaward is the continental shelf. It too, is a contiguous zone, but it is the subject of a separate convention which is particularly interesting to us because it deals specfifcally with mineral resources.

A word as to the background.

In 1945 President Truman issued a proclamation declaring that the United States regarded the natural resources of the subsoil and seabed of the continental shelf contiguous to the United States as "appertaining to the United States, subject to its jurisdiction and control." It disclaimed any assertion of interference with the status of these waters as high seas, a term to which we will come in a moment. Twenty-five other nations, with alacrity, issued similar proclamations, some of them

not so modest in their disclaimers.

In 1958 agreement was reached at Geneva on a "Convention on the Continental Shelf." It defines the term continental shelf as "referring (a) to the seabed and submarine areas adjacent to the coast but outside the area of the territorial sea, to a depth of 200 metres, or, beyond that limit, to where the depth of the superjacent waters admits of the exploitation of the natural resources of said areas; (b) to the seabed and subsoil of similar submarine areas adjacent to the coasts of islands." I will return later to the built-in ambiguity in this language.

The convention goes on to say that "the coastal State exercises over the continental shelf sovereign rights for the purpose of exploring it and exploiting its natural resources." These rights are stated to be "exclusive in the sense that if the coastal State does not explore the continental shelf or exploit its natural resources, no one may undertake these activities, or make a claim to the continental shelf, without the express consent of the coastal State." Moreover, "the rights of the coastal State over the continental shelf do not depend on occupation, effective or notional, or on any express proclamation." Where the same continental shelf is adjacent to the territories of two or more states whose coasts are opposite to each other, or is adjacent to the territories of two adjacent states, the boundary, if not otherwise agreed upon or controlled by special circumstances, is a median line every point of which is equidistant from the nearest points of the base-line from which the breadth of the territorial sea is measured.

Let us return now to the ambiguity in the definition of the continental shelf, compounded by this method of drawing boundaries on the shelf.

By definition, the coastal states exclusive jurisdiction does not end at the 200 metre depth, and does not end at the jumping-off point from the continental shelf into the deeps of the ocean, because the shelf itself is defined, not in geologic or factual terms, but in terms of legal fiction. The continental shelf, according to the convention, does not stop at the submarine precipice, but continues right on down to whatever depth exploitation of the minerals beneath the seabed becomes possible. How deep, how far out? No one can say; but if some stranger proves, by doing it, that wells can be drilled at very great depth at a distance of hundreds of miles from the nearest coast line, then if this language means what it says, he has automatically established, ex post facto, the exclusive jurisdiction of some coastal state which was incapable of this technical exploit itself, did not license the exploration, indeed, never heard about it, but now acquires sovereign powers to prohibit it, or police its operation, and collect taxes and royalties and control disposition of production. Perhaps this is a good and necessary result, but it is a curiously casual one. Is the coastal state bound to maintain order in this new outpost of its sovereignty and protect it from other powers? Moreover, what coastal state is entitled to get this windfall and/or headache? Remember the boundary language. The boundary between nations projected outward on the continental shelf, is not a straight line like a meridian of longitude, as that same boundary may be on dry land. If the coast is sinuous and curved, so is the boundary, because, when it puts to sea, it must bend and twist so as to make each point on it equidistant from points on the base-line which supposedly are themselves equidistant from

points on the base-line which supposedly are themselves equidistant from the point at which the boundary leaves the shore. And what if the coastal state is an island, like Cuba or the Malagasy Republic? What are the limits, if any, on its ex post facto jurisdiction, if aimed away from any other islands below the horizon?

The next topic is the high seas. The 1958 "Convention on the High Seas" says that this term "means all parts of the sea that are not included in the territorial sea or in the internal waters of a State". This definition thus includes the waters that overlie the continental shelf. The convention goes on to say, "The high seas being open to all nations, no State may validly purport to subject any part of them to its sovereignty." Thus, with respect to sovereignty, opposite rules apply to the use of the surface of the sea--with which this convention primarily deals--and, on the other hand, to the use of the seabed, as stated in the Convention on the Continental Shelf. The High Seas Convention's only direct cross-reference to the continental shelf is in a statement that "All states shall be entitled to lay submarine cables and pipe lines on the bed of the high seas," and "Subject to its right to take reasonable measures for the exploration of the continental shelf and the exploitation of its natural resources, the coastal State may not impede the laying or maintenance of such pipe lines or cables."

But at some point, at some great depth, at some great distance from land, the continental shelf must be presumed to end, even as a legal fiction. When we reach that point, we have arrived, let us day, at the bottom of the high seas, beyond the reach of the jurisdiction of any coastal State, outside the scope of any treaty, ungoverned by any judicial precedent. What law shall govern the exploration and exploitation of mineral resources beneath the bed of the high seas? In groping for an answer, it is natural that we turn first to the principles that underlie the law of the sea, principles which have evolved over the centuries, and which brought the nations of the world into the consensus evidenced by the 1958 convention.

When we examine these principles, we will find two philosophies in collision. One is what the international lawyers call "inculsive interests". By this, they mean the common interest that the whole community of nations has in making access to the resource available to everyone. This inclusive interest is expressed, for example, in the principles stated in the Convention on the High Seas, which defines "freedom of the high seas" as including freedom of navigation, freedom of fishing, freedom to lay submarine cables and pipe lines, and freedom to fly over the high seas. The contrasting principle is called the "exclusive interest," for example, the plenary sovereignty of the coastal State in its inland waters and territorial sea, and in the lands beneath those waters. The community of nations, over the centuries, has reached a consensus which recognized that the "Public order of the oceans," as some writers have called it, is best served by recognizing both of these principles. Where they come into collision, the consensus, expressed in these conventions, attempts to accommodate them. It does so, for example, by stipulating for a right of innocent passage of vessels through territorial waters of a coastal State.

What equilibrium between exclusive and inclusive interests should we seek to establish on the bottom of the high seas? To answer this, let us first examine the necessities of the mineral industries.

The petroleum and mining industries, whether operating on dry land or beneath the sea, require two things above all to attract capital to the ultra-risky business of exploring for minerals; the discoverer's exclusive right to exploit the minerals discovered and security of tenure while he does so. At sea, these risks are multiplied. The question is: What governmental authority can best assure this sort of protection in a latitude and longitude which is, by hypothesis, not only outside the boundaries of any nation, but is beyond the continental shelf?

In speculating on this, and speculation is all that anyone can offer at present, the following concepts have been suggested:

1. The solution recently proposed by a Committee on Natural Resources and Development to the White House Conference on International Cooperation was this: Treat the minerals beneath the high seas as the common property of mankind, but recognize that "producers must have exclusive mining rights to areas that are sufficiently large to permit them to operate economically and without fear of congestion or interference. And if rights are to be granted for resources that are the common property of the world community, then decisions on the allocation of these rights or on the methods of acquisition must be made within the framework of international law. A specialized agency of the United Nations would be the most appropriate body for administering the distribution of exclusive mining rights." My comment is that this administrative solution is a long way off, and will become necessary only after some major discovery is made at great depth, and touches off competition. Right now, there is plenty of room.

2. Assume, until the contrary fact develops, that all practicable undersea mineral development is sufficiently close to a coastal State that the Convention on the Continental Shelf applies, and that the nearest coastal State therefore should have plenary jurisdiction. My comment is that this factual assumption will quite probably be correct for a long time, but it begs the question with which we are now wrestling, which relates to the minerals beneath the deeps of the high seas.

3. Treat the seabed beneath the high seas as open to appropriation and occupancy by all, free of the licensing authority of any State or international organization, but subject to the qualification that conflicting appropriations must be accommodated either by agreement or by resort to some rather general principles of reasonableness of use, to be evolved piece by piece as need arises. This is about what is likely to happen, but it simply postpones the questions of what nation's laws shall govern, and what the content of those laws should be.

4. Let the exploratory operation carry the flag of some nation with which it has a "genuine link--this is the test of recognition of the flag of a vessel under the High Seas Convention. This is exactly what is required as long as the operation is both sea-borne and mobile, and it is arguable that there is no reason to change its status when a drill stem or dredging bucket or mobile crawler or submersible habitation established permanent contact with the bottom. As a practical matter, the explorer thereby appropriates a segment of the seabed, and the jurisdiction--let us go further and say sovereignty--of his flag attaches to the discovery. This is the way in which sovereignty has been extended to unoccupied and unclaimed lands above the sea. There is no necessary inconsistency between such an exclusive appropriative right in the seabed and the inclusive

rights of all nations in the use of the overlying high seas--just as the Truman proclamation said with respect to the continental shelf. There is no argument about the geographical extent of the appropriative right unless and until a neighbor sets up operations close enough to create friction. This has been the way in which, on dry land, the mining laws and water laws of the western states have evolved. Sooner or later, when friction does develop beneath the sea, it will become necessary to arrive at some understanding of the reasonable area of the seabed to be deemed appropriated, relating this to the character of the minerals and the areas reasonably required for exclusive rights of exploration and production, large enough to justify the exploration investment. When the first significant discoveries are made, the flag nations of the sea-borne exploitation mechanisms are likely to arrive at an accommodation, just as Venezuela and Great Britain did in the Gulf of Paria. If they fail at an accommodation by agreement or arbitration, and if enough nations sense an interest of their own in the outcome, then we can forecast the negotiation of another Geneva convention.

In conclusion, I would leave this thought. While it is natural that we look first to the law of the sea in constructing a regime for the development of the minerals beneath the sea, we are nevertheless dealing here with fixed and firm real estate, not with the trackless ocean. To make real estate valuable it must have ascertainable boundaries and be subject to clear and exclusive rights of occupancy. These are just the reverse of the attributes which make a sea lane valuable to commerce. The problem on which we are engaged in the present discussion is really a search, first, for the appropriate jurisdiction to assure exclusive occupancy of a segment of the seabed, and, after that, for a workable method of accommodating conflicting claims to that same assurance. To the extent that the law of the sea answers these, it is useful, and we find that it now does answer these questions with respect to minerals underlying the continental shelf, by sending us to the law of the coastal State. With respect to the minerals beyond the continental shelf, I suggest that we have available a better analogy, in the laws of appropiation of minerals and of water, evolved in the western United States, than we can find in any facet of the law of the sea. Finally, I suggest that until enough international competition and friction develop to justify creation of some advance licensing scheme for administration by the United Nations, recognition of the flag of the craft or other surface mechanism from which the exploration is controlled sufficiently identifies the jurisdiction which ought to have plenary control over that exploration and over the exploitation of the resources so discovered.

THE LEGAL STATUS OF MINERALS LOCATED ON OR BENEATH THE OCEAN FLOOR BEYOND THE CONTINENTAL SHELF

William C. Tubman

Prior to discussing the legal status of minerals located on or beneath the ocean floor beyond the continental shelf the following definitions are offered:

CONTINENTAL SHELF: Geographically, the continental shelf commences at the low water mark and is a "gently sloping plain which underlies the seas adjacent to most land masses, extending seaward from shore to the point at which there is a marked increase in the gradient of the decline and where the continental slope leading to the true ocean bottom begins." (1) At that point where the shelf breaks sharply downward (continental slope), there generally exists a water depth approximating 200 metres (100 fathoms or 600 feet). These undersea platforms vary from very narrow (less than three miles) to relatively broad (250) miles extensions of continent or islands. In certain locations such as off the coast of southern California, the continental shelf takes on the topography of plateaus and steep undersea valleys which descend to much greater depths than 200 metres before the true edge of the shelf is reached.

Legally, the continental shelf, as defined within the Convention on the Continental Shelf, of United Nations Conference on the Law of the Sea, is:

> "THE SEABED AND SUBSOIL OF THE SUBMARINE AREAS ADJACENT TO THE COAST BUT OUTSIDE THE AREA OF THE TERRITORIAL SEA, TO A DEPTH OF 200 METRES OR, BEYOND THAT LIMIT, TO WHERE THE DEPTH OF THE SUPERJACENT WATERS ADMITS OF THE EXPLOITATION OF THE NATURAL RESOURCES OF THE SAID AREAS,"
>
> and
>
> "THE SEABED AND SUBSOIL OF SIMILAR SUBMARINE AREAS ADJACENT TO THE COASTS OF ISLANDS."

TERRITORIAL SEA: That belt of sea adjacent to the coast of a state, measuring in most instances three miles seaward from the low water line over which

(1) United States v. Louisiana et al, 363 U.S. 1, Note 3

the coastal State exercises sovereign rights in addition to sovereignty over the seabed and subsoil of the territorial sea and its superjacent airspace.

SOVEREIGN RIGHTS OR JURISDICTION AND CONTROL: The quality of authority claimed by coastal states over the adjacent sea, seabed, subsoil and superadjacent airspace is expressed as the exercise of its sovereign rights or of its jurisdiction and control. There does not appear to be a universally acceptable distinction between the two terms other than that sovereign rights could be interpreted as a somewhat higher quality of authority than the authority claimed by the exercise of jurisdiction and control. To illustrate the confusion, some delegates to the United Nations Conference on the Law of the Sea urged that the use of the term "sovereign rights", in connection with the seabed and subsoil of the continental shelf, might lessen the previously enjoyed full freedom of the superjacent sea and airspace above the continental shelf. Subsequently, it was agreed that such superjacent sea and airspace would remain internationalized but nevertheless the term "sovereign rights" was retained. Perhaps it should be mentioned that the United States Government when referring to the continental shelf employed in 1945, "jurisdiction and control" and, in 1958, "sovereign rights."

II

At the present time there does not exist case precedent, treaties, or proclamations which define the legal status of minerals lying on or beneath the ocean floor beyond the continental shelf. Nevertheless, it is my position that no state has the unilateral right to exercise its sovereign rights or its jurisdiction and control over minerals lying on or beneath the ocean floor beyond the continental shelf.

In support of this position I will discuss the Convention on the Continental Shelf which presently is federal law since the United States is a party to that Convention. Additionally, a brief relation of the legal history of the ocean floor beyond the territorial sea will be presented. Admittedly, neither the Convention nor the legal history is necessarily determinative, since the locus of my concern is the ocean floor beyond the continental shelf, but nevertheless I believe that such a discussion and relation are pertinent to defining by contrast the legal status of minerals located on or beneath the ocean floor beyond the continental shelf.

III

On April 12, 1961 the United States ratified the "Convention on the Continental Shelf" which was formulated at the United Nations Conference on the Law of the Sea held in Geneva during 1958. (2) This Convention defined the continental shelf as the seabed and subsoil beyond the territorial sea to a depth of 600 feet or "to where the depth of the superjacent waters admits of the exploitation of the natural resources of the said area." The same Convention grants to the coastal state "sovereign rights" over the continental shelf "for the purpose of exploring it and exploiting its natural resources."

Furthermore, it states that the exploration and exploitation rights are exclusive to the coastal state and that the coastal states' rights over the continental shelf are not dependent upon occupation of the shelf or on any express proclamation regarding the shelf.

Analyzing the Convention definition of the continental shelf and the rights derived therefrom I have come to the following conclusion:

> For the purpose of exploring and exploiting the natural resources of the continental shelf the coastal state exercises sovereign rights over the shelf to a superjacent water depth of 200 metres, which in general is the geographically accepted superjacent water depth at the edge of the shelf. If such shelf extends beyond and beneath a superjacent water depth exceeding 200 metres, the coastal state exercises sovereign rights over that portion of shelf lying beneath a superjacent water depth which admits of shelf exploitation, the furthermost limit of the exercise of such sovereign rights being the geographic edge of the continental shelf, i.e. that point at which the shelf breaks sharply downward (continental slope).

It should be noted that I have interpreted the limitation of the coastal state's exercise of sovereign rights to the edge of the geographic continental shelf and, therefore, such sovereign rights cannot be exercised over the continental slope, which is that portion of the undersea continental land mass which breaks sharply downward from the edge of the continental shelf to the ocean floor. Although it could be argued that the continental slope should be subject to the coastal states sovereign rights since it forms a part of the undersea geographic extension of the coastal state, I do not believe that the drafters of the Convention had this in mind. In the first instance they use the term "continental shelf" rather than "continental shelf and continental slope" and secondly they used an ocean depth or exploitability test rather than a test tied to the natural undersea geographic extension of the coastal state itself.

(2) See Appendix B for the text of Articles 1, 2 and 3 of Annex IV of the United Nations Conference on the Law of the Sea.

If they intended that the continental slope be included within the jurisdiction of the Convention, the drafters probably could have formulated a definition of that, over which they intended the coastal state to exercise jurisdiction, more easily than the definition drafted. They simply could have given to coastal states sovereign rights over the undersea land mass naturally flowing from the state to sea and terminating the definition at that point where the land mass reaches the ocean bottom. Additionally, oceanographers make a distinction between the continental shelf and the continental slope and since the drafters relied at least in part upon geographic considerations, it is reasonable to assume that the drafters made the same distinction. Finally, Webster's New International Dictionary, Second Edition, unabridged, published by G. & C. Merriam Company [1961] in its definition of the continental shelf, makes a clear distinction between the shelf and the continental slope in the following manner:

> "CONTINENTAL SHELF: A submarine plain of variable widths forming a border to nearly every continent. The water above it is comparatively shallow (usually less than 100 fathoms). The rapid descent from it to the ocean depths is known as the CONTINENTAL SLOPE."

Further note should be taken that the geographic concept of the continental shelf includes the Convention concept of the shelf but the Convention concept does not include, at all times, the geographic concept although such Convention concept virtually does so include. Legally, those states that have consented to the Convention have agreed thereby to delimit their sovereignty at that point where the shelf, as it is defined in the Convention, ceases. This point of legal delimitation need not coincide with the geographic extent of the shelf, it has the power to do so but such power rests upon the coastal States' ability to exploit the shelf to its geographic limit.

In order to more fully support my contention that the phrase "... or, beyond that limit, to where the depth of the superjacent waters admits of the exploitation of the natural resources....", appearing in Article I of the Convention on the Continental Shelf, defining the continental shelf, is limited to waters above the geographic continental shelf and does not extend ad infinitum seaward to wherever exploitation is possible, I offer the following summarized statements extracted from the record of meetings of delegates to the 1958 Geneva Conference.

Miss Gutteridge, the United Kingdom delegate to the Geneva Conference, commenting upon the exploitability criterion, was summarized as stating that "...the criterion of exploitability needed further consideration, since it was open to the criticism that it would make the extent of

the continental shelf uncertain."[3] If the right of exploitability were to extend, without limit, to sea, there would be no reason for tne United Kingdom delegate to voice concern over the uncertainties connected with the "extent of the continental shelf." Furthermore, when she subsequently was summarized as saying that: "She felt that the article should only apply to detached areas of Shelf which were in genuine proximity to the continental shelf...", [4] it would be unreasonable to assume that Miss Gutteridge was not speaking of a specific limitation to the geographic continental shelf when she referred to detached areas of the shelf and their proximity to the continental shelf; the use of the phrase "detached area" connotes that the speaker was contemplating a geographic definition of the continental shelf. She modified the words "detached areas" by the phrase "of shelf" and, therefore, I conclude that she had in mind one concept, that is the shelf, and that tne shelf comprises detached areas separated from other areas of the shelf by steep underwater valleys. All of this area is continental shelf - much like that off the coast of southern California - and, therefore, by using tne words "detached areas of the shelf" she was contemplating the geography of the shelf rather than a legal concept of the shelf.

Mr. Carl Stable, the Norwegian delegate was summarized as follows: "Although the conception of the continental snelf in the International Law Commission's draft was not based strictly on geographic considerations it has been greatly influenced by them."[5] The most conservative posture to assume with respect to Mr. Stable's statement would seem to be that the coastal State's exercise of sovereignty is to be guided by geographic considerations. Although his statement could be used as an argument contrary to the position I have taken, since he stated that the "International Law Commission's draft was not based strictly on geographic considerations"*, I do not believe that this position would be reasonable. The first part of the Convention definition recites a 200 metre test and this in fact is an inadequate geographic test if we are to determine what comprises the continental shelf. Such definition had to be carried further, that is, to the exploitability test because in fact the geographic continental shelf is not at all times covered by 200 metres of ocean. As Mr. Stable subsequently said, "it (the International Law Commission's conception of the shelf) has been greatly influenced by them (geographic considerations)." In fact the Commission's conception was influenced as far as it could be.

Finally, Mr. Garcia Amador, the Cuban delegate, in urging the acceptability by the Conference of the exploitability test was summarized

(3) The Official Records of the United Nations Conference on the Law of the Sea, Volume VI A/Conf. 13/42, page 4
(4) IBID at page 4
(5) IBID at page 4

* Emphasis mine.

as follows: "....for his country the problem under consideration was an academic one since the continental shelf lies entirely under internal waters of the territorial sea..." (6) It is to be presumed that Garcia Amador endorsed that which he understood. He said of the definition of the continental shelf that, as to Cuba, the problem is academic. This is so since the geographic continental shelf of Cuba lies within its territorial sea, and therefore, as to Cuba, the problem of conflicting claims to the seabed and subsoil of the Cuban shelf shall never come to pass. If Garcia Amador understood the exploitation criterion to extend beyond the geographic limitation of the shelf, how could he say, with apparent certainty, that the problem is academic other than if he had in mind a geographic definition of the continental shelf? It is apparent from Mr. Garcia Amador's statement that he was contemplating the geographic continental shelf rather than some legal definition of the continental shelf which would extend beyond Cuba's territorial sea.

Statements, such as the preceding three, were made consistently by delegates to the Conference, which statements, I believe reflect the state of mind of said delegates. Such state of mind, in my estimation, includes a definition of the continental shelf which, in its broadest sense, delimits the coastal state's exercise of its sovereign rights to the geographic edge of the continental shelf.

To sum up, there are two Convention tests, depth or exploitability, both of which can be applied to the geographic continental shelf. What is the purpose of the depth test? Why did not the delegates submit the exploitability test by itself and not consider depth? Why not give the coastal state sovereign rights as far to sea as that state can exploit the seabed and subsoil? I contend that the 200 metres test is the first criterion to be applied because that is the generally accepted water depth at that point where the continental slope commences. The delegates knew that this was an imperfect definition, since the shelf at times extends beyond and beneath a much greater water depth and, therefore, they fostered a further condition. This other condition was exploitability beyond the 200 metre depth which, therefore, would give to the coastal state a reasonable working rule to follow in exercising its sovereign rights to the continental shelf.

In order for this Convention to be binding upon signatory states twenty-two ratifications or accessions or such numerical combination thereof are necessary.

As of December 31, 1963 this Convention received fourteen rati-

(6) IBID at page 25

fications and seven accessions;[7] therefore, making one additional ratification or accession necessary before it becomes binding upon those states who have ratified or acceded thereto. The Convention shall enter into full force as to states ratifying or acceding thirty days after the deposit of the twenty-two instruments of ratification or accession with the Secretary General of the United Nations.

With the exception of Articles 1 to 3 inclusive, any state, at the time of ratification or accession, may make reservations to the Articles. In the event that this Convention shall enter into force a request for a revision of the Convention may be made by any contracting party following the expiration of five years from the date the Convention enters into force.

IV

Turning now to a legal history of the ocean floor beyond the territorial sea, the United States Department of State in 1919, replying to a letter from a citizen who allegedly had discovered oil in the Gulf of Mexico about 40 miles from land declared that: "the United States had no jurisdiction over the ocean bottom of the Gulf of Mexico beyond the territorial waters adjacent to the coast." [8] The Department added that although it "could give no assurances" it would "seem possible" in certain specified circumstances that "this Government would assume some sort of control over the island" which might be erected in the area.

In 1942 Venezuela and Great Britain concluded the Treaty of Paria by which each annexed one-half of the submarine area underlying the Gulf of Paria. The Gulf of Paria lies between Venezuela and Trinidad on Venezuela's northeast sea coast. Considering the configuration of the opposing coasts, the Gulf of Paria is much like an inland sea being somewhat less than 100 miles wide at its greatest breadth and a few miles wide at its opposing most narrow points.

In 1945 President Truman proclaimed in part that: "...the Government of the United States regards the natural resources of the subsoil and the seabed of the Continental Shelf beneath the high seas, but contiguous to the coasts of the United States as appertaining to the United States, subject to its jurisdiction and control." [9] This proclamation resulted in many unilateral claims to the resources of the continental shelf. These resulting claims to adjacent submarine areas varied greatly in extensiveness, as to the authority asserted in terms both of resources and area, but

(7) See Appendix C for a list of those states ratifying or acceding to the Convention on the Continental Shelf

(8) The Public Order of the Oceans, Myres S. McDougal and William T. Burke, Yale University Press, 1962, pg 636, Footnote 218

(9) Proclamation No. 2667, September 28, 1945, Harry S. Truman U.S. Code Congressional Service, 79th Congress, 1st Session, 1945, pg 1199-1200. (For Proclamation No. 2667 set out in its entirety see Appendix A).

were unaminous in extending exclusive coastal authority to the exploitation of mineral resources. By 1956 approximately 25 states claimed in terms of "sovereignty" or "jurisdiction and control" or "territory" or some other label, exclusive coastal control over mineral resources in the adjacent continental shelf. Within five years of the initial unilateral claim by the U.S., commentators on international law expressed the opinion that the continental shelf doctrine, e.g. exclusive control over adjacent submarine areas of the coastal states, had become a principle of international law.

In the matter of an Arbitration between Petroleum Development (Trucial Coast) Ltd. and the Sheikh of Abu Dhabi, (10) the arbitrator rejected the contention that the continental shelf doctrine was part of international law in 1939 and went on to add that it was not yet a part of that law. The arbitrator stated that the "Continental Shelf Doctrine" could "in no form....claim as yet to have assumed hereto the hard lineaments or definitive status of an established rule of international law." The arbitrator stated, referring to the International Law Commission's formulation as to the continental shelf, that he was unable to agree that they "are, or are intended to be the expression of principles which are already part of the international law..." He stated that those prescriptions were rather attempts at "progressive development" of international law.

Nevertheless the arbitrator concluded: "Someone....should have the right to exploit the subsoil of the submarine area outside the territorial limit;" and that "...the contiguous coastal Power seems the most appropriate and convenient agency for this purpose."

In 1954 the International Law Association recommended allocation of exclusive authority to the coastal state by declaring the following to be principles of existing international law: (1) Control and jurisdiction over the seabed and subsoil of the Continental Shelf inside territorial waters vest ipso jure in the coastal state, and (2) Control and jurisdiction over the seabed and subsoil of the Continental Shelf outside territorial waters can be vested in the coastal state by effective occupation, insofar as the Continental Shelf does not extend to the territorial waters of another state and is not shared with an adjacent state.

Additionally, the Association recommended that international law should be developed in order that control and jurisdiction over the seabed and subsoil of the continental shelf, outside territorial waters, should be recognized as being vested in the coastal state ipso jure, i.e. even in the absence of a proclamation.

(10) 1 International and Comp. L.Q. 247 (1952)

The Inter-American Specialized Conference, meeting at Cuidad Trujillo (now Santo Domingo), Dominican Republic in 1956 accorded exclusive rights to coastal states, at least for the exploitation of mineral resources. The Conference agreed in recognizing that certain submarine areas "appertain exclusively to [the coastal] state and are subject to its jurisdiction and control."(11)

The American Law Institute in its Proposed Official Draft on May 3, 1962 of the Restatement of the Foreign Relations Law of the United States stated, in Section 23 entitled: "Continental Shelf," that: "A state has jurisdiction to prescribe and to enforce rules of law concerning the exploration and exploitation of the continental shelf off its coast and beyond the outer limit of its territorial sea." and that: "The exercise of this jurisdiction must be consistent with the provisions of the Convention on the Continental Shelf of April 29, 1958."

Comments following Section 23 noted that: "this section gives to a state jurisdiction on the Continental Shelf off its coast only for the purpose of exploring and exploiting its natural resources." The comment went on to say that jurisdiction is exclusive and does not depend on occupation or express proclamation.

Lastly, in a memorandum (12) dated May 5, 1961 to the Director, Bureau of Land Management, Department of Interior, from the Associate Solicitor, Division of Public Lands, Department of Interior, passing upon the propriety of leasing, pursuant to the Outer Continental Shelf Lands Act (43 USCA 1331-1343) phosphate deposits, located some forty miles off the coast of California, the author related that the designated area lies in the open sea and between this area and the mainland lies a deep channel in which soundings are of at least 600 fathoms and that soundings in the designated area range between 43 and 670 fathoms, the greater part of the area being at a depth of far more than 100 fathoms.

Of this area it also has been said that: "The sea floor between the mainland shoreline and the continental slope off southern California is much more complex than the typical continental shelf of most other areas of the world. For this reason it was named the continental border land...to distinguish it from ordinary continental shelves. The continental border land is an arrangement of high and low areas having a general elongation that ranges from southeast-northwest to east-west, more or less parallel to the topographic trends of the nearby land areas. Some of the topographic highs extend above sea level to form islands, whereas others rise almost to sea

(11) Op. Cit. McDougal, Burke Page 643, Footnote 233
(12) See Appendix D for the text of the Department of Interior Memorandum

level constituting banks, most of which are flat-topped. Still other highs are deeply submerged. Bordering the high areas are slopes that lead down into adjacent deep areas formed by thirteen closed basins and several open but flat-floored troughs." (13) The flat basin and trough floors comprise about 17% of the total 30,370 square statute mile area of the continental border land. Seventy percent (70%) of the area consists of slopes, bank tops, and shelves similar to underwater mountain ranges. Within this general area lies the designated phosphate deposits and this area is considered by oceanographers as continental shelf.

Consequently, it becomes apparent that the "legal definition of the true edge of the Continental Shelf, raises many difficulties, owing to the varied depth of the shelf-break from place to place, to its commonly unsounded nature, and to the question of clarification of shelf indentions such as submarine canyons, troughs, depressions and deep basins." (14)

The question presented by the memorandum is "whether there is in fact a seaward limit to the applicability of the Outer Continental Shelf Lands Act. After finding that "Outer Continental Shelf" as used in the Act is not a geographic term, but rather "A special statutory definition in order that it may apply to all submerged lands over which the United States has asserted jurisdiction and control seaward of the boundaries of the states." and interpreting Article I of the Convention on the Continental Shelf as giving to the United States "jurisdiction, control and power of disposition" over an area such as that designated, the memorandum concluded that "the Act is applicable to all submerged lands seaward of the states' boundaries of which the subsoil and seabed appertain to the United States and are subject to its jurisdiction and control. Since the United States has now asserted rights to the seabed and subsoil as far seaward as exploitation is possible*, it is clear that the Outer Continental Shelf Lands Act is now applicable to all these areas. There is no question that the area designated....falls within the scope of the definition in the Convention and is, therefore, subject to leasing under the Act."

Although the memorandum's author is correct in finding that the designated area falls within the jurisdiction of the Outer Continental Shelf Lands Act and that, within this set of facts, there does not exist a seaward limit to the applicability of the Outer Continental Shelf Lands Act at the 100 fathoms line and that therefore, the granting of the lease is proper, his statements could be interpreted as meaning that the United States could exercise jurisdiction and control over the seabed and subsoil lying beyond the continental shelf when such area becomes susceptible to exploitation. To support this possibility I submit that nowhere in the memorandum does the author limit

(13) The Sea Off Southern California, K.O. Emory, John Wiley & Sons, 1960, pgs 4-5

(14) IBID. pg 325

* Emphasis mine.

the jurisdiction of the Outer Continental Shelf Lands Act to the furthermost edge of the geographic continental shelf. To wit, when using the phrase "as far seaward as exploitation is possible", the author does not join with it a limitation other than that of exploitability.

On the contrary, when considering the continental slope as the outer limit of jurisdiction to be exercised by the United States the author states, after referring to the irregularities of the submarine terrain, that: "This does not, therefore, appear (to be) a satisfactory test of the seaward limit of the continental shelf. It is not required by the statute and was abandoned in the definition of the continental shelf recently adopted by the United States." These statements, which I believe to be not representative of the law, would seem to indicate that the author does not accept the edge of the continental slope as the outer limit of United States jurisdiction. Although the author admits that the continental shelf Convention sets a "seaward limit", he apparently feels that this "seaward limit" is defined only by the possibility of exploitation.

Since the area considered by the memorandum fell within the geographic confines of the continental shelf, it was not necessary for the author to extend his comments beyond such area. Nevertheless, his comments were so extended, which comments are subject to the interpretation that the jurisdiction of the Outer Continental Shelf Lands Act extends beyond the geographic limit of the continental shelf. This conclusion results from the author's unlimited application of the exploitability test. Therefore, this expansive concept must be kept in mind whenever one contemplates exploring the ocean floor at a point beyond the geographic limitation of the continental shelf and off the coast of the United States.

Notwithstanding the expansive attitude of the Interior memorandum and conceding the fact that the designated area fell within the scope of the Convention definition of the continental shelf, thereby subjecting it to leasing under the Outer Continental Shelf Lands Acts, it nevertheless would not be true to say that the United States exercised jurisdiction and control over the seabed and subsoil lying beyond the continental shelf, since the issue raised in the memorandum did not contemplate the exercise of such expansive jurisdiction. Therefore, the Interior Department memorandum could not be cited as precedent and there is no seaward limit to the applicability of the Act other than the exploitability limit and that the United States has exercised jurisdiction and control over the seabed and subsoil beyond the geographic continental shelf.

V

To reiterate, Part IV of this paper has been devoted to a legal history of the continental shelf so as to contrast those relatively recent events to the present complete lack of case precedent, treaty or proclamation concerning the seabed and subsoil lying beyond the geographic continental shelf. Since great pains have been taken by those persons entrusted to define the legal status of the natural resources of the continental shelf and, since to date there is an absence of commentary regarding the legal status of that which lies beyond the shelf, I cannot help but conclude that the seabed and subsoil of the ocean floor beyond the geographic continental shelf is internationalized and, therefore, subject to no one state's "sovereign rights" or "jurisdiction and control."

VI

Notwithstanding the position I have taken I feel it necessary to draw your attention to the fact that a state might interpret the exploitation test of Article I of the Convention on the Continental Shelf as permitting that state to exercise sovereign rights beyond the geographic continental shelf to some mid-ocean median point.

If the United States took such an interpretation, one interested in exploiting the ocean floor, beyond the geographic continental shelf off the coast of the United States, would be required to secure a lease from the United States Government for such lands pursuant to the Outer Continental Shelf Lands Act.

A conversation had with Luther T. Hoffman, Assistant Director, Bureau of Land Management, Department of Interior, has disclosed that in order to prospect or explore, in a locus over which the United States has exercised its sovereignty or its jurisdiction and control, a prospecting permit is required. Such permit can be had by application to the Department of Geological Survey; also State Department permission is required. After prospecting has been accomplished and the seabed appears to contain that for which prospecting was commenced, a formal request is made by the party interested that the area concerned be subject to competitive bidding. This action results in a "Call for nomination" which is published in the Federal Register. Such "Call" means that competitive bidding to obtain the lease will ensue. The highest bidder thereupon is awarded the lease.

In the event the ocean floor sought to be exploited lay off the coast of a state other than the United States and, if that state took the same interpretation of Article I, it would be necessary, therefore, to negotiate with that state in order to pursue the desired exploitation.

VII

At this juncture, it should be noted that exploitation of the ocean floor beyond the continental shelf should take into consideration problems that may arise as a result of existing sea lanes and fishing areas. Furthermore, every attempt should be made to prevent pollution of the seas and superjacent airspace resulting from the exploration and exploitation activities. In this connection, Articles 24 and 25 (15) of the "Convention on the High Seas" requires every state to draw up regulations to prevent pollution of the seas by the discharge of oil from ships or pipelines, or resulting from the exploitation and exploration of the seabed and its subsoil. States are also required, by the provisions of these articles, to cooperate with competent international organizations in the prevention of the pollution of the seas or superjacent airspace. With respect to this Convention, the requisite number of ratifications and accessions have been deposited with the Secretary General and as such, the Convention was entered into force as international law on September 30, 1962.

Another problem involved in exploiting the ocean floor beyond the geographic continental shelf is that of conserving to oneself the technology of economically extracting minerals from the ocean floor. Two methods are available: that of patenting the exploitation procedure or maintaining the procedure as a trade secret.

Although application for a patent to the exploitation procedure may be had in any country that provides for patent protection, it is necessary to point out that the application for a patent contains a hazardous element. Since the material contained in the patent would be open to public scrutinization, such information could fall into the hands of nationals of countries in which a patent right is not obtainable. Therefore, the protection sought by legal means would be destroyed. If this lack of protection is combined with the fact that such person could subsequently exploit a site in proximity to the patent holders exploitation activities, this would result in competition from one who neither had to go to the expense of developing his own exploitation procedure nor of locating the exploitation site.

Since it is relatively impossible to protect the exploitation site from interlopers, other than by the employment of force, which of course is not recommended, it is therefore of utmost importance to devise some means to protect the technological knowledge incident to the exploitation procedure. To accomplish this end I am inclined toward recommending that exploitation technology be retained as a trade secret which at least would result in taking advantage of the jump acquired by the preceding research.

(15) See Appendix D for the text of Articles 24 and 25 of the Convention on the High Seas of the United Nations Conference on the Law of the Sea.

The last, but certainly not the least, problem will be that of policing the exploitation site and overlying waters.

Finally, I wish to point out that the present trend in matters concerning the exercise of sovereignty by coastal states is one of expansion rather than containment. Although the United States had adhered to the traditional three mile territorial sea, in connection with poaching by foreign fishermen, legislation (16) now being considered by Congress extends to the United States the right to penalize foreign fishermen engaging "...in the taking of any Continental Shelf fishery resource which appertains to the United States..." Although this goes no further than the Convention on the Continental Shelf, it clearly defines the intention of Congress to propose implementing legislation.

In the past other countries have extended their jurisdiction beyond the three mile limit, i.e.: Mexico claims nine (9) miles, Canada twelve (12) miles, Chile, Peru and Ecuador two hundred (200) miles.

Although these extensions of sovereignty are related to fishery resources, it does not necessarily mean that coastal states will not also feel the economic need to claim that which lies beneath the sea, compelling them to exercise their sovereignty to unreasonable dimensions.

WILLIAM C. TUBMAN

(16) S. 1988 88th Congress, 1st Session

APPENDIX A

PROCLAMATION NO. 2667

POLICY OF THE UNITED STATES WITH RESPECT TO THE NATURAL RESOURCES OF THE SUBSOIL AND SEABED OF THE CONTINENTAL SHELF

WHEREAS, the Government of the United States of America, aware of the long range world-wide need for new sources of petroleum and other minerals, holds the view that efforts to discover and make available new supplies of these resources should be encouraged; and

WHEREAS, its competent experts are of the opinion that such resources underlie many parts of the continental shelf off the coasts of the United States of America, and that with modern technological progress their utilization is already practicable or will become so at an early date; and

WHEREAS, recognized jurisdiction over these resources is required in the interest of their conservation and prudent utilization when and as development is undertaken; and

WHEREAS, it is the view of the Government of the United States that the exercise of jurisdiction over the natural resources of the subsoil and sea bed of the continental shelf by the contiguous nation is reasonable and just, since the effectiveness of measures to utilize or conserve these resources would be contingent upon cooperation and protection from the shore, since the continental shelf may be regarded as an extension of the land-mass of the coastal nation and thus naturally appurtenant to it, since these resources frequently form a seaward extension of a pool or deposit lying within the territory, and since self-protection compels the coastal nation to keep close watch over activities off its shores which are of the nature necessary for utilization of these resources;

NOW, THEREFORE, I HARRY S. TRUMAN, President of the United States of America, do hereby proclaim the following policy of the United States of America with respect to the natural resources of the subsoil and sea bed of the continental shelf.

Having concern for the urgency of conserving and prudently utilizing its natural resources, the Government of the United States regards the natural resources of the subsoil and sea bed of the continental shelf beneath the high seas but contiguous to the coasts of the United States as appertaining to the United States, subject to its jurisdiction and control. In cases where the continental shelf extends to the shores of another State, or is shared with an adjacent State, the boundary shall be determined by the United States and the

State concerned in accordance with equitable principles. The character as high seas of the waters above the continental shelf and the right to their free and unimpeded navigation are in no way thus affected.

IN WITNESS WHEREOF, I have hereunto set my hand and caused the seal of the United States of America to be affixed.

DONE at the City of Washington this 28th day of September, in the year of our Lord nineteen hundred and forty-five, and of the Independence of the United States of America the one hundred and seventieth.

HARRY S. TRUMAN

APPENDIX B

UNITED NATIONS CONFERENCE ON THE LAW OF THE SEA

CONVENTION ON THE CONTINENTAL SHELF

ARTICLE I

For the purpose of these articles, the term "continental shelf" is used as referring (a) to the seabed and subsoil of the submarine areas adjacent to the coast but outside the area of the territorial sea, to a depth of 200 metres or, beyond that limit, to where the depth of the superjacent waters admits of the exploitation of the natural resources of the said areas; (b) to the seabed and subsoil of similar submarine areas adjacent to the coasts of islands.

ARTICLE 2

1. The coastal State exercises over the continental shelf sovereign rights for the purpose of exploring it and exploiting its natural resources.

2. The rights referred to in paragraph 1 of this article are exclusive in the sense that if the coastal State does not explore the continental shelf or exploit its natural resources, no one may undertake these activities, or make a claim to the continental shelf, without the express consent of the coastal state.

3. The rights of the coastal State over the continental shelf do not depend on occupation, effective or notional, or on any express proclamation.

4. The natural resources referred to in these articles consist of the mineral and other non-living resources of the seabed and subsoil together with living organisms belonging to sedentary species, that is to say, organisms which, at the harvestable stage, either are immobile on or under the seabed or are unable to move except in constant physical contact with the seabed or the subsoil.

ARTICLE 3

The rights of the coastal State over the continental shelf do not affect the legal status of the superjacent waters as high seas, or that of the air space above those waters.

APPENDIX C

COUNTRIES RATIFYING OR ACCEDING TO THE CONVENTION ON THE CONTINENTAL SHELF*

Byelorussian S.S.R.
Cambodia
Colombia
Czechoslovakia
Federation of Malaya
Guatemala
Haiti
Israel
Romania
Senegal
Ukranian S. S.R.
U.S.S.R.
United States
Venezuela
Australia
Bulgaria
Denmark
Madagascar
Poland
Portugal
South Africa

*Since the preparation of this paper in February, 1964, and by virtue of the ratification of the Convention on the Continental Shelf by the United Kingdom, on June 10, 1964, the Convention has become binding as among those States who ratified or acceded thereto.

APPENDIX D

94127-61

M-36615

APPLICATION OF OUTER CONTINENTAL SHELF LANDS ACT TO DESIGNATED AREA OFF THE COAST OF CALIFORNIA

Outer Continental Shelf Lands Act: Generally

The applicability of the Outer Continental Shelf Lands Act extends to all submerged areas lying seaward of the States' boundaries over the seabed and subsoil of which the United States has asserted jurisdiction. Since the United States has now asserted jurisdiction over the seabed and subsoil of the submarine areas adjacent to the coast of the mainland and islands as far as the depth of the superjacent waters permits exploitation of the natural resources, the Act is now applicable to those areas.

UNITED STATES
DEPARTMENT OF THE INTERIOR
Office of the Solicitor
Washington 25, D.C.

May 5, 1961

Memorandum

To: Director, Bureau of Land Management

From: Associate Solicitor, Division of Public Lands

Subject: Application of Outer Continental Shelf Lands Act to designated area off the coast of California

This is in reply to your memorandum of April 13, 1961, inquiring whether phosphate deposits in a designated area off the coast of southern California may be leased under the Outer Continental Shelf Lands Act (67 Stat. 462; 43 U.S.C. secs. 1331-1343).

The designated area lies some forty miles off the coast of southern California. While it lies closer to the mainland than San Clemente Island, the designated area does not lie between that island and the mainland but rather in the open sea. The soundings in the designated area range between 43 and 670 fathoms, the greater part of the area being at a depth of far more than 100 fathoms. Between the designated area and the mainland lies a deep channel in which the soundings are of 600 fathoms and more.

The question of the propriety of leasing phosphate deposits in this area under the Outer Continental Shelf Lands Act has been presented to us because it has been frequently said in the past that the continental shelf extends seaward to a point where the water deepens rapidly and that this outer limit is set at the 100-fathom line. Under such a definition the designated area would lie beyond the outer Continental Shelf, and, consequently, the crux of this problem is whether there is in fact a seaward limit to the applicability of the Outer Continental Shelf Lands Act set at the 100-fathom line. The distance of 40 miles from the mainland is of little importance since in the Gulf of Mexico activities under the Act are conducted at a greater distance; there, however, the depth of the water increases very slowly.

The question presented is rather novel. Previous questions as to the applicability of the Outer Continental Shelf Lands Act have concerned

the metric system, the outer limit of the shelf is generally regarded as a depth of 200 meters, which is approximately the same as the 100-fathoms mark adopted by England and America.

"In his testimony in 1949 before the Senate Interior and Insular Affairs Committee, the former Secretary of the Interior gave the following description of the Continental Shelf:

> 'These lands begin at the low-water mark along the open sea, or at the seaward boundary of inland waters - such as bays, ports, and the mouths of rivers - and extend seaward for varying distances at different places.
>
> 'The Continental Shelves are slightly submerged portions of the continents that surround all the continental areas of the earth. Along some portions of the coasts they are very broad, gently sloping platforms; and at other places they are narrow. The outer boundary of each shelf is marked by an increase in the gradient of slope of the sea floor. This occurs generally at a depth of approximately 100 fathoms, or 600 feet. Beyond the 100-fathom line, the outer slopes of the Continental Shelves are inclined more steeply toward the ocean deeps.
>
> 'Along the Atlantic coast and in the Gulf of Mexico the Continental Shelves are generally very broad. Off the New England coast, where the width is greatest, the shelf extends seaward about 250 miles. Elsewhere along the Atlantic coast it ranges in width from about 40 to about 100 miles except for a relatively narrow strip along the east coast of Florida. In the Gulf of Mexico the average width of the broad shelf off the west coast of Florida is about 150 miles, and elsewhere in the Gulf the shelf is from 40 to 150 miles wide except where the land area formed by the Delta of the Mississippi River has been extended across the shelf almost to its outer edge.

the landward limits of the outer Continental Shelf and the disputes between the States and the Federal Government as to boundaries. The question here is not similar because there is no other party to assert jurisdiction over the seabed and subsoil of this area if the United States should fail to do so.

The definition of the "Outer Continental Shelf" in section 2(a) of the Act (43 U.S.C., sec. 1331(a)) is silent as to how far in a seaward direction the continental shelf extends. The definition merely states:

> "(a) The term 'outer Continental Shelf' means all submerged lands lying seaward and outside of the area of lands beneath navigable waters as defined in section 2 of the Submerged Lands Act (Public Law 31, Eighty-third Congress, first session), and of which the subsoil and seabed appertain to the United States and are subject to its jurisdiction and control."

It should be noted that section 2(a) defines the shelf in terms of the subsoil and seabed under the jurisdiction and control of the United States, while section 3(a) (43 U.S.C., sec. 1332(a)) declares that the subsoil and seabed of the "the outer Continental Shelf appertain to the United States and are subject to its jurisdiction, control and power of disposition ***." Thus the term "outer Continental Shelf" appears to be used in the Act not as a geographic term generally understood by geographers but as having been given a special statutory definition in order that it may apply to all submerged lands over which the United States has asserted jurisdiction and control seaward of the boundaries of the States.

While the statute is silent as to the seaward limits of the continental shelf, the legislative history is vague. It, unlike the statute, does contain a description of the continental shelf as it is regarded by geographers. However, as we have pointed out above, the statute does not employ the term as it is ordinarily used by geographers, but employs it rather as describing all the submerged lands seaward of the States' boundaries over which the United States asserts jurisdiction and control. Consequently, any description in the legislative history of the continental shelf as a geographic concept may be regarded as an effort to give the Congress a general idea of the area over which the United States was asserting jurisdiction rather than a precise defintion applicable to the statute. The Senate Interior Committee report on S. 1901, 83d Congress, states (S. Rep. No. 411, 83d Cong., 1st Sess., page 4):

> "The Continental Shelf is defined as the extension of the land mass of the continents out under the waters of the ocean to the point where the continental slope leading to the true ocean bottom begins. This point is generally regarded as a depth of approximately 100 fathoms, or 600 feet, more or less. In countries using

'Off the Pacific Coast States the Continental Shelf is relatively narrow, ranging in width from 5 miles or less to a maximum of about 40 miles.'"

Why the 100-fathom line was generally accepted as the seaward limit is not explained in the report except as set forth in the former Secretary's testimony.

The first action by the United States Government with respect to the continental shelf was the issuance by President Truman of a Proclamation (No. 2667) on September 28, 1945 (59 Stat. 884). That proclamation declared that the United States regarded the natural resources of the subsoil and seabed of the continental shelf beneath the seas but contiguous to the coasts of the United States as appertaining to the United States, subject to its jurisdiction and control. As justification for the proclamation, it was stated that "with modern technological progress" the utilization of those natural resources "is already practicable or will become so at an early date." Nowhere in the proclamation is there any mention of the seaward limits of the continental shelf. The press release which accompanied the proclamation (printed at page 53 of the Senate report, supra) did state:

> "Generally, submerged land which is contiguous to the continent and which is covered by no more than 100 fathoms (600 feet) of water is considered as the continental shelf."

However, the last paragraph of the press release (at page 54) emphasized the importance of technology in determining the seaward limits of exploitation as follows:

> "The advance of technology prior to the present war had already made possible the exploitation of a limited amount of minerals from submerged lands within the 3-mile limit. The rapid development of technical knowledge and equipment occasioned by the war, now makes possible the determination of the resources of the submerged lands outside of the 3-mile limit. With the need for the discovery of additional resources of petroleum and other minerals it became advisable for the United States to make possible orderly development of these resources. The proclamation of the President is designed to serve this purpose."

It is thus clear that at the time when the Outer Continental Shelf Lands Act was passed the Congress did not contemplate the immediate development of areas beyond the 100-fathom line. The reason that such development was not contemplated was apparently the existing technological inability to develop resources at such great depths. Nevertheless, the Congress did not prescribe a limit on the depth of water beneath which the subsoil and seabed appertain to the United States and may be developed under the act. Without such a seaward limit it is possible to hold that with technological progress the act may be applied to areas at greater and greater depths.

The Senate Report also refers to the shelf as extending to a point where the gradient of the decline of the sea floor has a marked increase and where the slope to the true ocean floor begins. Language to this effect is also found in footnote 3 of United States v. Louisiana, 363 U.S. 1 (1960). The determination of such a point presents difficulty and would require the careful study of experts in this field. We do not presume to be competent to determine this point. However, we note that the sea floor in this general area does not slope steadily to the true ocean floor. Instead it is cut up with channels, ridges, and plateaus. This does not, therefore, appear a satisfactory test of the seaward limit of the continental shelf. It is not required by the statute, and was abandoned in the definition of the continental shelf recently adopted by the United States.

On May 26, 1960, the Senate ratified the "Convention on the Continental Shelf" (106 Cong. Rec. 10374; daily ed. May 26, 1960). That Convention has not, we understand, yet come into effect, but it may be regarded as expressing the present views of the United States on the continental shelf. Article one of that Convention is as follows:

> "For the purpose of these articles, the term 'continental shelf' is used as referring (a) to the seabed and subsoil of the submarine areas adjacent to the coast but outside the area of the territorial sea, to a depth of 200 metres or, beyond that limit, to where the depth of the superjacent waters admits of the exploitation of the natural resources of the said areas; (b) to the seabed and subsoil of similar submarine areas adjacent to the coasts of islands."

This is the first definition of "continental shelf" officially adopted by the United States which sets any seaward limit. Though it is not an amendment of the Outer Continental Shelf Lands Act, it is an indication of the extent of the area of seabed and subsoil over which the United States asserts jurisdiction, control, and power of disposition. As we have pointed out above, the Act is applicable to all submerged lands seaward of the States' boundaries of which the subsoil and seabed appertain to the United States and are subject to its jurisdiction and control. Since the United States has now asserted

rights to the seabed and subsoil as far seaward as exploitation is possible, it is clear that the Outer Continental Shelf Lands Act is now applicable to all these areas. There is no question that the area designated on the map which you have sent us falls within the scope of the definition in the Convention and is, therefore, subject to leasing under the Act.

It is difficult to see how a case or controversy concerning our interpretation of the applicability of the statute will arise under the present circumstances. If the applicant had proceeded to develop these phosphate deposits without regard to the Outer Continental Shelf Lands Act, we could have objected, and on our assertion of the applicability of the Act the question could have been settled judicially. However, here the company has applied for a lease under the Act and we are aware of no party with standing to object to the granting of such a lease.

We agree with Mr. Caplan, in his memorandum of April 13, that there appears to be no reason to regard this area as within Mexican jurisdiction.

(Sgd) Thomas J. Cavanaugh

Thomas J. Cavanaugh
Associate Solicitor
Division of Public Lands

APPENDIX E

UNITED NATIONS CONFERENCE ON THE LAW OF THE SEA

CONVENTION ON THE HIGH SEAS

ARTICLE 24

Every state shall draw up regulations to prevent pollution of the seas by the discharge of oil from ships or pipelines or resulting from the exploitation and exploration of the seabed and its subsoil, taking account of existing treaty provisions on the subject.

ARTICLE 25

1. Every State shall take measures to prevent pollution of the seas from the dumping of radio-active waste, taking into account any standards and regulations which may be formulated by the competent international organizations.

2. All States shall co-operate with the competent international organizations in taking measures for the prevention of pollution of seas or air space above, resulting from any activities with radio-active materials or other harmful agents.

OUR NEWEST FRONTIER: THE SEABOTTOM
SOME LEGAL ASPECTS OF THE CONTINENTAL SHELF STATUS

By

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Quietly, without much fanfare or public notice, the United States, on June 10, 1964, was confirmed, by international agreement, in the acquisition of basic rights in new territory larger in size than any territorial acquisition since the Louisiana Purchase in 1803. The land involved, though of somewhat different nature, may yet prove to be, in the century ahead, of similar importance and strategic value to the growth and development of the nation.

The "territory" referred to is, of course, the Continental Shelf off the shores of both coasts of the continental United States including Alaska, as well as off the State of Hawaii, and our island territories. The date June 10, 1964 refers to the date thirty days after the date on which Annex IV, the Convention on the Continental Shelf, of the Final Act and Annexes of the United Nations Conference on the Law of the Sea, held at Geneva in 1958 was adopted by its twenty second signatory, the United Kingdom, and thereupon became effective.

The term "Continental Shelf" as referred to in this international agreement consists generally of the "seabed and subsoil of the submarine areas adjacent to the coast but outside the territorial sea to a depth of 200 meters" (slightly over 100 fathoms). In the case of the United States, this covers total areas amounting to in excess of 750,000 square miles of submarine land. As a means of comparison, the Louisiana Purchase included about 828,000 square miles, and our two largest states, Alaska and Texas contain approximately 586,400 square miles and 267,400 square miles, respectively. It is therefore obvious that the seabottom involved comprises a sizeable territorial responsibility and opportunity with which our national policy must increasingly concern itself.

Implicit in the foregoing remarks, but carefully not specifically so stated, is the implication that the adoption of the treaty per se effectively constituted an act under which the United States legally acquired title and sovereignty to the Continental Shelf lands. This is undoubtedly true, but there are some necessary qualifications. In the first place, the convention may be construed merely as a confirmation of previously existing rights substantially claimed in a Presidential Proclamation issued several decades ago. Under this construction, we already had title. Secondly, the agreement of the signatories may be questioned as a confirmation of rights as against non-signatory nations. Finally, the convention itself contains no language of general title or sovereignty, but merely states basic sovereign rights over the shelf for the purpose of exploiting its resources. This would give us limited title only.

Despite these caveats, there are strong grounds to believe that the treaty adoption can be considered as the landmark date of acquisition of the new territory. In support of such a thesis, some of the traditional and historical concepts of international law relating to the subject must be carefully examined, but very summarily it may be pointed out that when almost the same rights covered by the convention were claimed for the United States by

the Presidential proclamation of President Truman in 1945, our claim was in the years immediately thereafter, followed by claims of sovereignty over their respective Continental Shelves by more than a few nations, particularly those in Latin America and in the Middle East.

In this connection, it is also interesting to consider the remarks of Sir Cecil Hurst, a distinguished jurist and international legal scholar, in addressing the Grotius Society in 1948 (Vol. 34, p. 161, Proceedings, Grotius Society). In his remarks, he stated that "stripped of the semi-philosophical language, I do not think sovereignty denotes more than the right and determination of a State to be master in its own household...One cannot read this Proclamation (i.e., President Truman's on the Continental Shelf) without feeling that within the area of its Continental Shelf, the United States is claiming rights which are as large as sovereignty."

The Convention on the Continental Shelf contains the clear and unambiguous statement in its Article 3, however, that "the rights of the coastal state over the continental shelf do not affect the legal status of the superjacent waters as high seas, or that of the airspace above those waters." Thus the control and jurisdiction over the shelf is clearly limited, as far as the convention applies, to the seabed and subsoil beneath it. There are still many claims by other nations, however, to sovereignty even over the waters over the Continental Shelf areas. Most of such claims followed in time the original United States proclamation in 1945, and purportedly followed its tenor. But the Truman proclamation explicitly was limited to control over resources on the seabed or in the subsoil beneath it, and clearly stated that it did not affect the status of waters above as high seas, while the succeeding actions in most cases claimed complete sovereignty.

The first of such proclamations was made by Argentina in October, 1946, proclaiming sovereignty over the epicontinental sea and the entire continental shelf of Argentina. This was followed by similar sweeping claims by Panama in 1946, by Chile and Peru in 1947, Nicaragua and Costa Rica in 1948, and Brazil, Honduras, and El Salvador in 1950. The language of the various laws and proclamations differ, but only Mexico of the American states which followed the U.S. proclamation with its own in 1945, retained the definite acknowledgement of the character of the seas above the shelf as high seas. It would definitely seem, however, in view of the new treaty that extravagant claims will not be generally accepted as of any validity.

There have been several recent cases in which fisherman were involved which have highlighted the conflict in the present still uncertain situation. Ecuador in 1963 seized two American crews for fishing within 200 miles of her coast without payment of fees of $8,000 per one time license. This action in turn resulted in a rider to the next foreign aid bill in the U.S. Senate which limited the assistance given to any countries which impose penalties on U.S. fishing vessels, or make exaggerated claims of fishing rights.

In March, 1963 Brazilian warships chased off six French boats fishing for lobsters 60 miles off the Brazilian coast. They indicated that socalled "sedentary" fishery for sea animals that move along the bottom is under the control of the coastal state that controls the seabed. France despatched a destroyer, but luckily, the controversy was settled amicably, and the ship

was recalled.

Mexico has barred our shrimp boats from fishing within nine miles of her shores. Turkey has extended her fishing boundary to 12 miles, as has also Canada. In September, 1958 Iceland banned fishing within 12 miles of her coast, causing the Fish War with Great Britain, in which British trawlers fished in the disputed zone with British Navy escort for almost two years. Luckily no guns were fired and no one was hurt. A conference was held in Geneva in 1960 as a result of which Iceland's twelve mile limit was recognized for fishery control.

It is interesting to consider the other conventions adopted with the Convention on the Continental Shelf. Especially pertinent are Annex I, The Convention on the Territorial Sea and the Contiguous Zone, Annex II, The Convention on the High Seas, and Annex III, The Convention on Fishing and the Conservation of the Living Resources of the High Seas.

The Convention on the Territorial Sea and the Contiguous Zone stated that a nation's sovereignty extended to a belt of sea adjacent to its coast, known as the territorial sea, which extended from low water mark to seaward for the breadth of the territorial sea, which was left undefined. It confirmed the right of innocent passage for all ships. It then provided for a contiguous zone, contiguous to the territorial sea, to be used by a coastal state to exercise control necessary to prevent violation of customs, fiscal, immigration or sanitary regulations within its territory. This Convention became effective on September 10, 1964.

The Convention on the High Seas guaranteed freedom of navigation, freedom of fishing, freedom to lay submarine cable and pipelines, and freedom to fly, over the high seas. It required states to regulate pollution arising from discharge of oil from ships or pipelines, and contained various provisions relating to piracy. It went into effect on September 30, 1962.

The Convention on Fishing and Conservation of the Living Resources of the High Seas takes a long step toward providing a mechanism for solving recurrent fishery problems. The coastal state is looked upon as having a special interest in fishery regulation, but if the nationals of more than one state are involved, the states are urged to develop an agreement by negoitation. If none is reached, a five member panel is to be agreed upon by the states involved or in default thereof chosen by the U.N. Secretariat. Thus some reasonable means of settling disputes is now available. This Convention has, however not yet been adopted by enough signatories to make it effective. (Became effective March 20, 1966)

The width of the territorial sea has still remained in open question. At the 1958 Conference when the convention drafts were being prepared, twenty-one nations including the United States, favored the three mile limit, seventeen nations claimed four to six miles, eleven nations including Russia claimed twelve miles, five nations wanted 200 miles, and nine claimed the sea above the continental shelf. After extensive debate, no proposal received a majority and the Conference adjourned without taking action.

A Second Conference on the Law of the Sea was convened in Geneva in March, 1960 to consider solely the width of the territorial sea and the extent of fishing rights. The United States and

Canada offered a compromise proposal for a six mile territorial sea with an additional six mile restricted fishing zone. The Soviet Union joined by 17 nations proposed that each state establish its own territorial sea within a three to twelve mile belt, and that any country choosing less than twelve miles be allowed exclusive fishing rights in the contiguous zone out to the twelve mile limit. However, once again the Conference failed to agree, the United States - Canada position receiving 55 votes, one vote short of the required two thirds majority of the 86 voting nations. The present United States position is therefore, as before, that the three mile limit is the only one sanctioned by international law.

As doctrines in international law, territorial waters and the Continental Shelf are inextricably intertwined with the consideration of the even more basic doctrines of sovereignty and territorial acquisition, and with our concern for freedom of the seas.

Grotius, known as the Father of International Law, published his famous treatise "Mare Liberum" in 1609 in which he contended that the open sea could not be property of any state, even though the contrary opinion was at that time more prevalent. A number of his critics published answers as for example John Selden's "Mare Clausum." They pointed out the Republic of Venice had long been recognized as sovereign over the Adriatic Sea, the Republic of Genoa as sovereign over the Ligurian Sea, that Portugal claimed the Indian Ocean and the Atlantic south of Morocco, and that the Papal Bull of 1673 had divided the New World between Portugal and Spain. Similarly, Denmark and Sweden claimed the Baltic Sea, and Great Britain claimed jurisdiction over the Atlantic from North Cape to Cape Finisterre. The desirability from the international standpoint, of such claims lay in the fact that the privilege also was encumbered with a responsibility, that of keeping the claimed areas free of piracy, and in general policing the sea lanes. These claims of sovereignty were also well recognized. As an historical example, Frederick III, Emperor of Germany, requested permission of the Republic of Venice before transporting corn on the Adriatic. Likewise, Great Britain made fishermen of all nations obtain licenses before fishing in the North Sea. When in 1636, the Dutch refused, they were attacked and fined 30,000 pounds. As late as 1805 British Admiralty Regulations contained an order requiring foreign ships to strike their flags when they met His Majesty's ships "within His Majesty's seas," and if they refused, naval commanders were under orders to take compelling action.

On the other hand, historically many such unilateral claims were never recognized by other nations, and others openly contested. The Spanish Ambassador back in 1580 protested against Sir Francis Drake's traverse of the Pacific without permission. To this Queen Elizabeth replied that "the use of the sea and air are common to all and no title to the ocean can belong to any nation". The continuing struggle for supremacy between Spain and England in that age, and the growth of the great British naval tradition in the centuries to follow had much to do with the final ascendancy of the intellectual doctrine of freedom of seas which Grotius was then stating.

Claims to sovereignty through the years were thus shown to depend for validity on occupation or control. Grotius made the point that fish swimming in the sea represented two types of things, viz. res nullius a thing which belonged to no one but which could be caught and become owned property, and res communis,

a thing which belonged to all and could be appropriated to none, and that the open sea was such.

During the eighteenth century, authors began to support Grotius, but a distinction began to be made as to the littoral sea adjacent to a nation and within its effective control. In 1702, Bijnkershoek published "De Dominio Maris" to which the suggestion of the distance a cannonball could be fired from a shore battery, as the width of territorial waters is generally attributed. Mouton, in his Grotius Prize essay published in 1952, has shown that the three mile limit as the cannonball range was first stated by Galiani in 1782. Actually, as he points out, this is an interesting confusion of two separate things. The marine league, which was three sea miles, was actually set down as the marginal belt in the British instruction for Ambassadors as early as 1673. On the other hand extreme gunnery ranges of stationary port batteries of the time of Bijnkershoek have been shown to have been under a mile. The important conclusion, however, is well symbolized by the cannonball symbol, namely that sovereignty, then as well as now, in the final analysis, depends on the power to control.

The argument made therefore for an extension of territorial waters beyond three miles at the present time has rested on the rationale that if physical control was based on cannonball range in Bijnkershoek's time, it can be greatly extended now with the greatly increased ranges of a variety of weapons.

There are good reasons why this logic is not acceptable, however. The first is that there is a wide discrepancy in the ability of coastal states to actually physically control their littoral areas. Secondly, for nations with significant naval power, the increase in the extent of territorial waters would have a limiting effect. Thirdly, extending these waters adds many responsibilities both in time of peace and in war. A fourth reason is that the three mile limit most safeguards the interests of commercial navigation and the free use of the sea lanes. A fifth reason is the effect such increase might have on some important straits.

There are also some good reasons for extension of the limit. The necessity for an orderly solution of the fishery problem is one. A wider field for enforcement of conservational and protective legislation is another. It may be, however, that the Continental Shelf approach, used in the convention previously discussed, coupled with the conventions of fisheries and on the high seas, and preserving the status of superjacent waters as high seas may provide a satisfactory approach to this difficult problem.

Within this framework, let us now look for a moment at the practical steps being taken now and the prospects for future use of the Continental Shelf that affect developments.

Lauterpacht in his revision of Oppenheim's famous treatise on International Law makes the following observation: "As natural resources become more and more exhausted and as scientific invention and engineering skill advance, it may be expected that mankind will devote increasing attention to the exploitation of the surface of and subsoil beneath the bed of the open sea." This comment made in 1937 is rapidly coming to fruition in the increasing attention being given to oceanography by the governments of the world.

Many programs are now underway which should rapidly increase our knowledge and understanding of the seabottom and our ability to control it.

One of the first giant steps in the direction of exploration of the deep was taken by the father and son team Auguste and Jacques Piccard in building the bathyscapth, Trieste which was purchased by the Navy and which plunged (manned) to a depth of 35,800 feet to the oceans deepest point, the Marianas Trench. The Trieste still belongs to the United States Navy and was used in the search for the remains of the U.S.S. Thresher.

Another important underwater vehicle is the diving saucer DS-2, commonly known as the Sous Coup, built by the Frenchman, Jacques Yves Cousteau. This has an operating depth limitation of only about 1,000 feet, but has more horizontal mobility than the Trieste. It was extensively used by Cousteau in his recent well-known experiment in which divers lived below the sea for several weeks.

Other vehicles currently being developed include the Deepstar and Deepstar II which are being built by Westinghouse, Alvin, by Litton Industries for the Office of Naval Research, and the Aluminant, by Electric Boat Company for Reynolds Metals Company.

At the Naval Ordnance Test Station at China Lake, California, tests are being conducted on two modern submersibles, the Deep Jeep, which has exceeded 2,000 feet and the Moray which is designed primarily for speed rather than depth.

While the foregoing vehicles are important portents of future means of exploring the shelf, of even more importance is the effort going into studies of prolonged underwater stay by aquanauts. We have already cited Cousteau's pioneer experiment, memorialized in his outstanding documentary film "World Without Sun".

Similar in many respects, and accumulating added information about man's adaptability to the undersea is the Office of Naval Research's Sealab I and II under the direction of Dr. George Bond. Other pioneering in this important field is being conducted by Edwin Link.

There is an increasing interest in all forms of ocean science in colleges and universities, and more and more programs can be expected to be developed within the next few years.

There is also a definite opportunity now for industry to finance further research into this opening horizon. Three industries especially have an important stake in the new frontier, the petroleum industry, the mining industry, and the fishing industry. All of these already have substantial investments in the undersea development of the Shelf.

The petroleum industry has already invested in excess of several hundred million dollars in offshore oil exploration and drilling activities. At least 28 companies are participating in this type of industrial activity, and wells have been sunk in over 300 feet of water. The oil company interest was, it will be remembered, the cause of the legal controversy which raged some years ago between the Federal Government, which the Supreme Court in three cases decided in favor of the Federal Government - the cases being U.S. vs. California, U.S. vs. Texas, and U.S. vs. Louisiana. It is estimated that over 14 billion barrels of oil reserves are contained in already discovered offshore fields.

The extent of involvement of the fishing industry can be gained from one example, the report of sightings of fishing vessels in 1963 in the North Pacific fishing grounds which are recorded as 5,170 Russian vessels, 810 Japanese, 44 Canadian, 741 United

States, and 1917 unidentified.

The possibilities for the mining industry are also very considerable. Scripps Oceanographic Institution, for example, has reported finding a mountain of magnesium in the Pacific at a depth of 2,000 feet. The possibilities of mining many other types of ore have led to the establishment by the Bureau of Mines of a research center and plans for underwater mining demonstration laboratories, and floating submerged laboratories for research, and analysis.

In such a new environment as the seabottom, many new uses, technologies, and industries are bound to develop. Marine farming and growth of food from the sea is bound to be one such. The scientific herding and raising of edible fish is an immediate prospect. It has been estimated that science could thus add from five to one hundred times the present supply. Aquaculture will undoubtedly develop forms of seaweed as important parts of the world diet. The production of fresh water and the extraction of mineral salts from water may well go hand in hand, solving a dual problem. There will undoubtedly be established many undersea recreational areas, as the more complete adjustment of man to this environment takes place.

From a Navy standpoint, the rapid growth and expansion of the Deep Submergence Systems Project is a necessity and a foregone conclusion: the needs of the times demand it. And as the newest frontier is the natural habitat of the Navy, a large responsibility falls on its shoulders.

The Continental Shelf needs to be thoroughly mapped. Extensive underwater navigational facilities must be planned and constructed. Permanent island boundary stations will be needed. An orderly plan for the discovery and development of undersea resources should be drawn. The currents at various levels must be determined. New instruments for underwater travel must be devised. Methods of immediately tracking and identifying all undersea vessels on the shelf are necessary. Some system of title allocation will have to be inaugurated.

At the same time, in the international and diplomatic area, the failure of the 1960 Conference on the Law of the Sea by a single vote, should, if possible, be overcome by some new international agreement. Preservation of the right of passage through all international straits should be guaranteed in any such agreement.

While thus carefully preserving traditional rights to freedom of the seas, our newly acquired rights in a new frontier - the seabottom - can present a tremendous opportunity for progress.

THE ENGINEERING OF SEA SYSTEMS

John P. Craven
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The engineering of sea systems would not be markedly different than the engineering of land systems were it not for the fact that the environment is inaccessible, is not tolerant of mistake and, in general, is most unique at the most crucial part of any engineering system--the subsystem interfaces. The essential features which so distinguish sea systems are probably best described by the case history method. This method is, in any event, chosen for this paper.

Three examples are employed for comparative purposes and to lend insight by differentiation. These are: a system whose engineering is well advanced--the Polaris Fleet Ballistic Missile System; a system in the process of engineering development--the rescue system of the Deep Submergence Systems Project; and a system assembled ad hoc for a specific mission--the search and recovery system for the lost nuclear weapon at Palomares, Spain.

Comparisons between these systems and for the purposes of this paper are best made if the similarities between the systems are first identified and then compared. Aside from the obvious generality that they are all sea-systems, they all possess the general characteristic common to many military systems of belonging to the class of transportation systems. Specifically, the object is to deliver or have the capability of delivering a specific object or objects to specific addresses. Within this classification, the Polaris Fleet Ballistic Missile System is classified as a pure delivery system where the system goal is to maintain in continuous readiness the capability of delivering a nuclear warhead to specified targets and in the face of all conceivable obstacles to delivery. The rescue system and weapon recovery system is on the other hand more in the nature of a collection system where the object is to initially sort and/or separate the object or objects to be delivered from a field of potentially interesting objects and to then retrieve and deliver the specific object or objects, animate or inanimate.

In this context, the components of each system can be identified. For the weapon recovery system, these are:

(a) The overseas transport (i.e., the system for transporting equipment to the site).

(b) The site-support and maintenance complex.

(c) The command and control system.

(d) The communication system.

(e) The navigation system.

(f) The search, classification and identification system.

(g) The object preparation and recovery system.

For the Deep Submergence Rescue System, the system elements are functionally almost identical, as follows:

(a) The overseas transport (i.e., the system for transporting equipment to the rescue site).

(b) The site support and maintenance complex.

(c) The command and control system.

(d) The communication system.

(e) The navigation system.

(f) The search and distressed submarine identification system.

(g) The hatch clearance, mating and personnel recovery system.

The Polaris Fleet Ballistic Missile System, while not in the identical category as a transportation system, has nevertheless remarkably similar elements:

(a) The overseas logistic transport (i.e., the transport of equipment to deployment sites).

(b) The site support and maintenance system.

(c) The command and control system.

(d) The communication system.

(e) The navigation system (external references).

(f) The deployed submarine (avoidance and readiness system).

(g) The missile launch and delivery system.

This similarity permits a basis for comparison of the engineering problems of each system and a highlighting of problems common to sea-systems. Consideration of the elements in inverse order (i.e., considering item (g) first) permits, in addition, a more orderly description of each ocean system.

The final phase of the Palomares, Spain, operation was the recovery of the weapon. The great depth of the weapon (2,900 feet) and its precarious location on the slope of a canyon and its entanglement by its own parachute indicated the need for caution and a sure approach to the recovery. It seems to the authors, however, that the prime difficulty stemmed from the problem of connecting a cable, whose motions are

determined at one end by the response of the lift ship to the sea way, to an object which is at rest. In order to make the attachment, it is necessary to decouple the motions of the submerged end of the cable from the motions induced by the free surface.

A number of techniques were employed before a successful recovery was made. The first attempt to decouple motions was an attempt to send a slack lift line from the surface down a buoy line anchored close aboard the bomb. Having sent down a lift line, Alvin would connect it to the bomb. To provide an anchor point, Alvin whose lift or external weight carrying capacity was but 50 pounds was to imbed a fluked stake in the bottom near the bomb. Being neutrally buoyant, Alvin could not merely place and push on the stake. To imbed it, Alvin backed off, so to speak, and "charged" the bottom like a lancer--no mean trick at 2400 feet, in a research vehicle, performing an unrehearsed evolution. It speaks well of Alvin's pilots that they actually did get the stake imbedded. However, when the buoy line was tightened, in order to send down the slack lift line, that is, when the sea-surface was ever so slightly coupled to the bottom, the stake pulled out and the scheme was aborted.

The second attempt to decouple involved use of MIZAR's underwated-towed sled, to which were attached several lift lines which Alvin would attempt to hook onto the bomb. This scheme involved precise surface station keeping by MIZAR so as to put her sled directly over the bomb. MIZAR, which has neither a bow thruster nor dynamic positioning equipment, was assisted by two LCM-8's acting as tugs. This attempt, too, was unsuccessful due to station keeping problems; again due to the inability to decouple work on the bottom from the sea-surface. The third attempt was to decouple motions by dropping an anchor with stored lift lines on the bottom and again employing the Alvin to connect slack lines from the clump to the parachute on the weapon. This technique was successful insofar as the attachment technique was concerned. Its lack of success resulted from the impossibility of foreseeing problems of engineering detail when assembling an ad hoc system. As a result, the attachment line cable parted, probably as the result of chafing or cutting on a portion of the recovery assembly.

The final and successful technique employed the "dynamic decoupling" of a remote controlled propelled vehicle known as CURV (Cable Controlled Underwater Research Vehicle). The CURV is a tubular frame on which is mounted four large buoyancy tanks, propulsion units, optical equipment, television, acoustic equipment, a hydraulically operated arm and a recovery buoy. It is cable controlled from a console mounted on a surface ship. The cable is neutrally buoyant and as such is not a tether. CURV is free from the effects of surface motion and thus was free to attach a line which then could be buoyed on the surface. Two such attachments were successfully made (to the surface ships PETRELL and LUISENO). On a third attachment run, CURV became entangled with the parachute. The previously mentioned precarious location of the weapon then dictated its immediate recovery by PETREL.

The final sea phase of the Polaris-FBM system is the launch of the ballistic missile. While this problem appears initially to be non-comparable to the recovery of the nuclear weapon, it is indeed similar in that the essential problem is to decouple the motions of the launch platform from the sea-surface and to prevent the emerging missile from being adversely affected by near-surface wave effects. The first of these is partially accomplished by a dynamic ballasting system to insure an effective hover capability on the part of the submarine even at very high sea states. The ability of the missile to transit the free surface is insured, in part, by a launch system which measures ship motion and wave profile, and computes and predicts the effect of the sea on the missile thus permitting launch in the optimum phase of the wave. This, in effect, is an attempt to minimize the coupling between submarine and surface by having them in proper phase relationship at time of launch. Residual coupling effects do, however, remain and they are taken care of by the initial velocity imparted to the missile, the initial light off of the missile and the choice of launch depth.

The final phase of the rescue mission is the mating and transfer of personnel from the distressed submarine, the transit to the mother craft and the transfer of personnel from the rescue craft to the mother craft. The decoupling of the system from the sea-surface is accomplished by use of a submersible as a mother submarine. If this were not done, it would not be possible to conduct the rescue operation in all sea states or under ice. This system choice thus focuses the major engineering problem on the configuration of the deep submersible rescue vehicle and its mating with the distressed submarine. In the expected situation (based on previous accidents and average environments) the orientation of the distressed submarine will be one of near normal trim and the bottom currents will be small. In such circumstance, the mating can be accomplished with relatively unsophisticated control systems. At the maximum design conditions, however, (mating hatch at 45° orientation and currents of two knots) the control requirements become very stringent. This condition results from a fundamental characteristic of elements of sea-systems which are required to hover or to maintain a small relative velocity with respect to the current. In this instance, the destablizing nature of the moment induced by changes in direction of the added mass (the hydrodynamicist refers to this as the Munk moment), the high cross coupling of forces and moments resulting from the lack of a preferred velocity and the long response times characteristic of hydrodynamic vehicles impose control conditions not amenable to solution by an unaided operator. This situation is aggrevated in the case of the hovering of the FBM submarine by the free surface effect. This effect (the Cummins forces) derives from the fact that the wave velocity varies exponentially with depth and, as a result, imposes a depth dependent and wave amplitude dependent effect upon the submersibles which is destabilizing in the direction of broach.

It may be said, therefore, that the major common problem in the design of subsystems for the final phase of the operation is the avoidance of the forces, moments and perturbations created by the free surface which impede the delivery of the object to its final destination.

Let us emphasize this point by coining a pair of phrases: "Physical Interface" and "Environmental Interface." By physical is meant the interface at the actual scene of the evolution--that is, the attachment of lift line to bomb; the transfer of personnel from stricken submarine to rescue vehicle and on to mother vessel; and the firing of the Polaris missile from the SSBN. By environmental interface is meant another distinct interface, distinct in either time or distance (or both) from the scene of the evolution. In the three evolutions just described, the final phase evolutions of the three sub-sea-systems, the sea-surface is the environmental interface. What we mean by decoupling is, in fact, the elimination of the environmental interface--or at least the minimization of residual environmental effects. The unique point about the engineering of sea, and especially under-sea, systems is that one can seldom completely eliminate the environmental interface--the sea-surface. It is clearly our experience, however, that the engineering complications of an underwater evolution vary at least exponentially as a function of the degree of environmental interface effect. Thus, SEALAB and the saturated diver, and the totally submerged rescue system.

Now one might say that this is not a unique problem, that a similar environmental interface is experienced in aviation. While this is true, it does not seem to the authors that it occurs in anything like the same degree. Consider for a moment two environmental interfaces: one is the sea-surface; the other, the land-surface. One is dynamic in both time and motion; the other is static. Further, by definition of the aviation system, there is near-total decoupling in the final phase evolution, say to release of a bomb. It is such a near total decoupling that one must engineer in the sub-sea-system.

SEARCH AND CLASSIFICATION

The focus of each of the systems is that element which is most unique to its specialized mission. For the Polaris-FBM this is the deployed submarine; for the Palomares system, it is the search classification and identification system; and for the rescue program, it is the search and distressed submarine identification system. From these focal elements stem the payload elements--the missile, the recovery vehicle, and the rescue submersible. Too often the system developer will concentrate on only these elements of the total system to the detriment of the less glamorous or apparently more conventional elements. It is equally true, therefore, that while major problems of system are often solved, systems fail due to neglect of the subsystems. The Palomares conglomeration of search, classification and identification equipments if therefore instructive in examination. To begin with, the search problem posed at Palomares was text book in nature in that it encompassed a wide range of search environments. On the basis of plausible scenarios derived from available evidence, the weapon could have been located either on the shore, in shallow water, deep water in relative flat terrain, in deep water in rugged terrain, or on bottoms ranging from hard to soft-and-silty. It was therefore necessary to assemble varied equipments and to carefully match capabilities to the environment.

While it was possible to use various sub-systems for search, the large amount of aircraft debris and other objects in the area limited the final problem to one of employing either optical or visual sub-systems for classification. The classification sub-systems available were Navy divers (approximately 140) capable of identification in water depths up to 200 plus feet; the Cubmarine, a manned submersible with a 600 foot depth capability; the Deep Jeep, a two-manned submersible with very limited mobility and a 2000 foot capability; a number of tripod mounted television cameras; the Aluminaut, a six-man submersible; the Alvin, a two-man submersible; and the television and camera equipped towed fish of the surface ship MIZAR. The latter four were all capable of use to any depth experienced in this operation. CURV can be listed as a classification sub-system, though it was not so used. CURV could be modified only to a 3000 foot depth limitation and in this sence we were quite lucky the bomb was found at only 2900 feet.

The search-and-identification-of-contact phase permitted the use of both acoustic devices and optical sub-systems. Those optical systems sufficiently mobile for search work were the divers (to a depth of 150 feet), the Cubmarine, Aluminaut, Alvin and the MIZAR fish. The acoustic sub-systems employed included a number of Westinghouse side-looking sonars towed from surface ships, the Honeywell Sea Scanner and Bottom Profiler, Westinghouse side-looking sonars mounted on Aluminaut and on the MIZAR towed fish, and various models of Navy Mine Hunting Sonars, both installed (in MSO (Ocean Minesweepers)) and portable.

Recognizing that the identification and recovery of any piece of aircraft debris was an essential part of the search operation because it provided additional information and clues as to the weapon disposition, it can be said that the majority of these systems were effective in the operation. Indeed, the mobility of Alvin permitted its use in the steep and deep ravines where other craft could not operate: Aluminaut and MIZAR operated in the deep, but less rugged terrain where their longer endurance permitted sustained and more rapid search; the towed sonars permitted relatively rapid search in intermediate and deep waters; the ship and boat-mounted sonars permitted rapid search in shallow and intermediate water; and Cubmarine and divers made visual classification of contacts so developed.

There were, of course, many problems associated with the heterogeneous set of equipments. Had it been necessary to continue the search for an extensive period of time, it would have been difficult to have made an estimate of the effectiveness with which each area was searched. This is particularly true of those areas covered by unrecorded visual search. The large numbers of equipments made it difficult to conduct a centralized analysis of the data and records. The relatively poor mobility of the Deep Jeep and dipped television, and the lack of precision in locating acoustic contacts made it virtually impossible to employ these devices for effective classification, and as will be discussed, each sub-system had its own mode of navigation and communication. In retrospect, however, and in view of success, it should be realized that the heterogeneous nature of the equipments provided a large array of quite different

search and classification techniques which from a game theoretic standpoint increased the probability of eventual success. The maintenance of this type of flexibility in a single unit or in unity with a high degree of commonality is, indeed, the challenge in the design of the secondary mission suit (a search and classification suit). Fortunately, the large sphere in the rescue vehicle which is designed for personnel transfer is available for electronics in the secondary mission mode. It is, therefore, possible to provide weight and space for side-looking sonar, for optics, and for television and the full gamut of sensors available in the assemblage at Palomares. The diver-lockout capability should provide the further ability to employ them for recovery or search in shallow, but otherwise inaccessible areas of the bottom.

It might appear to be the most strained part of the comparison to compare the Polaris Submarine with the Search and Identification systems of the other two examples. It should be noted, however, that many environmental problems are similar in that the Polaris Submarine attempts to blend with its environment (i.e., to minimize effects of environmental interfaces) to remain hidden within it, whereas the search systems are seeking to penetrate the environment to discover. In the rescue vehicle case, this penetration is aided by the cooperative nature of the distressed submarine. Indeed, an essential part of total system design will be to insure a proper alerting and identification system for submarines in distress.

NAVIGATION

Already alluded to, the problem of external referents for navigation is common to all systems. The precision required in search systems is such that position must be known with less error than the swept path of the search sensors. For most sensors, acoustic or optical, the navigation error should therefore be in the order of 20 feet or less. Initially, it was not even possible for surface craft to maintain this position accuracy at Palomares. The installation of a Decca Hi-Fix Net however permitted repeatability (this is all that is required for search) for surface ships at this order of magnitude. For vehicles operating under the water, it is then possible to track them from the surface through use of an acoustic pinger or transponder on the submersible and an azimuth, declination range plot from a receiver on the surface ship. Provided the vehicle is either on the bottom or at a known altitude above bottom, this system may then be independent of a knowledge of bathymetry.

At deeper depths such a scheme is unmarkable because of the beam pattern of the acoustic elements. The surface ship MIZAR employed a scheme using a transponder beacon on its towed sensors and three receiver hydrophones mounted on the submersibles hull for triangulation on the signal. The Aluminaut was configured with a system for bottom navigation employing transponder beacons laid in a grid at two mile centers on the bottom with doppler sonar dead reckoning between fixes. The Aluminaut was also configured to track transponder beacons albeit at a different frequency. The diversity of systems and frequencies which were employed made coordinated navigation extremely difficult, particularly during recovery operations. Indeed, the weapon was discovered before a completely satisfactory navigation technique for the deep submersibles had been perfected.

In its secondary mode of search, the Deep Submergence Rescue System will rely primarily on the navigation mode intended to be used by Aluminaut, since this mode frees the submersible or the towed-fish from the surface navigation net.

Surface navigation nets of the precision required for object search require, in general, a fixed shore-based installation with a precisely measured base-line. The Polaris-FBM System uses as external navigation references, LORAN C, Celestial fixes and satellites. Only the former is of the type admitting of high precision and at most practical distance from the LORAN stations the precision is not within that required for ocean bottom search. The latter represent probably the most precise reference available in the open ocean, but its accuracy is insufficient when viewed in context with the search problem.

COMMUNICATIONS

The next major subsystem, communications, is always difficult in underwater operations in that the electromagnetic spectrum is denied the underwater element unless extremely high power and low frequencies are employed. The extensive and powerful VLF station at Maine is an example of one of the FBM Communication modes required for this ocean-deployed system.

The close proximity of vehicles in the search and recovery operation permits use of higher frequency acoustics as employed in the underwater telephone for voice communication. Nevertheless acoustics is the primary mode of communication and, as such, is limited by thermal gradients and, in particular, by the topography of the bottom. At Palomares, the noncommonalty of receivers and transducers used by the different vehicles was a source of continuous difficulty. As an example, the communication link between the Cubmarine and its contact vecturing ship, the MSO, is cited. The communication path was from the MSO CIC of the MSO to the MSO bridge via sound-powered phones, then via walkie-talkie radio to the tending motor whaleboat and finally via Aqua-Sonics to the Cubmarine.

COMMAND AND CONTROL

Related, but distinct from communications, is command and control. Here the command and control systems of the Polaris-FBM is markedly different from that of the weapon recovery or rescue system in that it is strategic whereas the others are purely tactical. Again, at Palomares, the very large number of surface ships which were required for the support of the operation and the limited communication facilities on each dictated that command and control be located on a ship capable of a wide variety of communication staff support and operational evaluation capabilities. The cruiser, ALBANY, was employed as the center for this operation. The uniqueness of the operation was such that no preplanned operations plan was in existence. The closest approximation to doctrine was drawn from minehunting doctrine and from experience with THRESHER. The Military and technical staff had to be assembled from a number of communities and was heavily comprised of officers of the Office of Naval Research; the Deep Submergence Group, Ballast Point, San Diego; the Mine Sweeping Squadron assigned to the operations; officers having

previous experience with bathyscaphes, sealabs or recovery operations; and civilian talent with similar range of experience.

While it is equally true that it is not possible to predict the actual situation that might obtain requires the use of the rescue system (indeed, the weapon recovery is one such situation) the basic command and control features will have been identified, command staff designated, and doctrines spelled out. The ASR-rescue submersibles group will comprise the team which is employed for the command and control group and the ASR or mother submarine will act as command center. It is anticipated here that the concentration of functions in a single mother craft will facilitate the performance of an otherwise difficult element of the operation.

SITE SUPPORT AND MAINTENANCE SYSTEM

Perhaps the most frequently overlooked and under-engineered aspect of system design is the site support and maintenance system. The subsystem common to all three examples is, for Polaris, so closely related to the overseas transport system that no clear interface exists between them and will be covered in the discussion of that element.

At Palomares, the heterogeneous collection of equipments which were employed necessitated the use of a small fleet of surface ships to meet total maintenance and support requirements. The small submersibles required a variety of support facilities. The Cubmarine was supported operationally by a minesweeper, and was hoisted in and out of the water by the cruise command ship. Its small size permitted an over-the-side lift and deck storage for battery recharge and maintenance. The Alvin vehicle, normally cradled in catamaran engineered for its specific configuration, was tended by the LSD, Fort Snelling. The use of the LSD permitted battery recharge and maintenance in sheltered water. The Aluminaut required two support ships: Privateer, which furnished control and ballast shot, battery recharge capability and surface support during her dives; and the LSD, Fort Snelling, for docking and out-of-the-water maintenance and repairs. The pier at the small port of Garrucha was also used by Aluminaut. A destroyer tender was utilized for on-the-scene machine repair. All of the small submersibles found the greatest engineering difficulty in the handling and support at the free surface by surface ships. The small submersibles are not designed for surface stability and relative motion between the submersible and the surface ship makes transfer of personnel and cargo precarious at best. Sea state limits operations and was a limiting factor at Palomares suspending operations for all or a part of thirteen days out of fifty-two on station. On at least one occasion the deep submersibles had to remain with crews aboard tethered to a buoy at the free surface in heavy seas.

The Deep Submergence Rescue Vehicle system looks to have two engineering resolutions to this problem. In the case where the rescue submersible is carried on a mother submarine, the mating and support is conducted in the submerged condition, thus avoiding the free surface situations. In this instance, the support and maintenance equipment are

limited to those furnished the mother submarine at the time of embarkation. It is, therefore necessary to design high reliability and redundancy in the rescue vehicle to compensate for the maintenance and support limitation. In the second mode of operation, the rescue submersible operates from an ASR. The newest design of this ship is a catamaran specifically configured for the surface retrieval operation. The present proposed technique for recovery employs a trapeze suspended between the twin hulls at a depth which effectively decouples it from the motions of the free surface craft. The submersible mates with the trapeze and is then taken under tow by the surface ship with the submersible steaming aft in a configuration sufficiently stable to permit take-up of the tow cable and bringing the submersible into a cradle between the catamaran hulls. The cradle is then raised to permit deck stowage of the submersible. The ASR is configured to support either conventional or saturated diving through use of deck decompression chambers and personnel transfer capsules. The rescue submersible will also be capable of lock-in and lock-out of saturated divers. It is possible in principle, therefore, for the new design ASR to support the full search operation from diver to submersible as employed in the Palomares operation. It is of significance to note that the personnel capsule and deck decompression chamber employed in this instance will be compatible with similar facilities on all Navy procurements of the future. This emcompasses man-in-the-sea, the entire salvage program and the rescue and search vehicles of the deep submergence project.

LOGISTICS

Finally, all three systems have deployed logistics problem--supplies, men and equipment which have degrees of time criticality. For this phase of the operation, the rescue system is most critical requiring as it does response which is short as compared with emergency life support systems on the distressed submarines. A careful design of vehicle transporter to permit rapid loading of the rescue vehicle and attachment to interfaces in specified aircraft, an analyses of raods and road capabilities to the mount-out port, the preconfiguration of a specific set of submarines to act as mother craft as well as the same arrangement for support equipment and command and control modules are absolute necessities of this system. Specific problems which arise are the avoidance of mass distributions in the rescue vehicle which match fundamental vibrational frequencies of the transporting aircraft, the design of transporter to meet road loads, bridge clearances and other transportation tolerances between airport and port, the port facilities abailable for assembly and launch of the rescue submersible and the assembly of mating cradles and installation of equipments aboard the mother submarine.

A similar problem of time criticality was faced in the Palomares case. National and International interest in the location and recovery of the missing weapon placed a burden of urgency and expeditious prosecution of the mission not otherwise required for its technical accomplishment. Swimmer equipments, light search equipments such as side-looking sonars, television cameras, navigation systems and miscellaneous underwater electronics gear could be and were expeditiously flown to either the Madrid area or the Naval Air Station, Rota, Spain, and were road-transported to the site of the operations. Even the manned

vehicle, Deep Jeep, was capable of rapid transit by this means. The major deep water search units; the submersibles, Alvin and Aluminaut; and the surface ship, MIZAR, were transportation-limited in reaching the site. The MIZAR proceeding on her own power required sixteen days to reach the site. The Aluminaut, at 80 tons, was not air transportable, but was loaded in operational configuration aboard the LSD, Plymouth Rock, and spent ten days in transiting from Florida. The Alvin was in weight and tonnage capable of air transport, but was not designed or engineered for immediate air transport. It was necessary therefore to partially disassemble the vehicle for air shipment, to reassemble and test at the point of debarkation. The result was that the shipborne Aluminaut arrived at Rota, Spain, at about the same date Alvin had completed post flight grooming and both vehicles proceeded to Palomares aboard Plymouth Rock arriving on 10 February. The MIZAR arrived nine days later. As a consequence, the commencement of serious operations in the area did not commence until almost a month after the initiation of the operation. This time delay was created not by inadequacy of men or equipment, but by the absence of a well engineered, high speed, port-to-port, transport system.

The matter of time-criticality bears further mention. It is obvious that the rescue evolution is indeed time-critical, based on the survivability of personnel trapped in the stricken submarine. And time is an equally important factor, from both a strategic and tactical standpoint, in the Polaris system. In the case of a salvage operation--be it bomb, aircraft, or ship--time is no less critical. Consider this from two aspects: that of economics and of security. If a bomb or aircraft, or for that matter a stricken submarine, is fitted with an acoustic pinger good for "X" number of days, the recovery system must have rapid response time so that the search phase is minimized--so that recovery can commence, or at least so that contact can be made before the pinger goes dead. This is clearly a matter of economics. In the Palomares operation, where no such markers were available, most of the time and expense were devoted to the search phase. Economics is also involved in being able to recover or solve before the situation degrades due to the environment--before the bomb slides into a deeper canyon or into the bottom ooze. As to security, particularly if the lost object is in contested waters, the operation could evolve into a race to see who can retrieve it first. This is the classical case in salvage with two competing salvors racing to a stricken ship. Imagine a similar situation, not encountered at Palomares, but in International waters where two opposing navies are racing to retrieve a bomb--with or without a pinger broadcasting its location.

The Polaris-FBM system has also a tight time constraint resulting from the limited in-port time between patrols and the necessity of determining the need for spare parts, locating them in the tender inventory or transshipping from the United States and installing and checking out prior to departure for patrol. In this regard, the problems and time constraints are not dissimilar from those encountered in Palomares. Their resolution on a continuous basis is, in part, the result of preplanning and prelocation of spares aboard the tender and, in part, due to a carefully engineered logistic system. The Polaris

supply ships are designed to match in terms of hatches, holds and cranes, the location aboard the tender of missiles, subsystem parts, supplies and ships parts. The tender in turn is designed to match the submarine in terms of delivery of missile systems and in terms of the location of workshops to accomplish routine or recurring maintenance and overhaul tasks. The process is further accelerated through the use of a general purpose computer aboard the tender which receives as initial inputs the replenishment and repair requirements of the homeward-bound submarine and which programs the location and shipment of spare parts and the work schedules of the various tender shops. As in most logistic systems involving high cost, low cube items, the inventory and stock level is most effectively and economically maintained if air shipment is employed. Thus, the rapid ordering and air shipment of electronic and mechanical spares is both efficient and economical and an effective air transport link has been established to utilize this type of flow. Thus, the combination of preplanned movement of large volume or low cost items; the air shipment of high cost, low volume items; the tailoring of logistics transport to meet physical interfaces at the transfer points; and the use of preplanned logic in high-speed computers permits rapid accomplishment of logistic transport denied to the Palomares system because of its ad hoc nature, and partially denied to the deep submergence rescue system because of uncertainty as to its port of embarkation.

In summary, the authors have employed these three examples to highlight three basic elements of sea-system engineering; The minimizing of environmental interfaces, the consolidation of functions to minimize the total number of vehicles and the attention required in total system design. Other examples could have been chosen which reinforced the first of these points, such as the off-shore drilling systems which have wrestled with fixed structures, jack-up rigs, and floating platforms. Certainly this problem will be ultimately resolved by systems almost totally removed from the free surface.

The second point, the need to minimize the number of vehicles, was evident at Palomares. In retrospect a Cruiser, a Destroyer Tender, and an LSD are an overwhelming complex for the operation of two relatively small submersibles.

Finally, the Polaris system has demonstrated the efficacy of total system design. Here the high initial cost has been amply demonstrated in its pay off in terms of the high percentage of the total force continuously deployed and the long cycle between overhauls. The Palomares operation is a made-to-order example to show the consequences in cost and time of not having a total system design. The matter of time-criticality as it relates to economics has already been mentioned. The very large number of Navy ships--some 27 in all--and personnel and sub-systems employed in this ad hoc operation clearly increased the cost by an order of magintude. The Spanish Bomb Operation or as it was labeled "Aircraft Salvage Operations--Mediterranean" clearly accentuates the efficacy of total system design for sub-sea-systems.

POWER UNDER THE SEA

J. C. Louzader and G. F. Turner

ABSTRACT

This paper presents a discussion of electrical power supplies to meet the needs of deep-ocean submersible systems. Cognizance is taken of existing and anticipated deep-submersible vehicles and bottom-mounted structures.

Use of batteries, radioisotope-dynamic power plants, and fuel cells are compared relative to cost factors, weight, and load requirements. The text includes supporting tables and figures.

INTRODUCTION

Accelerated activity by government and industry in developing submersible systems has been prompted by increased interest in exploration and exploitation of the deep ocean for military and commercial purposes and for the associated Man-in-The-Sea program. At Lockheed, this is reflected by a heavy commitment in oceanography, ocean mining, and construction of the deep-diving utility vehicle, Deep Quest. As a result of this activity, a new class of submersible systems is evolving which enable man to live under water for extensive periods and to perform useful tasks at both intermediate depths and in the deep ocean.

Power requirements for some of these systems can be readily satisfied with off-the-shelf hardware; however, other systems have unique requirements for which no satisfactory solution is readily available. Since the power system often represents a major limiting technology, Lockheed has undertaken studies of both advanced mission requirements and advanced power systems; continual in-house engineering effort is devoted to the evaluation and test of power systems for undersea application.

REQUIREMENTS: DEEP-OCEAN SUBMERSIBLES

Experiments which have been conducted as part of the Navy's Man-in-The-Sea program indicates that free divers soon may be able to operate at a depth of 1000 feet and, within a few years, possibly at 1500 feet. As this capability is developed and incorporated into underwater work systems, new equipment will be required to support the work force. Some of the equipment needed is listed in Table 1 together with the power required and the anticipated duration between resupply.

Table 1

MAN IN THE SEA SUPPORT

Equipment	Power Required	Duration Without Resupply
Habitat	60 kw peak 30 kw average plus 30 kw thermal power for cabin heating	30 – 45 days
Personnel Heaters	400 k cal/hr	8 hr
Two-Man Transporter	3 kw max. 1-1/2 kw avg	8 hr
Five-Man Transporter-Work Vehicle	8 kw	8 hr

The habitat will be a bottom-mounted structure. It will house the divers during their off-duty periods and act as the main supply center for the entire operation. Power requirements may increase as technology evolves, but the expected near-term need is for about 30kw average power with sustained peaks to 60kw. An additional 30kw of thermal power must be supplied or else the electrical load must be increased accordingly. Sea Lab II, for example, has a 75 kw installed capacity of which 25 kw were for heating the structure. Part of the remaining 50 kw was used for water heating and cooking. Power was supplied from shore through an underwater transmission line; the factors of dollar cost, power-plant weight, and energy storage were not a problem. These things, however, are a prime concern when self-supporting systems are considered, and particular attention must be given to using as much of the power-system waste heat as possible.

During off-peak power periods, the habitat power supply would recharge batteries used for vehicle power, tool power, suit heaters, etc.

Habitat occupation may eventually extend to 6 months or more, but the immediate need is for a power system which can operate for at least 30 days without resupply.

Heated diving suits are among the most critical needs of the Man-in-The-Sea program. If divers operate much deeper than their habitat, wet suit materials compress to the point where all insulation properties are lost. Currently being developed are both electrically-heated suits and ones which use a circulating hot fluid. Of course, the heat required to maintain a comfortable condition for the diver varies with his activity, but an installed capacity of about 400 k cal/hr for 8 hours duration with adjustments for suit temperature would be desirable. Shorter durations might be quite acceptable for the early designs.

Two types of vehicles are envisioned for diver support. The first, a two-man transporter would provide transportation for a two-man team and their tools. It would also provide power for lights, tool operation, and perhaps the suit heaters, for about 8 hours of total operation. Average power needed is about 1-1/2 kw. This vehicle would be small with no provision for dry passengers.

The second vehicle, a five-man transporter-work vehicle, would transport and support five men for 8 hours. Although not a high-powered craft, it would be large enough to provide a dry passenger compartment. Average power of 8 kw is required.

In addition to these two specialized vehicles, utility-type submersibles, such as Deep Quest, will perform a wide variety of tasks in support of diver operations.

Although eventually fairly large deep-diving submersible vehicles might be constructed, those presently in operation or under construction are small one- to six-man systems which are limited to about 8 hours maximum duration because of available power, life support, and crew endurance. Only the larger vehicles, such as Aluminaut and Deep Quest, can extend to 24 hours or more. Table 2 lists the vehicles designed for maximum operating depth of 1,000 feet or more which have been built or are under construction. It is obvious that most of these are small research vehicles designed primarily for observation. Only Aluminaut and Deep Quest can carry fairly large payloads.

Electric propulsion motors appear to be the only practical propulsion method for deep operation. All vehicles constructed to date have used batteries to supply power for the propulsion motors as well as for life support, navigation, lights, etc.

There are many employment areas of small deep-submersible vehicles for military, scientific, and commercial operation. Some of the more immediate ones are listed in Table 3 along with the projected power requirement and endurance-without-resupply data.

These vehicles fall into the same general weight class as such utility vehicles as Deep Quest, and they will be expected to perform a variety of tasks in addition to

their primary mission. Utilization rate for these vehicles is estimated to be initially not over 1,000 hours per year with possible growth to about 1,600 hours per year.

Table 2

DEEP-SUBMERSIBLE VEHICLES

Name	Operator	Crew	Payload (lb)	Maximum Operating Depth (ft)	Status
Aluminaut	Reynolds International, Inc.	3 + 3 observers	6,000	15,000	Undergoing sea trials
Alvin I	Woods Hole Oceanographic Institute	1 + 1 observer	–	6,000	Operational
Cubmarine PLC4	Ocean Systems, Inc.	2 + 2 divers	1,500	1,500	Under construction
Deep Jeep	NOTS, China Lake	1 + 1 observer	–	2,000	Operational
Deep Quest	Lockheed Missiles & Space Co.	2 + 2 observers	7,000	6,000	Under construction
Deep Star 2000	Westinghouse Electric Corporation	2 + 1 observer	100	2,000	Under construction
Deep Star 4000	Westinghouse Electric Corporation	2 + 1 observer	100	4,000	Undergoing test
Diving Saucer	Westinghouse Electric Corporation	1 + 1 observer	100	1,000	Operational
Moray	NOTS, China Lake	1 + 1 observer	150	6,000	Operational
Star II	General Dynamics Electric Boat	2	250	1,200	Under construction
Star III	General Dynamics Electric Boat	2	1,000	2,000	Under construction

Table 3

DEEP-SUBMERSIBLE VEHICLE MISSIONS

Mission	Power Requirement	Maximum Duration Between Resupply
Ocean Survey/Bottom Mapping	20 kw avg – 40 kw max.	12 hr
Salvage/Recovery	30 kw avg – 60 kw max.	8 hr
Rescue of Personnel	20 kw avg – 40 kw max.	2 hr*
Search	10 kw avg – 40 kw max.	12 hr
Bottom Base Support	20 kw avg – 40 kw max.	8 hr

*Very short resupply time (about 10 minutes) is required, otherwise the duration must be extended. A 30-hour duration would be very advantageous.

POWER SYSTEMS: FEATURES, COMPARISONS, COSTS

Lockheed has been primarily concerned with identifying the best power-system candidate for deep-submersible vehicles. The following factors are important in this evaluation:

- Weight
- Volume
- Operational handling
- Packaging and adaptability
- Maintainability
- Reliability
- Cost

Some desirable features of the power plant are:

Locating the Power Plant Outside the Pressure Hull. Designing pressure hulls at minimum size to obtain necessary strength recommends and, in some cases, demands locating the power plants, in addition to a maximum of other equipment, in the free flooding space outside the pressure hull. Not only the powerplant, but also the conditioning and the distribution equipments need to be so located. The cost of pressure hulls is basically high and increases rapidly with hull size. Location of equipment items within a pressure hull results in a significant increase in propulsion power requirements because of the added weight and size of the hull. Servicing becomes a major problem because it is impractical to provide sufficient ports in the pressure vessel for easy access to the power supply. Fueling the vehicle also becomes more difficult because the lines and connections terminating outside the pressure hull must withstand the high differential pressure between the pressure hull and ambient sea pressure. They must effectively seal against leakage at pressures of several thousand pounds per square inch.

The desirability of locating specific equipment items outside of a pressure hull is generally proportional to the size of the item. Since the powerplant will be sufficiently large, its location outside of a pressure hull will constitute a major advantage in overall vehicle cost effectiveness. This advantage becomes greater with increased power requirements and/or submerged mission duration.

Minimum Size and Buoyancy Requirements. Since the overall vehicle is inherently negatively buoyant, buoyancy material and buoyancy chambers must be installed to enable trimming the submarine to neutral buoyancy in the submerged condition by use of variable ballast tanks. Due to the high cost of buoyancy material for deep use and the limitations of space available for the installation of buoyancy material or chambers, it is essential that the weight of equipment and machinery, particularly the powerplant, be as small as possible.

Minimal Support and Refueling Times. In order to obtain the maximum operational convenience and utilization rate, as well as to minimize support costs, such as replenishment, refueling, and recharging, the low-maintenance-rate power system must be as simple as possible. This is particularly true for small submersibles to be carried by large submarines or towed to the area of operations. Rapid turnaround may be vital to the success of a rescue mission requiring multiple round trips to evacuate survivors from a bottomed submarine. In such a situation, long powerplant recharging delays could be tragic. In any case, they are costly in terms of delay and manhours required.

Meeting the Mission Load Profile and Total Energy Requirements. The powerplant of a small submarine must be able to supply power to a load which varies widely in its demand. High-propulsion motor-starting currents, wide speed range, and high demands under emergency conditions give a load profile ranging from about one-fourth rated load to several-times rated load. A tolerable voltage regulation must be maintained for this load profile. Equipment and instruments needing special voltage regulation would require an auxiliary voltage regulator.

Propulsion requirements of small submarines are modest for the most part. Systems of 5 to 50 shaft horsepower are considered adequate to provide for most small submarine requirements.

Safety and Reliability. The absolute essential of any system pertaining to deep submersible performance is reliability. The importance of mission accomplishment and the safety of the crew, coupled with the extreme hazards of the environment and the fact that size and weight limitations preclude much of the redundancy incorporated in most marine design, make design for reliability imperative.

Ease of Maintenance and Repair. Maintenance and repair of the power plant and other externally-installed equipment are impossible for the duration of an operation on many of the missions appropriate to small, deep submersibles. Maintenance in the submerged condition is limited to equipment inside the pressure hull.

After initial screening, the following power systems were selected for evaluation:

Batteries. Rechargeable lead-acid batteries are presently being used extensively for submersible service. This type of battery has been perfected to the point where highly reliable performance can be expected over several thousand rechargeable cycles. To adapt the lead-acid battery for deep submersible use, the system must be designed to equalize the external environmental pressure for operation outside the pressure hull. This can be accomplished by interposing an oil layer between the cells and sea water. Methods such as these are currently being perfected and improved.

Recently, high-energy rechargeable silver-zinc batteries have been adopted for undersea use; for example, silver-zinc alkaline batteries are used in the Aluminaut Vehicle inside the pressure hull. To locate these batteries outside the pressure hull, pressure-balancing provisions must be included in the system.

Other battery systems such as silver-cadmium, nickel-cadmium, etc., have characteristics which are compromises between lead-acid and silver-zinc. Battery characteristics assumed in this study are listed in Table 4.

Table 4

BATTERY CHARACTERISTICS

Characteristic	Battery Lead-Acid	Silver-Zinc
Weight	11.2 w-hr/lb	35 w-hr/lb
Volume	0.695 ft^3/kwh	0.26 ft/kwh
Life Cycle	500-2000 cycles	100-150 cycles
Voltage Control	2.07-1.75 v/cell	1.45 v/cell
Temperature Tolerance	0-158°F	0-90°F
Initial Procurement Cost	$65/kwh	$460/kwh
Redemption Value	7% of cost	15% of cost

One type of advanced power system under consideration is a radioisotope heat source coupled with a Brayton, Rankine, or Sterling cycle heat engine. Such systems have the advantage of no exhaust products, long times between refueling, and relatively low weight.

Availability limits isotope selection to Ce-144, Po-210, and perhaps Sr-90. It should be noted, however, that Ce-144 represents the only reasonable fuel cost for this application. Other isotope costs exceed Ce-144 by an order of magnitude or more. Therefore, based on cost, availability, and acceptable half-life, Ce-144 was selected as the most acceptable fuel.

Cerium-144 emits gamma radiation plus a high energy (2.1 Mev) beta which results in heavy shielding requirements. Powerplant shielding was sized so that the heat-source surface dose rate was 50-mr per hour or less for short-time handling and installation. Additional shielding was added so that the attenuation of shield and powerplant containment sphere resulted in 2.5-mr per hour at the outside surface of the containment sphere. Powerplant weights were based on the closed-cycle gas turbine system shown schematically in Fig. 1.

Both hydrogen-oxygen and hydrazine-hydrogen peroxide fuel cell systems are considered applicable for deep submersible use. These systems are shown schematically in Figs. 2 and 3. The hydrogen-oxygen system must be contained within a pressure chamber and, for evaluation purposes, was assumed to be supplied from cryogenic fuel storage. The hydrazine-hydrogen peroxide system, on the other hand, was assumed to operate at ambient sea pressure with reactants stored in soft tanks.

The following ground rules were used for all fuel-cell weight and volume calculations:

- Fuel-cell stack specific weights are based on average current density of 100 amps/ft^2.
- Reactant consumption rates are based on current state-of-the-art.
- Ten-percent excess loading has been allowed for all reactants.
- Fuel cells have been oversized to account for internal parisitic power for tank heaters, separators, pumps, and controls. Thus, the power outputs quoted represent net power available to the vehicle.
- A 5-percent structural allowance has been applied to the fuel-cell systems.
- In reactant storage systems, an amount of fuel and oxidant equal to the tank volume at design fuel cell operating pressure and ambient sea temperature (40°F) is assumed unavailable for conversion to power.
- Gas tankage has been designed with the following ground rules:
  - Design Stress – 65,000 psi.
  - Tank metal density (Ti alloy) – 276 lb/ft^3.
  - Outer cryogenic tanks are designed to depth pressure except when encapsulated.
  - Inner cryogenic H_2 tanks are designed to 350 psi or design fuel cell operating pressure, whichever is larger.
  - Inner cryogenic O_2 tanks are designed to 850 psia or design fuel cell operating pressure, whichever is larger.
- Weights include all fuel cells, structure, regulators, tanks, and controls necessary to automatic fuel-cell operation with DC output up to 110 volts. Weights do not include power-conditioning equipment or power distribution wiring and switches.
- Volumes include actual volume of the power system plus a 25-percent allowance for voids due to packaging in the case of encapsulated systems.

Figure 4 shows specific weight of candidate power systems for a 10-hour mission duration. The hydrazine-hydrogen peroxide and hydrogen-oxygen fuel-cell systems appear to offer the lowest weight and volume for most missions of interest. This weight and volume advantage becomes much more dramatic when the necessary flotation material for buoyancy compensation is added.

Of prime importance to the submersible-vehicle designer are the characteristics of the power system with regard to packaging, refueling, and maintenance. The battery systems have fair packaging characterizations, since the cell modules can be arranged to conform to a variety of compact shapes. The requirement for 8 to 10 hours recharge time places a serious limit on turnaround time for several missions of interest. Maintenance normally involves module replacement and can be accomplished with minimum difficulty.

In the case of the hydrogen-oxygen fuel-cell system, one or more spherical pressure shells are required to provide reasonable powerplant weights. Because of these pressure vessel constraints, H_2-O_2 fuel cells will not be as versatile as batteries

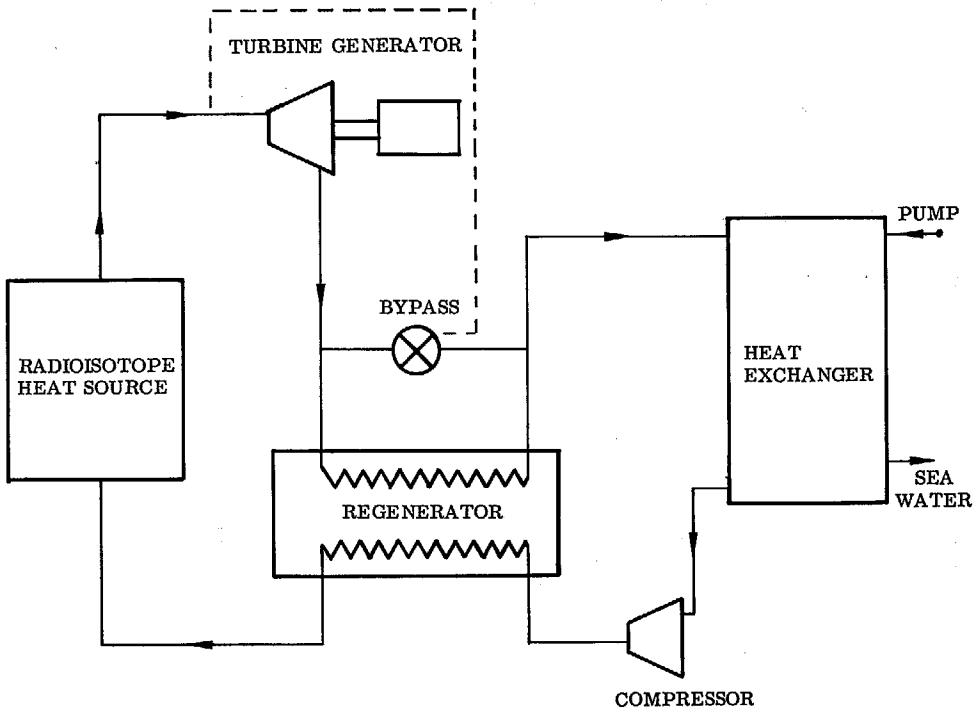

Fig. 1 Closed-Cycle Brayton System

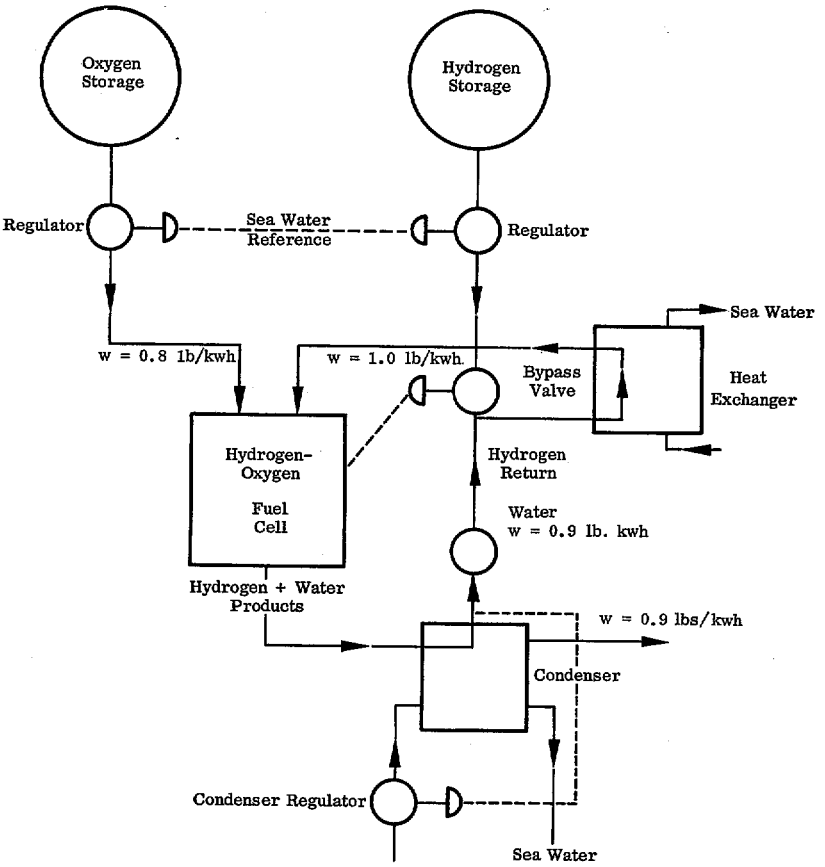

Fig. 2 Hydrogen-Oxygen Fuel Cell System Schematic

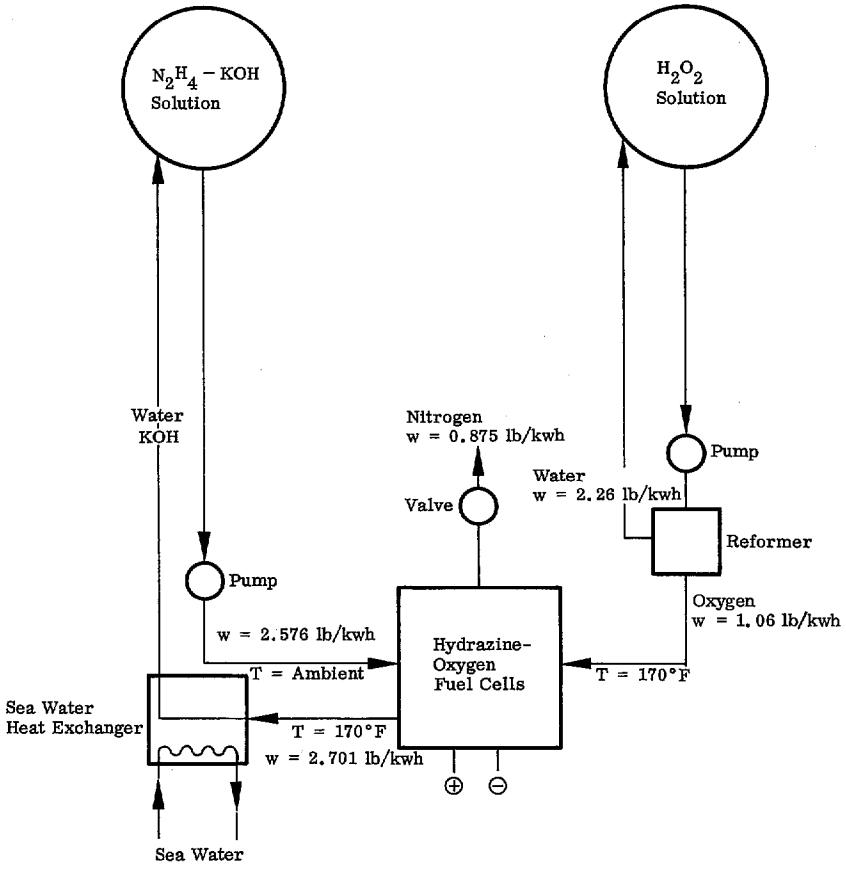

Fig. 3 Hydrazine-Peroxide Fuel Cell System Schematic

for packaging in a variety of vehicles. The cryogenic refueling sequence is anticipated to be at least a four-hour operation. This operation must be performed with double-walled, evacuated supply lines to keep "boiloff" within reasonable limits; the refueling operation, will be complex with respect to conventional refueling practice. Bringing the tanks supercritical after a fueling will take from 1 to 3 hours, depending upon heater sizes.

The hydrazine-hydrogen peroxide fuel-cell system was found to have excellent operational characteristics. The all-liquid fuel system allows operation at ambient sea pressure with minimum system complexity. "Soft" tankage can be employed for fuel and oxidant, allowing conformity to a variety of vehicle shapes. The refueling operation should require minimum turnaround time. Since the subsystems are not encapsulated, repair and maintenance are possible with minimum difficulty. One further advantage of this system is that the specific gravity of the fuel system is very close to unity. This allows the versatility of expanding and contracting fuel loadings for various missions with little perturbation in vehicle stability.

The radioisotope systems appear to have the least attractive operational characteristics for short-duration missions in deep submersibles. Since all components must be protected from sea pressure, a "hard" installation would be necessary. Since the pressure shell serves double duty as a shield, direct access to the heat source involves biological hazards and therefore requires special loading facilities. One further drawback is that the heat source must be cooled continually whether in service, in transit, or in storage.

The development costs for battery systems, even for special applications, can be expected to be low. Fuel-cell development should fall in the $1 to 6 million range. The development costs of isotope systems, are expected to be well in excess of $10 million because of the high fuel cost, the need for special test facilities, and general lack of experience in isotope heat sources greater than about 100 watts.

Fixed and operating costs for a 20 kw average, 40 kw peak vehicle system are compared in Table 5.

Although the radioisotope system has a distinct weight and volume advantage for the habitat applications, this is not a particular problem area because the central power plant is envisioned as a separate module and would certainly be lighter and smaller than the habitat itself. Consequently, consideration was given to using the same power system with larger fuel tanks for this application as well. The costs associated with this adaptation are also included in Table 5.

In view of the broad range of mission requirements and the high anticipated development cost of any advanced power system, development dollars should not be spent on an optimum system for a specific application, but on a system capable of doing a reasonable job for the majority of anticipated missions.

Based on weight, volume, packaging, and cost considerations, fuel cells offer the most reasonable advanced system choice for the missions anticipated.

Because of cost and availability, however, batteries will continue to play an important role.

Lockheed is continuing to evaluate both the hydrogen-oxygen and hydrazine fuel cell for missions of current interest and has initiated the following steps in its in-house engineering program:

- Continual evaluation of high energy density batteries and vendor-supplied fuel cell modules both for indoctrination of personnel and evaluation of candidate systems.

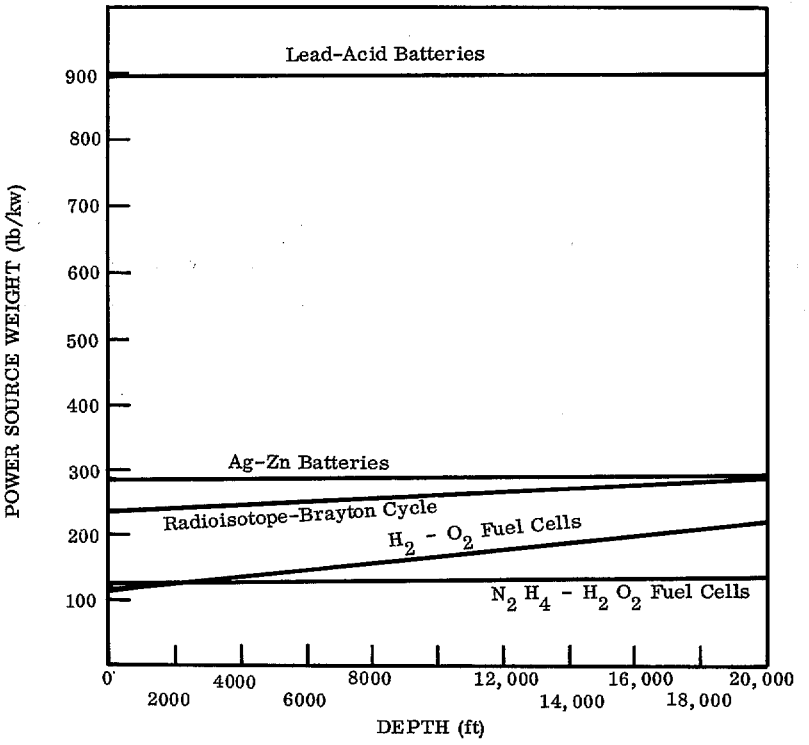

Fig. 4 Submersible Power System Weight Comparison (10-hr Mission)

- Continuing evaluation of power supplies with emphasis on broad, cost-effective applications to the spectrum of mission requirements.
- Incorporation in the Deep Quest payload area, provisions for test and evaluation of advanced power supplies.
- Provisions in the basic Deep Quest design for incorporation of a fuel-cell system to provide all or part of the primary power for extended duration missions up to 24 hours.

Table 5

POWER SYSTEM COSTS

40 kw Peak, 20 kw Avg.

Deep-Submergence Vehicle System

System	Fixed Cost	Annual Operating Cost 1000 hr/year	Annual Operating Cost 1600 hr/year
Hydrogen-Oxygen Fuel Cell (Cryogenic Storage)	$420,000	$122,000	$190,000
Hydrazine-Hydrogen Peroxide Fuel Cell	142,000	78,300	125,000
Radioisotope (Ce-144)	469,000	218,000	218,000

45 Day Habitat System

	Fixed Cost	45 Day Operating Cost
Hydrogen-Oxygen Fuel Cell	$1,200,000	$167,000
Hydrazine-Hydrogen Peroxide Fuel Cell	203,000	88,350
Radioisotope (Ce-144)	469,000	218,000

"THE DEVELOPMENT OF AN INTEGRATED LIFE SUPPORT SYSTEM FOR THE DEEP DIVING RESEARCH SUBMERSIBLE DS 4000"

by

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ABSTRACT

The development of a manned deep diving submersible necessitates the design and development of a life support system compatible with the requirements of the specific vehicle on which it will be used. The system which has been designed, fabricated and tested for the DS 4000 (Westinghouse's Manned submersible, for operation to depths of 4,000 feet) provides a habitable environment for three men for a maximum duration of 48 hours. Experience has indicated that normal mission time ranges from 4 to 12 hours. Thus a 300% reserve is available to provide for vehicle operation emergencies. Sufficient oxygen is carried, in the form of compressed gas, to maintain the cabin atmosphere at 21 $\pm$ 4% and enough chemical carbon dioxide absorbent is carried in cannisters, to prevent the CO_2 content of the atmosphere from exceeding 2%. Instrumentation is provided to monitor the partial pressure of oxygen and the carbon dioxide percentage in the atmosphere. There are also instruments which show the pressure, the temperature and the relative humidity of the cabin environment. The oxygen supply system is equipped with gauges showing the oxygen storage pressure and the flow rate to the cabin in liters per minute and cubic feet per hour. Circulation of air through the carbon dioxide removal cannisters is provided by a low speed cylinderical blower resulting in a very low noise level for the entire system. To provide emergency breathing for the occupants in the event of a failure of the oxygen supply or scrubbing equipment or if the cabin atmosphere becomes contaminated, three sets of completely independent closed-circuit oxygen breathing equipment are provided. During operational tests of the basic life support system all equipment functioned in a highly satisfactory manner.

INTRODUCTION

The life support system of the DS 4000 was designed to meet the requirements of the vehicle as established in the preliminary specifications and was modified to its present form as more precise information became available. The primary information source was data from experiments carried out by the DEEPSTAR group at the Westinghouse Underseas Division. The early specifications called for a life support system capable of supporting 3 men for 48 hours in reasonable comfort. To keep the costs of the complete system moderate and to keep the research necessary for the design of the system within reasonable bounds the decision was made to use gaseous oxygen stored at 2000 psi and to absorb carbon dioxide by chemical means. A search of the available literature was planned to determine the optimum chemical for our use. The various pieces of hardware required were to be intensively studied to insure high reliability and to keep weight to an absolute minimum. Redundant equipment to increase reliability would be limited to the oxygen flow control system.

To explain our insistance on light weight equipment, it is appropriate here to describe another of the many similarities which exist between vehicles for outer-space and vehicles for inner-space. In a ship for outer space every ounce possible is trimmed from all hardware so that the largest weight budget

can be allocated to the fuel for propulsion. Their primary problem is overcoming gravity. In deep diving vehicles we must also go to great lengths to keep all hardware as light as possible. This is done so that the maximum practical weight allocation can be assigned to the pressure capsule in which the crew and the sensitive equipment are carried. Our primary problem is overcoming hydrostatic pressure.

The term "reasonable comfort" previously mentioned, was used because the decision was made not to provide any means of cabin temperature control. This decision was based on the experience gained during many dives in the Cousteau-Westinghouse Diving Saucer. Although it was necessary to wear warm clothing to remain comfortable the high energy requirements of a temperature control system was deemed prohibitive. During the early phases of the program it was felt that a humidity control or abatement method would be highly desirable and several techniques to achieve this were investigated. However, all the humidity control systems which were investigated were found to be very heavy or to consume large amounts of power, or both. The conclusion was soon reached that since the Diving Saucer, The Archimedes, and the Trieste are getting along without air conditioning, the DEEPSTAR will do the same.

DEVELOPING THE BASIC DESIGN

Basic Requirements

Before progressing with the system design it was necessary to decide just what service the system would be called upon to provide. As a preliminary goal it would be desirable to have the condition in the pressure sphere as nearly normal as it could be made. This goal would then be tempered by practical considerations. The final system as worked out provides an effective control over atmospheric composition and pressure but no effort is made to control temperature or relative humidity.

Mission Duration

The starting point for specific design considerations was the anticipated mission time. From experience gained while operating the Diving Saucer and from educated guesses about the tasks the vehicle might be called upon to perform, it was expected that normal mission time would be 4 to 8 hours with exceptional missions requiring as much as 12 hours. An arbitrary decision was made to provide a 300% safety margin for all life support equipment. The 12 hour maximum mission time coupled with the 300% safety margin meant that the equipment would have to provide a habitable atmosphere for 3 men for 48 hours. In order to decide just what would be required to provide this 144 man hours of life support time, a search of pertinent literature and an examination of the performance of other vehicles was made. It was then possible to prepare a chart of the basic parameters. Such a list is shown at figure 1. It is prepared for a healthy male, sitting and doing light work. It was felt that this was about as close a description of the crew's activity as could be predicted. The chart shows that one man at this level of activity for one hour will require 0.85 cubic feet of oxygen and will produce 0.73 cubic feet of CO_2 in addition to 550 BTU of heat. The other numbers have been worked out to simplify the task of comparing information from different sources. Each authority consulted had a different way of presenting the same information. Also shown in figure 1 is a listing of the specific material required to provide 144 man hours of life support time. Figure 2 is a listing of the properties of the principal constituents of the vehicles' atmosphere. Here again the information is provided in several ways so that computations can be made without resorting to conversion factors.

LIFE SUPPORT BASIC PARAMETERS - ONE MAN					
Activity	Units used at 70°F, 1 ATM.	Oxygen Consumption O_2	Respiratory Volume Air	Production Rate CO_2	Production Rate H_2O Vapor
Sitting Doing Light Work 550 BTU/Hour	Std. Cu. ft/Hr.	0.85	20.0	0.73	105.
	lbs./Hr.	0.07	1.50	0.084	0.12
	Liters/Hr.	24.1	566.	20.6	2960
	Std. Cu. ft/Min.	0.014	0.33	0.012	1.75
	Liters/Min.	0.40	9.32	0.344	49.3
	Grams/Min.	6.42	11.32	6.23	0.91

VEHICLE REQUIREMENTS DS 4000					
3 MEN/48 HOURS		Required O_2	Sphere Volume	Total CO_2	Total H_2O
144 Man Hours 79,200 BTU	Std. Cu. Ft.	122.5	125	105	14,400
	Pounds	10.1	-	12.4	17.3
	Liters	3,450	-	2,960	42.5×10^4

FIGURE 1

PHYSICAL PROPERTIES OF GASES						
Conditions 70°F 760 mm hg		AIR	OXYGEN O_2	CARBON DIOXIDE CO_2	NITROGEN N_2	WATER VAPOR H_2O
Weight of 1 cu. ft.	Lbs.	.0749	.08281	.1145	.07247	.00115
	Grams	33.97	37.56	51.94	32.87	.5216
Volume of 1 Pound	cu. ft.	13.35	12.08	8.734	13.80	869.5
	Liters	378.1	342.1	247.3	390.8	24,620
Weight Ratio Same Volume	Air Unity	1	1.105	1.549	.9675	.0153
	O_2 Unity	.9045	1	1.383	.8751	.0139
Volume Ratio Same Weight	Air Unity	1	.9048	.6542	1.035	65.13
	O_2 Unity	1.105	1	.7231	1.142	71.98
Molecular Weight		28.9	32.00	44.01	28.01	18.00

FIGURE 2

SYSTEM PLAN

With the basic parameters determined it then became possible to consider the integration of the various components into a coherent system. The first and rather obvious step was to consider the use of the carbon dioxide scrubber as an air circulator. A second feature is the utilization of air from the oxygen mixer for defogging the viewports.

For the future it is planned to divert a portion of the scrubber air blast and use it for the mixer and defogger. This would reduce the system complexity by one item and the noise level by one blower. The final over all system plan is shown at Figure 3.

THE OXYGEN SUPPLY SYSTEM

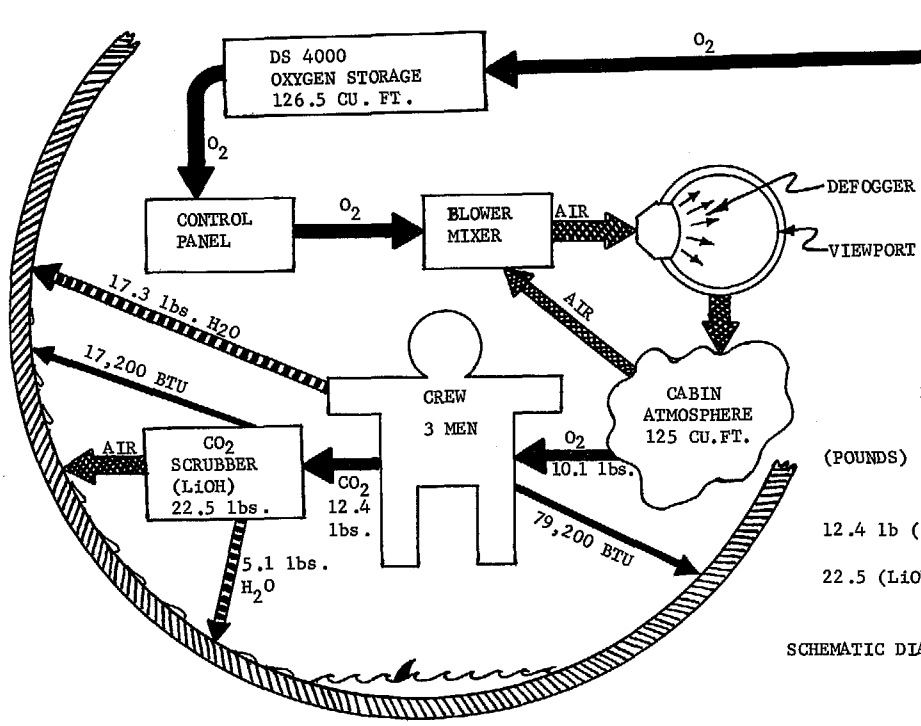
Storage Cylinders

Oxygen is stored in two steel cylinders with a combined internal volume of 1500 cubic inches giving them an oxygen storage capacity of 126.5 Standard cubic Feet, at 2,000 psi. A standard cubic foot is measured at one atmosphere and 70°F. These storage cylinders are made of chrome-moly steel with their inner surfaces left bare and their outer surface primed and given one coat of light green paint per (MIL-1-7178).

Although several materials are presently on the market for coating the inner surfaces of pressure cylinders, their primary use has been to protect the walls of SCUBA tanks, which are filled with air compressed from the local atmosphere. Since our system is filled with oxygen transferred from storage cylinders containing relatively dry gas, it was felt that any coatings on the inner cylinder walls would serve little practical purpose and would cause considerable apprehension, with regard to contamination of the oxygen supply.

The decision to use two cylinders for the storage of oxygen was because of the shape of the available space in the pressure hull. Very precious pounds could have been saved if we could have used a single larger cylinder or a sphere. Figure 4 gives the details of the two cylinders used and lists some of the other possibilities which were considered. In order to make any significant improvement in the weight of the entire system it would be necessary to use a stretch formed stainless steel sphere which has a high cost and a long delivery time or to operate the system at 3,000 psi which would have presented supply problems in world wide operations. We planned to fill the system by the cascade technique from a bank of four or five standard oxygen cylinders.

The use of liquid oxygen in a vacuum flask appears very attractive and will be given serious consideration for future use.



$$2LiOH + CO_2 \quad Li_2CO_3 + H_2O + \triangle$$

$$48 + 44 \quad 74 + 18$$

(POUNDS) $1.09 + 1.0 \quad 1.69 + .409$

1390 BTU

$$12.4 \text{ lb } (CO_2) \times 1.09 \frac{\text{lbs. LiOH}}{\text{lb } CO_2} = 13.5 \text{ Reqd.}$$

22.5 (LiOH) x .6(efficiency) = 13.5 Effective

SCHEMATIC DIAGRAM - LIFE SUPPORT SYSTEM - DS 4000

FIGURE 3

CYLINDERS USED ON DS 4000		
CYLINDER NO.	1	2
Internal Volume Cu. in.	1,000	500
Oxygen Capacity at 2000 psi and 70°F SCF	84.3	42.2
Diameter Inches	7.25	6.75
Length Inches	29.7	18.6
Weight Pounds	21.7	18.7
Neck Opening NPT	1"	1"
Operating Pressure psi	2,000	2,000
Test Pressure	3,000	3,000

COMPARISON OF OXYGEN STORAGE METHODS				
Storage Method	Size of Container inches	Capacity SCF O_2	System Weight Pounds	Figure of Merit O_2 lbs/LB
2 cylinders at 2,000 psi	As Above	126.5	40.4	3.14
1 cylinder at 2,000 psi	9.0 D. x 29.6 1500 cu in	126.5	32.5	3.89
2 cylinders at 3,000 psi	6.8 D. x 18.8 500 cu in ea.	126.5	34.0	3.72
1 Sphere at 3,000 psi	14.3 O.D. 1300 cu. in.	164.2	33	4.97
Stretch Formed Sphere at 2000 psi	14.5 O.D. 1530 cu. in.	129.0	20	6.45
Liquid O_2 in DEWAR	10.8 O.D. Sphere	160.0	8	20.0

FIGURE 4 OXYGEN STORAGE

OXYGEN SUPPLY SYSTEM

At the recommendation of the U.S. Bureau of Ships the remainder of the high pressure portion of the oxygen supply system was made almost entirely of nickel-copper alloy. Of the nickel-copper alloys there is only one which was found to be readily available in the form of tubes, fittings, valves and general hardware. This was "Monel 400". The reason for this preference of nickel-copper over stainless steel, which was the only other material seriously considered was that it has been found that if a fire gets started in a high pressure oxygen system made of stainless steel, the metal will be burned in a self propagating blaze about as readily as steel bar stock is burned by an oxyacetelene torch. Experience with Monel indicates it will not burn. For low pressure systems copper-nickel and copper are recommended depending on the pressure.

Referring to Figure 5, a schematic diagram of the entire supply system, it will be noted that valves are not screwed directly into the necks of the storage cylinders which is the usual procedure. In our arrangement we have a short length of tubing vetween the cylinder and its shut off valve. This makes it possible, for inspection or maintenance, to remove either the cylinder from the plumbing or the plumbing from the cylinder without exposing the remainder of the system to possible contamination. These cylinder valves are normally kept in the open position at all times. For this reason valves were selected which have stem packing designed to seal high pressures without binding or leaking.

Oxygen Control Panel

Downstream from the cylinder valves is the storage pressure indicating gauge. It is a 3,000 psi, all monel bourdon type gauge and it is mounted directly on the oxygen control panel (see Figure 6). This gauge shows the storage pressure at all times since the operating system is shut off only at the shut off valves. The oxygen flow path during normal operation is through the main oxygen supply system. This goes first through the main shut off valve which has a Kel-F button tip to insure a gas tight seal in the closed position. The flow then is thru a pressure regulator which

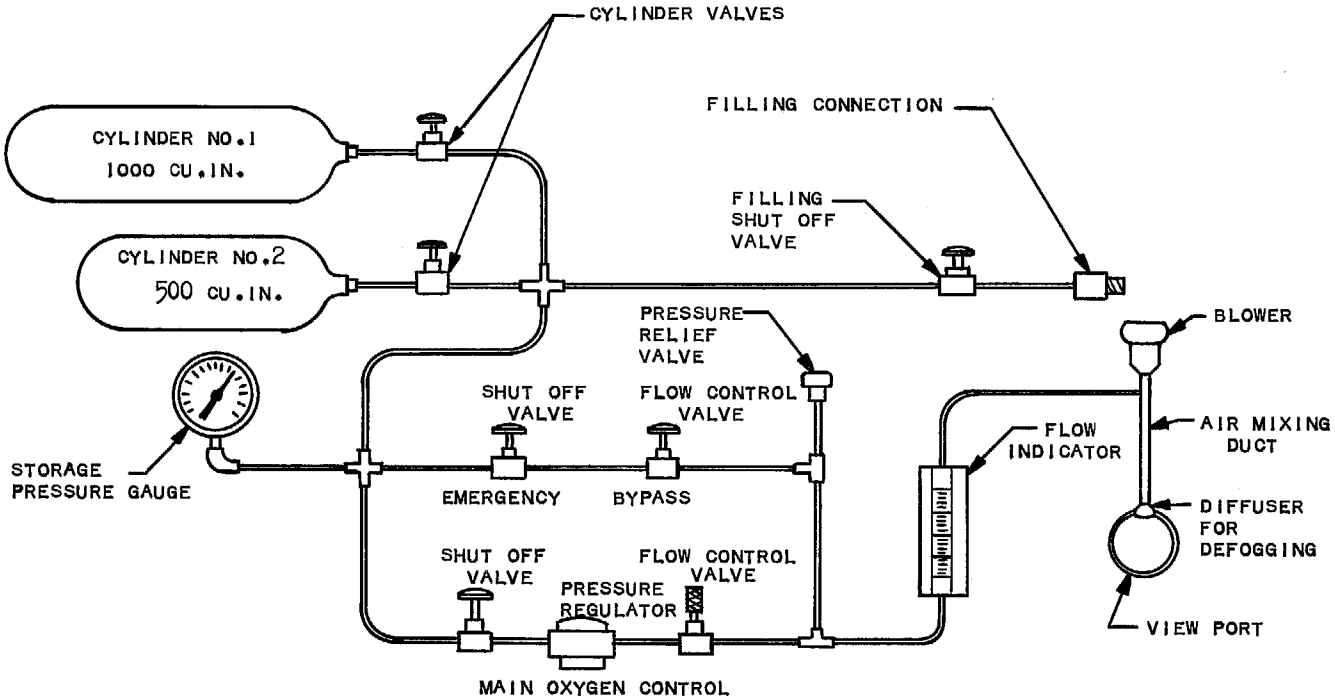
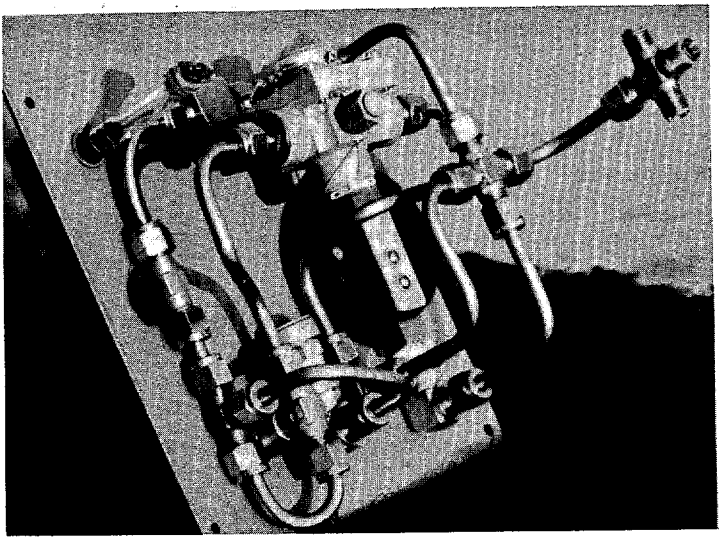


FIGURE 5 OXYGEN SUPPLY SYSTEM DS 4000



REAR VIEW

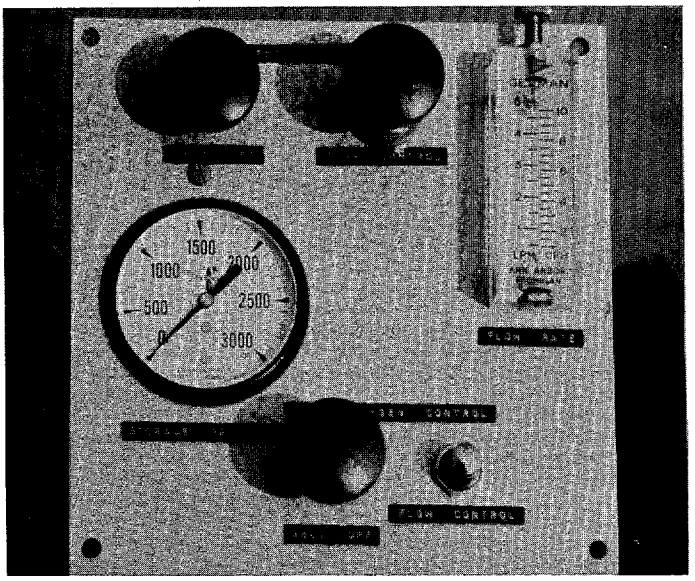


FIGURE 6 OXYGEN CONTROL PANEL

FRONT VIEW

maintains a downstream pressure of 80 ± 10 psi as long as the storage pressure is above that value. When the storage pressure drops below 80 psi it delivers the remainder of the gas at approximately storage pressure. Except for the storage cylinders this pressure regulator is the only part of the high pressure oxygen supply system not made of monel. It has an aluminum body and the internal parts are made of stainless steel KEL-F and Silicone rubber. This same model regulator has been used in the life support system on several of the space programs. It is of course very reliable and weighs only ounces. From the regulator the flow is then through a micrometer needle valve which makes it possible to smoothly adjust the oxygen flow. The use of a pressure regulator ahead of the needle valve makes it possible to set the needle valve for a desired flow rate and have the rate remain constant even though the storage pressure varies as the oxygen is used. From the flow control valve the oxygen goes through a flow indicator with a scale graduated to read 0 to 5 liters per minute and 0 to 10 cubic feet per hour. This indicator is the simple ball in a tapered tube type. The body of the unit is a rectangular block of clear plastic with the tapered hole bored through the plastic. This indicator has given good service so far and its accuracy is at least equal to our needs. The fact that the indicated flow will vary with attitude of the vehicle is of no concern since a specific flow rate is set only at the beginning of a dive. As the dive progresses the flow rate is adjusted to meet the requirements of the vehicles occupants and the flow scale is only used to show relative changes. The flow indicator also serves to show in a very direct manner that the oxygen supply is functioning properly. It is a reassuring sight to see the little ball riding on its column of oxygen as the vehicle descends into the ocean.

AUTOMATIC OXYGEN SUPPLY

When the life support system was first planned the intent was to make the oxygen supply automatic. The concept was that if a sensitive demand regulator was set to deliver oxygen whenever the cabin pressure went below 14.7 psi, the crew would be relieved of this necessary chore. This system was supposed to work in the following manner. The occupants would breathe the air and consume the oxygen. They would then exhale an amount of carbon dioxide approximately equal to the oxygen consumed. This carbon dioxide would then be removed by the scrubbing system and the cabin pressure would drop. As the pressure dropped the demand regulator would keep supplying make-up oxygen. A demand system of this type however does not work this way in actual practice. Unfortunately the system is coupled more closely to the internal temperature of the cabin than to the needs of the occupants. In the first place the CO_2 scrubber hardly works at all until the CO_2 level reaches 0.5% and during a dive the equilibrium level is about 1.0% this increases the cabin pressure. If the cabin temperature should now go up 10°F, the automatic system will not deliver any oxygen until the cabin oxygen level drops to about 17%, a very undesirable condition. The heat to cause that 10°F temperature rise is readily available from the body heat of the occupants, the heat given off by the electrical equipment in the cabin and from the heat released by the chemical action of the carbon dioxide absorbtion material. In the DS 4000, the steady flow system previously described is being used, and it is completely satisfactory.

THE EMERGENCY BYPASS

As previously mentioned there is a redundant circuit in the oxygen supply system. This is referred to as the Emergency Bypass. It is used in the event of a malfunction in the main oxygen supply system. This bypass consists of a shut-off valve and a flow control needle valve, and it delivers oxygen in the same manner as the main supply circuit to the flow indicator. The bypass has no pressure regulator. Therefore, in order to maintain a desired oxygen flow it is necessary to adjust the flow control needle valve as the storage pressure drops. To protect the low pressure circuit against accidental overpressure, a relief valve set at 100 psi is connected to both the main oxygen circuit and the emergency bypass.

OXYGEN DISTRIBUTION METHOD

As the oxygen leaves the flow rate indicator it is delivered to a duct on the downstream side of a small blower. In this duct the oxygen is thoroughly mixed with cabin air and the mixture is then released through openings at the base of the viewports where it serves to defrost the inner surface and subsequently becomes part of the cabin atmosphere.

FILLING THE STORAGE CYLINDERS

To refill the storage cylinders with oxygen a special Oxygen Fill Control panel has been provided. (See Figure 7) It consists of a shut-off valve and a standard CGA-540 screw type oxygen connection. The panel is located inside the sphere high on the port side where it can be readily reached through the hatch from the outside. There is a single line connecting the Fill Control to the vehicle's oxygen storage cylinders which are carried low on the port side.

A twenty-foot length of high pressure flexible hose is used to connect the mother ships' oxygen bank to the oxygen fill connection in the DS 4000. The hose has a working pressure of 5000 psi and an inner lining of Buna-N. At the storage bank end the hose is provided with a pressure gauge and a bleed valve. The process of filling the oxygen storage cylinders on the submersible is carried out in the following sequence. The hose which is connected to the mother ship's storage bank is first connected loosely to the submersible's fill port. It is then purged of air by gently opening the valve of the storage bank and permitting a small quantity of oxygen to flow through the hose. The bank valve is then closed and the hose connection in the submersible is made up tight. Next, the pressure in the hose is brought up to the pressure shown on the gauge in the diving vehicle. Finally, the shut-off valve of the oxygen fill control is opened and the storage cylinders on the submersible are then filled. The valves at each end of the filling hose are then closed and the pressure in the hose is released through the bleeder valve. The filling hose is then disconnected from the submersible and the filling operation is complete. This filling sequence, which is performed without anyone entering the pressure sphere, may seem a bit elaborate, but each of the steps has a function in minimizing the hazards associated with handling high pressure oxygen.

THE CARBON DIOXIDE REMOVAL SYSTEM

Blower and Housing

The carbon dioxide removal system consists of three principal components; the cannister and chemicals, the blower assembly and the scrubber housing. The blower is a nylon drum type impeller (see Figure 8) driven by a 1/50 H.P. plain bearing motor. The motor operates directly from the 120 volt main power supply so that it will continue working if the 28 volt internal power supply is shut down. The power consumption is about 47 watts with 1.1 amperes required for starting and .4 amperes for running.

The blower assembly is mounted inside the scrubber housing. (see Figure 9). The motor and blower have been inverted from the usual layout. In our arrangement the motor has been place inside the blower wheel and directly in the path of the air flow. While this probably improves the cooling of the motor it was done to conserve space. A series of tests have shown that there is no significant difference in the air flow through the system whether the motor is inside or outside the housing.

The scrubber housing is made of fiberglass, fire retarded with antimony trioxide. It's average wall thickness is 1/10 inch providing ample strength for the task. The scrubber assembly is mounted in the DS 4000 so that the chemical cannister lies horizontally and the air blast is directed aft against the inner surface of the sphere. This arrangement provides a gentle

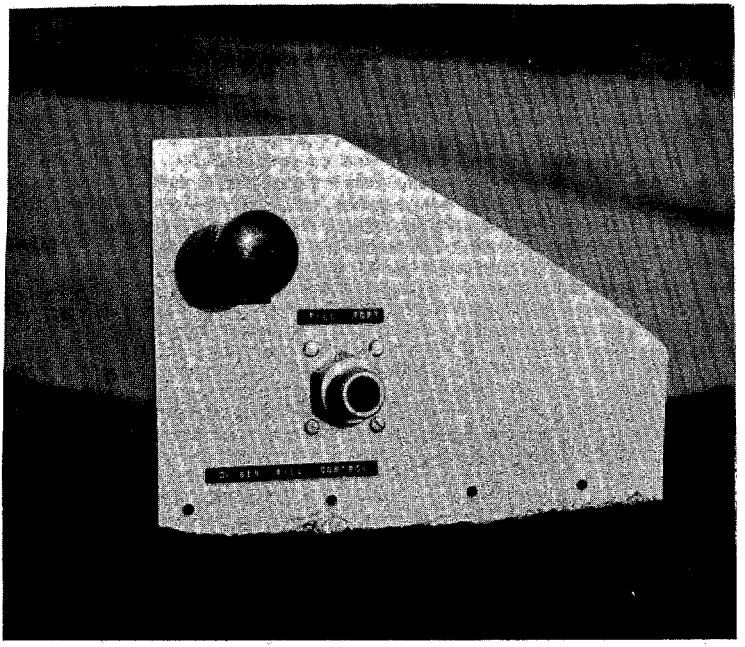


FIGURE 7 OXYGEN FILL CONTROL PANEL

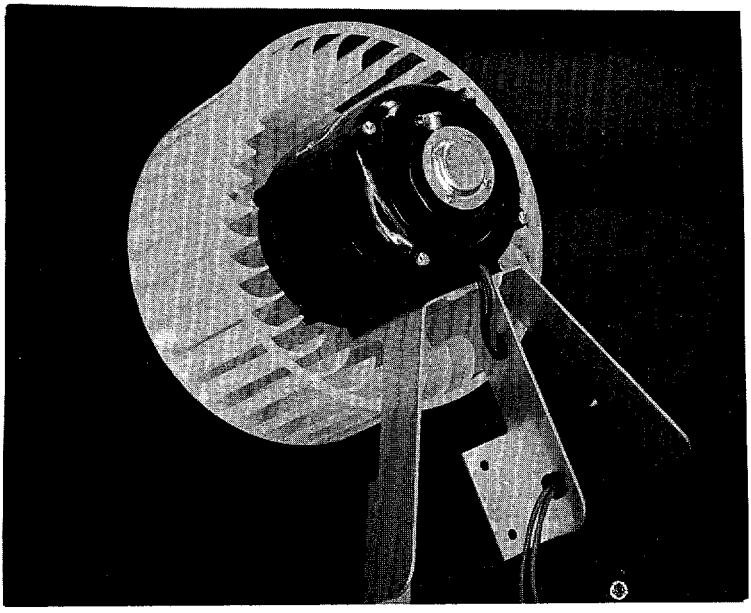


FIGURE 8 MOTOR AND BLOWER

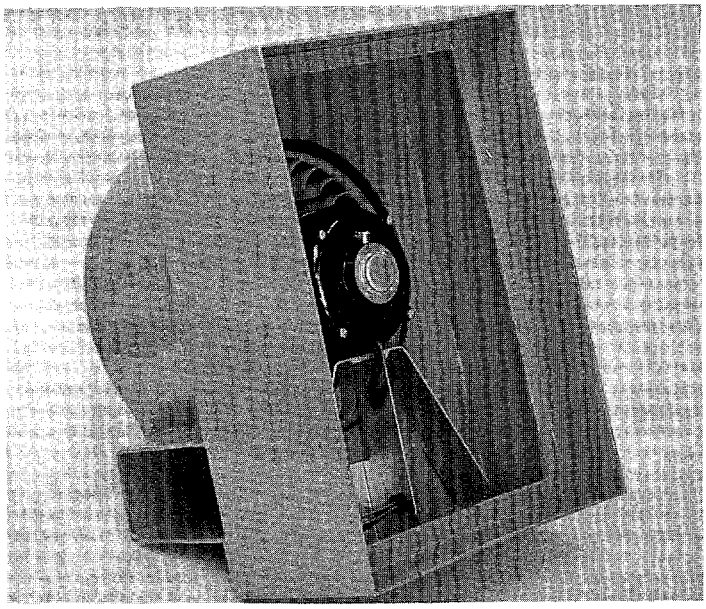


FIGURE 9 CO_2 SCRUBBER ASSEMBLY

circulation of the cabin air without any discomforting drafts. The operating noise level of this scrubber assembly is 64 decibels (ASA standard reference of 0.0002 microbar at 1,000 cps) on the B scale of a General Radio Type 1551-C Sound-Level Meter, when measured at a distance of 2 feet. This is about the noise level of a busy office. This noise level measurement has been described in some detail because a high noise level from a scrubber-blower which operates continuously can become very annoying during a dive which lasts 6 hours or more. The weight of the complete scrubber assembly is 7 1/2 lbs.

The Chemical Canister

Since it was desirable to keep the carbon dioxide removal method simple, "Baralyme" and lithium hydroxide were the only materials given serious consideration Although "Baralyme" is used quite successfully on the "Diving Saucer" the decision to use lithium hydroxide on the DS 4000 was made when it was found that for a 48 hour life support capability 22 lbs. of lithium hydroxide would do the work of 48 lbs. of "Baralyme". The cannisters which the Navy uses are 6 5/8" in diameter and 10 1/2" long, and they contain 6.3 lbs. of LiOH.

For a 48 hour capacity it would be necessary to carry 4 of these cannisters and because of their cylindrical shape they would be quite a problem to stow in the sphere. Another consideration is the fact that a 6.3 lb. charge of LiOH will last about 15 hours for three men. This means that at the end of a 6-hour mission we would either throw away a cannister which was only 1/3 used or start the next mission with a charge that was only 2/3 useful. At a price of nearly $6.00 per pound, this is worth considering.

Our decision was to make small cannisters which would stow compactly. Preliminary estimates indicated that 25 ounces of LiOH would be sufficient for three men for 4 hours. In addition, it was considered necessary to include some activated charcoal to absorb odors. If we think of three men in a 6-foot sphere for 6-hours, the charcoal certainly seems like a good idea. Most other systems in use today put the charcoal in a separate container, but when we consulted our chemists and the supplier of the LiOH they could think of no detrimental effect which would result from mixing the charcoal directly with the LiOH. Since the amount of charcoal is not critical, it was decided to use 5 ounces and mix it directly with the 25 ounces of LiOH. The final design of the cannister which we are using looks very much like a box for a dozen eggs (see Figure 10). The container is a rectangle slightly more than 1 1/2" thick. A stainless steel screen is secured in the top and bottom. To complete the similarity to an egg box, there is a lattice which is used to prevent the contents from shifting and leaving free air channels through the container. This lattice divides the cannister into 12 small pockets. When the cannister is filled, a piece of 1/2" fiberglass filter mat is placed against the screening to prevent the very irritating LiOH dust from getting into the atmosphere. In use, the cannister is held in the top opening of the scrubber assembly with an elastic band.

The cannisters are filled in advance and sealed in individual, dated vapor-tight bags. The chemical charges for the cannister come from the supplier in individual sealed bags. Each bag contains one charge to eliminate the need for weighing when the cannisters are filled. For each dive 12 cannisters are carried, one is in place on the scrubber and the 11 remaining units, being flat rectangles, stow easily and compactly.

The necessity for the charcoal in the cannisters was an open question and remembering that the Diving Saucer used no charcoal in its system, it was decided to run some tests. Accordingly, several cannisters were made up containing no charcoal. These units were then used in tests and on dives, and surprisingly no objectionable odors were detected Either we don't smell as badly

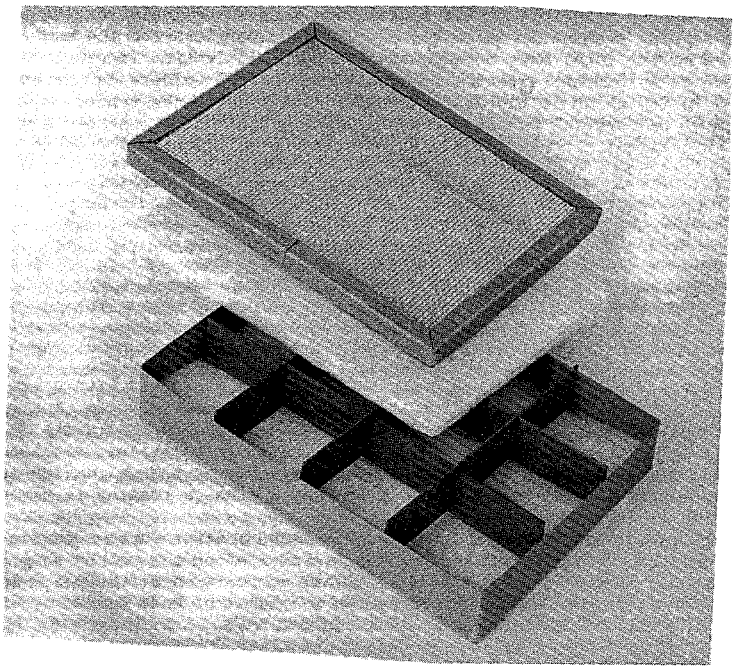


FIGURE 10 LiOH CANNISTER

as we think we do, or when we are in confined spaces our noses mercifully can no longer tell the difference. In any event, we are now filling our cannisters with just lithium hydroxide. It will be interesting in the future to learn if any of our passengers can notice the lack of charcoal.

INSTRUMENTATION

To properly and safely operate the life support system a reliable set of instruments are essential. On board the DS 4000, to monitor the cabin atmosphere are the following instruments:

The Oxygen Indicator

To indicate the concentration of Oxygen in the cabin atmosphere a Westinghouse-Krasberg Oxygen Partial Pressure Monitor is provided (see Figure 11). It operates on the principle of a fuel cell and when molecules of oxygen impinge on the sensing element it generates a voltage proportional to the partial pressure of the local oxygen concentration. The indication is continuous and is shown on an electrical meter reading from 0 to 50%. There is a green band from 17 to 25% which is the desired operating range for the vehicle. The instrument calibration can be checked at 21% in a normal atmosphere and at 0% by an internal circuit. The unit operates normally on 28 VDC ships power and requires about 0.1 amperes In case of a power failure, the unit will operate on internal batteries when a button on the front panel is depressed. The internal batteries are kept charged by ship's power when they are not being used The instrument is a single package 7 x 5 1/4 x 2 1/2 inches, weighing 3.3 lbs. Its accuracy is on the order of its readability which is about $\pm$0.2%.

The Carbon Dioxide Indicator

A chemical absorbtion type CO_2 indicator is used to test the cabin atmosphere. It is a 3-chamber unit modified slightly from a Dwyer model 800-5 instrument, (see Figure 12). It reads from 0 to 5% CO_2 and the scale has been green lined at 0.5 to 1.5% which is the concentration range considered normal and acceptable for the DS 4000. This instrument is easy to use and quite reliable, the reading however, is not continuous. A series of operations, requiring about one minute to complete, must be gone through each time a reading is desired. Approximately every half hour during a dive, a reading is taken.

To check the calibration of the Oxygen Indicator, and the Carbon Dioxide Indicator, three mixtures of test gasses are carried on the mother ship in push-button cans (see Figure 13). The nominal composition of the gases is listed below. The exact composition is marked on the label of each can.

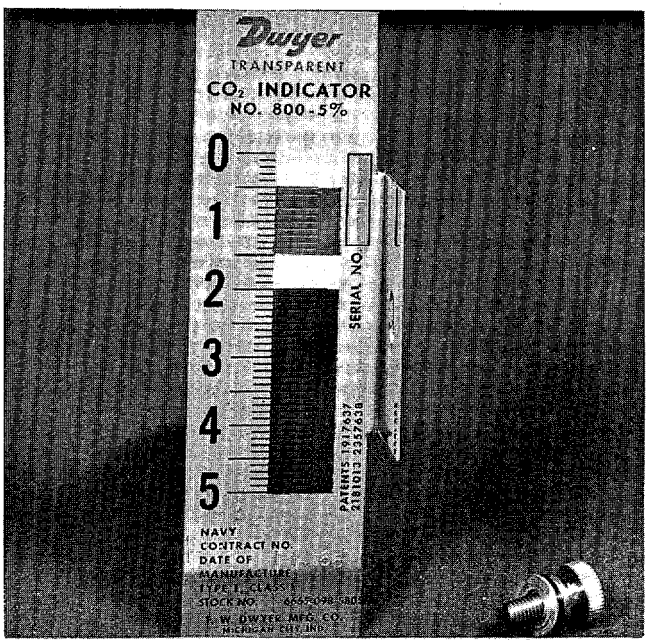
Nominal Mixtures of Test Gases %				
Mixture	Oxygen	CO_2	Argon	Nitrogen
1	17.0	3.0	.9	Remainder
2	20.0	1.0	.9	Remainder
3	25.0	2.0	.9	Remainder

To check the Oxygen Indicator a funnel, as shown in the photograph is used to concentrate the test gas around the sensor. To check the CO_2 indicator a small quantity of gas is placed in a plastic bag and the content of the bag is then checked by normal procedure.

Backup CO_2 Indicator

If the readings of the Dwyer CO_2 Indicator are questioned for any reason a backup in the form of a Kitagawa Gas Analyzer is carried. This device, which

FIGURE 11 WESTINGHOUSE-KRASBERG OXYGEN MONITOR



MODIFIED SCALE FOR CO_2 INDICATOR

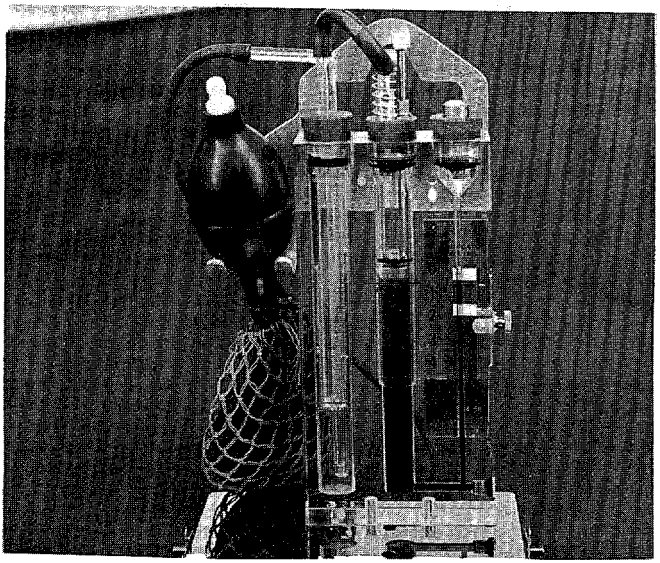


FIGURE 12 MODIFIED DWYER CO_2 INDICATOR

FIGURE 13 PUSH-BUTTON CAN OF TEST GAS

looks like a precision bicycle pump operates by drawing a 100 cc sample of gas slowly through a small glass tube which contains a carefully arranged chemical preparation. This preparation changes color starting from one end when CO_2 is drawn through it. The length of the discoloration becomes an accurate indication of the CO_2 concentration. This device is easy to use and the crew have considerable confidence in its accuracy and reliability. It is not used as the main instrument because a fresh indicator tube is required for each reading.

The Cabin Pressure Indicator

The atmospheric pressure in the cabin being an important piece of information for the crew, an effort was made to locate a suitable commercial instrument. A regular barometer has sufficient sensitivity but its range is limited approximately to 14.7 ± 1.0 psi and we need at least ± 5.0 psi. As an experiment we tried using an aircraft altimeter and it worked very well but it was slightly confusing to measure the cabin pressure, for example, as down 780 feet. The altimeter however, worked well, clearly showing changes in the cabin pressure as small as 0.01 psi. We therefore, decided to modify one for our use. Accordingly a Sensitive Altimeter was obtained and its internal linkage was modified so that one turn of the sensitive pointer was equivalent to 1.0 psi, the pressure capsules were shifted so that 15.0 psi was in the center of the range and it was given a new face. We now have a Cabin Pressure Indicator with a range of 15.0 ± 7.0 psi which is very sensitive and easy to read. A photograph of the final instrument is shown at Figure 14.

Knowledge of the cabin pressure is important because the oxygen flow rate is usually adjusted by noting changes in the cabin pressure. A variation of 1.0% in the oxygen or carbon dioxide content of the atmosphere shows up as a 0.15 psi change in pressure. It is, of course, necessary to take into consideration the effect of cabin temperature when adjusting the oxygen flow rate.

The Temperature Humidity Indicator

An easy to read temperature indicator was required for use in conjunction with the pressure indicator. For this purpose an instrument was obtained with the form of an electrical meter and a scale length of 3 1/2". As an extra the instrument could be obtained with a relative humidity indicator in the same housing. Although we make no effort to control the relative humidity, its level is of interest to the crew. This instrument is shown in Figure 15.

The temperature sensing element is a bi-metallic spiral and the humidity sensor is a conical diaphragm of hygroscopic animal membrane. A series of tests of the instrument showed its accuracy to be about $\pm$ 1°F for the temperature indication and about $\pm 5\%$ on the relative humidity scale, between the limits of 20 and 85%.

The Oxygen-Carbon Dioxide Range Chart.

To assist the pilot in understanding the significanee of changes in temperature and pressure and to relate them to the oxygen and carbon dioxide concentration in the cabin atmosphere a chart was prepared. It is shown at Figure 16 Use of the chart makes it possible to determine the conеentration of either oxygen or carbon dioxide if the level of the other one is known. To simplify the use of the chart the cabin pressure indicator is arbitrarily set to 15.0 psi at the beginning of each dive. The crew member monitoring the atmosphere, must then arrange the oxygen flow rate so that when the dive is over the internal pressure indication is returned to something close to 15.0 psi. This is necessary because if the cabin pressure is as much as 0.5 psi above the outside air pressure the vehicles occupants will be subjected to a very discomforting explosive decompression when the hatch is opened.

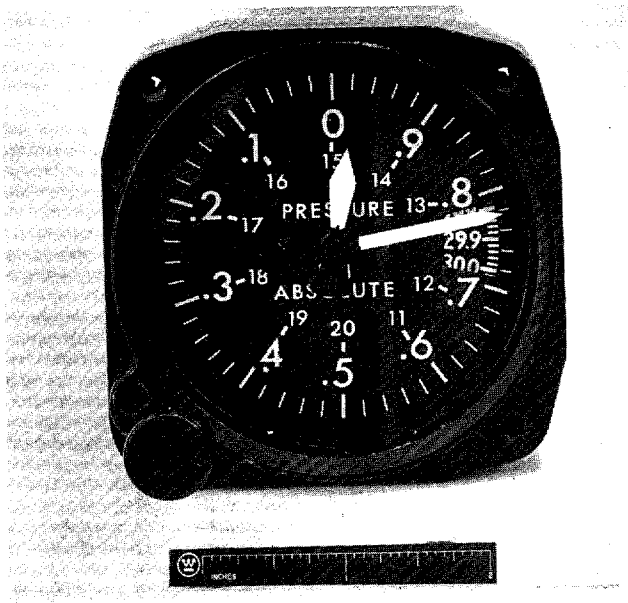


FIGURE 14 CABIN PRESSURE INDICATOR

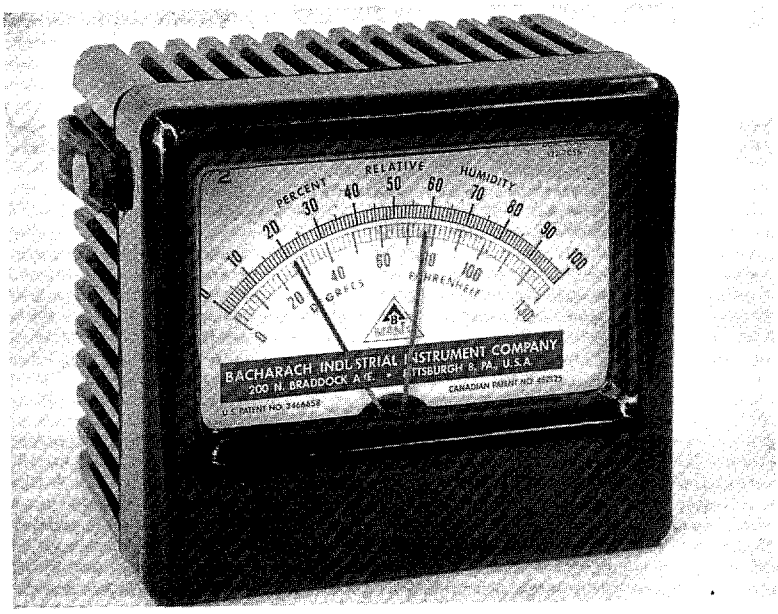


FIGURE 15 TEMPERATURE-HUMIDITY INDICATOR

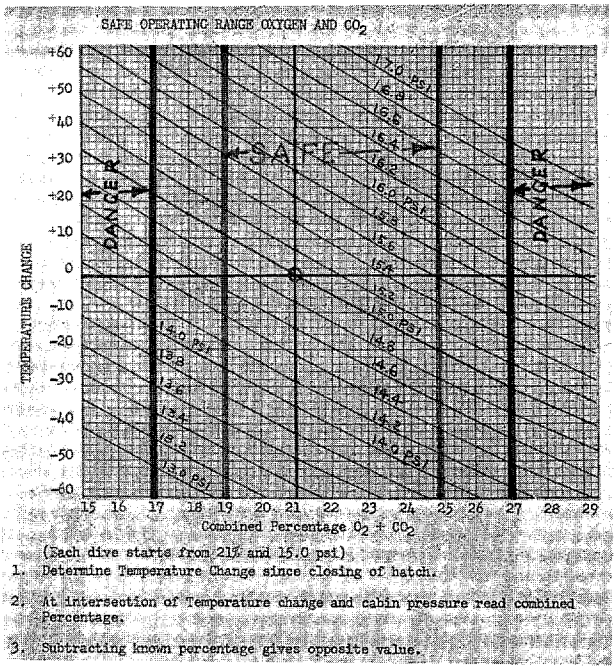


FIGURE 16 OXYGEN-CO_2 RANGE CHART

EMERGENCY BREATHING EQUIPMENT

In the event that the cabin atmosphere becomes contaminated by hazardous vapors or smoke, three sets of closed circuit oxygen breathing equipment are provided for the vehicles' occupants. The primary concern is the possibility of an electrical short and the development of noxious fumes from burning insulation.

The original concept was to provide open circuit SCUBA equipment for this purpose but a careful analysis of the problem indicated that this would be an undesirable method. Since the vehicle can descend to 4000 feet it is essential that enough breathing time be provided to return to the surface from that depth with a little extra for time at the surface. To do this it was estimated that about one hour of breathing time would be adequate. To provide this time using SCUBA equipment would require 3 cylinders with about 35 cubic feet of air in each. When using this equipment the occupants would utilize only about 5% of the gas in the cylinders, the remainder would be released into the cabin. This addition of nearly 100 cubic feet of gas to the cabin atmosphere, which was approximately 125 cubic feet to start with, would raise the cabin pressure to almost 2 atmospheres. Under these conditions, when the hatch was opened at the surface, the occupants would be subjected to an explosive decompression equivalent to a depth change of about 30 feet. The use of closed circuit oxygen breathing equipment will not increase the cabin pressure in this fashion. The closed circuit gear being used is the Min-O-Lung manufactured by Westinghouse (see Figure 17). Each unit provides about 1 1/2 hours of breathing time and weighs about 15 lbs.

Additional Emergency Equipment

An additional piece of emergency equipment which is carried on board is euphemistically referred to as a "Human element range extender". This device is a polyethylene container made for the light plane industry and each unit is guaranteed to hold, without spilling, one quart of urine. (Figure 20)

SYSTEM WEIGHT

A listing of all the components that make up the life support system, and the weight of each item is given in Figure 18. The list tends to emphasize the important fact that since most of the weight of the scrubber system is active lithium hydroxide the only other items of significant weight are the oxygen storage cylinders and the emergency breathing equipment. In the emergency breathing equipment the heavy item again is the oxygen storage cylinder. It therefore appears that the most fruitful area for saving weight is the oxygen storage cylinders.

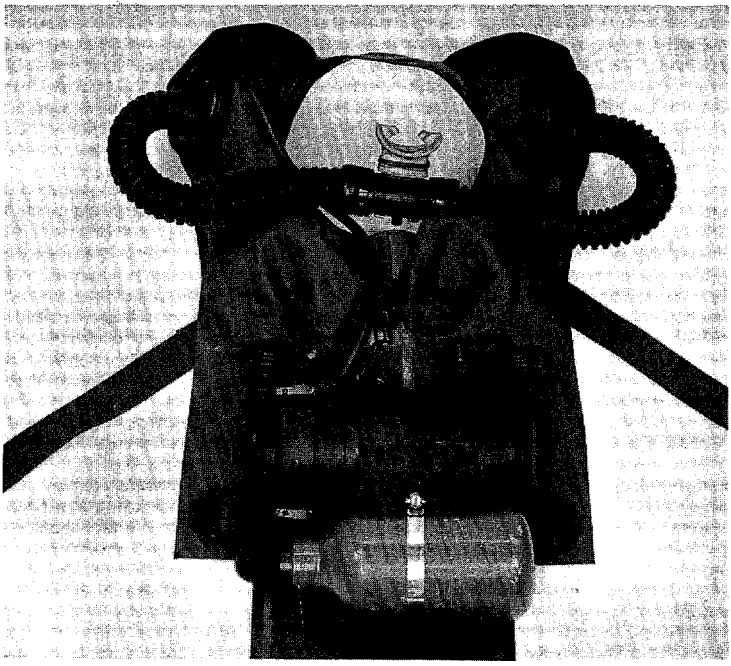


FIGURE 17 WESTINGHOUSE MIN-O-LUNG

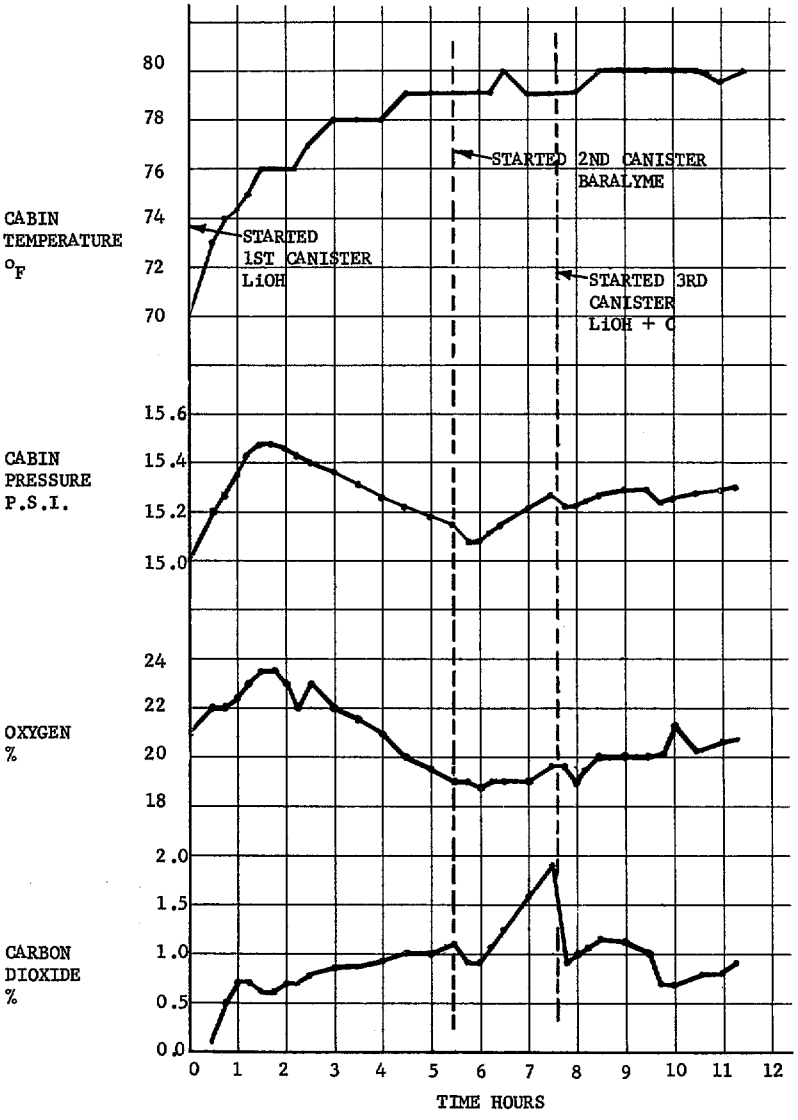
WEIGHT OF LIFE SUPPORT SYSTEM COMPONENTS		
Item	Weight Pounds	%OF Total
Oxygen Storage Cylinders	41.7	
126.5 cubic feet of oxygen	10.5	
Oxygen Control Panel	4.4	
Oxygen Fill Panel	1.6	
Oxygen Plumbing	2.0	
Total for oxygen supply	60.2	39.4
CO_2 Scrubber	7.5	
12 Cannisters of LiOH (2.65 ea.)	31.8	
Total for scrubber	39.3	25.6
O_2 Meter W Krasberg	3.3	
CO_2 Indicator Dwyer	2.0	
CO_2 Indicator Kitagawa	1.5	
Cabin Pressure Indicator	1.1	
Temperature - Humidity	.6	
O_2 CO_2 Chart	.1	
Total for instruments	8.6	5.6
Emergency Breathing 3 Units at 15 pounds each	45	29.4
Total for entire system	153.1	100.1

FIGURE 18

TEST OF SYSTEM

To determine the performance characteristics of the complete system a test was run during which all the pertinent data that could be measured was recorded. The test was performed by having three men sit in the sealed sphere for a period of just over 11 hours. The vehicle was not in water when the test was made but all equipment affecting life support were in operation. Some of the results of this test are illustrated in Figure 19, which shows the variation of the oxygen concentration, the carbon dioxide conecntration, the cabin pressure and the cabin temperature. The chart clearly indicates the close relationship between cabin pressure and oxygen content.

A LiOH cannister was in the scrubber at the beginning of the test after 5 1/2 hours the CO_2 level rose to 1.2% and the cannister was replaced by one containing Baralyme. During the next two hours the CO_2 level continued to increase to 1.9% at that time the second cannister was replaced by a third cannister. This one contained LiOH and charcoal. The CO_2 level immediately dropped to approximately 1.0% and remained there until the conclusion of the test. The air flow through the scrubber was measured at more than 70 cubin feet per minute and it remained at about that level throughout the test. The relative humidity in the cabin was 80.5% at the start of the test. It rose to 85% in the first hour and fluctuated between 85% and 91% for the remainder of the test.



LIFE SUPPORT SYSTEM PERFORMANCE DS 4000

FIG. 19 RESULTS OF 11 HOUR TEST

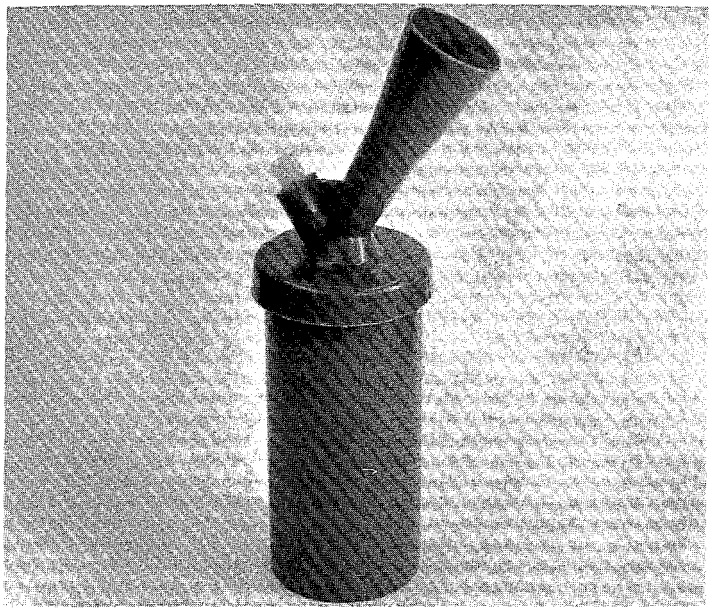


FIGURE 20 HUMAN ELEMENT RANGE EXTENDER (H.E.R.E.)

THE END

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AUTOMATIC VERTICAL PROFILING OCEANOGRAPHIC DATA SYSTEMS

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Beckman Instruments, Inc.

Abstract

Although a number of techniques and systems have been devised for the purpose of collecting information regarding the physical and chemical parameters of sea water, only a few of these have been intended for the purpose of obtaining vertical data profiles. Among the variables which have been measured in this manner are temperature, salinity, as measured by electrical conductivity, and sould velocity. While these are of great importance to those concerned with submarine warfare tactices, they represent only a small portion of the total characteristics of the ocean masses. As we turn toward the ever-increasing problems involved with effective exploitation of the resources of the sea, we must turn our attention toward the development of equipment which will provide us with a wealth of data - and which will accomplish this task rapidly, economically, and accurately. Whether the primary interest is in the biology of the oceans, the marine mineral resources, or in basic research, the problems of extracting meaningful data from the sea are much the same. This paper describes two recently developed in-situ oceanographic instruments which may be used for obtaining vertical profiles of dissolved oxygen and dissolved carbon dioxide, and discusses several other types which can be adapted for this application.

INTRODUCTION

Vertical profiling of the temperature of the sea has come to be accepted as one of the basic measurements required for most types of oceanographic surveys. The development of the reversing thermometer provided early oceanographers with one of their most valuable tools, and at the same time exemplified the importance of data which was collected according to a well defined plan. Almost concurrently, the use of Nansen bottles judiciously spaced along a vertical line provided a means of obtaining representative water samples which could provide an approximation of a vertical profile for a number of properties which could be measured in the laboratory. More recently, the development of shipboard survey systems has provided more highly sophisticated equipment which has given truly continuous vertical profiling of temperature, and of salinity as well.

From this beginning, it is possible to visualize the eventual collection of a broad spectrum of profiles, including not only the physical properties of the sea water, but also the chemical composition. Without adequate data-processing facilities, information obtained in the form of continuous profiles would overwhelm the oceanographer by the sheer bulk of the data. We are accustomed, however, to expect that equipment for recording, collating, and transmission of oceanographic data will be available in some form on most of our oceanographic survey vessels. Hence, the accumulation of vast quantities of data no longer poses an awesome problem. It is only reasonable that the oceanographic community turn its attention toward the development of instrumentation that can provide vertical profiles of the more important properties.

Of particular interest to the fisheries industry are those factors which influence, either directly or indirectly, the distribution of those species which are of import to their activities. Ocean engineering, as related to underwater construction, is concerned with the problem of corrosion; often this is accelerated if dissimilar conditions are encountered at different

depths. The marine mining industry, still in its infancy, is already seeking explanations for and the significance of the localized accumulations of some of the more extensive sea-floor deposits. Other groups in need of detailed oceanographic data are those concerned with disposal of radioactive wastes and with pollution of both marine and lacustrine waters.

It would be ridiculous, of course, to think that instrumentation suitable for vertical profiling of all of the pertinent and important parameters can be developed in the forseeable future. But at the present time, several such measurements are definitely possible with recently developed equipment, and there is no doubt but that many others can be made as the need arises.

REQUIREMENTS FOR PROFILING SYSTEMS

Since the equipment for raising, lowering, and shipboard handling of oceanographic data survey systems is presently available, and has been developed to a high degree of dependability, equipment of this type will not be discussed here. Data processing equipment, similarly, has been developed highly-both the recording equipment which can be used aboard smaller vessels, with subsequent shore-based data processing, and the complete collecting, collating, storing, and plotting systems now being installed aboard the larger ships.

Our present concern lies in the area of sensory equipment-the nerve ends from which information bits are transmitted to the brain of the system. One of the prime requirements for sensors suitable for vertical profiling is, of course, the capability of operating under conditions of high ambient pressure. Until quite recently, this requirement eliminated all but a few types of sensors; it is now apparent that the pressure factor may be overcome for several types of sensory systems. Another problem lies in the temperature extremes encountered, and the effects of temperature variations upon the accuracy of the measurements. For the most part, these problems have also been solved, at least sufficiently to make in-situ measurements possible with the required precision. Another, and more difficult problem, arises from the required speed of response; obviously, the time required for obtaining a vertical profile, or even several profiles simutaneously, must be considered seriously, and must be sufficiently short to permit maintenance of ship operating schedules.

Other factors which must be considered, and which control in some instances the sensor configuration, are the availability of power and the need for output signals compatible with existing data transmission links. It would be most desirable if several sensors could be housed in a single instrument pod, utilizing a common power supply, and having provision for a multiplexed frequency modulated output signal. In short, some of the most troublesome aspects of instrumentation of this type lie within the realm of electronics; the development of suitable electronic systems and subsystems is approaching state-of-the-art, however.

RECENTLY DEVELOPED IN-SITU SENSORS

One of the most important variables in the sea, to those concerned with biological investigations, is the dissolved oxygen content of the sea water. Although vertical profile approximations have been obtained by means of sequential Nansen vottle casts and subsequent laboratory analysis by the Winkler method, it has not been possible until recently to obtain a continuous determination of dissolved oxygen. Another complicating factor has been the degassing as the samples are removed from their ambient conditions of high pressure and low temperature, leading to possibly erroneous determinations.

The development of the polarographic oxygen sensor provided for the first time a practical means of continuously measuring the dissolved content of

a solution. Sensors of this type have been used for several years to a very limited extent for oceanographic work, but have not found general acceptance because of certain operational difficulties. A few systems have been developed for shipboard use, with a sensor attached to a cable permitting lowering to one hundred feet or so beneath the surface. The limiting factors for these were first, the depth limitations, and second, the necessity for insuring a flow of water past the sensor.

In response to an inquiry from the Deep Submergence Group of the U. S. Navy Electronics Laboratory, engineers at Beckman Instruments, Inc., conducted an intensive theoretical analysis of the probable effects of high ambient pressure on a sensor of this type, and concluded that it should be possible to design a pressure-compensated unit which would operate at pressures of several thousand pounds per square inch. After some preliminary laboratory experimentation indicated that this could be done, a sensor was designed and fabricated which could operate at depths as great as 4000 feet beneath the surface of the sea. The Dissolved Oxygen Sensor is shown in Figure 1.

This sensor represented the initial stage of development for an oceanography in-situ oxygen measuring system. The response time of the original unit was not sufficiently fast to permit continuous vertical profiling from a fast-moving vehicle or by the use of a winched line system. Two factors precluded the use of this initial unit for this use; one was the nature of the oxygen-permeable membrane, which was selected to permit operation in still water. The other was the fact that the temperature compensating thermistor was located well within the stainless steel body of the sensor, causing a considerable temperature response lag. In a subsequent unit, a different membrane was used, permitting more rapid response to dissolved oxygen; an externally mounted thermistor will permit a rapid response to temperature changes.

Thus, the In-Situ Dissolved Oxygen Sensor provided the first sensor suitable for profiling of one of the chemical parameters of the sea at depths greater than one hundred feet. Since the power consumption is very low, it would be possible to operate such a unit from self-contained batteries; the electrical output is a DC signal, which can be used to drive an oscillator to provide a suitable frequency-modulated signal.

The performance of the in-situ oceanographic oxygen sensor encouraged investigation of the feasibility of developing a sensor for in-situ measurement of dissolved carbon dioxide. Preliminary tests with dummy glass electrodes proved that a spherical bulb of pH-sensitive glass could withstand pressure of up to 3000 pounds per square inch, and a system for measurement in-situ of dissolved carbon dioxide was proposed to the Navy Electronics Laboratory. A system was ultimately developed for this purpose. The In-Situ Dissolved Carbon Dioxide Sensor is shown in Figure 2. Although this system operates at the design depth of 4000 feet, and the range of measurement is that prescribed by NEL, this system was not developed for continuous vertical profiling, the response being too slow.

These two sensory systems indicate the manner in which laboratory-type instruments can be adapted to in-situ oceanographic applications. Both systems were fabricated successfully, and performance was better than had been anticipated for either. Both of these sensors can now be made available for inclusion into survey systems.

FUTURE DEVELOPMENTS

Another system which has been considered is one for in-situ measurement of the pH of sea water. This has been suggested as an aid to biological studies, and as an exploration tool to aid in the search for commercially attractive phosphorite and manganese modules.

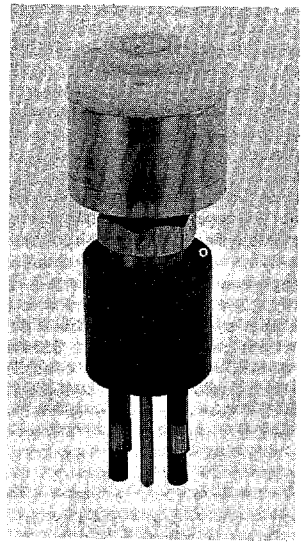

FIGURE 1. Dissolved Oxygen Sensor

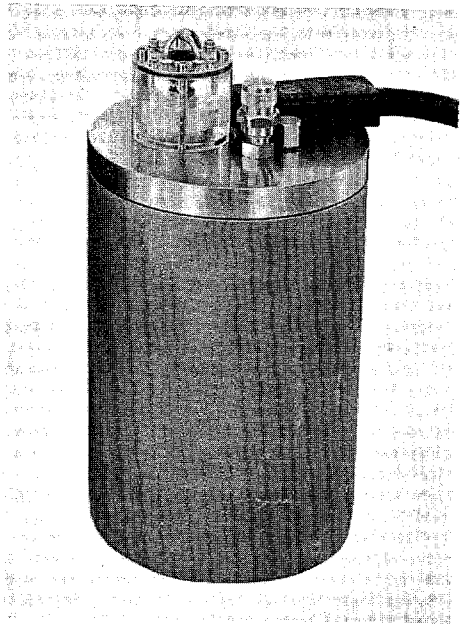

FIGURE 2. Dissolved Carbon Dioxide Sensor

Another in-situ system which has been considered is that for measurement of the hydrogen sulfide content of sea water, as well as in the bottom sediments. Vertical profiles for this measurement will probably be confined to the lowermost hundred feet or so of water, rather than throughout the oceanic masses as indicated for previously mentioned determinations. However, due to the importance of this measurement to biologists, ecologists, and geologists interested in sea-floor sedimentation and mineral deposits, this measurement is of considerable importance.

Specific ion sensory systems have been developed for laboratory applications, and these may well be applied to oceanographic measurements as the need arises. Among the ions which have been measured in this manner are sodium, potassium and lithium. The sensors will be similar to those previously described for measurement of pH or hydrogen sulfide.

Ideally, a vertical profiling system should include sensors for simultaneous measurement of a number of parameters such as dissolved oxygen, pH, temperature, and salinity, in order to use mose efficiently the shipboard equipment required for winching and data processing. Compared with the cost of individual shipboard laboratory analyses for each item, and the possibility of misleading results due to chemical and physical changes in surfaced samples, the cost of building and operating in-situ continuous profiling systems will be small.

As our attention turns even more to explitation of the natural and almost limitless resources of the sea, it is only natural that sensory instrumentation will eventually be required to provide additional data. The systems can be utilized to our knowledge of the oceanic masses.

UNDERWATER ELECTRICAL CABLES & CONNECTORS ENGINEERED AS A SINGLE REQUIREMENT

Don K. Walsh, Vice-President
Marsh & Marine, Division of Vector Cable Company

ABSTRACT

The purpose of this paper is threefold:

First, bring to the attention of the Design Engineer the fact that his problem of a cable and related connectors must be treated as a single problem if maximum performance is to be achieved.

Second, cite typical areas of compatibility and incompatibility between cables and connectors.

Third, present current trends based on available materials and industry activity.

This paper will briefly review the historical development of underwater electrical connectors from early waterproofing techniques to the high reliability assemblies offered on todays' growing market. The junction area between cable and connector will be discussed in detail since this is the area that is most often overlooked in the design of an electrical cable and in the selection of the connector assembly to be used. Cable and connector materials will be discussed briefly even though this subject should require considerable thought to insure maximum performance.

SCOPE

Historically, the cable problem has been treated as an after-thought. The connector was often not considered until the cable was to be connected to some associated equipment. During the planning stages little or no thought was given to either the cable or the connector. In most cases, when the time came to assemble the equipment, the person involved went around looking for any useable cable. Whatever cable was lying around that seemed adequate would be used and then the problem developed as to how to anchor, terminate, or secure it to the associated equipment and achieve a water-tight junction. If this was not successful during trial runs, it became necessary to remove the cable and find a replacement. The instrumentation may have worked, but now it became desireable to have a cable which could be removed, replaced, or disconnected. This was particularly true if the cable became damaged or other requirements developed which would alter the basic connecting link that had been chosen.

After a number of years as more thought went into underwater projects, the cable became an Engineered Cable or one specifically designed for the project. This received more attention because of problems that have been experienced in earlier phases of marine work. Still, however, little thought was given to the connector. Consquently, when the special cable would be received, the problem of securing, terminating, or joining the cable to the associated equipment was as it had always been. Again, no thought had been given to the connector except by the individual who was to put the various components together and there was little time to consider what should be done, so he used whatever method came to mind. Sometimes these junctions proved satisfactory, sometimes they did not. In most cases there was no connector at this point; there was just a termination or junction. This eliminated the possibility of replacing the cable, the instrument, or electrical equipment as became necessary. Such replace-

ment was a major overhaul since it usually involved cumbersome, homemade efforts to achieve water-tight integrity.

The Connector, used with the remainder of the electrical system, would have to fit or match whatever was procured in the way of cables and other electrical equipment. It may have been necessary to use a bulkhead connector, it may have been necessary to use an electro-mechanical connector, but progress in this area had been left pretty much to the last several years before any appreciable engineering or consideration was given to cable connectors.

An Engineering Approach to the best combination of cables and connectors for any specific project will be covered toward the latter part of this paper.

EVOLUTION OF THE COMBINATION OF CABLES AND CONNECTORS

In early days with the Oil Industry and with Oceanographers, single conductor cables were generally used and splices were made instead of using disconnects or connectors. Splices were made with tapes of various types where "field" taped joints were put in the water and, in many many cases, worked with satisfaction. In an effort to progress from these taped joints and to reduce the human element there came into existence what many know as the "Schlumberger Splice". A typical splice is shown in Fig. 1. The Schlumberger Splice consists of a piece of surgical tubing, specifically procured for the particular size wire that was to be spliced. Normally, a crimp type sleeve or barrel was used to join the two conductors together and then the piece of surgical tubing was slipped over the metallic splice so as to extend at least one inch over the insulation on each side of the splice. The inside diameter of the surgical tubing was smaller than the outside diameter of the wire so that it had to be stretched into position. At each end the tubing was tied once or twice with fish line as tight as possible; this made a completely water-tight splice but of questionable life because of "cold-flow" of the insulation underneath the tie would result in deformation of the conductor insulation permitting water leakage. Many such splices have been used for years; we used them ten years ago in the Gulf of Mexico with excellent results. This solution was not very sophisticated; it did have a number of drawbacks but it did do the job and worked satisfactorly.

Another cable terminating or cable splicing development was the Gland Seal which has been in use for years and still is used in many areas. There have been many types of Gland Seals including those with environmental spring type washers to compensate for temperature changes. The Gland Seal or Packing Gland, as it is sometimes called, has served its purpose admirably. A typical assembly is shown in Fig. 2. This compression sealing around the cable jacket also results in deformation of the compressed surface degrading the reliability of the junction.

Then came the need for actual multi-pin water-tight connectors --- disconnect type connectors. In the early years such connectors were usually rubber molded directly to cables making them both rugged and inexpensive. See Fig. 3,4,5. Many such assemblies could be considered as "throw away" assemblies since they did not represent much money and a replacement unit could be installed in a matter of minutes at a cost of less than would be encountered to repair a damaged assembly. Such connectors often served the purpose of creating a positive water barrier installed in a cable assembly so as to prevent the flow of water past any sectionalizing or terminating point. Many such connectors are in use today. It is necessary to point out that this catagory of underwater electrical connectors has been subjected to all sorts of abuse for several years. The principle area of abuse has been in misapplication, mishandling, and careless installation.

The Rubber Molded type of connectors had much to do with combining the cable problem with the connector problem since a rubber molded connector could only be installed on or molded to a vulcanizable type of cable, such as a Neoprene jacketed cable. This often influenced the type of conductor insulation that could be used in a cable having a rubber or Neoprene jacket over all. This was the beginning of engineering a Cable System which included both the cable and the associated connectors.

There is so much to be said concerning rubber molded water-tight connectors that this would have to be a topic within itself. For the sake of brevity one last comment on the conventional "Rubber Molded" connectors: properly designed components function satisfactorily for an indefinite period when properly installed and applied.

THE ENGINEERED CABLE SYSTEM

With increasing activity in underwater work, new and more demanding requirements have developed. With Deep Submersibles and Electronic Instrumentation accounting for much of the underwater projects, high performance electrical systems have become essential. These demands have resulted in a combination of a cable with a connector and a suitable junction in what we now define as the Cable System. This compels the design engineer to give careful consideration to both the cable and the connector in order to insure the best performance from any system. The junction of cable to connector must be considered as a vital part of the system; usually representing the least expensive portion of the assembly with the greatest chance for trouble.

The systems engineer must develop the cable construction with full knowledge of the associated connectors and the types of junctions to be used. Since the systems engineer or design engineer is usually not a cable engineer, the basic cable construction should be left to a cable designer. Similarly, the basic connector design should be left to the connector design engineer. The following points, however, need to be considered to insure compatibility and optimum performance:

Cable Design (Fig. 6)

A. Conductor flexibility
   1. required for finished cable handling and establish bending radius.
   2. as required for termination at the connector.

B. Type of conductor insulation
   1. to satisfy electrical requirements.
   2. to comply with finished cable diameter limitations.
   3. must be suitable for operating pressures.
   4. suitable for mechanical handling.
   5. compatible with type of junction to be made.

C. Cable sheath (if not free-flooding design)
   1. material must be compatible with conductor insulation.
   2. material must be selected on basis of type junction required.
      a) Neoprene or similar type elastomer
      b) Polyethylene type of thermoplastic
      c) Polyvinylchloride type of thermoplastic
      d) Polyurethane materials
   3. should be selected to satisfy the mechanical and any electrical requirements of the working assembly.
   4. must be compatible with the connector selected.

D. An electro-mechanical cable must be compatible with connector selected to permit strain termination as well as water-tight integrity.

Junction or Termination of Cable to Connector (Fig. 7,8,9)

A. Determine if junction is to be a factory or "field" installation.
B. Is junction to be molded or vulcanized or is an interference seal intended?
C. Should junction become a positive water seal?
D. What pressures will be encountered?
E. Is repairability an essential factor?
F. Is junction to be electro-mechanical?
G. What flexing conditions will be encountered at junction?
H. Should junction be for an "in-line" or right angle connector?

Connector Design (Fig. 10,11,12)

A. Is connector to be electrical or electro-mechanical?
B. Mechanical requirements
    1. metallic shell or body
    2. non-metallic shell
    3. corrosion and dissimilar metals problems
    4. possible accidental open-face exposure to sea water
        a) need for hermetic seal
    5. cable clamping method
    6. slack conductor cavity
    7. space limitations
    8. maximum cable diameter that can be accommodated
    9. indexing methods to insure proper polarity
    10. mating and disconnect methods employed
    11. type of water-tight seals employed
    12. types of mountings for mating connectors.
C. Electrical requirements
    1. number of contacts required and sizes of each
    2. operating and test voltages
    3. current carrying capacities
    4. shielding
    5. repairability
    6. special characteristics needed for special instrumentation

COMPATIBILITY OF CABLES AND CONNECTORS

The area of conflict between cables and connectors usually concerns the junction to be made between them. There are cases where a #4 AWG wire is to be put into a #14 contact but this is not practical. Less obvious conflicts develop where a rubber molded connector is required to be installed on a polyethylene jacketed cable and similar incompatibilities. Vulcanizing temperatures for standard rubber and Neoprene compounds exceed the melting point of common polyethylenes.

Such incompatible junctions are being furnished today but not without reservations. To insure satisfactory performance from a cable system, materials for the cable and connectors should be selected on the basis of the required junction first, and on the operating environment second. This may require a compromise on materials but will usually result in a finished system offering greater operating possibilities. This area of incompatibility should decrease as more reports are published on satisfactory performance of elastomers used as cable sheaths in sea water environments. Recent reports are most encouraging.

First, the trend is toward more and more contacts in connectors which can be vulcanized or molded to multi-conductor cables. Field repair is being circunvented by sectionalizing cables providing replacement cable sections coupled together with connectors. The most corrosion resistant materials are being widely used and at increased costs. Connector designs are directed toward handling by inexperienced personnel with provisions to insure correct assembly.

Pressure testing of complete cable systems is becoming mandatory where optimum performance is essential. The establishment of recognized standard test proceedures for complete cable systems is an important step that needs to be taken in the very near future. To be meaningful, the cable, the junction, and the connector must be tested as a working assembly and be evaluated as a single unit. (Fig. 13) This is now being done extensively on the basis of individual standards.

The End

SCHLUMBERGER SPLICE

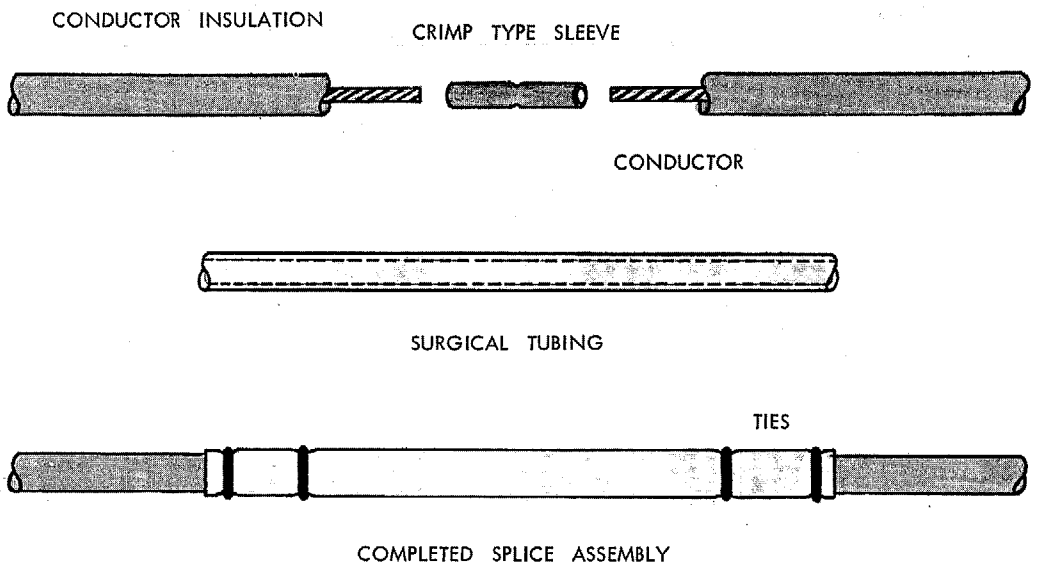

Fig. 1

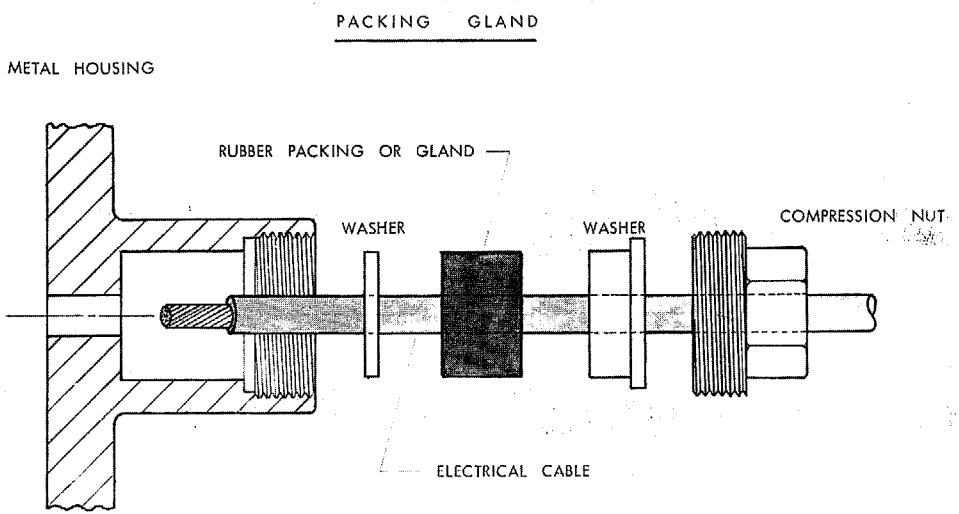
PACKING GLAND
METAL HOUSING
RUBBER PACKING OR GLAND
WASHER
WASHER
COMPRESSION NUT
ELECTRICAL CABLE

Fig. 2

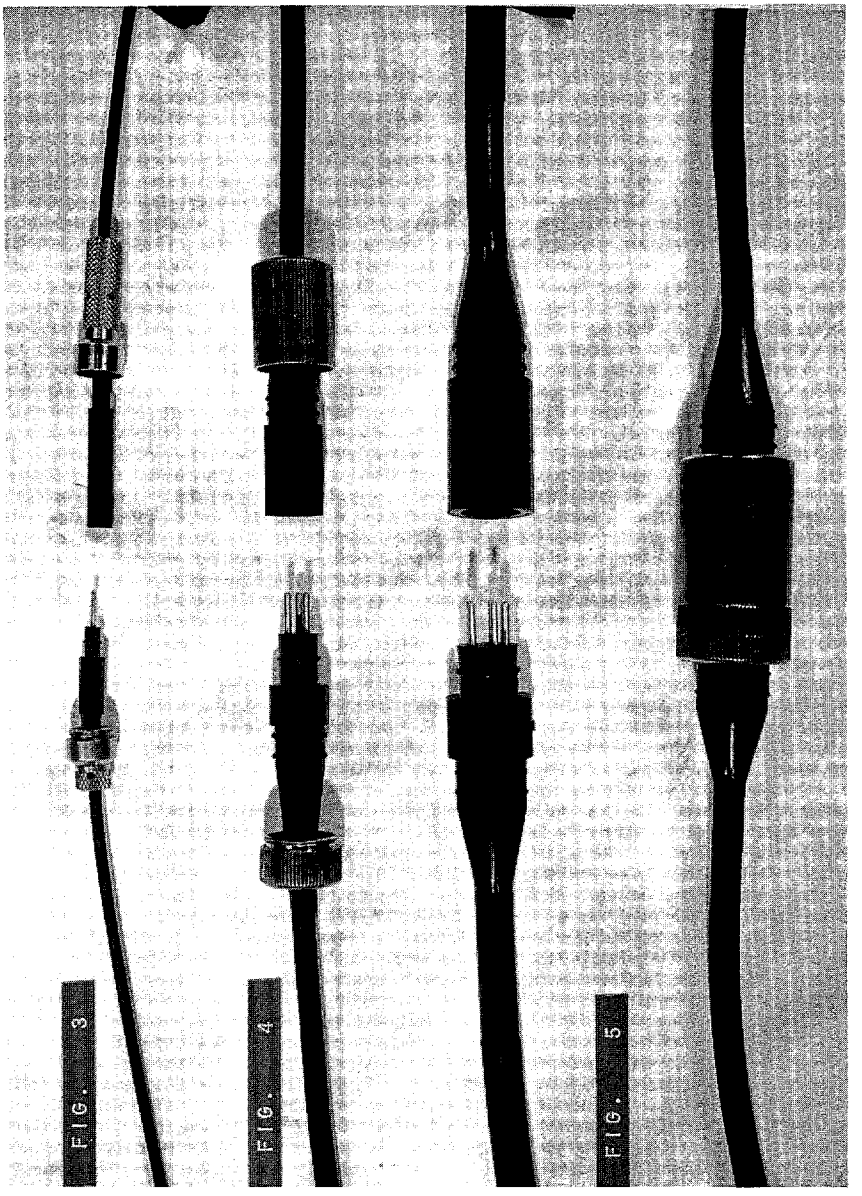
FIG. 3
FIG. 4
FIG. 5

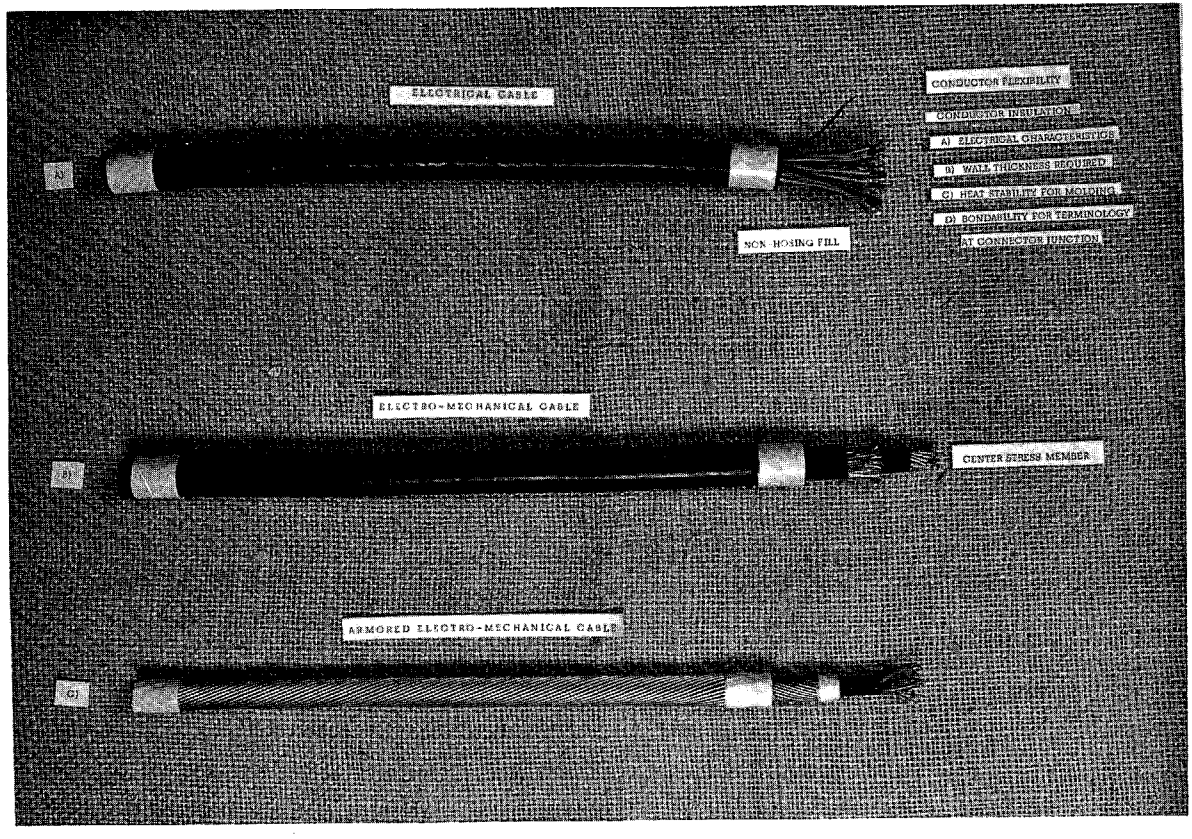
ELECTRICAL CABLE
CONDUCTOR FLEXIBILITY
CONDUCTOR INSULATION
A) ELECTRICAL CHARACTERISTICS
B) WALL THICKNESS REQUIRED
C) HEAT STABILITY FOR MOLDING
D) BONDABILITY FOR TERMINOLOGY
AT CONNECTOR JUNCTION
NON-HOSING FILL
ELECTRO-MECHANICAL CABLE
CENTER STRESS MEMBER
ARMORED ELECTRO-MECHANICAL CABLE

Fig. 6

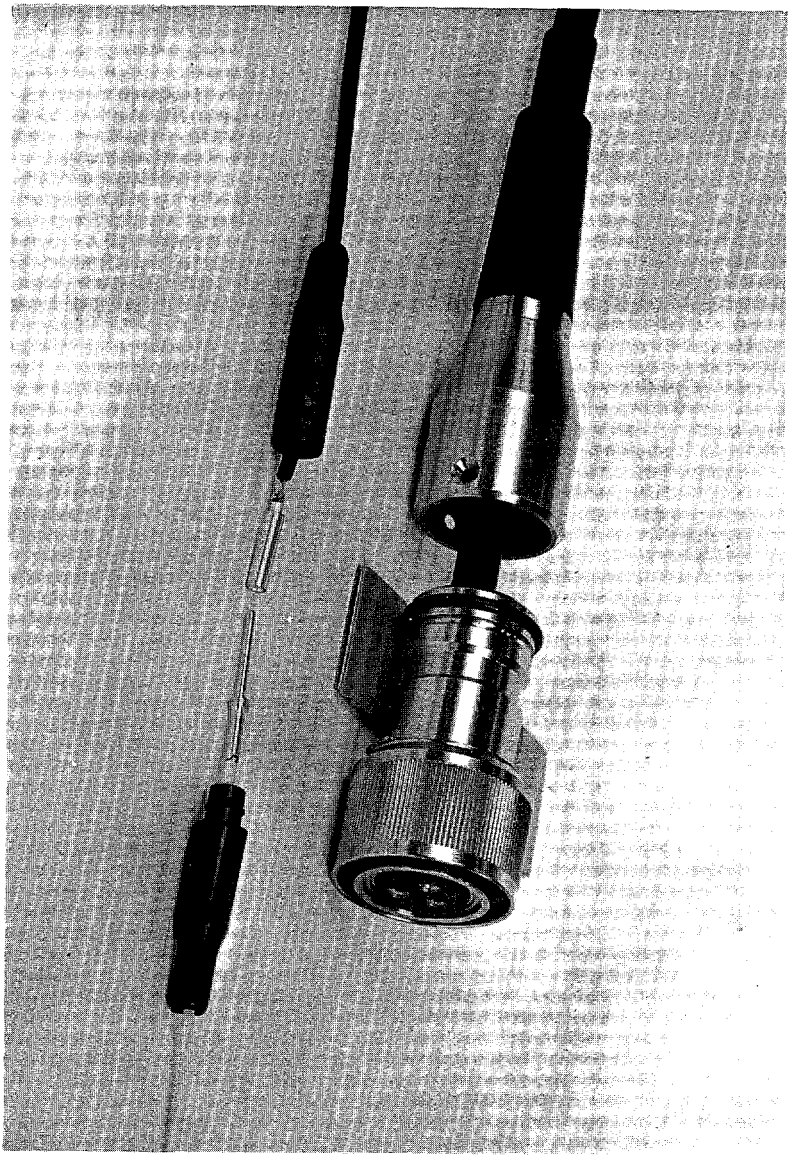

Fig. 7

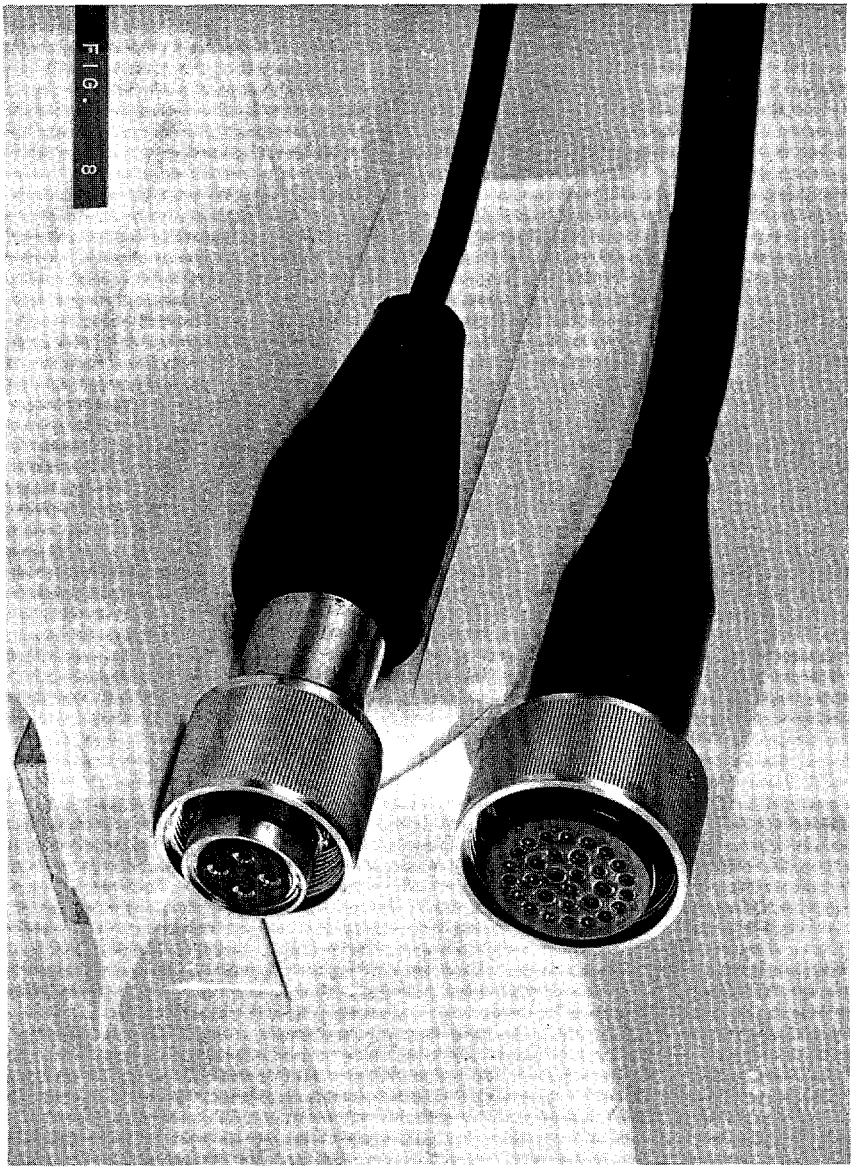

Fig. 8

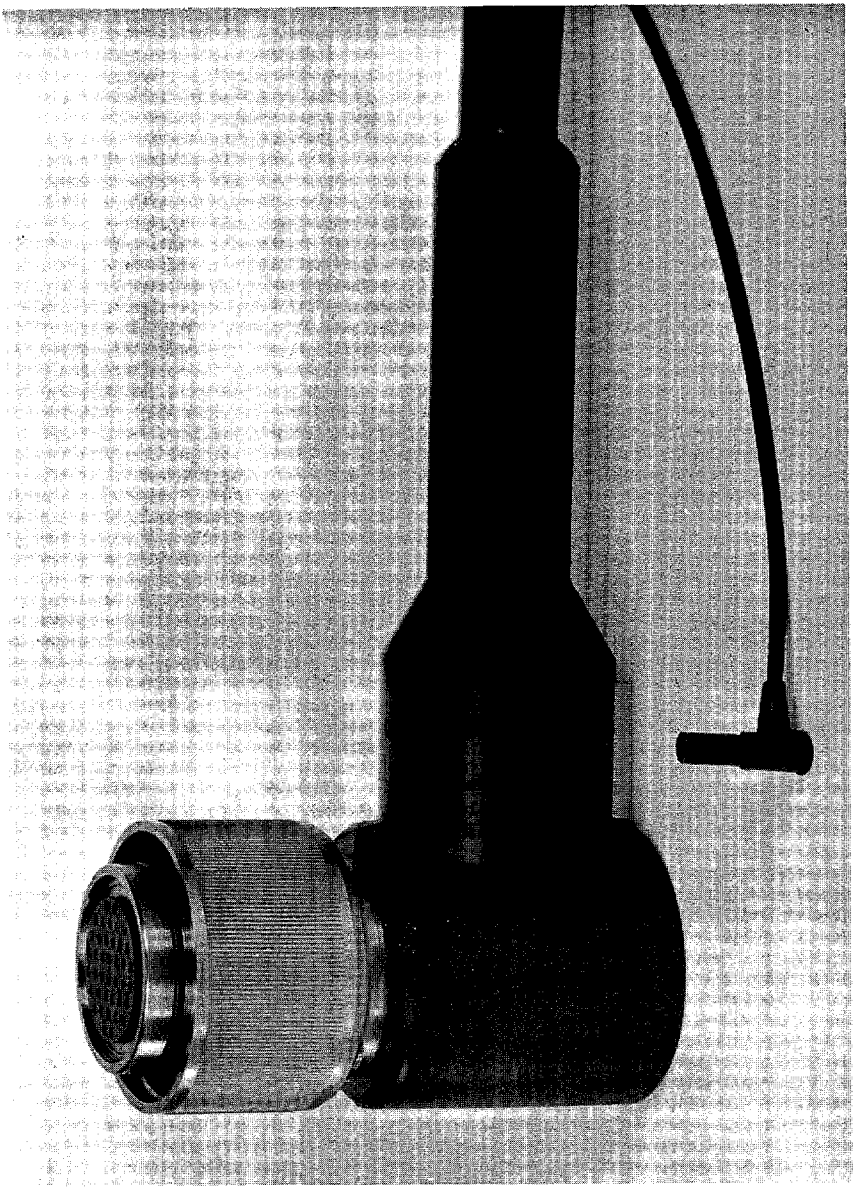

Fig. 9

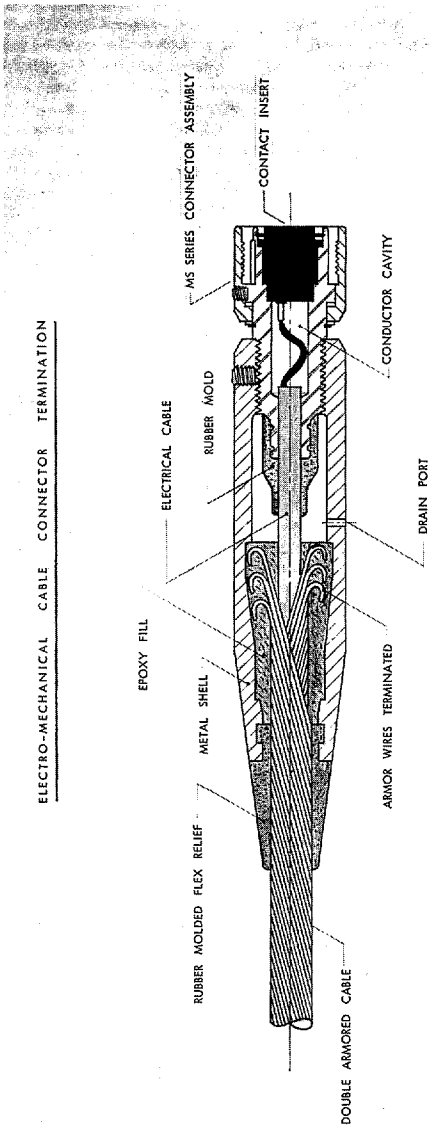
ELECTRO-MECHANICAL CABLE CONNECTOR TERMINATION
MS SERIES CONNECTOR ASSEMBLY
CONTACT INSERT
CONDUCTOR CAVITY
ELECTRICAL CABLE
RUBBER MOLD
DRAIN PORT
EPOXY FILL
METAL SHELL
ARMOR WIRES TERMINATED
RUBBER MOLDED FLEX RELIEF
DOUBLE ARMORED CABLE

Fig. 10

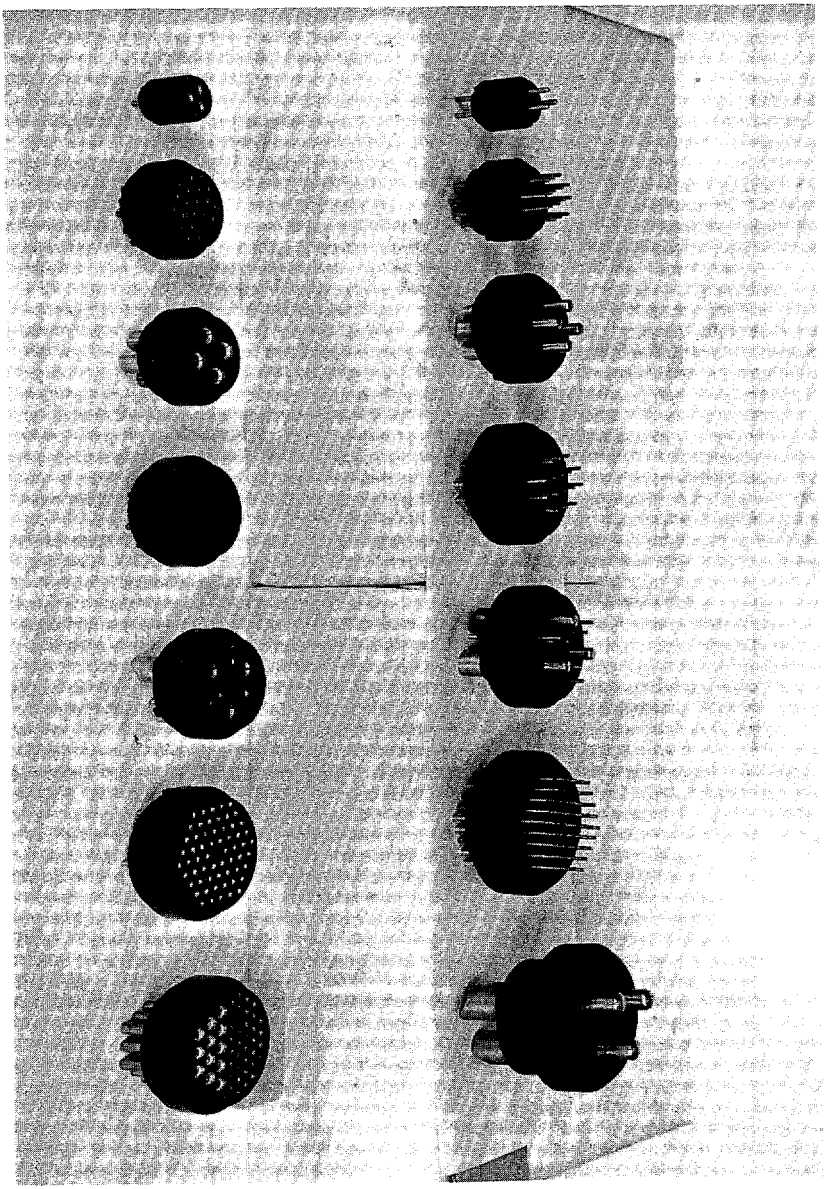

Fig. 11

Fig. 12

NOTE:
1. 1000 VOLT D.C. 10 MEGOHM
2. 500d VOLT D.C. 10 MEGOHM
3. 6 VOLT D.C. 10 MEGOHM
ALL SHIELDS

PRESSURE & ELECTRICAL TEST

PIN No.	50 CYCLE TEST 0-4000 PSI (HOLD AT PRESSURE 10 SEC. MINIMUM)														8 HR. TEST AT 7500 PSI				5 PSI	
	CYCLE #1				CYCLE #2		CYCLE #25				CYCLE #50				AT 2 HRS.		AT 8 HRS.			
	0 PSI		4000 PSI		0 PSI		0 PSI		4000 PSI		4000 PSI		0 PSI							
	GR.	COND.	GR.	COND.	GR.	COND.	GR.	COND.	GR.	COND.	GR.	COND.	GR.	COND.	GR.	COND.	GR.	COND.	GR.	COND.
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HARDWARE — STRUCTURAL TEST

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Q. C.	DATE	CERT. NO.	DATE	CERT. NO.	DATE	CERT. NO.	DATE	CERT. NO.
MAGNA FLUX		MILL		MILL		MILL		MILL
HEAT								
CONN. TYPE								

	1ST	FINAL	1ST	FINAL	1ST	FINAL	
Q. C.	DATE	CERT. NO.	DATE	CERT. NO.	DATE	CERT. NO.	M&M PRODUCTION Dwg. NO.
MAGNA FLUX		MILL		MILL		MILL	
HEAT							LOCKHEED Dwg. NO.
CONN. TYPE							

NO.	DATE	BY
1		
2		
3		
4		
5		
6		

MARSH & MARINE
HOUSTON, TEXAS
TEST SCHEDULE
PART NO.

DRAWN BY	SCALE	MATERIAL
CHECKED	DATE	DRAWING NO.
RELEASED		

FIG. 13

DYNAMIC TESTING OF CABLES

J. C. Poffenberger, E. A. Capadona, R. B. Siter

Research and Engineering Department
Preformed Line Products Company
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ABSTRACT

Dynamic failures of strength cables during an underwater operation can hinder or even seriously impair the success of the entire operation. Dynamic cable stresses arise from a wide variety of sources — forced and self-excited vibration; flexure and compression during passage over sheaves; resonant magnification of the body motions of ships, buoys, and towed vehicles; and from transient impulses. When static and dynamic stresses combine to exceed the critical state of stress of the cable material or its fatigue strength, failure will occur. Failure is accelerated by corrosion, fretting, and abrasion.

Field testing of prototype designs prior to operations is time consuming and expensive. However, field conditions can be simulated with dynamic equipment in the laboratory. Cable stresses from vibration, cyclic tension, cyclic impact, high energy impact, sheave passage, and other dynamic loading can be reproduced under controlled conditions which permit isolation of variables. Information regarding the magnitude of various dynamic loads likely to be encountered in a specific operation is required for accurate laboratory simulation. Even though knowledge of these parameters is presently incomplete, dynamic testing is a valuable aid to a designer in enhancing the operational reliability of underwater systems.

INTRODUCTION

Every oceanographic or underwater cable operates in a hostile environment where the possibility of failure from dynamic loading is an ever present threat. Although the degree of threat varies from installation to installation and ranges from a relatively innocuous hazard to a serious menace, dynamic forces should be given design consideration in all cases.

Dynamic stressing of underwater cables occurs during paying-out or retrieval operations; during forced vibration; during self-excited vibration; when there is pitching, heaving, and other body motion of ships, or buoys, or towed vehicles, particularly if small motions are magnified by resonance; and finally from the propagation of transient impulses along the tensioned cable.

Depending on the circumstances under which various static forces and dynamic loads combine, the spectre of failure may indeed become a reality, with failures being accelerated by corrosion, fretting, and abrasion. Fatigue fractures, parting of cables, and loss of a buoy or towed vehicle are sometimes disastrous, generally unexpected, and always a cause for concern.

This concern is frequently manifested in design changes, but until the new design has been tested, there is no basis for comparing the relative adequacy of the old and the new. While field testing is extremely valuable, it is also time consuming and expensive. Fortunately, the type of mechanical loading encountered in the field is susceptible to laboratory simulation with dynamic test equipment.

In the laboratory it is possible to isolate variables in controlled testing, and this permits potentially troublesome components of the cable and cable hardware system to be identified and redesigned. When coupled with field testing, dynamic testing in the laboratory is an extremely powerful tool for upgrading total system performance.

Scope of Paper

The source and nature of dynamic loads commonly encountered in underwater cable installations as well as methods of dynamic testing currently being used are described in the paper. The factors involved in conducting mechanical tests in a corrosive environment are not treated in the paper, though it should be apparent that the possibility for such combined testing exists.

There is a wide diversity of types of underwater installations and a correspondingly broad diversity in types of cable materials and construction. Materials used in the strength elements of underwater cables include carbon steels, stainless steel alloys, titanium alloys, bronze and copper alloys, and even non-metallic materials such as polypropolene. Cable constructions include multi-filament, multi-strand rope; concentrically stranded multiwire cable; and double armored instrument lead cable.

The profusion of types of installations and cables limits the paper to fundamental concepts and general description of testing and equipment. It should be recognized that there are subtleties, qualifications, and even contradictory exceptions in special cases to most of the general concepts. In the interest of brevity, these will not be considered.

Similarity to Overhead Line Problems

Although the two fields seem far removed at first glance, many of the dynamic problems experienced by underwater cables have a pronounced similarity to those encountered on overhead power transmission lines and overhead communication lines. Dynamic problems in overhead lines, particularly those associated with forced and self-excited vibration, have been a source of concern and the subject of research for the past forty years. A convenient literature source in this field is the Institute of Electrical and Electronics Engineers, "Transactions".

Much of the equipment described in this paper was initially constructed for use in research and development activities connected with overhead cable problems. The inherent capability of this equipment for testing all types of cable and cable fittings led us to extend our research activities to other fields, including the study of underwater cables. Complete parallels are not drawn in the paper between overhead and underwater problems, but where pertinent, similarities will be noted. For interested readers, Reference 1 containes a rather complete description of overhead line problems.

DYNAMIC LOADING OF UNDERWATER STRENGTH CABLES

Only two broad categories of underwater or oceanographic cables are considered in this paper — tow cables and buoy cables. We will further specialize by considering only taut, strength cables in these two broad classifications. However, the major portion of mechanical failures are encountered with these two, and the principal sources of dynamic loading are described below.

Passage Over Sheaves

During paying-out or retrieval operations as a buoy, anchor, or towed vehicle is being lowered or raised from its operating depth, the cable passes over single or multiple sheaves. During this passage, the cable is flexed, acted upon by radial compressive forces where the cable seats on the sheave, and exposed to abrasion of the outer surface and fretting of inner wires.

Since every cable, no matter how flexible, possesses some degree of flexural rigidity, flexural stresses accompany the bending over the sheave. The magnitude of the bending stress is dependent upon the sheave diameter and the cable construction. Here, "cable construction" means a particular geometric arrangement of the individual elements of the cable and further implies the diameter, material, surface hardness, modulus of elasticity, and other physical characteristics of those elements.

The radial compressive stresses are dependent upon several factors; cable tension, cable construction, sheave diameter, and the dimensional relationship between cable diameter and sheave groove radius. Another aspect of sheave passage is that a cable may be flattened somewhat. While not necessarily damaging in itself, flattening creates an aerodynamically unstable profile that leads to the possibility of self-excited vibration.

Abrasion of the outer surface depends upon the material in the sheave groove and that in the outer layer of the cable and the ability of the sheave to rotate freely under load. Fretting is caused by minute relative motion between two mating surfaces pressed firmly together. Flexing of a multi-wire cable and sheave seating pressure satisfy these two conditions.

The effect of sheave passage obviously can vary widely from system to system. If it is a single shot application as in the case of a buoy, then the high stresses encountered during the sheave passage may be of no concern. On the other hand, if the cable is being let out and reeled in frequently, then that same degree of stress can result in a severe stress history which contributes to the possibility of failure.

Ship, Buoy, and Towed Vehicle Body Motion

The principal ship motions of pitch, yaw, roll, and heave impose dynamic stressing of various types and of varying levels. These depend on the magnitude of the ship motion and the manner of shipboard attachment. For example, with a stern mounted attachment, pitch would cause dynamic tension changes; yaw would result in dynamic tension and transverse flexure; roll would cause transverse flexure; and heave would produce dynamic tension changes.

Similarly, the motion of the towed vehicle can be resolved into different components of dynamic loading. Or, if the fish is entirely stable, body motion loading at the tow staff of the fish will be in the form of transient impulses propagated along the tensioned cable; where the tow staff is rigid, these transients will be seen as dynamic flexure and dynamic tension.

The dynamic loading caused by buoy motion can also be resolved with the magnitude of the load depending on the stability of buoy and the mode of attachment of the anchor line.

The effect of these forces in contributing to the ultimate failure of the cable depends on load intensity and the number of repetitions the cable is likely to experience.

Forced Vibration

It is well known that a fluid moving across a cylindrically shaped body generates alternating forces on the body. These forces are periodic and transverse to the flow direction. It does not matter whether the fluid is liquid or gaseous, though the magnitude of the force varies with fluid density.

If the frequency of the periodic alternating forces coincides with a resonant transverse frequency of the cable, standing wave vibration will result in a direction transverse to the flow. This results in alternating flexural stresses in the cable. The magnitude of the stresses depends upon the geometry of the loop or standing wave (loop length and anti-node displacement), the cable tension and construction, and the degree of joint fixity where hardware is attached.

Excitation and Response Frequencies

The excitation frequency, or frequency of the alternating forces generated by fluid flow, can be approximated by the following elementary relationship which is reasonably accurate for Reynolds Numbers from 5×10^2 to 5×10^5;

$$f = 3.75 \frac{v}{d} \tag{1}$$

The spectrum of resonant response frequencies of the cable can be approximated by the well-known "vibrating string" formula;

$$f_n = \frac{n}{2L} \sqrt{\frac{T \cdot g}{w}} \tag{2}$$

It is often necessary to calculate the loop lengths in standing wave vibration. This can be done with equation (2) but it is more convenient to transpose terms and make the calculation directly;

$$LL = \frac{1}{2f} \sqrt{\frac{T \cdot g}{w}} \tag{3}$$

The symbols used in the equations (1) through (3) have the following significance;

f = excitation frequency, cps
f_n = response frequency of the nth mode
v = fluid velocity, knots
d = cable diameter, inches
n = integer, (1, 2, 3....)
L = cable length, feet
LL = loop length, feet
T = cable tension, pounds
g = acceleration due to gravity, ft/sec^2
w = cable weight, pounds per foot

Illustrative Examples

Consider a buoy anchored on the continental shelf in a current of four knots. The anchor cable is bronze rope and has a diameter of .375 inches; a weight of .25 pounds per foot; a tension of 500 pounds; and a working length of 300 feet.

Using equation (1), the frequency excited by the current flow would be 40 cps.

The fundamental natural frequency, using n = 1 in equation (2), would be .425 cps for 1 loop vibration. However, the cable would not vibrate in one loop, since the excitation frequency is 40 cps. It would tend to vibrate in 94 loops (40/.425 = 94.1).

Under these conditions each loop would be approximately 3.19 feet long (300/94 = 3.19). The same loop length, of course, is obtained directly by substituting the excitation frequency in equation (3).

Now, consider the case of a deep submergence system being towed at 4 knots. The tow cable is a double armored instrument cable with a 1.00 inch diameter, a weight of 1.5 pounds per foot, and an operating tension of 10,000 pounds.

The excitation frequency calculated from equation (1) would be approximately 15 cps. Since the length of the cable is not given, the fundamental natural frequency or values of harmonics, cannot be calculated. However, the loop length of individual loops can be calculated from equation (3). At 15 cps, those loops would be approximately 15.4 feet long.

Limitations

In the equation and examples above, all parameters were considered constant for a particular case. That is, cable weight, cable diameter, cable tension, flow direction, and flow intensity were all considered constant over the full length of the cable. Further, the vibrating string equation presupposes a cable with no flexural rigidity, no tension change due to loop formation, and no damping, either internally or externally. With the exception of cable with nominally constant diameter and density, not one of these assumptions is correct in actual practice!

Cable tensions vary along the length of the cable. Current direction and velocity vary with depth. Damping is introduced internally and externally. Even cable diameter and density can vary as in the case of tapered cable.

Actually, an underwater cable should be treated as a stiff string with a variable longitudinal tension that is subjected to multiple excitation frequencies. Nonetheless, the elementary formulas are useful because of three factors. First, a multiplicity of frequencies can exist simultaneously on a vibrating string; second, tension is essentially constant over a finite length of the cable; and third, flexural rigidity is small in comparison to tension.

Self-Excited Vibration or Dancing

In this paper we will use the term dancing to mean a self-excited vibration resulting from aerodynamic instability. It is a low frequency, high amplitude oscillation which is more or less transverse to the current flow.

Should the basically circular cross section of the cable be modified to an out of round, elliptical, or quasi-airfoil shape, it becomes aerodynamically unstable at critical values of fluid velocity and angle of attack. Similarly, if streamlined fairings are attached rigidly to the cable with no articulation, the necessary airfoil shape has already been introduced.

When the cable goes into an unstable mode, the resultant of the lift and drag forces is in the general direction of cable motion. With energy being added on every cycle, oscillations can build up from small values to amplitudes of catastrophic proportions. Since the application of force is controlled by the motion of the cable, dancing will synchronize automatically with a resonant frequency of the cable itself.

We are not familiar with the mode form of underwater cable dancing. However the similar phenomenon on ice-coated overhead power lines is visually observable and dancing typically occurs at the fundamental frequency or one of the lower harmonics of the span involved. That is, n = 1, 2, 3, or 4 in equation (2). As an example of the violent motion involved, there have been reliable reports of 50-foot peak-to-peak amplitudes in a 1,400-foot span on an overhead transmission line.

Violent dancing imposes large dynamic tension loads on cables, of course. Also, high levels of bending stress occur at the mouth of cable fittings which are restrained against rotation and cannot follow the motion of the dancing cable.

Force Magnification Through Resonance and Longitudinal Vibration

As just discussed, relatively small excitation forces or motions can excite large amplitudes or forces in the driven member, if that member is excited at resonance. The periodic impulses involved in forced vibration are small. The excitation forces in dancing are larger, but they are still relatively small compared with the violence of the motion they cause. Resonant magnification can occur easily with other types of motion as well, and we will cite a simple example of longitudinal vibration to illustrate the point.

Consider the case of a "spring mass" system in which a buoy anchor is the mass and the underwater cable is the spring. Say the anchor has a net weight of 10,000 pounds. The underwater cable has a net weight of 3.0 pounds per foot and has an effective cross sectional area of 1.0 square inches. The effective modulus of elasticity of the cable is 15×10^6 psi. The line is being payed out for a deep anchorage and has reached a depth of 5,000 feet.

The natural period of vibration can be approximated by the elementary formula:

$$\zeta = \frac{1}{f} = 2\pi \sqrt{\frac{y_s}{g}} \qquad (4)$$

where ζ is the natural period in seconds and y_s is the elastic static deflection, and the other terms are as previously defined,

The value of the static deflection y_s can be calculated by the elementary formula:

$$y_s = \frac{TL}{AE} \tag{5}$$

where A is the cross sectional area of the strength member in square inches and E is the modulus of elasticity in psi.

To account for the distributed mass of the spring in elastic vibration, 1/3 of the total spring weight is added to the suspended mass. Adding 1/3 of this cable weight to the anchor weight establishes an effective cable tension of 15,000 pounds for calculating the static deflection. Using this tension and the previously given values in equation (5) yields a static deflection of 5.0 feet. Using this value of y_s in equation (4) gives a period of approximately 2.5 seconds.

Now, assume that the sea state existing at the time is imparting vertical motion to the ship at the same, or nearly the same, period of oscillation. Resonance of the "spring mass" system would be excited. The vertical displacement of the ship would be greatly magnified at the buoy anchor end of the "spring". In one case of this sort, the anchor weight oscillations were measured and were found to be on the order of 25 to 30-foot peak-to-peak displacements.

At the risk of intermixing actual and hypothetical examples, consider the implication. The tension in the cable depends upon the amount of elastic elongation. For simplicity, assume the relative elongation between ship and weight to be 10 feet at the maximum load condition. If a 5-foot static elongation results in a 25,000-pound cable tension at the ship (anchor and total weight of cable), then 10 feet would produce a 50,000-pound tension. Granted, this is a gross simplification and bypasses practically all of the dynamics involved, but it does serve to illustrate the magnifying effect of resonance.

Magnitude of Dynamic Loads

There is a surprising lack of readily available knowledge regarding the magnitude of dynamic loads in various types of installations. Surprising, because sophisticated and advanced technology is employed in the instrumentation packages contained in present-day buoys and towed vehicles. Instrumentation techniques for the measurement and recording of dynamic motion and force are inherently much simpler than the complex systems used to measure other parameters in the ocean.

From the standpoint of laboratory simulation, it would be desirable to have a convenient source of information regarding the realistic frequency spectrum typically encountered in various types of underwater installations for both forced vibration and self-excited vibration. Realistic values of dynamic tension changes under various circumstances would also be helpful. Similarly, the displacement levels involved in vibration and in dynamic tensioning would aid in the collateral laboratory studies. There are indications that more of this information is now being obtained by those interested in the problem.

COMBINED STRESS AND FATIGUE

Mechanical failure of cables can be attributed to overstressing from static and dynamic forces. Failure can occur, of course, during the first cycle of static, or slowly applied, loading. In field operations, it is more likely that first cycle failure will occur due to the combination of static and dynamic forces. But in either event, failure will occur when axial, torsional, flexural, and radial compressive stresses, acting singly or in combination exceed the critical state of stress of the material. Although the critical state of stress is defined analytically by a number of theories of strength, (e.g. VonMises-Hencky theory), certain complexities and lack of knowledge at this time make application of these theories impractical in the solution of the cable problem.

However, the type of operational failure most likely to be encountered occurs at stress levels well below either the ultimate tensile strength or the critical state of stress of the material for first cycle failure. This type of failure can be broadly classified as fatigue.

Fatigue

Fatigue failures are caused by repetitive fluctuation of stress at levels below the critical first cycle level. The number of cycles that a material can endure depends upon the stress amplitude. Empirical data on the number of cycles is obtained by cycling a specimen at a particular stress amplitude until failure occurs. Then another stress level is chosen, and then another, and so forth. Display of these data, customarily plotted on semi-logarithm paper, yields the well-known S-N curves. The S-N curve, Figure 1, indicates the maximum number of cycles which may be imposed on the material at a particular stress level. Testing is commonly conducted on single wire specimens in a machine which produces equal alternating stresses about zero base stress. The rotating strut machine in Figure 2 is one of the types commonly employed.

Endurance Limit

At lower stress levels, the S-N curve becomes asymptotic to a limiting stress, known as the endurance limit. The endurance limit can be defined simply as the maximum stress level which may be cycled infinitely about base zero without fatigue failure of the material. The endurance limit is indicated graphically in Figure 1. The number of cycles to obtain the endurance limit in testing varies according to type of material. Aluminum alloys, for example, require 500 million cycles as the necessary minimum number.

Endurance Limit Inadequate for Combined Stress

Reversed bending or other completely reversed stress tests are not applicable to combined stress conditions, in our opinion. We believe that it is futile to attempt a prediction of vibration or dynamic life from such data. In one case, we found a 10 to 1 difference in the vibration life of two different materials which had almost identical reversed bending endurance limits.

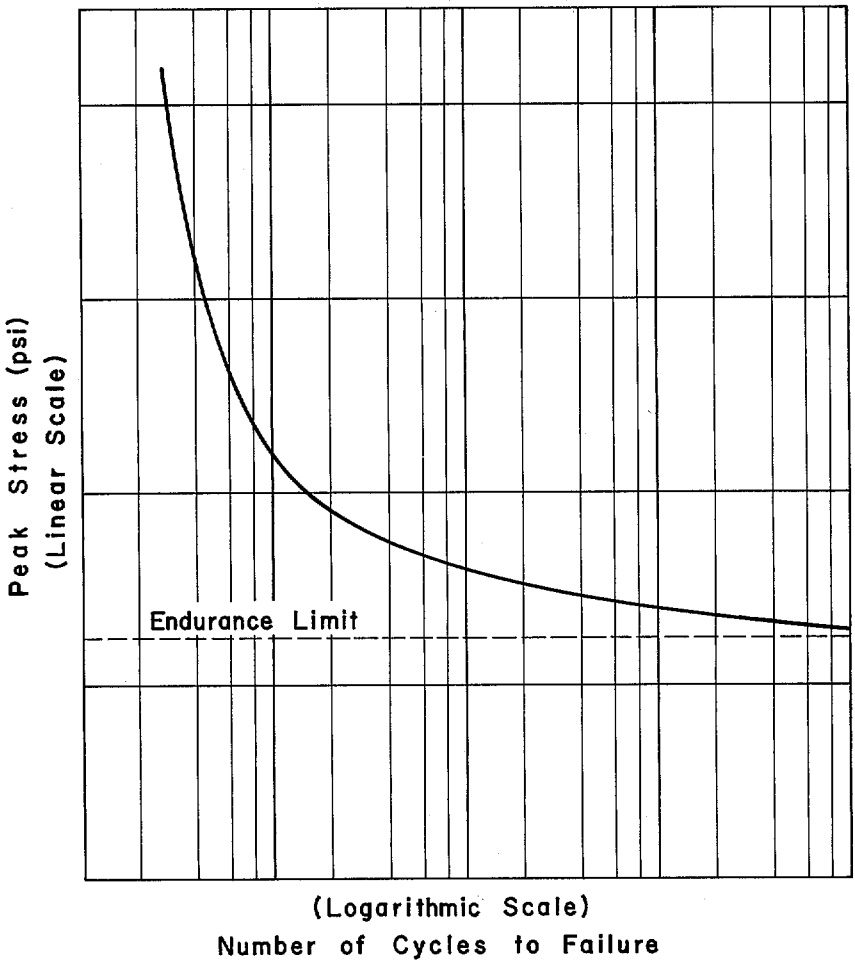

Figure 1. Representation of typical S - N curve. Stress level is plotted against number of cycles to failure for single wire specimen in completely reversed bending. Endurance limit is maximum stress which specimen can tolerate for an infinite number of reversals.

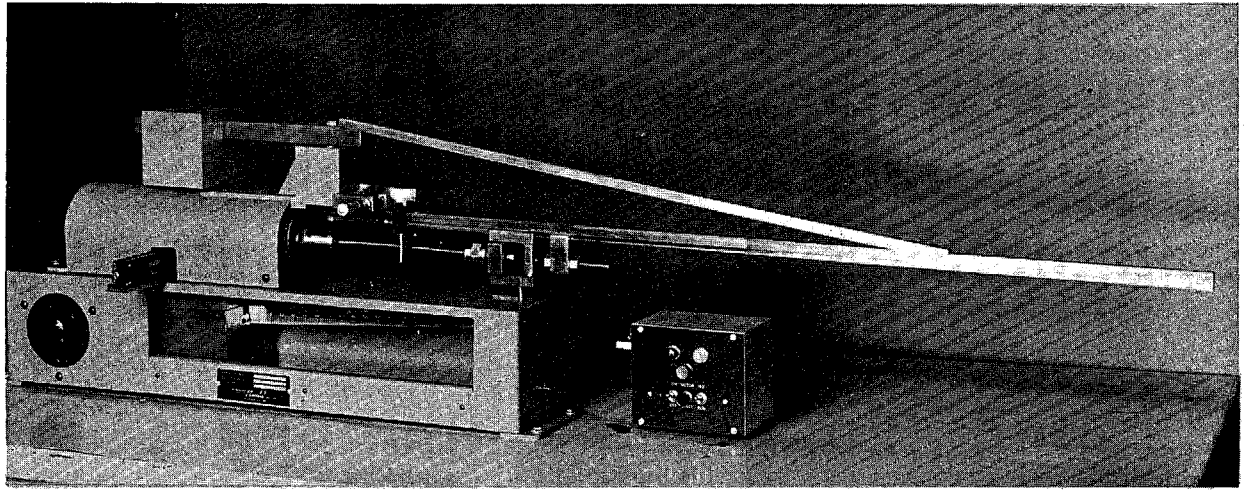

Figure 2. Rotating-strut fatigue machine is used to apply completely reversed bending to single wire specimens. Speeds as high as 12,000 cpm are useful in tests requiring large number of cycles; e.g. 500 x 10^6 cycles are specified in establishing endurance limit of aluminum alloys.

Combined Stress Fatigue Testing

A more realistic method of testing involves the cycling of dynamic stress about a finite stress level. Data from such tests can be displayed on various types of diagrams, including the Goodman-Johnson diagram shown in Figure 3. This is a more logical representation of conditions found in actual practice. The tolerable dynamic stress range decreases as the static base stress is increased. At zero base stress, the tolerable dynamic range is the endurance limit. At the other end of the scale, where the base stress level closely approaches the critical state of stress, the specimen can tolerate little or no dynamic loading.

The state of stress cannot be defined completely for combined loading except for the simplest conditions. While tensile and flexural stresses can be calculated with some confidence, the compressive stresses are less susceptible to analytical solution. Despite this analytical difficulty, the compressive stress should not be regarded lightly. It is of great significance in the combined state of stress and contributes to high levels of localized stress concentration.

In double armored cable for example, the two layers of armor wire are stranded with opposite lay directions. Consequently, the wires of the inner layer make point-to-point contact with the wires of the outer layer. Any radial compressive force sustained by the cable results in higher localized stresses between the individual wires than if the two layers were stranded with the same lay direction and had line contact between wires. This concentration leads to plastic deformation and permanent indentations which constitute stress risers. Then too the possibility of fretting is increased, and in general most fatigue failures initiate at a fretting location. Figure 4 taken from a dynamic test in the laboratory, shows indentation and fretting.

As another example, Smollinger and Siter (Reference 2) conducted tests to determine the effect of compressive stress on the life of steel cable. These tests were conducted in a pulsating tension machine and only two variables were involved — tension and compressive force. Bare cable specimens were cycled at predetermined tension stress levels over selected dynamic ranges. The same conditions were applied to cable samples having a bolted clamp at midspan. Twenty-four specimens in all were tested and the fatigue life of the bare specimen was six times greater than the cable with compressive stress. Damage in Figure 5 is representative of the type of failure which occurred at the midspan clamp.

STATIC TENSION TESTING

A static tension test to ultimate load is commonly the starting point in mechanical tests. The ultimate tensile strength of cable and fittings is a convenient reference point on which to base initial designs and working loads. Such testing is useful in evaluating fundamental mechanical properties of the cable but by no means is it sufficient to permit prediction of cable performance under all loading conditions. It is good practice to test the cable with the dead-ends or terminal fittings that will be used in service. Although failures of the fittings prior to cable failure in static tension tests occurs relatively infrequently, the incidence is high enough to warrant their use rather than special laboratory dead-ending techniques.

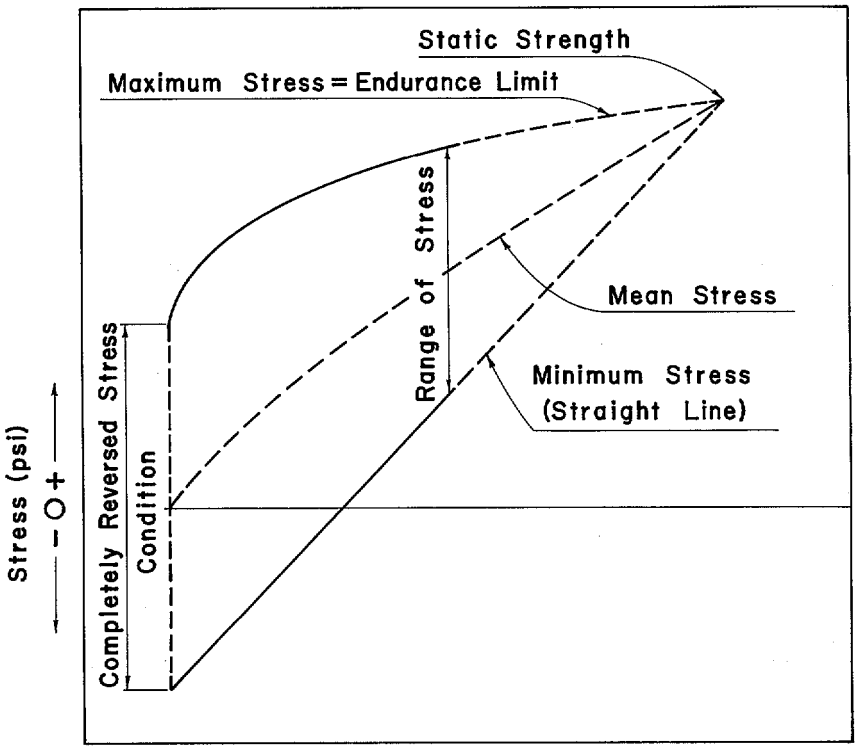

Figure 3. Generalized Goodman-Johnson diagram introduces the parameter of base stress. Tolerable dynamic stress range depends on level of base stress. At zero base stress, the dynamic range is the endurance limit. For base stress levels very near the ultimate strength of the specimen, little or no dynamic stress can be tolerated.

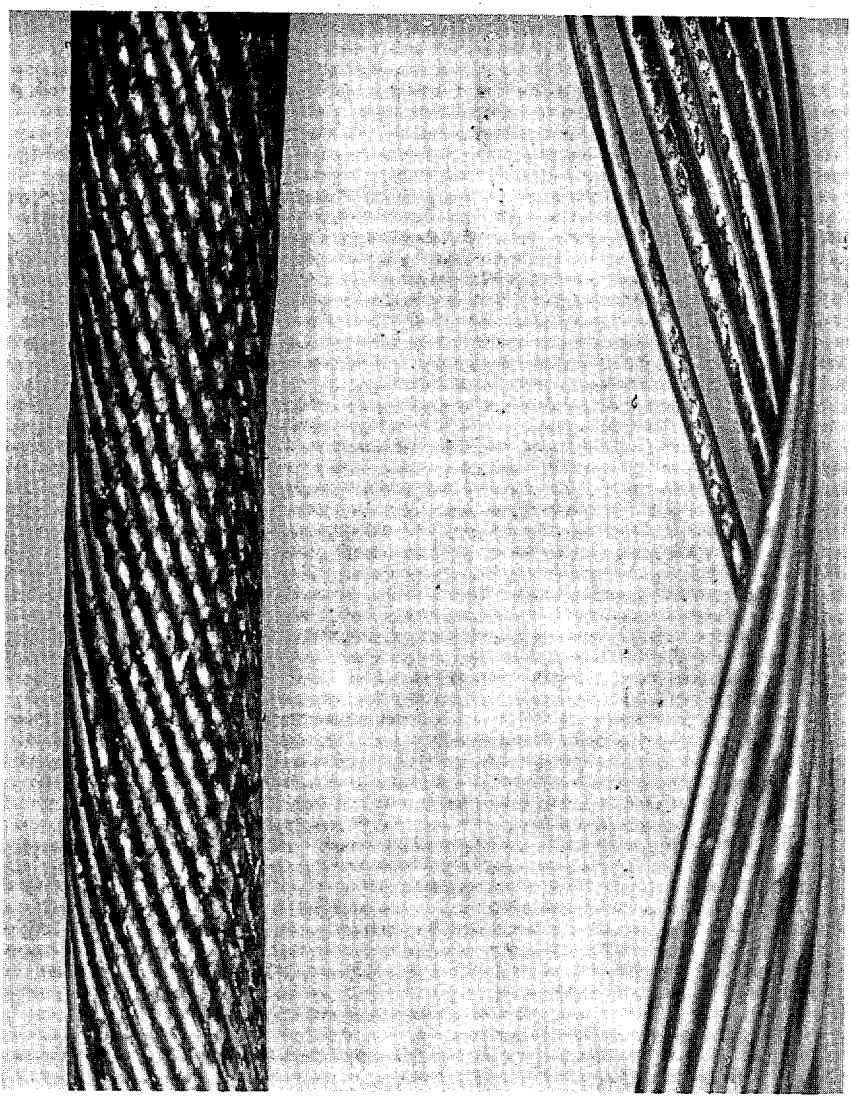

Figure 4. Indentations and fretting of both inner and outer wires result from the repeated passage of a tensioned cable over a sheave. Alternate lay directions of successive layers of wires contribute to stress concentration.

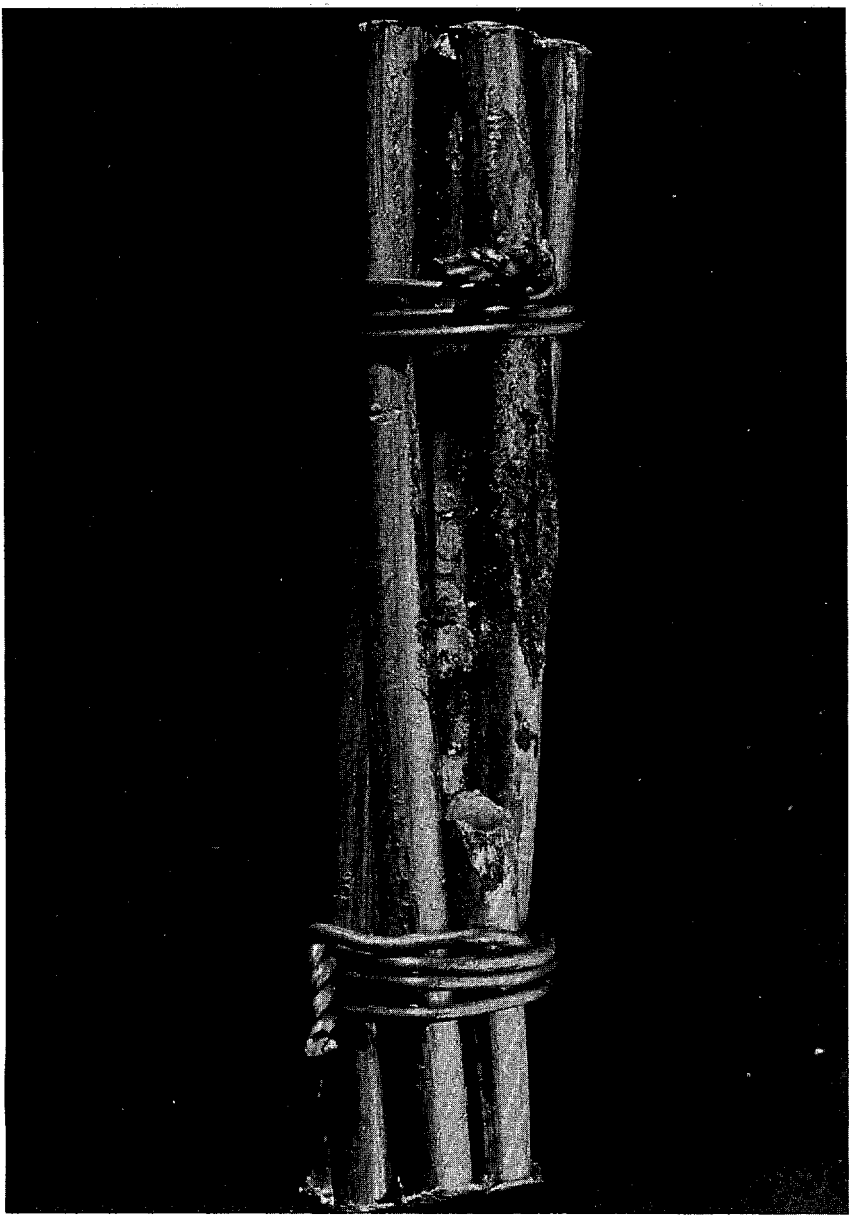

Figure 5. Fretting and fatigue occurred beneath a bolted clamp on a test cable subjected to dynamic tension fluctuations about a selected base tension. Fatigue life of bare cables subjected to same dynamic conditions was six times greater than cables with bolted clamp at midspan.

Aside from cable strength determinations, static tension tests are useful in obtaining load-elongation data that can be translated into stress-strain curves. This information is important in determining the amount of elasticity in a cable and is necessary if the effect of suddenly applied loading is to be calculated analytically.

Most cable manufacturers have static tension machines of the chain puller type with a large throat. The major portion of our testing is carried out on 50,000-pound capacity machines located in Cleveland, Ohio. This capacity can be increased to 100,000 pounds by use of a pulley arrangement. For high-strength cables, we use a 600,000-pound capacity machine with a 90-foot throat; see Figure 6. This machine is located at our test facility in Brooklyn, New York.

CYCLIC TENSION TESTING

Possibly the simplest form of fatigue testing involves the cycling of predetermined tension variations about a finite base tension. See Figure 7, cyclic tension fatigue testing is carried out on one or both of two 50,000-pound capacity machines. These are situated back-to-back in the laboratory and have a combined throat length of 60 feet when operated in tandem configuration. These machines can be preset to alternate at any predetermined interval of tension between 0 and 50,000 pounds. They cycle automatically day and night with provision for cycle counting and for automatic shutoff in the event of specimen failure. The maximum ram speed is 8 inches per minute for each machine. If both rams are employed in a single test, the specimen can be loaded at a rate of 16 inches per minute.

The length and elasticity of the field cable must be taken into account in designing the laboratory simulation. For example, to reproduce the effect that a wave amplitude of 4 feet with a 4-second period would have on a buoy cable 5,000 feet long having a modulus of 15×10^6 psi, a loading rate of 1.20 feet per minute would be required on a 50-foot laboratory specimen of the same cable.

For simulation of actual loading rates involving shallow-moored installations with large displacements, higher speed drive and provisions for mounting shorter specimens between the two rams would be necessary. Both of these equipment modifications can be made fairly readily. The importance of other field input parameters must be recognized. Some estimate must be made of the number of cycles as well as the magnitude of the stress levels that are to be encountered during the service life of the installation. For example, there is no need to attain a cyclic life of 10 years, if the service life is anticipated for only one year.

FORCED VIBRATION TESTING

Our laboratory vibration testing simulates the forced vibration, commonly referred to as strumming, which is encountered underwater. In overhead power and communication lines, the same type of vibration is termed "aeolian". It is a standing wave phenomenon, and, as explained previously, is caused by the flow of fluid across a circular section. The characteristics of strumming are; relatively short loop lengths; high frequency; and small displacement amplitudes, say one cable diameter peak-to-peak.

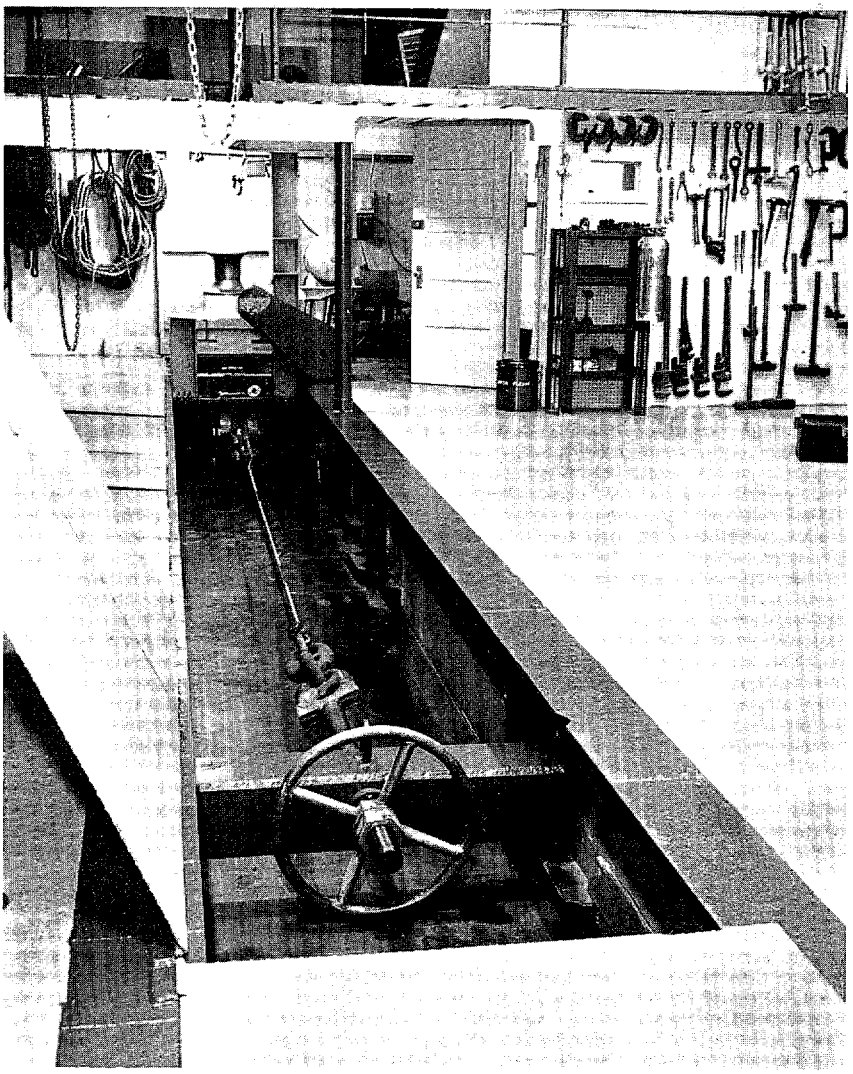

Figure 6. 600,000-pound tension machine uses only small portion of its 90-foot throat in testing dead-ends and splices on small diameter, high strength cable.

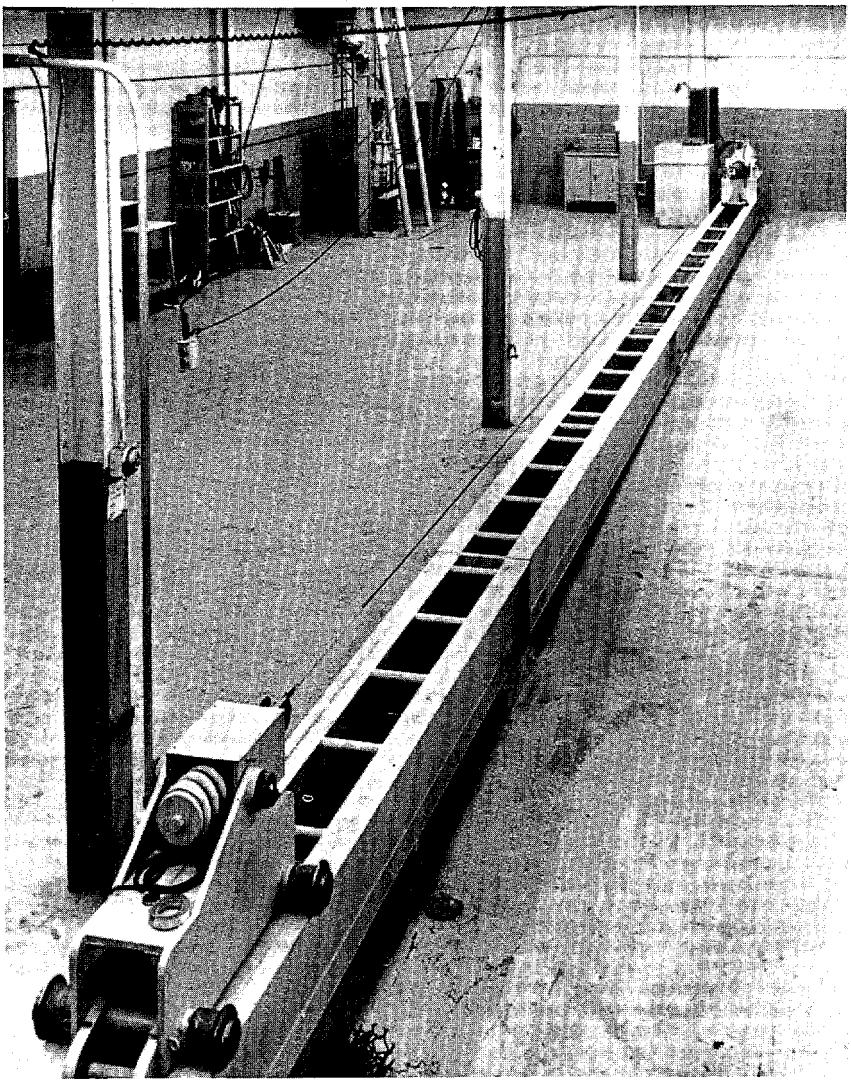

Figure 7. Cyclic tension test of 60-foot specimen of fiberglass cable requires use of combined throat length of two identical 50,000-pound tension machines.

Strumming results in an alternating flexural stress which will cause fatigue at termination devices or other rigid hardware, provided the base stress or alternating stress levels are of sufficient magnitude. The magnitude of the dynamic flexural stress is related to the loop geometry of the standing wave, and is also dependent upon the degree of fixity associated with the termination hardware, the axial tension, and the cable construction.

Laboratory Equipment

Our equipment was initially designed to investigate the effect of aeolian vibration on overhead cables but proved readily adaptable to oceanographic cables. Figure 8a, a line drawing, shows a typical vibration bed and the associated controls used in testing cables in strumming type vibration. Cable is installed between two dead-end structures and is tensioned to a predetermined level, and constant tension devices maintain this tension throughout the duration of the test.

The tension selected is generally the field operating tension of the cable. In establishing the mode of vibration, a frequency must be selected since tension and frequency are inextricably related as shown in equations (2) or (3). The steady-state frequency should simulate a typical field condition, and in the absence of field measurement can be approximated by the use of equation (1).

Resonant vibration is induced in the cable with an electro-dynamic shaker motor coupled to the cable; see Figures 9 and 10. The transverse displacement is controlled by the amount of power delivered to the shaker. Once the desired steady-state conditions of vibration have been established, they are controlled automatically on a 24-hour per day basis through the use of a unique control system combining feed-back circuitry with electromechanical components.

A more complete description of the laboratory vibration facilities — test beds and drive motors, instrumentation devices, and radiographic equipment — is contained in Reference 3.

Instrumentation Techniques

During the test, various transducers such as accelerometers, differential transformers, and strain gages can be used to monitor the flexural strain in the cable. Strain gages are especially suited to the laboratory since direct strain read-out is obtained.

The maximum dynamic strain usually exists at the last point of contact between the moving cable and the mouth of rigid termination hardware. Although it is impossible to obtain strain measurements at this precise location, data can be obtained very close to this point, approximately 1/8 of an inch away, and a strain value close to the true dynamic maximum can be measured. In cases where the cable is made up of small, individual wire elements, such as found in wire rope, the use of strain gages is impractical because of the relative size of gage.

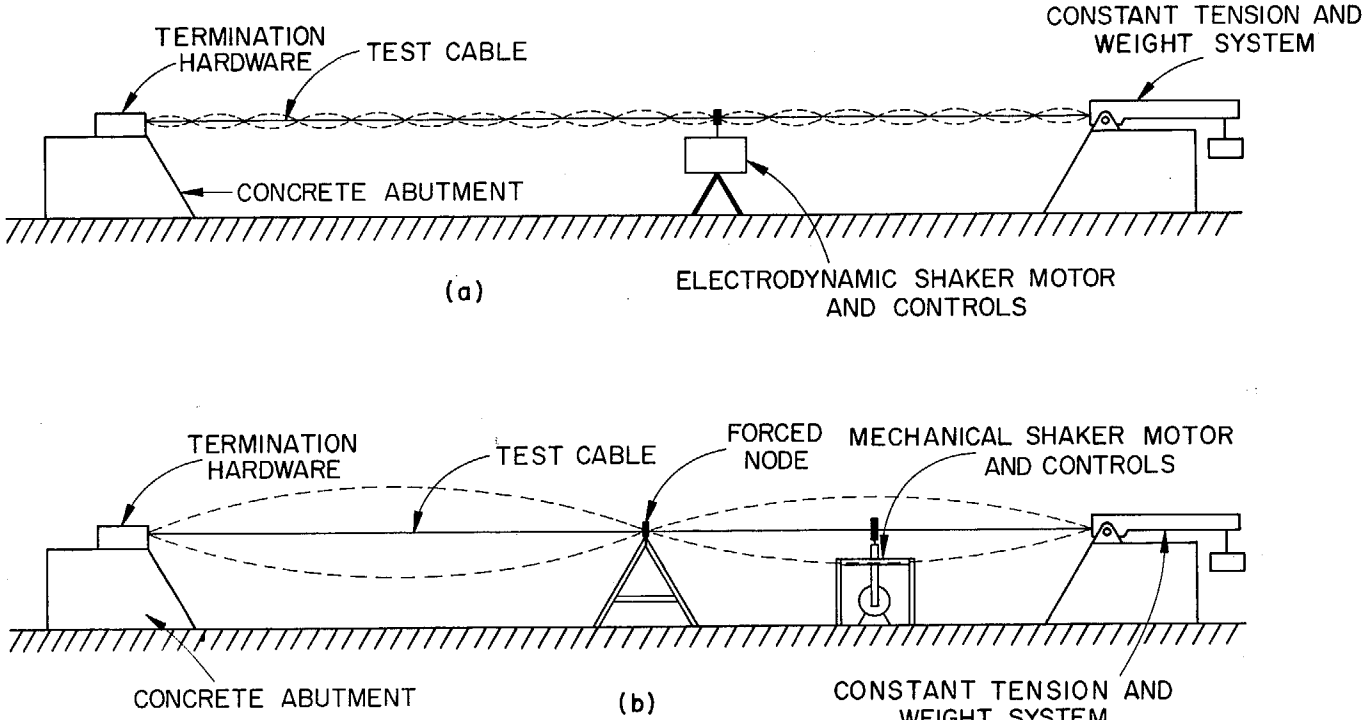

Figure 8. Typical vibration test beds and equipment.
a) Standing wave vibration excited by electrodynamic shaker is characterized by short loop lengths, small amplitudes, and high frequency. Tension loads up to 15,000 pounds are maintained constant for duration of test.
b) Dancing is simulated with low frequency, large amplitude oscillations excited by rugged mechanical drive system.

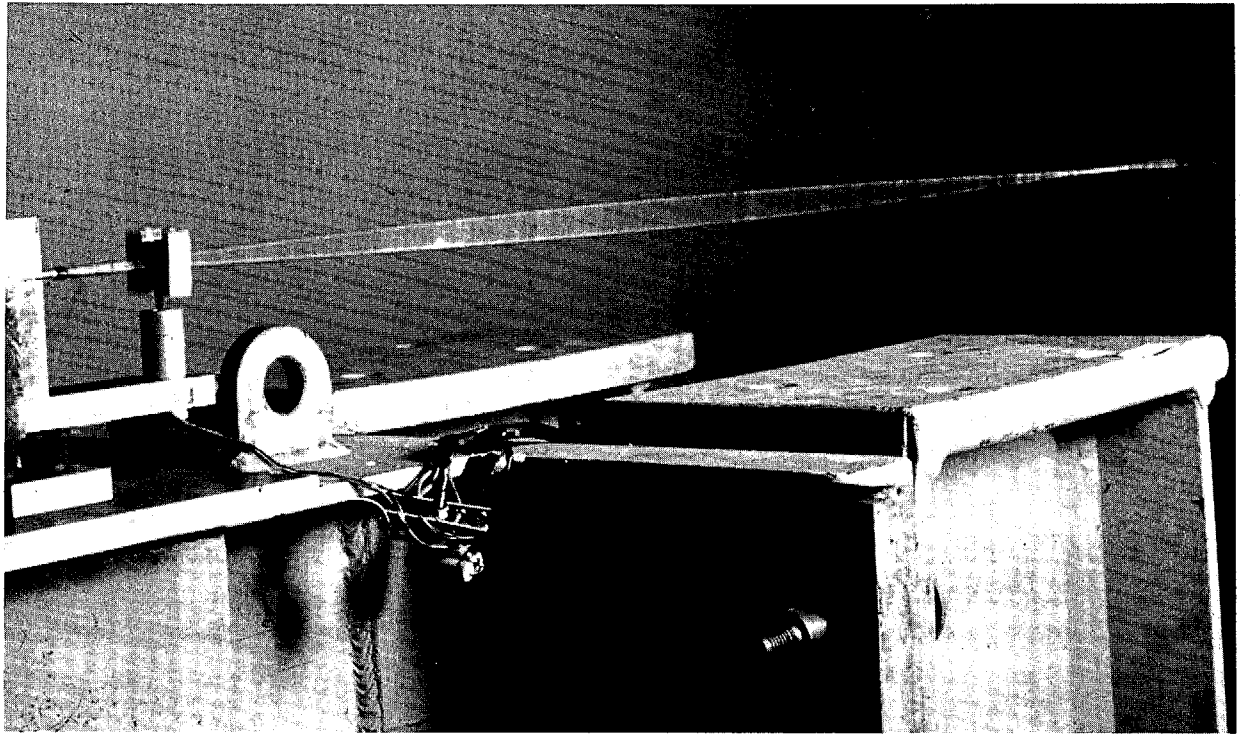

Figure 9. Nodes and anti-nodes are clearly visible in standing wave simulation of underwater strumming. Differential displacement is being measured near mouth of clamp on left.

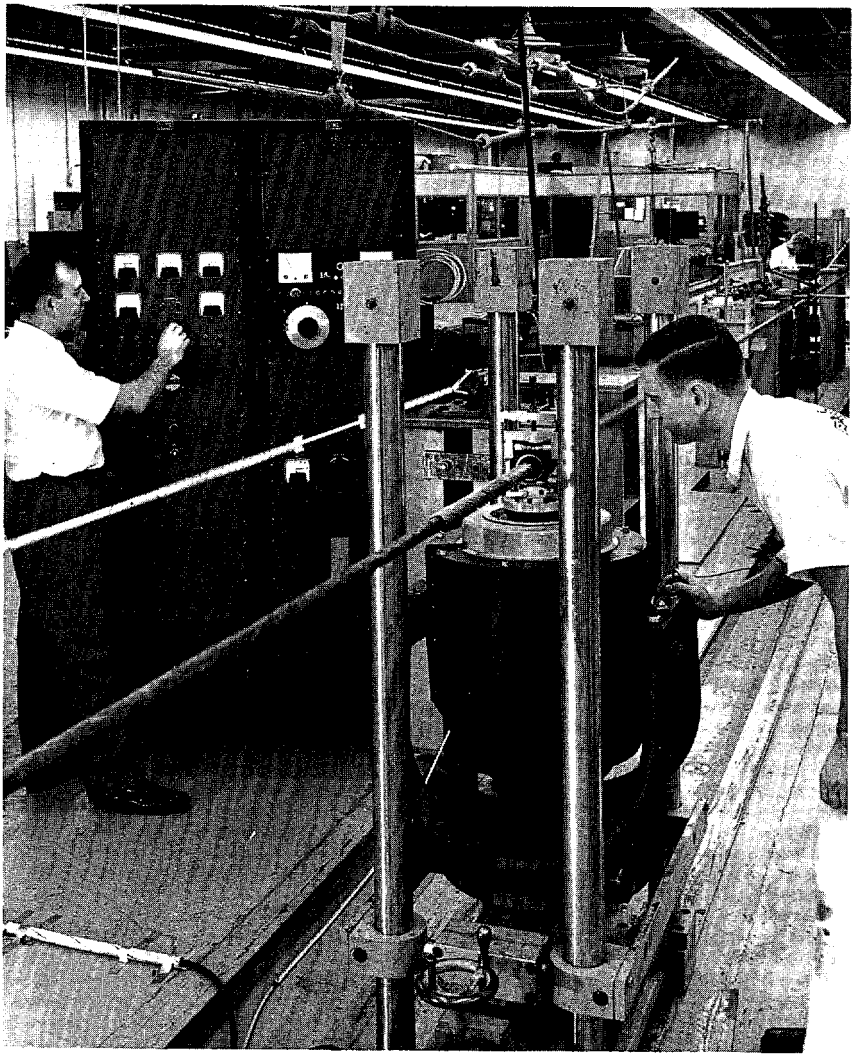

Figure 10. Technicians adjust a high capacity electrodynamic vibration exciter to obtain desired laboratory simulation. Once steady state vibration is established, the conditions are controlled automatically 24 hours per day.

Where strain gages cannot be used, it is possible to deduce the bending strain by amplitude measurements combined with certain analytical relationships. In the laboratory it is possible to set up termination hardware so that it is completely fixed against rotation. In this case, measurement of the peak-to-peak anti-node displacement at the center of the loop can be related to bending stress at the mouth of the terminal fitting by means of an analytical relationship developed by methods similar to those shown in Reference 4. It can be shown that the maximum bending stress at the clamp mouth is given approximately by the following expression:

$$\sigma_o = \frac{\pi\, y_m\, E_w\, d}{4j\,(\ell - 2.57j)} \qquad (6)$$

Where:

σ_o = single amplitude stress at mouth of clamp, psi
y_m = peak-to-peak amplitudes at mid-loop, inches
d = diameter of individual wire, inches
ℓ = loop length, inches
j = $\sqrt{EI/T}$
EI = composite flexural rigidity of cable, inches^2-lbs.
T = cable tension, pounds
E_w = modulus of elasticity of individual wire, psi

From this it can be seen that the stress is a function of the loop length, the anti-node displacement, the modulus of elasticity and diameter of the individual wire, the composite flexural rigidity of the cable and — somewhat surprisingly — the square root of tension.

Now in actual practice, the terminal hardware has some degree of joint freedom. Unless the degree of freedom is known without doubt, measurements of anti-node displacement are virtually meaningless in stress calculations. But another method of deducing stress through displacement measurements is available. It is the differential displacement method and involves measuring cable displacement close to the mouth of the hardware while taking the clamp rotation into account automatically.

In this method, the rotation of the dead-end body is accounted for by attaching a rigid deflection arm to the dead-end. The displacement probe is mounted at the end of the arm a short distance from the mouth of the clamp, approximately 3 or 4 inches. Since the displacement measured is the arithmetic difference between the absolute cable displacement and the rotational displacement of the probe at the end of the deflection arm, the technique is called the differential displacement method. The cable displacements are small, close to the clamp, and the probe used should be able to measure to .001 inches.

The rigorous derivation of the relationship between differential displacement and dynamic strain involves transcendental relationships and hyperbolic functions. Valid approximations simplify these relationships to a form that can be handled by the slide rule. These derivations and simplifications are contained in Reference 4. The approximate value of bending stress at the mouth of the clamp in terms of differential displacement is given by the following expression:

$$\sigma_o = \frac{y_a d E_w}{2j^2 (e^{-a/j} - 1 + a/j)} \quad (7)$$

Where

j^2 = EI/T
a = distance from mouth of clamp to displacement measuring station, inches
e = 2.71828
y_a = differential displacement, inches

The bending stress is still proportional to the modulus of elasticity of the wire under consideration, the wire diameter, and the intrinsic relationship between flexural rigidity and cable tension. Also, the bending stress is directly proportional to the differential displacement. But in contrast to equation (6), the length of the loop does not enter into the relationship.

Inspection for Failure

Since strumming can cause fatigue of cable elements at termination hardware and the instrument package, frequent inspections must be made in laboratory tests. Visual and radiographic techniques are used to determine wire failures.

Radiographic inspections are especially helpful in determining the existence of inner layer failures on multi-layered cables as well as failures within the body of the termination hardware itself. In Figure 11, radiographic equipment is set up for a routine inspection during a laboratory test of an overhead power cable. Figure 12 shows a photograph of a radiographic negative taken of double armored wire which had undergone forced vibration testing; several inner wire fatigue failures are in evidence. These show up on the reproduction as short dark lines.

In some instances it is not possible to obtain good definition in the radiographs in shooting through steel clamps, particularly if those clamps are thick walled. To circumvent this obstacle to reliable inspection, we have at times placed strain gages on each wire of the cable while making up the dead-end assembly. Monitoring the gages will indicate when individual wires fail with reasonably good accuracy. However, this technique is time-consuming and expensive in setup.

SELF-EXCITED VIBRATION TESTS

To review briefly, dancing is caused by aerodynamic instability and generally results from having a non-circular cable cross section. Dancing is typified by relatively large amplitudes, long loop lengths, and low cyclic frequency. Associated with dancing are high tensile forces which can result in catastrophic damage in a comparatively short period of time.

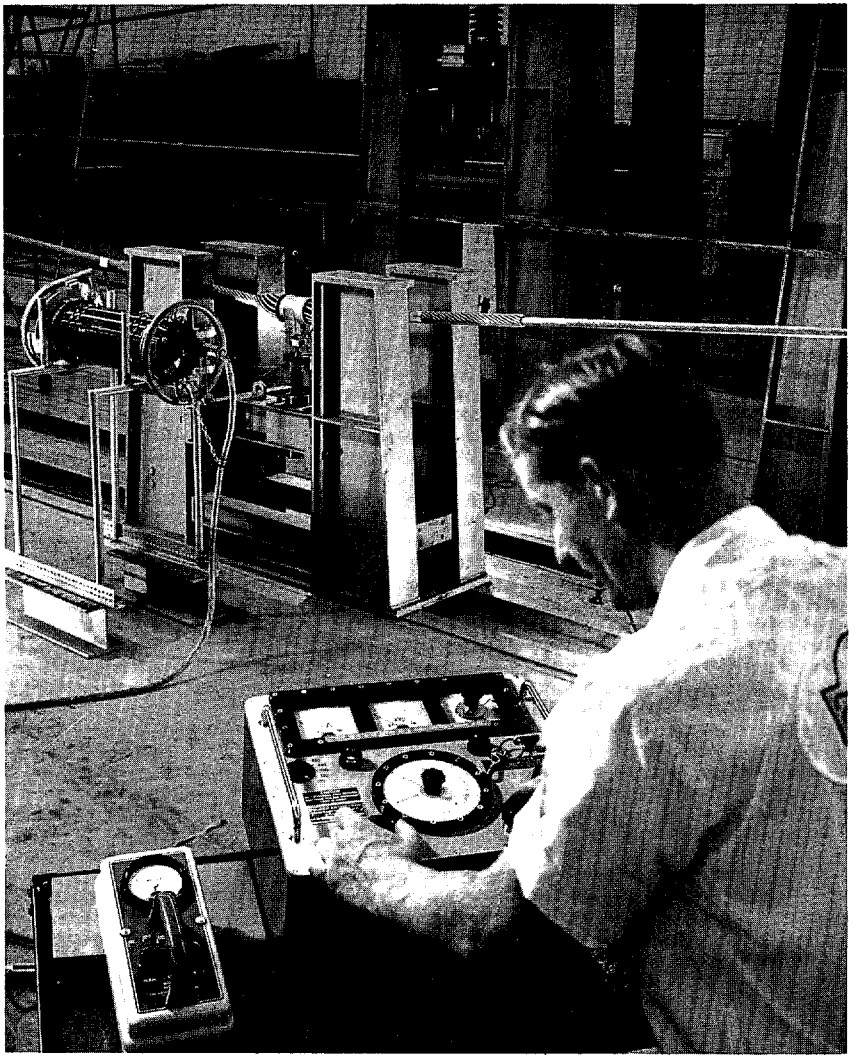

Figure 11. Radiographic inspection is needed to determine the condition of inner layer wires in multilayer cable. Initial fatigue failures generally occur in wires of the inner layers.

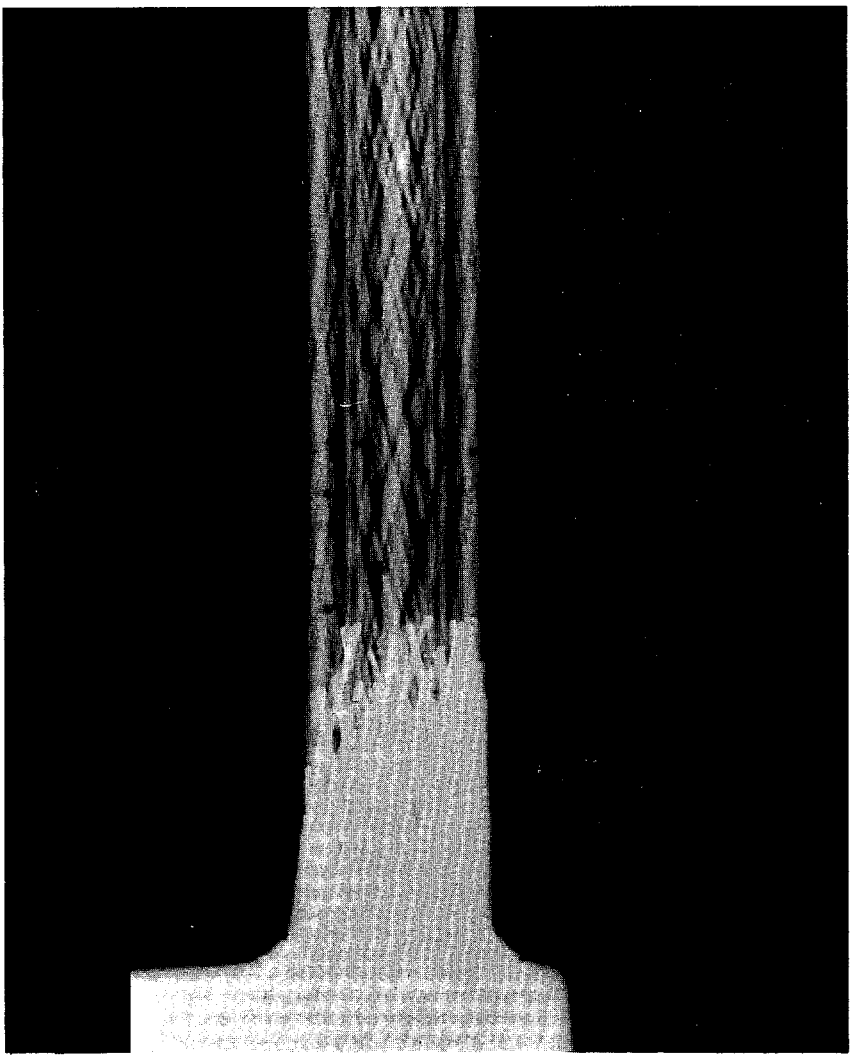

Figure 12. Radiograph reveals fatigue fractures resulting from laboratory vibration tests. The width of the short, dark lines shows that fractured wires have separated slightly.

Laboratory Simulation

Dancing is simulated in the laboratory on a scale basis as far as loop length and amplitude are concerned. These parameters are chosen to produce the same bending stress at the termination hardware as encountered in field applications. Since the bending stress is proportional to the curvature of the cable in the area of support, scaling is primarily a matter of duplicating the amplitude-loop length ratio found in the field. Unfortunately, the mode of underwater dancing is not as well known as its counterpart on overhead lines, and test conditions have to be based on considered judgment for the most part.

Once the test parameters are established, low frequency resonant vibration, usually the fundamental frequency of the laboratory span, is induced in the test cable through the use of a specially designed mechanical shaker. Figure 8b is a line drawing showing a typical dancing test with important test equipment. Figure 13 is a time exposure of a dancing test on a power cable and the peak-to-peak envelope of cable oscillation can be clearly seen. The high dynamic stresses associated with the violent motion result in failures occurring rapidly. Serious abrasion is often incurred in this type of testing and this accelerates the failure.

The instrumentation employed is generally similar to that previously described, except that the use of instruments which could be damaged by the violent action of a dancing cable should be avoided. Stroboscopic illumination is often used to study the relative motion between components between the test specimen and is especially helpful in visually pinpointing troublesome areas.

CYCLIC IMPACT TESTING

Tow cable and buoy cable are typically exposed to shock loading due to the erratic motion of the surface objects which are at the mercy of the sea. Travelling waves which are set in motion on undersea cables must be absorbed and reflected at termination fittings; this can result in repetitive impact loads of constant magnitude at termination hardware if regular trochoidal waves are assumed.

Test Machine

Figure 14 is a schematic drawing of the test machine used to simulate cyclic impact loading. Figure 15 photographically shows this same test equipment. Test specimens are installed between a stationary support and the free end of the boom. The free end of the boom is raised by an automatic pneumatically operated piston to a desired height and dropped; the result is a damped cyclic impact load on the test specimen. The magnitude of the impact load may be adjusted to the desired level by adjusting the weight of the boom, varying the height the boom is dropped, or changing the angle of the test specimen in relationship to the boom.

Instrumentation generally consists of a load cell which is installed in series with the test specimen, strain gages placed on outer cable wires, and appropriate display or read-out equipment in the form of a storage image oscilloscope, and light writing or pen recorders. Figure 16 is a typical display of cyclic impact loading produced by a pen recorder.

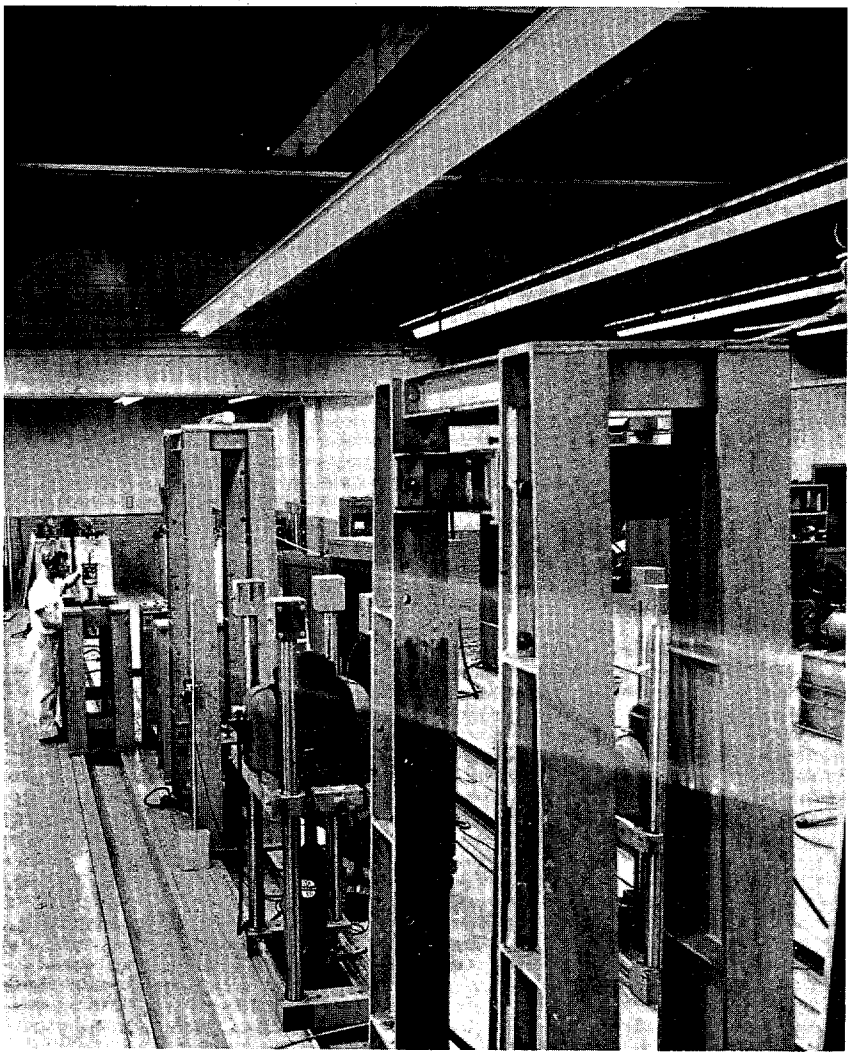

Figure 13. Envelope of oscillation is clearly visible in test simulating field conditions of self-excited vibration. High dynamic flexural and tensile stresses are associated with dancing. Failures occur rapidly and are accelerated by abrasion.

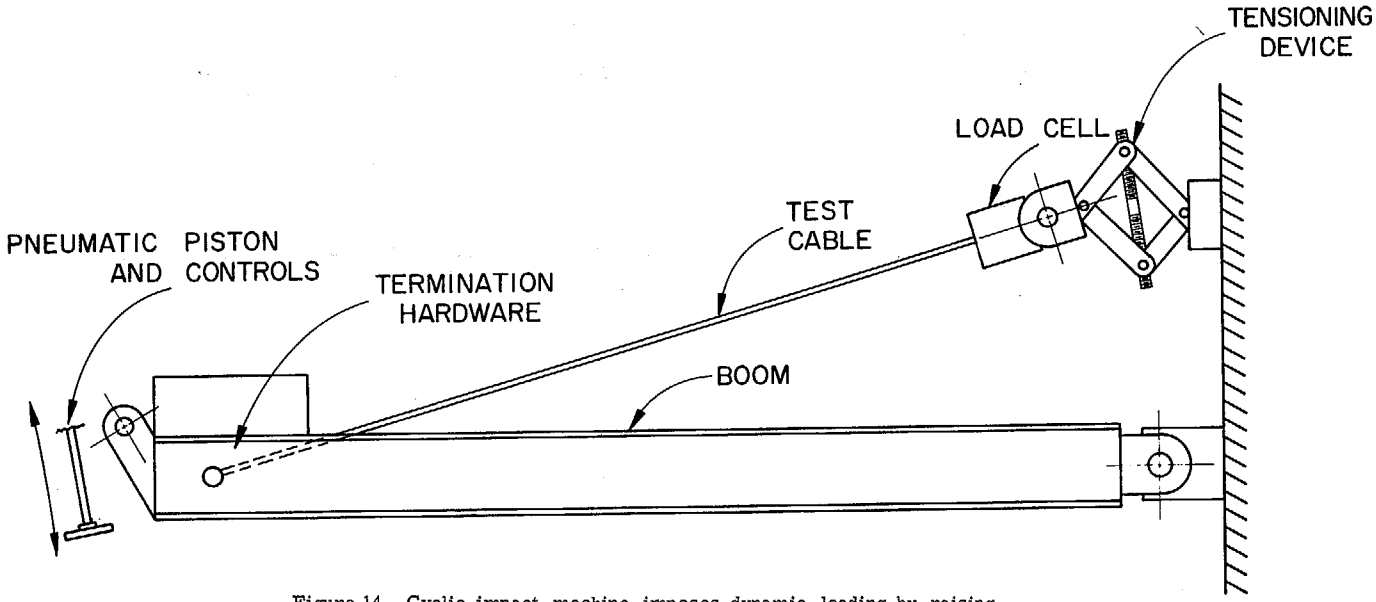

Figure 14. Cyclic impact machine imposes dynamic loading by raising and dropping a weighted boom supported by test specimen. Reaction load depends on height of drop, weight at end of boom, and angle between specimen and boom.

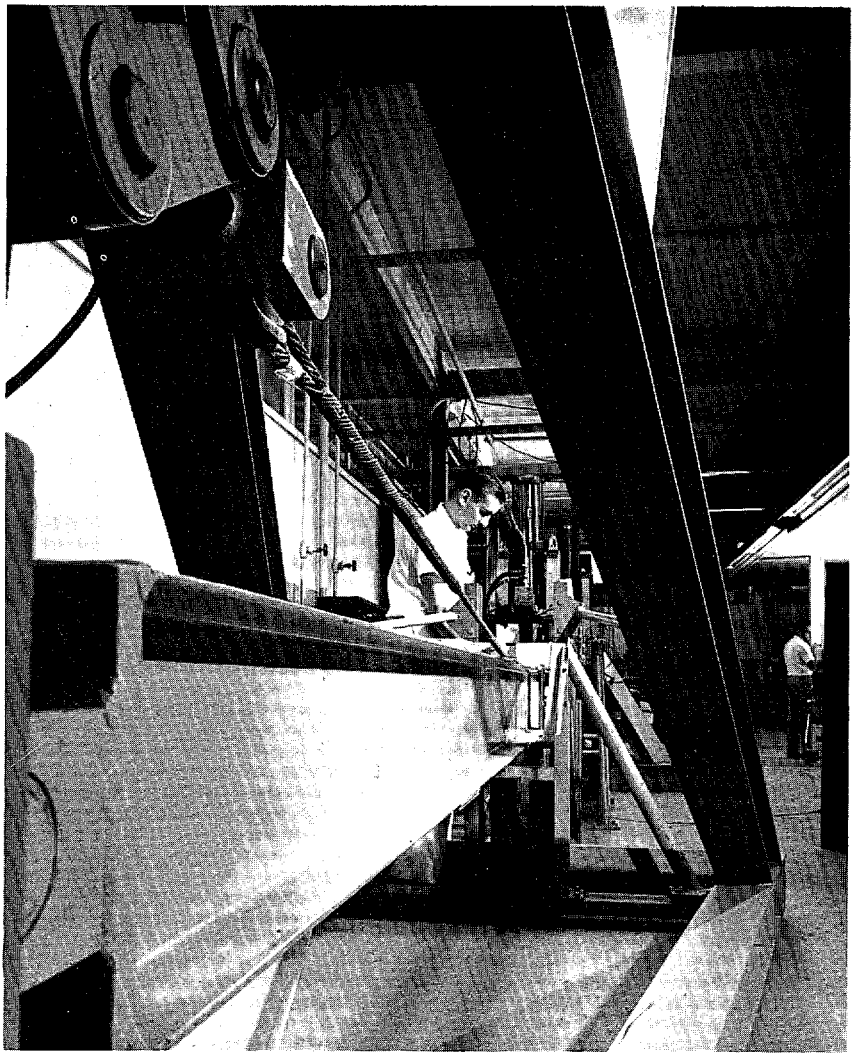

Figure 15. Severe shock loads encountered on underwater cables can be simulated. Machine is designed for 50,000-pound specimen reaction. Operating rate is 8 beam drops per minute.

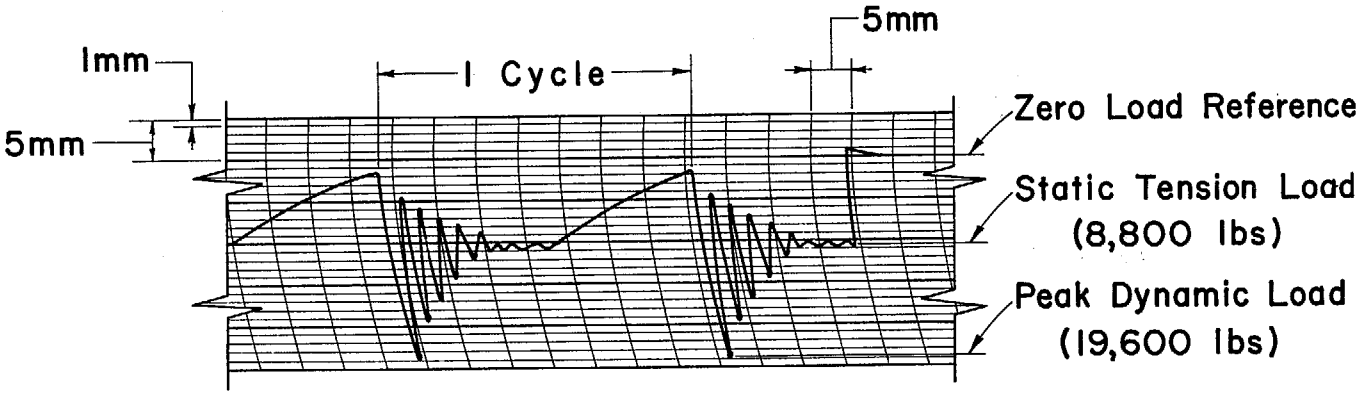

Figure 16. Copy of oscillographic trace from typical cyclic impact test shows several lower level oscillations following first impact of boom drop. These are attenuated by coulomb damping prior to boom being hoisted for the next drop.

HIGH ENERGY IMPACT TESTING

Our activities in the overhead line industry have led us to evaluate the effect of high energy impact on cables and cable hardware. Common causes of high energy impact loading are: collison between vehicles and structures or guy wires; fracture of cables due to ice loads, fatigue, or electrical burndown; and collapse of towers from structural overload.

In the oceanographic field high energy impact loads may arise from the sudden seizing of pay-out gear, the snagging of instrumentation packages on the ocean floor, high sea states, snap loads, or other circumstances.

Laboratory Tests

The purpose of the high energy impact machine, shown schematically in Figure 17 and photographically in Figure 18, is to investigate the effects of this type of loading on cables and cable hardware. In this machine a typical test specimen is installed between a fixed head beam and a load reaction platform. The loading mechanism is simply a freely falling mass dropped from a predetermined height. Once established, the desired input energy can be obtained by adjusting the height of drop or by the amount of weight on the drop platform, or both. Here again, knowledge of the field loading condition and cable elasticity is necessary for accurate laboratory simulation.

Instrumentation and Data Read-Out

Force measurement is obtained by a load cell installed in series with the test specimen. Through the use of a stored image oscilloscope or a light writing oscillograph, wave form and peak values can be recorded. The loading patterns can be studied to compare rate of loading, the effects of specimen elasticity on the loading rate, the maximum load a specimen can withstand under impact loading, the damping coefficient, and the energy absorption characteristics of cable and termination hardware.

Figure 19 is a photographic copy of stored impact loading traces obtained in comparative tests. The lower trace was obtained from an impact test on a solid steel bar. It can be compared to the upper trace obtained when a wire rope specimen was tested with a similar amount of energy input. Immediately apparent in this data are the differences in rise time (loading rate) which is a measure of the relative elasticity of the two test specimens.

SHEAVE AND CABLE TESTING

Damage arising from the passage of cable back and forth over sheaves has been a long term source of concern in wire rope usage, particularly where working lines are involved as in elevators or boom hoists. More recently, the advent of tension stringing machines in the overhead power industry has brought realization that a detrimental state of stress can be produced in power cables by passing them over sheaves in the tensioned condition. Essentially the same problem is prevalent in the oceanographic field.

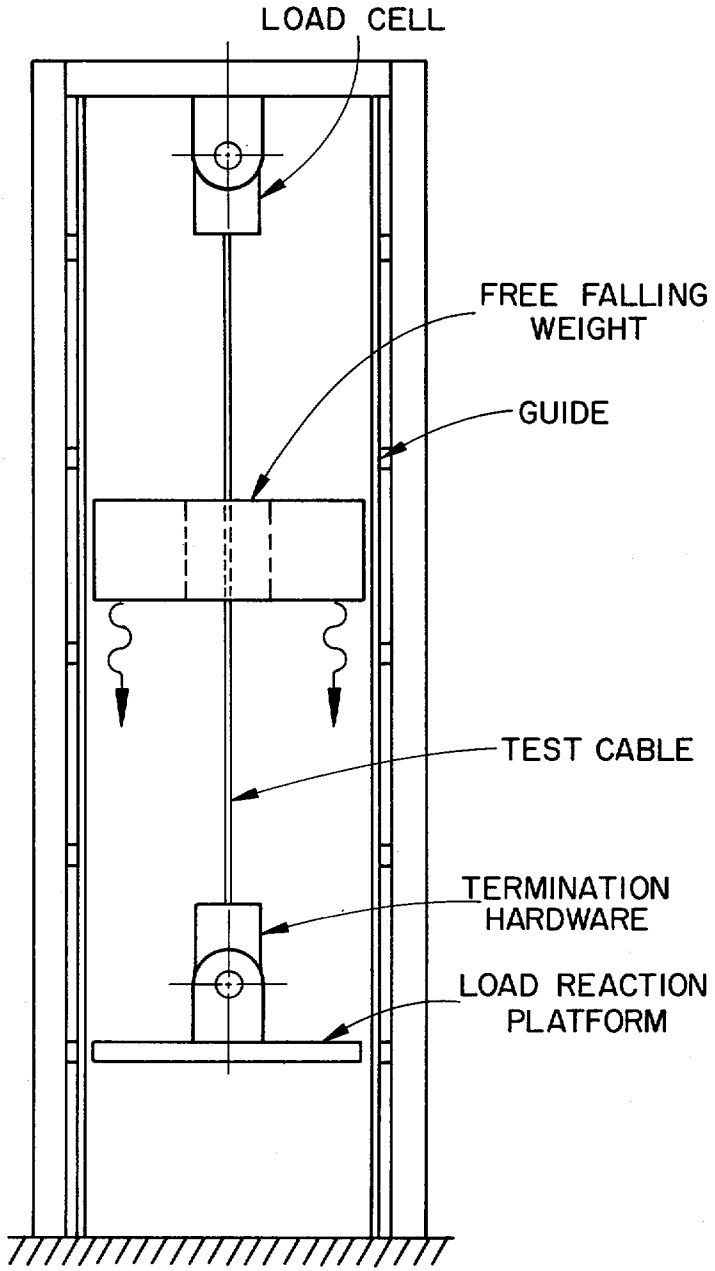

Figure 17. High energy impact load results when weight table is dropped from predetermined height onto a reaction platform supported by the test cable. A load cell connected in series with the test specimen measures impact reaction force.

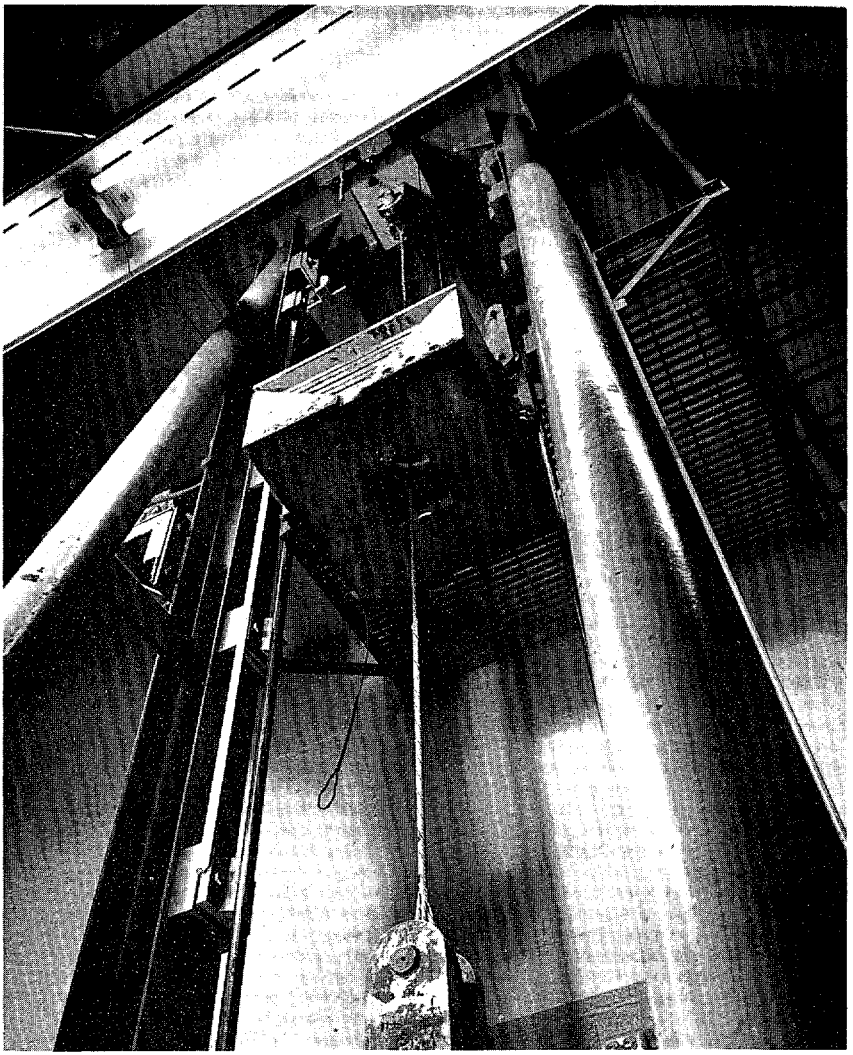

Figure 18. High energy impact machine was designed to develop reactive loads up to 100,000 pounds. Impact load in specimen depends upon height of drop, mass on weight table, and specimen elasticity.

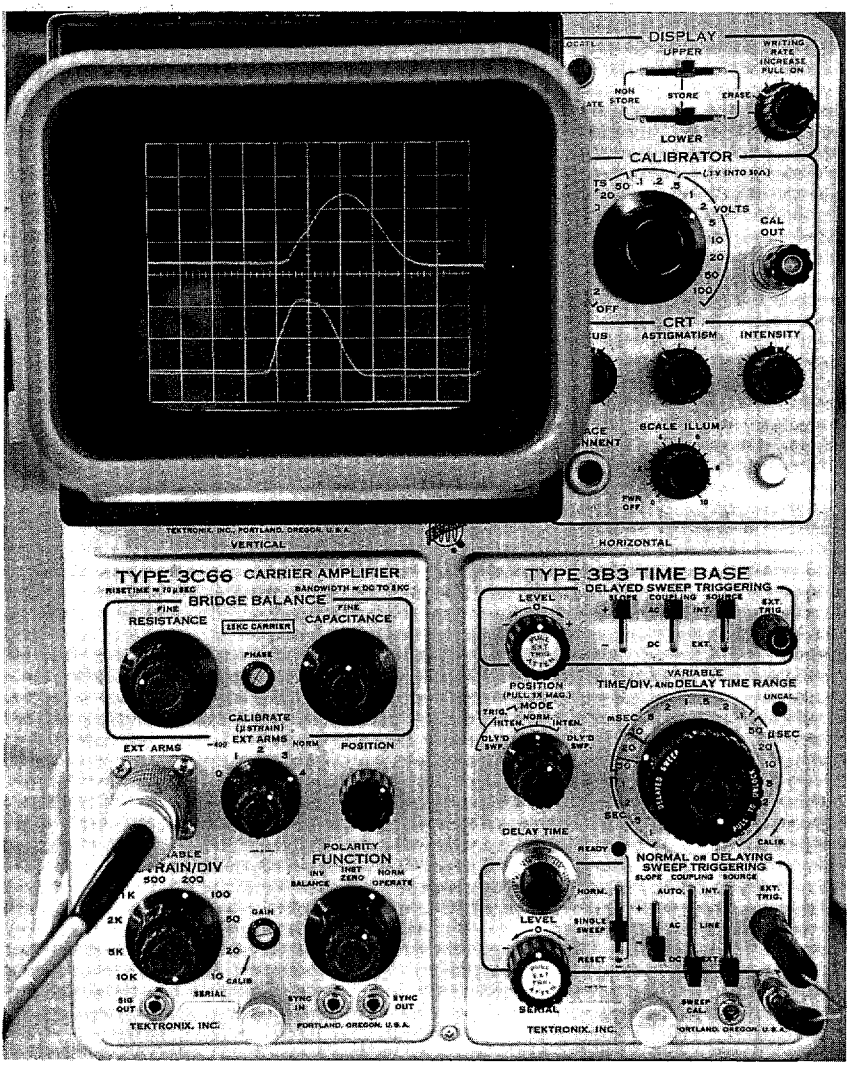

Figure 19. Stored image oscilloscope trace of two tests with same energy input. Upper trace is record of wire rope test. Lower trace with faster rise time is record of test on more rigid, solid steel bar.

Laboratory Testing

The sheave-cable testing machine shown schematically in Figure 20 and photographically in Figure 21 is designed to investigate sheave and cable variables which affect the service life of cables. In this particular machine, cable is installed over the test sheave or sheaves and brought to the specified tension by means of a turnbuckle in series with a load cell force indicator. Through use of an automatic pneumatically operated system, the cable is cycled back and forth over the test sheave at the specified frequency. It is a relatively easy matter to change out cable, alter cable tension, adjust the angle of wrap, and to change sheaves to study the effect of groove and radius parameters.

Although this machine has no provision for varying tension on a controlled basis during a given test, equipment for modulating the tension while the cable cycles is now being designed.

Sample Testing

Figure 22 shows the condition of an aluminum based power conductor after termination of a preliminary test to develop the relationship of tension to the life of the cable during sheave passage.

This test incorporated the following test conditions:

Cable	19-wire construction 18-.1368-inch diameter aluminum wires 1- .1368-inch diameter steel wire
Wrap Angle About Sheave	90°
Tension	2,156 pounds, (25% of ultimate)
Sheave Diameter	41 times cable diameter
Sheave Groove Radius	Compliant with cable diameter
Sheave Groove Material	Hot rolled steel

It is interesting to note several incipient areas of tensile failure in existence on one aluminum wire; these areas correspond to points where the cross sectional area has been reduced due to the compressive loading against the inner layer of cable wires. The result of the reduction in cross sectional area are high localized tensile stresses which are obviously detrimental to the cable.

CONCLUSIONS

1. Dynamic loading of underwater cables can occur in many forms. Whether the loading is serious enough to lead to cable or cable fitting failure depends on the type of underwater installation, the type of cable construction, and the nature of the operating environment.

2. Controlled laboratory testing offers the possibility of comparing the mechanical performance characteristics of alternate designs of cables and fittings in advance of field operation.

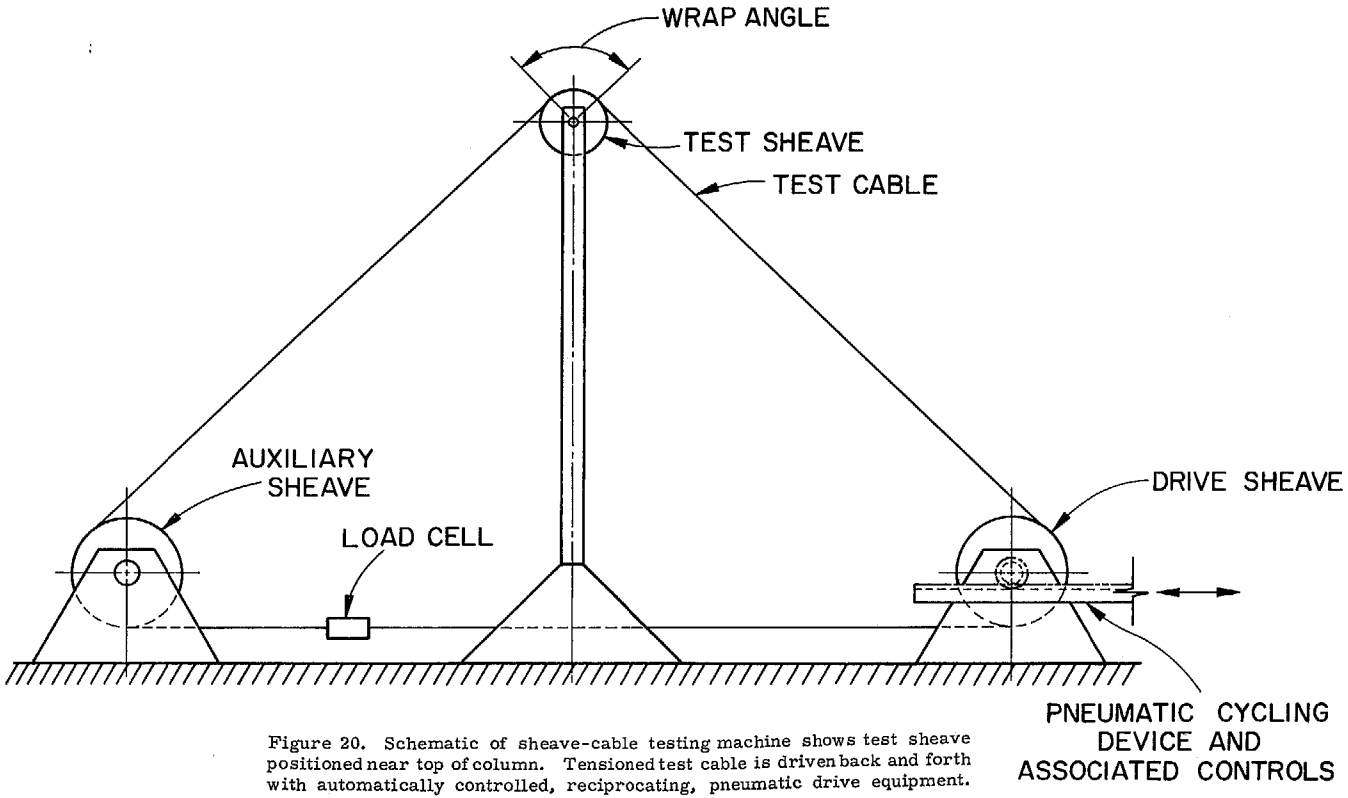

Figure 20. Schematic of sheave-cable testing machine shows test sheave positioned near top of column. Tensioned test cable is driven back and forth with automatically controlled, reciprocating, pneumatic drive equipment.

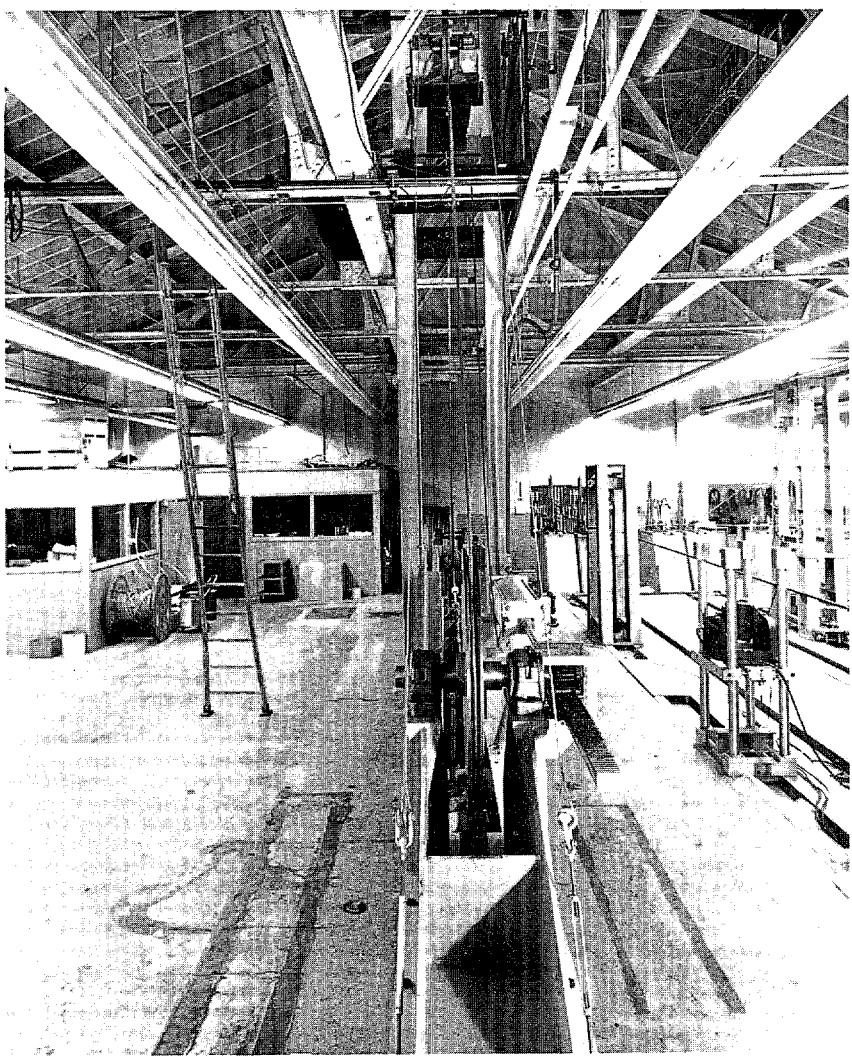

Figure 21. Test sheave and cable can be readily changed. Elevation of sheave can be varied to reproduce desired angle of wrap. Test variables include: cable tension, sheave diameter and groove radius, and groove lining material.

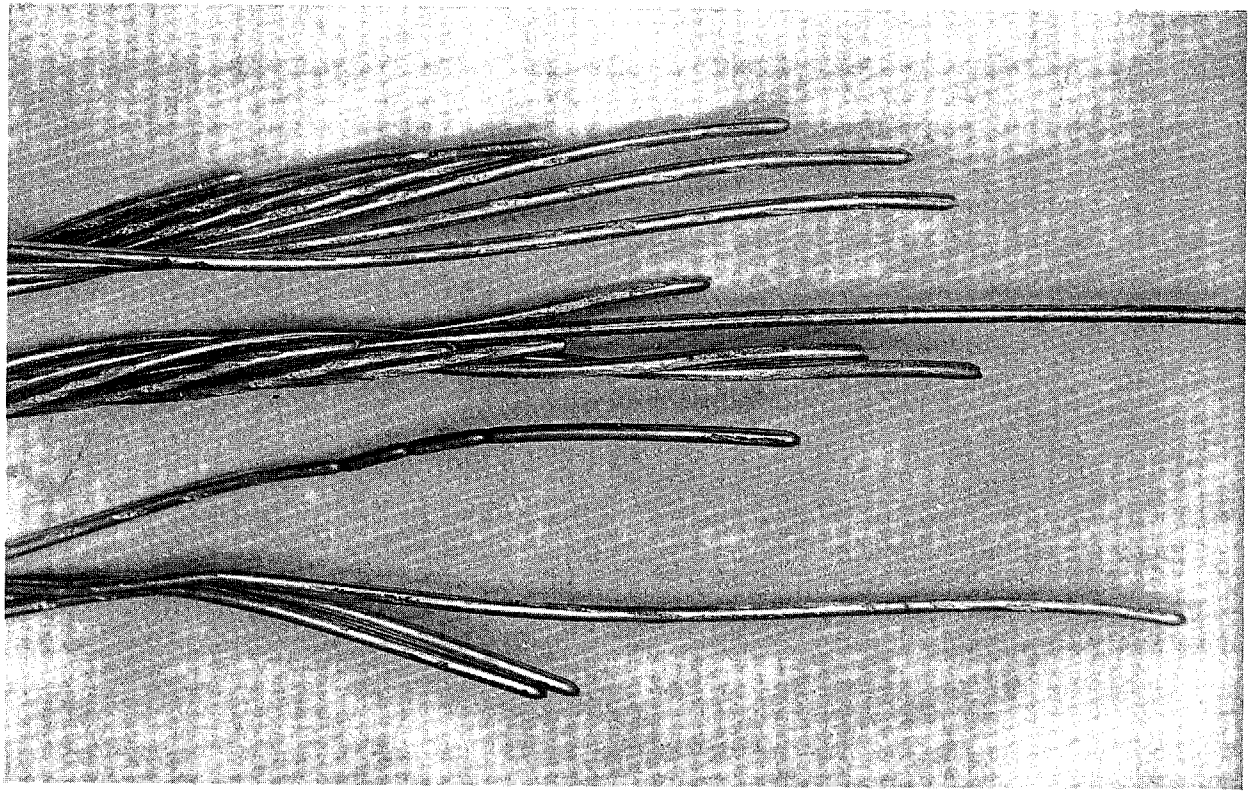

Figure 22. Aluminum wires in composite cable failed in sheave-passage test. Compressive indentation and severe fretting clearly visible. One wire has necked down at several locations.

3. Methods of testing which simulate various dynamic conditions in the field are currently in use. Extension of equipment and refinements in technique will be incorporated as the state-of-the-art advances.

4. To exploit fully the laboratory capability for dynamic testing, more knowledge must be acquired concerning realistic levels of pertinent parameters that are typical of specific installations in the field.

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Man in the Sea and Fisheries of the Future

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Abstract

The ability of man to live and work in the sea can lead to new or expanded utilization of bio-marine products. Production conceivably will pass through three evolutionary phases. The initial and today financially feasible phase will be the increased exploitation of high value resources: luxuries, delicacies, and pharmaceuticals adaptable to small scale harvesting operations requiring little or no culturing. Solution of legal problems and the discovery and growth of new markets including the support of new undersea establishments will lead to the second phase - the expansion of existing culture methods. Finally, the most promising future seems to lie in the establishment of large-scale farming operations in the sea. Vital to the success of these operations are undersea research facilities where studies in rearing, breeding, pest-control, in short all the processes that have made terrestrial agriculture what it is today, may be carried out with economically suitable marine organisms.

INTRODUCTION

There is little reason to doubt that the next few years will see man's occupation of the continental shelves. What will, in part, motivate this occupancy is the theme of this conference - Exploiting the Oceans. This extended capability to live and work in the sea will influence the exploitation of living marine resources. How this may happen is the theme of this paper.

Exploitation is an unfortunate word. Exploitation applied to fisheries implies the use of ocean resources with little regard to other than immediate monetary gain. With few exceptions this has been the historical fate of fisheries. Fortunately, there has been an increasing awareness that fishery resources are not limitless, and that the management and culture of marine organisms can have important economic advantages. These advantages will outweigh short-term profits taken without thought of continuing utilization. If, however, one is guided by the practices of the past it seems likely that the first commercial ventures to use man's extended submergence capabilities will be directed toward maximum profit in as short a time as possible. This type of venture is possible right now through the application of some of the new techniques to existing fisheries. These first commercial ventures will be followed in the next 5-10 years by attempts to increase and sustain production of certain marine resources through the application of culturing methods. These attempts to culture organisms in the deep sea will stimulate and in turn be aided by research made possible through the establishment of manned submarine laboratories. The knowledge

gained from such underwater research centers would eventually have a profound effect on the fisheries of the future. Many of the problems that will influence this pattern of development are apparent today. Consideration of some of them will serve to point out the difficulties that face man-in-the-sea-type fishing operations.

FISHERIES OF THE IMMEDIATE FUTURE - LIMITED EXPLOITATION

In fisheries, diving has been a method used when no other method would do the job. Diving is not productive in terms of yield per man hour. It is uncomfortable, hazardous work and divers expect a high return for their effort. Because the method is not very productive the resource harvested must have a high value per unit. Diver produced products amount to only a minute fraction of the total yearly landings of fishery products. The output is aimed chiefly at the luxury market. There is little reason to suppose that the new advances in diving technology and physiology will change this emphasis from high-value, low-yield products to low-value, high-yield products. Instead, we may expect, in the near future, a continued production of the traditional items with perhaps an increase in some products that previously occurred at depths too great for full exploitation, and perhaps the exploitation of some new products which have recently been found to be of value.

The traditional diver-produced items have been shellfish, shell and pearls, sponges, coral, algae, and small quantities of fish and invertebrates for local or exotic markets. With few exceptions the annual production of these products has been on the decline. Changing tastes and lower cost synthetics have made most of these fisheries unprofitable. The extension of time and depth now possible through saturated diving and lock-out habitations and vehicles may revive a few of these fisheries.

The red and the black precious corals, when properly engraved, at one time were popular jewelry items. The sources of coral were chiefly the Mediterranean Sea and the seas of the Orient. These corals are deep-water species, the best growth occurring at depths in excess of 150 feet. Diving for coral in the past has been necessarily restricted and most harvesting was done by boats using drags and nets to break off and catch pieces of coral. Production was limited to a few thousands of pounds of coral a year worth $10 to $20 a pound. Although its popularity is not great, and the world market could easily be saturated, it does appear to be an item together with pearls, the other sea gem, that could be gathered profitably from small lock-out submersibles.

The same is true of sponges and some invertebrates that have apparent pharmaceutical value. Ectyonon from sponges, Holothurin from sea cucumbers, and Paolin II from some mollusks are promising drugs that will require a constant supply of raw material until they are synthesized.

Shell collectors pay well for rare specimens. The Glory-of-the-Sea cone, of which less than 2 dozen have been collected, sell for $500 and up each. Many of the rarer shells were dredged from deep water that is now accessible to divers. Once these and other shells are found in quantity and are no longer rare the price will drop rapidly, unless of course, conchologists increase in proportion to the world's population.

FISHERIES OF THE NEAR FUTURE

The above are some ways for man in the sea to make money fast from biological resources. All are possible today and require a minimum investment in both time and money. A larger investment in time and money is required to culture and harvest marine organisms. There have been several efforts

to do this in the past, some have been highly successful such as the oyster and clam industries but these have not been true deep-sea farms. Others such as sponge farming, which in the Bahamas met with disaster in the form of a disease, have not been pursued in recent years.

There are a number of obstacles to cultivating marine organisms in commercial quantities. The most pressing is the legal question of establishing rights to a certain area of the continental shelf. Until this is decided there is little likelihood that any serious investments will be made in such ventures.

Even when the legal aspects have been solved the number of different organisms adaptable to culturing will be extremely limited for a number of years to come. Mariculture, the raising and harvesting of living marine products, to be economically successful requires the selection of a valuable product, knowledge of its growth needs, choice of a suitable locale, the ability to propagate the organism, the ability to control predation and disease, and the establishment of harvesting, processing and marketing facilities. These are all the problems faced by terrestrial agriculture transplanted to a difficult environment and complicated by a tremendous void in knowledge and practical experience. Taken in order the magnitude of these problems becomes apparent.

Selection of a Valuable Product

In this country, marine products are consumed as luxury items and gourmet foods, convenience foods, or used in manufacturing processes and agriculture. Marine products are not the chief source of our dietary protein nor are they likely to become so in the near future. With the exception of the luxury items chiefly shrimp, lobster, crabs, oysters, clams, scallops, other invertebrates, and a few fishes, the price to the producer, the fisherman, is very low. The harvesting of low-cost fishes covers vast areas of ocean and the yield in pounds per fisherman must be very high if a profit is to be made. The bulk of the catch is used for other than human consumption. The price to the fisherman for these fishes is on the order of 1¢ per pound. These species are not attractive subjects for mariculture. Of those species of fish used for human consumption a few bring more than 20¢ a pound and might be worth culturing. These values should be weighed against the price to the fisherman for invertebrates such as shrimp and lobster at better than 50¢ a pound.

Growth Needs

Most of the valuable marine organisms take several years to reach marketable size. The rate of growth depends to a great part on favorable oceanographic conditions that are poorly understood and even more difficult to control. The most valuable food fishes are carnivorous which means that their nutrient requirements will be a problem. Most of them are several links removed in the food chain from plants, the primary source of energy. Each link complicates and increases the cost of feeding the animal. Since these fishes are of a comparable monetary value with livestock and take longer to grow, it is difficult to imagine marine fish farming in the U. S. competing successfully with beef, pork, and poultry. However, the demand for sea food is increasing, partially as a result of successful promotion on the part of the industry, partially as a result of population growth. This increase in demand has resulted in an increase in value of some fishery products and may in time, coupled with a decrease in ocean fish stocks make fish farming more attractive.

Some fishes of potential value and many invertebrates are herbivores which should reduce the cost of production. Others feed on detritus or plankton which might be supplied through local enrichment of the water. These organisms which include abalone, sponges, the milkfish, some crabs, shrimp, bivalve mollusks, and some marine mammals, all have proved suitable subjects for cultivation.

Choice of Locale

All organisms have certain requirements for optimum growth. The choice of a site for an undersea establishment must consider the physical requirements of the animal with respect to temperature, salinity, available light which in some areas will limit the depth of the station, and a suitable surface or enclosure to contain the animals. A surface in the case of bottom dwelling forms may be artificially constructed or be an improvement of the natural bottom. In the case of organisms with high light requirements the surfaces might even be submerged rafts moored in deep water. Should the animal be an active swimmer, enclosures of some sort would be required. These might be fences or nets, curtains of air or perhaps electrical barriers. An intriguing possibility is the establishment of captive stocks in the hot water plumes offshore from proposed nuclear power plants. Cooling water from these plants may be expected to create pools of water several degrees warmer than the surrounding ocean. These pools might be stocked with tropical or semi-tropical species that could not cross the thermal boundaries of the pool.

Propagation

Many valuable marine animals undergo complicated and protracted larval development. The problems of rearing from egg to adult are great. Most successful culturing methods depend on natural growth through the larval stages, the organisms then being collected by providing a suitable bottom or surface on which the pre-adult can settle. The efficiency of this method could obviously be greatly increased were it possible to carry the larval stages through under controlled conditions or perhaps develop ways to shorten or eliminate some of the steps. This is an area in need of considerable research.

Predation and Disease

Predation losses in the sea may be expected to be highest during the early growth of the organism. Control of predators at this time in the life cycle will be very difficult unless hatching and rearing are carried out under artificial conditions. Once the organism has reached young adulthood the predators usually are sufficiently obvious that they can be controlled by physical or chemical means. (Grab the spear gun Henry the sheepshead is in the lobster hutch again.) Disease is a more serious problem. Some may be related to changes in the environment, others to cyclic changes in population densities, still others may be introduced through contamination. A disease can quickly wipe out a crop as has happened to the sponges in the Bahamas, oysters in numerous locations, the pearl oysters in the Gulf of California and other fisheries. Prevention and control of disease among marine organisms is still very poorly understood.

In the case of bottom dwelling forms this will probably be a job for divers or vehicles. Burrowing animals may be harvested electrically. Fishes may be rounded up using porpoise, men, nets, submarines, bubbles, electricity, even explosives. Processing the harvest may be done on the site and some of the by-products used for feed or fertilizer. It is doubtful whether it will be economical to establish sub-sea canneries and freezing plants, although this has been done for surface fisheries.

The sad state of fresh-fish markets in this country today is due in part to the lack of an assured supply of fish to meet fluctuating consumer demands. The establishment of stock-pens in the sea would allow orders to be filled on a day-to-day basis. Fresh fishery products might then become more prevalent in the large food-chain retail markets. The rapid turn over then possible would largely eliminate the many smelly, antiquated fish stores that have done little to help the popularity of sea foods in this country.

FISHERIES OF THE FUTURE

Mariculture depends ultimately on knowledge about the sea and its creatures. Most of this knowledge we do not have today nor are we likely to have it in the next few years. The greatest economic contribution that man in the sea can make to fisheries will be research. Scientific diving has been in existence for only a few years and its impact on biology has been remarkable.

The problems mentioned in connection with mariculture can be solved in the laboratory and field but the laboratory should be near the field - it should be in the sea. Laboratories on the continental shelves would be outstanding facilities for studying those problems that are difficult to simulate ashore. A laboratory complex extending from near-surface to depths of several hundred feet might be established either on a steeply sloping shore or as a series of tower complexes each with working surfaces and locks at various levels. A facility of this type would extend from the shelf up into the mixed layer and would simplify the study of a number of problems in marine biology. It would assure a continuous supply of sea water and nutrients and *in situ* conditions, so difficult to reproduce in shoreside laboratories, would prevail.

Those resources that apparently are not suitable for mariculture still may be assisted through the application of new knowledge gained by underwater observation and research. The improvement of fishing gear, in particular nets, has been aided in recent years by observation by divers, by manual sleds and submersibles, and at greater depths by cameras and television. Observations on the behavior of fishes at sea as opposed to their behavior in aquaria has been limited to date. In the future such observations should be possible for extended lengths of time and to much greater depths. Undoubtedly such observations will solve many perplexing problems that have limited the efficiency of some fisheries.

More important still, such observations may suggest ways to optimize the harvest of many marine resources. Aside from political considerations which often result in unrealistic measures, conservation of fishery resources tries to maximize the yield by controlling the size of the animal at capture and tries to limit the amount of the catch to a figure sustainable by the exploited population. The design of fishing gear that permits small fish or breeding stock to escape unharmed is a problem that may be solved through the study of fish behavior and fishing gear operation. Man's extended submarine capabilities make such observations feasible.

One of the most fascinating future possibilities is the use of marine animals as work animals. Training of porpoise and fishes may result in sub-sea "sheep-dogs" to tend fish schools and run errands. Some species of fish school with whales and porpoise. Recent successes with trained, free-swimming porpoise suggest that they might be used to lead schools of fish into nets or traps. Perhaps killer whales can be trained to ride herd on their commercially important cousins, the whale-bone whales. Here, incidentally, is a source of red meat from the sea that can be produced faster than the land can produce beef or pork. A blue whale doubles its birth weight in about a week, it grows from 2 to 20 tons in 6 months - about 200 pounds per day. Whales are a resource sadly in need of intelligent management today and perhaps some husbandry in the future.

The impact of man in the sea on fisheries will probably be slow, but eventually monumental. Diving technology has advanced much faster in this case than has fishery biology. The eventual economic contribution of man in the sea to fisheries may be far greater than the contribution of man in the sea to the exploitation of other marine resources. Fisheries, remember, can be renewable, inexhaustible resources if they are properly managed. This proper management can only come about through knowledge of the sea and its creatures. This knowledge can be gained by man in the sea.

MARINE PROTEIN CONCENTRATE

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Abstract

Alarming population gains in a world already grossly deficient in animal protein make it mandatory that we attend immediately to our oceans as the vast, self-replenishing, and inexpensive source of protein we know it to be. Unlike wheat, corn, milk, and eggs, fish has largely been consumed, fresh or preserved, only in a form closely resembling the raw material. Methods that are presently used in most protein deficient areas to preserve fish are inefficient and result in products that are largely ineffective in nutrient return. Efficient methods of preservation must be devised to permit the massive and effective use of fish as a protein concentrate suitable for incorporation into foods of lesser nutritive value. Since the protein concentrate will be incorporated into other foods, it is neither necessary nor desirable that the product retain even a semblance of the raw material. The problems involved in the manufacture of concentrates from fish are complex. They are not, however, unsurmountable. Through the application of science and engineering, as in the research program of the Bureau of Commercial Fisheries, they can be solved. The prize for their solution, while unassessable by financial and economic yardsticks is rewarding beyond the reaches of the imagination.

INTRODUCTION

In Macy's History of Nantucket we find that a group of persons in 1690 was standing on a high hill observing whales spouting and sporting when one pointed to the sea and observed: "There is a green pasture where our childrens' grandchildren will go for bread." The idea is far from new that population stress would some day compel us to exploit the sea for a significant supply of critical food--although some startling facts tempt us to believe otherwise.

I am told that the First Annual Conference of the Marine Technology Society contained not one specific and directed report on the need and value of our marine resources for food. I am told by marine biologists that only 10 percent of our annual marine fish potential is being harvested. I am told by many fishermen that nearly 50 percent of their catch is discarded at sea. I have been told that there are enough fish in the sea to supply annually all the animal protein needs of between 15 and 30 billion people.

How can we reconcile this food waste when we know that protein malnutrition presently stunts the health, vigor, and mental capacity of nearly two-thirds of the world's population. How can we reconcile the relative inactivity to exploit marine food when we know that during the next 40 years our world population will double. And agriculture cannot be counted on to solely fill the gap. In 40 out of 60 developing countries, we are experiencing a continuing decreasing per capita production of agricultural products. Except for a few of these countries, there is no evidence that this agricultural trend will reverse. Unfortunately, too, vegetable proteins, which are the world's principal source of this important nutrient are low quality and need

supplementation with animal protein to permit decent nutrition. In ordinary market form, animal proteins (if, in fact, enough were available) are prohibitively expensive for all but a small fraction of the world's population.

What is needed is an animal protein, available in enormous quantities and at low cost. Protein from the sea offers one practical solution. But, the nature of the product must be such that it can be stored, shipped, and marketed at normal temperatures throughout the world and yet retain high nutritional value. The product must also be available in a form that can be readily introduced into a wide variety of traditional food products, to ensure that it will find its way into the diets of the peoples who need it.

Such a product we call marine protein concentrate.

I should wish to briefly relate the background story of marine protein concentrate so that we might gain the proper perspective before going into the various research problems of producing product.

THE STORY OF MARINE PROTEIN CONCENTRATE

The story of marine protein concentrate begins with some problems and concepts in the utilization of fish. The story then traces the long history of some efforts to produce satisfactory concentrates from fish.

FISH UTILIZATION

Our knowledge that fish hooks were among the earliest forms of money suggests that fish played an essential role in the early existence of man. We know, of course, that fish spoils more rapidly than other protein foods such as meat, so that methods of preserving fish must have always been critical.

The processes of preservation developed to inhibit the growth of microorganisms and the digestive breakdown of fish tissues have been quite limited in number. In fact, drying, smoking, salting, pickling, cooling, freezing, and canning nearly complete the list. But more importantly, all these processes seem to follow man's desire to preserve his food supply in a form closely resembling that of the original raw material. This desire together with the problems of preservation are, unquestionably, the principal causes for the sad neglect of the vast food resources in our oceans.

Many other foods seem not to have suffered from this inflexibility of utilization. For instance, corn, a relative newcomer, is processed into cereal. Eggs and milk have found universal utility because, losing their identity, they have found their way into an infinite variety of other foods. One of the oldest of man's staples, wheat, was known by the name of the process which altered its identity--triticum which in the Latin means pulverized. In fact, the English word "wheat" is related to "white" which is the color of the flour. The examples that could be given are numerous; but fish, however, with a very few exceptions, is always consumed as fish.

We have advanced considerably from the stage in which man was primarily a fish gatherer, migrating along coast lines and up rivers. Even so, fish as a major source of food has not followed man's inland migration, mainly because of the problems of preservation, storage, and distribution. Today, however, we are compelled to advance concepts of fish utilization, especially in the face of exploding populations, if we are ever to realize optimum use of this vast self-replenishing supply of unutilized food. We must now conceive the massive use of fish as a rich additive to other foods, as an ideal nutrient supplement to existing foods. In conceiving the use of fish in this new way, we must once and for all cast aside our neolithic ideas of consuming fish in the form of fish and acquire the concept of fish as a concentrate, primarily of protein, suitable for incorporation into foods of lesser nutritive value.

HISTORY OF MARINE PROTEIN CONCENTRATE

Before the history of MPC can be told, we must precisely define what the term means. We define MPC as any inexpensive, stable, wholesome product of high nutritive quality, hygienically prepared from fish in which the protein and other nutrient materials are more concentrated than they were in the original raw material. This definition includes MPC products of varying characteristics ranging from tasteless, odorless, light-colored flour-like materials through coarse meals having a fish taste and odor to highly-flavored, dark-colored pastes or powders resembling meat extracts.

Having defined MPC, we shall now look at some of the efforts conducted since early times to produce concentrates from fish. And although none of these efforts resulted in a significant increase in fish consumption, they point out the fact that changing the form of fish to find increased utilization of their food wealth is not necessarily a new concept.

With a little stretch of the imagination, the classical Egyptians could be considered the first manufacturers of a concentrated protein food from fish. They discovered that the use of salt preserved and concentrated the food value of the fish. They elevated salt to a place of enormous importance in the food preservation process.

The MPC story becomes even more exciting when we consider some facts from Roman history. A vase was found not too long ago in Pompeii, bearing the inscription: "Liquamen optimum siccatum ex officino umbrici agathopi." This, freely translated means: "The best MPC in the world is made in the factories of Umbricus Agathopus." This is perhaps the real beginning of the long and arduous history of MPC manufacture.

We are fortunate that a cookery book has been handed down to us from those days, the first century A.D. The author of this book is Apicius who described in detail not only the recipes of the upper- and middle-class families of Rome, but also indicates the method of manufacture of one of the most important of all food supplements that the Romans knew: liquamen.

The manufacture of liquamen incidentally was one of the very few large-scale food processing industries in Rome.

The fishing industry, of course, has always been of great importance in Europe, huge amounts of fish coming from Newfoundland even before Columbus came to the New World. It is strange, therefore, that the art of making liquamen was completely lost. Probably the developing agriculture, the increasing consumption of meat, and a preference for fish as fish displaced this food processing and preserving industry.

However important the fishing industry was in Europe, it never had the same significance as in Asia. Two facts illustrate this point. The first is that, as stated earlier, the oldest known form of money in circulation in India and Ceylon was the fish hook. The second fact is that the manufacture from fish of MPC in the form of fish sauces and fish pastes, similar to liquamen, developed very early all over the Far East.

As far as the preservation of fish is concerned, the Asian people seem to have been in advance of the Europeans. Although the fishing industry in Europe was one of the few commercial undertakings organized on a huge international scale, no real advances in the preservation of fish beyond sun-drying, salting, and smoking were made for almost 2,000 years, when Appert started the canning industry in France.

As for the New World, we believe that the first commercial fishery in the United States was established in Medford, Massachusetts, on April 17, 1629, when the colonists were given instructions to "let the fish be well saved

with salt, packed up in hog's heads" to be sent home to England. But, we have to wait for another 250 years before anything really startling happens in the development of MPC. We read in a publication that appeared in 1880 and was published by the U. S. Commission of Fish and Fisheries that the Honorable S. L. Goodale of Saco, Maine, invented a process by which the juices of the flesh of fish could be extracted to form an article of food which promised to be of much commercial value. In the article the writer addresses himself to his readers and says: "No one needs less than yourself to be told how great are the possibilities for this new project. From each barrel of menhaden you can get three pounds of extract when the flesh alone is used and four pounds if the spine is retained in dressing." He goes on: "I cannot avoid the conclusion that a new source of food is within reach which, at no distant day, may contribute materially to human welfare." A little further in the same article biscuits are described which were made with "fish flour," and it was called such. These biscuits were exhibited by the Norwegian Department of Agriculture at an International Exhibition in 1876. In spite of the fact that they had been kept for one year in unsealed jars, the biscuits were found to be in perfect condition.

So we note that producing concentrated protein from fish is not a new endeavor. Only in the last 25 years, however, (and thanks in great part to the untiring efforts of such organizations as UNICEF and FAO of the United Nations, as well as private and government groups here and abroad) have any extensive endeavors been made. And it is only in the last several years that the potential of MPC, as a superior quality protein supplement, received any significant attention. But even yet, unfortunately, MPC has not received its full recognition in spite of the intense world-wide interest found in this product today.

MPC RESEARCH PROBLEMS

It is almost axiomatic that the keeping qualities of foods in general, and of fish in particular, are directly related to the water content of the product. Thus, salting and sun-drying techniques were long ago developed for the conservation of fish and other foods. Such dehydration procedures, although not very efficient, have, over the centuries, had considerable success. The widespread usefulness of these methods is based upon the fact that the removal of water from plant and animal tissues causes certain chemical changes to occur and reduce enzyme action. Concomitantly, by sufficiently lowering the amount of free water in the tissues, microorganisms, that are ubiquitously present and responsible to a large extent for the processes that we recognize as decomposition and decay are prevented growing and multiplying. The removal of water, then, just like the application of very low or very high temperatures for different reasons, is important for the establishment of bacteriostatic conditions. Another reason why drying has always been of importance is the reduction in weight and volume of the raw material, thus reducing transportation costs of the dried products. Thus, dehydration constitutes a means of preservation, and is the first and perhaps the most important process in the preservation of fish.

Apart from water, which makes up almost 80 percent by weight of the raw fish, reference must be made to fish oils, fats and related compounds which are present in smaller proportions than water and which are referred to by the generic term of "lipids." These, in general, are of great importance because of their highly reactive nature, especially as far as their tendency to react with oxygen is concerned. Under suitable conditions, fish lipids become rapidly rancid and can lead to the formation of compounds that are considered, by most, to be extremely unpleasant, and frequently reduce the nutritive value of the finished product.

In the simplest terms, then, the preservation of fish is based on the removal of water and lipids from the raw material, or conversely, the isolation of a water- and lipid-free protein fraction. In practice, however, the picture

becomes more complicated because of the fact that the dehydration and defatting processes must be so designed as to lead to end products that have nutritional properties closely similar to those of the raw material, which is excellent. The processed material to be useful must also, as stated, be suitable for incorporation into different diets. A closer look thus reveals a number of unique and closely interrelated engineering and biochemical problems requiring intense and well-coordinated scientific research. We are, for instance, faced by proteins that can be easily damaged by a variety of causes and our wish to preserve and separate them from complex lipids and other components to which they are firmly linked. At the same time, a multiplicity of seemingly mutually exclusive processing requirements, needed to separate these components, have to be considered. We are faced by elusive problems of taste preferences and acceptability, by novel storage and transportation parameters and delicate questions of digestibility of the products by infants and expectant mothers. We must also consider amino acid balances, physical characteristics, and a host of new economic and sociological problems.

However complex these problems may be, they are certainly not unsurmountable. Through the application of science and engineering, as in our program at the Technological Laboratory, Bureau of Commercial Fisheries, College Park, Maryland, the problems can be solved. The prize for their solution, while unassessable by financial and economic yardsticks is rewarding beyond the reaches of the imagination.

THE FUTURE OF THE GREAT LAKES FISHERIES

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ABSTRACT

The Great Lakes Fisheries have undergone many changes since the balance of nature was upset by the parasitic sea lamprey. Most of the choice species of fish have been reduced to a low level and the fishermen have been forced to concentrate on the cheaper and less desirable species. The alewife, a recent newcomer from the ocean, has experienced a population explosion that has had far reaching effects. The fish population of Lake Erie has been reduced to a low level because of an oxygen depletion in the bottom waters of hundreds of square miles of the lake. The lake fisheries were dealt another terrible blow several years ago when a number of deaths were traced to botulism poisoning in smoked fish. In view of all these difficulties it is remarkable that there is a fishery left on the Great Lakes. But there is, and in some localities the future looks much brighter. The sea lamprey is being brought under control, the trout are reappearing in greater numbers, the market for smoked fish is returning, the public is demanding more pollution abatement programs, and the federal government and the industry are cooperating in a program to process and distribute the cheaper varieties of fish. It appears that the crisis for some of the lake fisheries is passed, and while it is still a very sick industry a full and complete recovery is being predicted.

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The Great Lakes are a geographical phenomenon unparalleled on this planet. The five huge bodies of fresh water lie in a connecting chain that extends from Duluth, Minnesota, to Watertown in north central New York. Together they have an area of 95,000 square miles of which 610,000 lie within the United States boundaries. The lakes were not only a "Water Highway" for the early explorers and the settlers that followed, but were also an important source of food, as fish constituted an important part of the diet of the Indians and the first white settlers. Because of the abundance of many choice species of fish, and the ease with which they could be taken, it was inevitable that commercial fishing should become one of the first industries in many settlements bordering the lakes.

During the 60 years for which data are available the average annual catch for the Great Lakes has been 112 million pounds. To demonstrate the changes that have taken place it is necessary to separate these data into three periods: the early fisheries (1879-1928), pre-sea lamprey years (1929-1945), and the post-sea lamprey period (1946-1964). The average annual catch for each period is 120 million, 106 million, and 107 million pounds respectively.

It would appear from these production figures that the Great Lakes fisheries are still in a very sound and stable condition, but unfortunately this is not true. The lake fisheries are actually in a very depressed condition. The value of Great Lakes fish has traditionally lain in their quality, not in their bulk. During the early fisheries all of the choicer species were abundant. In spite of some severe fluctuations in the abundance of several species, the fisheries remained in a fairly stable condition during the 1929-1945 period when such highly prized species as whitefish, trout, walleye, blue pike, yellow perch and ciscoes were still taken in substantial quantities. Today the choice species have all but disappeared from the catch and the production is made up largely of the less desirable and cheaper varieties that were not harvested in the past, or species that have found their way into the lakes following the collapse of the trout fishery.

The decline of the lake fisheries began in the early 1930's when the parasitic sea lamprey became firmly established in Lake Huron and soon spread into Lakes Michigan and Superior. Because of its population growth, parasitic habits, and insatiable appetite the lampreys were able to eliminate commercial and sport fisheries for lake trout particularly, and several other species incidentally, within a relatively few years. By 1951, annual catches of the prized lake trout had dropped from an average of 11.5 million pounds to less than 500,000 pounds in Lakes Michigan and Huron. By 1961, the 4.4 million pounds usually produced annually in Lake Superior was below 370,000 pounds. At the same time production of trout had ceased completely in Lakes Huron and Michigan. Whitefish, burbot, walleyes and suckers also declined in abundance over the same period. Fishermen and scientists alike were amazed at the speed with which the lampreys destroyed the trout population in the upper lakes.

Just what kind of a critter is this sea lamprey that could so quickly destroy the trout population in such large bodies of water as Lakes Huron and Michigan, and make serious inroads in the Lake Superior stocks? Let's take a quick look at its habits and life cycle. First, it is a parasite that lives entirely upon the blood and body fluids of its victims. It has a voracious appetite and moves from one host fish to another. While some fish may survive as many as a dozen attacks the majority succumb to the first assault. When the viciousness of the individual is multiplied by the number of lampreys in the lakes it immediately becomes apparent that no force could stand up under its onslaught. Upwards of 19,000 lampreys were counted at the barrier in one Lake Huron stream in 1950. The total count of adults at 30 barriers on Lake Superior streams in 1961 totalled 70,113.

The life history of the sea lamprey consists of a short egg stage in a specially built nest in a stream tributary to the lake; a larval stage as a non parasite that lasts from 4 to 6 years during which time it is embedded in the mud; a metamorphosis into the adult form; subsequent downstream migration in spring and fall; a parasitic phase of 12 to 20 months' duration when growth is rapid (from 6 to 20 inches in length); an upstream migration in the spring, and a spawning phase following which the adults invariably die.

Early attempts to control the lampreys centered around the use of mechanical and electrical barriers in the spawning streams. High water causing washouts and occasional power failures permitted enough escapement to maintain the population. This is understandable when one 18 inch female deposits upwards of 50,000 eggs.

Recognizing the shortcomings of both types of barriers all efforts were directed to finding a selective chemical that would kill larvae in the streams without harming other fishes. After several years of testing more than 4,500 chemicals, the halogenated nitrophenols were found to be selective in the manner desired. TFM (3 trifluoromethyl-4-nitrophenol) was the best of such compounds. Exhaustive tests showed this chemical to be harmless, at concentrations used, to other animals (birds, man, mammals and wildlife of all types).

Application of the chemical TFM to Lake Superior streams in both Canada and the United States was first completed in 1960, and in 1962 the count of upstream migrants at the 30 barriers previously mentioned, dropped from 70,113 to 9,910.

Immediately following the reduction of lampreys in Lake Superior an intensive planting program of lake trout was instituted. Presently about 2 million yearling trout are being planted each year. Some of the planted trout have reached spawning size and the first naturally spawned young of the year were observed in 1965. In addition to the marked success of the plantings of hatchery reared fish in the inshore waters several discrete populations of trout have been discovered in outlying waters. These stocks apparently escaped serious damage by the lampreys, are in good condition, and are contributing to the rehabilitation of the trout population. There are some inshore waters where the trout population has already returned to prelamprey levels. Unfortunately this is not true of the entire lake and it will take some time to establish a brood stock on all known spawning grounds.

The amazing results in reducing the lamprey population in Lake Superior are now being duplicated in Lake Michigan, and it appears that the parasite can be reduced to a level where the fish can survive and that a profitable trout fishery will eventually be reestablished.

THE ALEWIFE APPEARS

With the disappearance of the lake trout, a vicious predator itself, the stage was set for a population explosion of the alewife (Alosa pseudoharengus) a recent newcomer to the lakes from the east coast. The alewife has been greeted with mixed emotions as it has proven to be a nuisance in many ways, yet forms the basis for an entirely new fishery.

The small fish foul the nets of the gill net fishermen seriously interfering with the capture of the more desirable species. But more serious, and certainly more costly to the public at large, is the annual die-off that is characteristic of the specie. Each year millions of pounds of alewife succumb to old age or physical weakness, before, during and after the spring spawning migration, and drift ashore. Public and private beaches have been so heavily littered with these dead and decomposing fish that parks have been closed and clean-up crews pressed into service to clear the beaches. The City of Chicago has been forced to close one of its largest water supply intakes on several occasions when the screens became plugged with thousands of alewives. Several large electric companies have also encountered difficulties with the fish plugging their cooling water intakes and have been forced to temporarily suspend operations.

On the plus side, the alewife has formed the basis for an entirely new

fishery. Trawls and impounding nets are being used to take the fish in tremendous quantities. The supply appears to be unlimited and the big problem is the developing of markets and the perfecting of mechanized equipment to handle the production in a fast and inexpensive manner. In 1956 only 400 pounds of alewife were taken from Lake Michigan waters. This production has increased steadily until the 1965 take exceeded 15 million pounds. Scientists estimate the alewife population of Lake Michigan at from 3 to 5 billion pounds and predict that 200 million pounds could be harvested each year.

The expansion of the trawl fishery for alewife has progressed slowly because of the opposition of many fishermen to the introduction of a new type of gear, which they fear will affect their particular fishery. Conservation officials have been reluctant to liberalize some of the regulations that were imposed on the fishery when it was first introduced on an experimental basis.

Those closely associated with the alewife fishery are looking forward to a profitable future as more efficient methods of catching and handling the fish are perfected, and a more stable market established. Currently much of the production is going for mink food and into the preparation of canned and dried pet food. The analysis of products produced in experimental fish meal plants indicate that the protein content, oil quality and nutritive value of alewife meal compares very favorably with meal made from marine species.

Those who look with disfavor on the trawl fishery are hopeful that the return of lake trout to Lake Michigan and the introduction of Coho salmon, recently undertaken by the Michigan Conservation Department, will materially reduce the alewife population and once more establish the old balance of nature when trout was king and other choice species of fish were found in abundance.

LAKE ERIE POLLUTION

At the present time the most publicized body of water in the world, in all likelihood, is Lake Erie. Millions of citizens are currently aware that something is wrong with the world's 12th largest lake, that suddenly it is being referred to as "highly polluted," unfit for man or beast. Conference after conference at high and low levels of authority have been called to discuss the situation. In spite of all the publicity about pollution, the Public Health Service reports that the waters of the open lake are of drinking water quality, and there have been only isolated complaints from operators of municipal water systems and industrial water users. Who then is being adversely affected by the changes that are taking place in Lake Erie?

At the moment, commercial and sport fishing and a variety of recreational interests are the most seriously affected. The damage to these activities is real, current and serious. Recreational interests (other than sport fisheries) are primarily harmed by the curtailment of water sports (swimming and water skiing) and the destruction of esthetic values due to either high bacterial counts in the inshore areas and/or beaches littered with dead plants and fish.

Aside from these inshore waters and some localized areas the waters of Lake Erie, by generally accepted criteria, are of adequate quality. Yet no fish and few forms of invertebrates can live near the bottom in hundreds of

square miles of the lake during certain periods due to oxygen depletion in the bottom waters. That changes have occurred and are occurring in Lake Erie are most evident in the commercial fish catch. One species after another has become commercially extinct in either the entire lake, or in a local area, and a once thriving industry is now fighting for survival.

The scientists report that although the nutrient level of Lake Erie is not exceptionally high compared with other eutrophic environments, the nutrient content has increased at an abnormal and accelerating rate. The biological community of Lake Erie has not reacted entirely in the traditional manner to the enrichment process. The plant and animal life has apparently increased in some areas while in others it is unquestionably reduced. Growth rates of some fishes have displayed large increases, but in the majority there has been a decrease because of the destruction of bottom feeding organisms.

Two hypotheses have been advanced to explain the low oxygen conditions. One maintains that algal production is great enough to produce a continuous "rain" of dead plankton cells on the bottom which, in turn, creates a continuous oxygen demand. This demand, the scientists believe, is satisfied annually and there is no residual demand carried over from year to year. The other hypothesis contends that the oxygen demand in the sediment on the lake bottom is not satisfied each year and has increased over the years to a point where a backlog of oxygen demanding substances has accumulated. These theories are similar in that they agree on the location of the oxygen demanding substances (the bottom sediments), and that bacterial action is responsible for the oxidation of this organic material, but they disagree on the origin of the substance.

The answer to the origin of the oxygen demand is of more than academic interest. If the fall-out of plankton cells is the primary source of the oxygen demand which is satisfied each year, then the solution of the low oxygen problem in Lake Erie requires only that the input of nutrients be reduced. This can be accomplished by the construction of more efficient treatment plants for domestic sewage and industrial waste.

If, on the other hand, the oxygen demanding materials are from a variety of sources (particularly in the western basin and Detroit River) and have accumulated for many years, the problem is more complex and will be more difficult to correct. Future research must be directed toward finding the origin, nature, and bacterial characteristics of the material primarily responsible for oxygen depletion. Fortunately federal, state and local officials are very much aware of the seriousness of the situation and additional research projects are being instituted. As soon as a definite appraisal can be made of the cause, or causes contributing to this oxygen depletion, corrective measures will be taken.

Production figures for Lake Erie fisheries point out repeatedly that a strong year class, that contributed heavily to the catch for several years, invariably originated from a small brood stock. It is therefore possible that once the oxygen deficiency in the bottom waters is corrected the remaining small brood stocks will produce substantial year classes on which to rebuild a profitable sport and commercial fishery.

THE BOTULISM INCIDENT

No review of the Great Lakes fisheries would be complete without some reference to the very damaging, world-wide publicity of several years ago that followed a number of deaths caused by botulism poisoning in smoked fish. The demand for smoked fish disappeared over night and both the producers of the raw fish, and the processors of the finished product, were out of business, at least on a temporary basis. It was subsequently proven that the tragic deaths were due to a mishandling of the fish, principally in transit, and were not caused by any irregularities in the processing procedures. But the damage was done and could not be corrected.

Rigid standards covering the handling of the catch, the salting and smoking of the fish, and the packaging and marketing of the finished product, were immediately established. Today, smoked fish is a safe and wholesome commodity but thousands of people who previously enjoyed this delicacy and bought it regularly will not touch it. The botulism scare was the straw that broke the camel's back for many Great Lakes fishermen. Those who had weathered the loss of the lake trout and other choice species through lamprey depredation by establishing a fishery for species in demand for smoking were left without a market for the only fish they could produce in quantity.

With all of the changes that have taken place in the Great Lakes, and the problems that are still unsolved, it is impossible for anyone to predict, with any degree of accuracy, what the future may hold for the Great Lakes fisheries. There are no firmly established guide lines on which to project the future, but on the basis of recent developments and trends, I am confident that:

1. The parasitic sea lamprey will be brought under control in the three upper lakes and lake trout will be reestablished in sufficient volume to support both a substantial and profitable commercial and sport fishery.

2. That with further refinements in the capture, processing and marketing of alewife, a profitable fishery will be established that will complement, rather than compete, with the old established gill net and pound net fisheries.

3. That with the return of lake trout, and the reduction of the alewife population, other choice species such as whitefish, walleyes and perch will again appear in the commercial catch in substantial numbers.

4. That through a continuation, and expansion of the present cooperative program to find ways and means of processing and distributing the cheaper and less desirable species of fish, a currently weak segment of the industry will be given new strength.

5. That the public will gradually regain confidence in the smoked fish industry and that sales will again reach, and even exceed, the pre-botulism period.

6. That the industry will adopt newer and more efficient methods of catching, handling and processing Great Lakes fish making it possible to reduce its present manpower requirements, and by using fewer people, make commercial fishing more competitive on the labor market.

7. That the present oxygen depletion problem on Lake Erie, and pollution in general will be brought under control throughout the entire Great Lakes region, and that fish stocks will improve.

No attempt has been made to comment on the future of the sport fisheries of the Great Lakes as the problems of the recreational and commercial fisheries, in most instances, are one and the same. Obviously then, sport fishing will improve in direct relationship to the improvement in commercial fishing when their common problems are solved. With the continuing increase in population, and a shorter work week that provides for more leisure time, the existing streams and inland lakes will soon be overtaxed, and sportsmen will direct more of their attention to Great Lakes waters. With this increased interest in the Great Lakes there will undoubtedly be more demands for additional research, stocking, and more efficient management, that will be beneficial to both the sport and commercial fisheries.

RECENT ADVANCES IN U. S. FISHING VESSEL DESIGN - FORECASTS AND TRENDS

By

Robert F. Allen

Abstract

American fishing industry production is primarily from coastal fishing grounds which are now subject to an increasing fishing effort by foreign distant-water fleets from Russia, Japan, and Europe. American fishermen operating in small coastal vessels are not competitive with the large distant-water vessels. The substantially smaller size, speed, and catching rate of our vessels, and the competitive fishing between our own individual boats, are resulting in a reduced share of the bottom fish caught on such traditional grounds as Georges Bank off Cape Cod. The resulting total annual catch is declining, and exports are rising yearly. Fishing vessel construction and technology have resulted in larger, better-equipped vessels in most every fishery, but not at a rate to change the declining productivity trends. The U. S. Government is now actively participating in the industry with loans and subsidies; however, this must be applied to new fisheries not now exploited, or to a change in catching or processing technology, in order to reverse the downward trend.

The recent publicity given to foreign fishing fleets operating on the coastal grounds of the United States and the continuing slight decline in catches by United States fishermen, resulting in annually increasing imports of fish products, lead one to conclude that, if the fishing industry as a whole continues its present course, the future does indeed look very dim for the development of a new fishing fleet capable of exploiting our coastal grounds.

The countries with aggressive national policies of exploiting the resources under the seas in all oceans - namely, Russia and Japan - are now the major competitors on our own fishing grounds. The appearance of Russian fleets, from Georges Banks off Cape Cod to Florida, and in Alaskan and Pacific Northwest coastal waters, is now provoking congressional action to protect our resources by extending fisheries limits and to provide funds for development of competitive fleets in the form of subsidized vessel construction, and even outright government construction of fishing vessels.

This aggressive activity by foreign vessels has not appeared overnight, but has grown continually as stocks and species in other areas of the world have become less productive. When the relative catch rates of vessels in U. S. coastal waters are compared with those of over-exploited areas adjacent to northern Europe and Asia, it is immediately apparent that we do indeed have a vast fisheries resource, which it has been estimated could result in an annual sustained yield of 22 billion pounds, over four times the present $4\frac{1}{2}$ billion pounds annual catch.

In this international fisheries game, the competitor who travels from distant ports across the oceans to the fish on the coastal grounds of North America seems now to have a decided competitive advantage, both in flexibility of movement to the most productive area, and in outright size and power of vessels. The psychological effect of fishing on an American vessel of 70 to 80 feet, with 300 to 400 hp, alongside a modern Russian or Japanese stern trawler three times the length and of three to four times the horsepower, is indeed demoralizing. The technology of these foreign vessels and their catching and processing methods are well known to our fishing industry, and within the bounds of economic consideration the American fishermen do use this technology and fishing equipment and methods, even though the hulls of our vessels are smaller and older.

The major difficulty in direct competition with these foreign trawlers on our coastal grounds is the relative inflexibility of individual competitive American boats which must operate within limited distances to their landing points, and which must constantly compete with one another for markets and catch, in contrast to the flexibility of the distant-water fleet of many vessels under one command, producing one unified effort, exploiting the short-term resource potential, then moving on to greener pastures. The size of foreign distant-water vessels and the intense cooperative organization of the distant-water fleet operations are the major competitive factors with which we must reckon in obtaining our share of fish stocks.

Statistics show that the annual consumption of fish products in the United States is increasing in proportion to the U. S. Population. The U. S. catches are declining slightly and the imports are rising rapidly, filling the gap which has now increased to a point where more than 50 per cent of the U. S. fish consumption is imported. The United States is the largest fish importing nation in the world. (Fig. 1.)

In considering the influence of American fishing interests, these statistics do not represent the whole picture, as many American firms are major investors in foreign fishing industries. Whereas the Russian policy is to conduct the entire catching and processing on board, delivering products to the mother land, the American industry policy is to develop a source of fish at the cheapest possible price, which more often than not results in substantial foreign investment in processing plant vessels and catching effort on grounds which are adjacent to other countries, where in fact territorial limits (sometimes up to 200 miles) preclude competition from the distant-water fleets of Japan and Russia. Much of these products produced with American capital and know-how are imported into our country.

My discussion of the present and future technology of American fishing vessels is primarily directed toward coastal and high seas fisheries, where vessels are capable of operating in international waters, as contrasted to the in-shore fisheries in bays, estuaries, rivers, and lakes. Even on coastal grounds, the American fishing industry is founded on small vessels. In 1964, the U. S. additions to the fishing fleet totaled 503 vessels, of which only 19 were 70 feet or longer in registered length. With the advent of the Fishing Vessel Construction Differential Subsidy Program, fisheries loan program, and fishing vessel mortgage insurance program, and with recent developments in new fishing grounds and fishing for unexploited species, a change toward larger vessels is now taking place. In every major U. S. fishery, new vessels of larger size are being added to the fleet. Recognizing that a change in length of vessels from 75 to 90 feet represents a 65 per cent increase in capital investment. The figures must be compared carefully to see the significance of the trend.

The American fishing industry can be, for the basis of our discussions of vessels, divided into certain geographical areas and certain species caught:

1) New England ground fish vessels
2) Menhaden fishing vessels
3) Shrimp trawlers
4) West Coast tuna fishing vessels
5) North Pacific combination boats
6) King crab vessels

NEW ENGLAND GROUND FISH VESSELS

The New England area, under the greatest direct foreign competition on the Georges and Browns Banks bottom trawl areas fishery, has had the longest record of subsidy utilization. During this time, more than a score of new draggers and scallopers have been built. The majority of these vessels are of the traditional side dragger type, and show little resemblance to the modern vessels with which they must compete. Notable exceptions to traditional designs, mostly

wood, are shown in Fig. 2. Several of these stern fishing designed vessels are under construction in up to 100 feet in length. Plans are now being prepared for a larger stern trawler, of 130 feet, which would be similar to the modern European vessels. The Russian trawlers are now taking substantial herring catches on Georges and Browns Banks, an area where American vessels are only trawling for bottom fish. At least one new combination vessel for trawling and purse seining is now being designed for this area.

Several modern steel swordfish long line vessels, 83 feet in length, fishing with 20 miles of line, are now operating out of New Bedford. This method of fishing is more productive than harpooning the fish. As a result, several subsidy applications have been submitted for this type of vessel.

Comparing the inactivity in new vessel construction with the intensive foreign competition developing along New England, it is apparent that further government support and stimulation is essential to growth, or even to maintaining our present rate of catch of New England ground fish. Considering the present inactivity in new construction in light of the size and age of the New England bottom fish fleet, prospects for new types of vessels and methods seem very limited. Government support and stimulation here seem increasingly necessary.

MENHADEN FISHING VESSELS

The menhaden fishery is little known to many, because this fish is used for reduction purposes and not as a food fish. Menhaden comprises 35 percent of the total tonnage landed in the United States during 1965. These fish gather in dense schools in the coastal waters from Cape Cod south to the north Florida coast, and in the Gulf of Mexico from Florida to Texas. The major tonnage in this fishery has been traditionally caught by the Atlantic Coast vessels; however, recent plant developments and fishing efforts in the Gulf of Mexico, and declining stocks along the East Coast, have shifted the major emphasis to Mississippi, Louisiana, and Texas.

Menhaden is a pelagic fish which is well adapted to purse seine fishing methods. This fishery was one of the first to utilize this method of catching, when in the earlier days small boats lowered from sailing vessels set their net while rowing around the fish. It is interesting to see the evolution of this fishery, with the application of power to the mother ships, engines in the small purse boats, mechanization of loading and unloading with fish pumps, the introduction of the Power Block as a mechanical net-hauling means, the introduction of airplanes for fish spotting, and the refrigeration of catches. Today, however, this fishery is still conducted in the same basic manner as originally conceived, utilizing a mother ship for carrying fish and two small purse boats for setting and hauling nets. This fishery is essentially non-competitive with foreign vessels operating on these grounds.

Virtually all of the menhaden vessels are owned by the processing companies, so their cost of operation is considered part of the total investment in the fish reduction business. This has resulted in substantial investments in new vessels during the past ten years. Presently there are approximately 135 vessels, ranging in size from 80 to 220 feet in length. The recent trends in vessel construction are toward vessels 150 to 160 feet in length (see Fig. 3). In 1965, two 220 x 32-foot refrigerated 850 hp twin-screw vessels, largest in the U. S., were constructed for J. Howard Smith, Inc., of Port Monmouth, N. J. Several companies are also advocating substantially smaller vessels for use particularly in areas where there is not such great competition between vessels for fish.

Since the major construction in new vessels has been for the warmer Gulf Coast, refrigeration of the catch has become standard procedure. A modern menhaden vessel is expected to stay out for durations up to one week or more. Under these circumstances, in the heat experienced in the Gulf Coast, and with such oily fish as menhaden, refrigeration is mandatory. Sea water is passed through

an ammonia chiller, cooled to 30 degrees, then circulated through the fish hold. Generally speaking, the fish holds are maintained at 35 to 37 degrees. Most of the new vessels are twin screw, shallow-draft, as they must often operate in very shallow water along the coasts and inlets. Six hundred horsepower per screw, resulting in a speed of 13 to 14½ knots, is typical.

A modern vessel is equipped with a 12-inch fish pump for loading the boat from the net. Winches are used on the carrier vessel to assist the crews of the small boats in "drying up" the catch in the bunt portion of the net so that the pumping can be effective.

Two aluminum or steel 34-foot diesel-powered purse boats are carried in davits. Each purse boat handles half the net and sets in a semi-circle; then the boats join to close the fish. Airplanes are used extensively in this fishery for spotting and setting; therefore radio communications are essential between the purse boats, the carrier vessels, and the spotter planes. The purse boats are equipped with Puretic Power Blocks, a hydraulic crane, a purse winch driven mechanically from the main engine, and a hydraulically driven purse line stowage reel.

The application of this mechanical equipment has greatly helped to increase the efficiency of the entire operation. Prior to 1959, menhaden vessels with their purse boats operated with a crew of 27 to 29 men. Subsequent to the installation of Power Blocks and winches for drying up the nets, this crew was reduced to 17 to 19 men, and further economic pressure from fish meal imports has further induced owners to reduce crews to the present 14 to 16 men, including the pilot, engineer, and cook of the carrier vessel, as well as the captain, mate, and crew on the small boats. With this mechanical net-hauling equipment, the maximum number of sets of the net which can be handled in a day is substantially increased by approximately 50 per cent.

The recent trend in vessel designs for this fishery has been toward larger, wider vessels with the same draft limitations. Experiments have been tried on numerous occasions to adapt a one-boat purse seining technique to this fishery, but to date the traditional mother ship-purse boat system has proven to be more flexible and more competitive, though it employs a larger crew than the one-boat system.

Some effort has been devoted recently to attempt to utilize these vessels for other fisheries in the off-season from December to April. Because of their shallow draft and low beam-length ratio and arrangement, these vessels have not proven to be good sea boats for trawling in the winter time on the East Coast. Further experiments are to be carried out soon in the New England herring fishery, utilizing the large vessels for setting and hauling the seine as well as carrying the fish, thus eliminating the purse boats. This change, however, would be in the nature of a conversion effort to utilize the vessels which have otherwise been idled by the declining fish stocks on the East Coast, and should not at this time be construed to be a combination fishing design.

Along the North Carolina and Florida coasts, the smaller vessels have been utilized for menhaden purse seining, with alternate attempts at shrimp trawling.

In the next five years we can expect a continued replacement program of older vessels in the same size range as those now being constructed, with the possibility of a smaller combination-type vessel, combining the trawling with purse seining from the purse boats with the two-purse boat method. We can also expect the greater use of underwater detection equipment for locating schools of fish.

AMERICAN SHRIMP VESSELS

1965 proved to be an excellent shrimp year for domestic producers on the East and Gulf Coasts, resulting in a boat-building boom which produced close to 200

vessels in the 60- to 73-foot size. This accounts for the most substantial element of vessel construction in the United States. Wood is still the dominant material in shrimp boat construction, particularly in Florida, where one firm dominates the boat-building industry, with a production close to 100 vessels per year. The trend, however, is unmistakably toward steel construction, and in Alabama, Louisiana, Texas, and Mississippi virtually all of the new shrimp boats are steel.

American shrimp-fishing vessels are almost all equipped with twin nets towed from outrigger booms. The geometry of two small nets sweeping a path across the bottom 70 to 80 feet wide is much more favorable than one large net used for the same purpose. This enables vessels to reduce their net expense, and also to tow at a higher speed than if one large net were used, thus covering more ground. Recent technology in fish-catching methods includes the use of an electrical foot rope tickler cable which has the effect of inducing the shrimp from the sand beds during the daylight hours, so that daytime catches can be substantially increased. This development by the U. S. Fish and Wildlife Service has been applied to some vessels; however, it is not yet universally accepted.

The present emphasis on modernization of the vessels is in the refrigeration of the catch by mechanical means rather than ice. This enables vessels to stay on the grounds for a substantially longer period, working continuously and returning to market at will. It is reported by the owner of one such vessel, with the ability to fish continuously, that almost three times the average catch was made with a refrigerated vessel of the standard iced boats which were fishing in the same area for the same period of time.

Presently some vessels are fishing the South American grounds off Venezuela, Guinea, and the north Brazilian coast. Shrimp boats of up to 83 feet in length, with a 23-foot beam, are under construction for this service. Such vessels will be able to store more than 60,000 pounds of shrimp and stay at sea for 60 to 80 days. Under these conditions, immersion freezing of the shrimp and cold storage in the holds is essential.

As more vessels become equipped with refrigeration, the capability of operating at sea for long periods of time will undoubtedly enable larger vessels to operate profitably in this fishery. Therefore, within the next five years we can expect a continued growth in the size of some vessels, possibly up to 100 feet or more. It is important to recognize, however, that the American shrimp producers are also making plant investments in facilities closer to the fishing grounds in South America. This will, however, tend to nullify the requirement for larger vessels that land their catches back in the United States.

WEST COAST TUNA FISHING VESSELS

The United States West Coast tuna fishery conducted from San Pedro, San Diego, and, more recently, Puerto Rico, is America's only distant-water fishery with a substantial investment in new equipment in recent years. Tuna purse seiners normally land their own catch in American ports, traveling up to 4,000 miles from the fishing grounds off the west coast of Central and South America. Trips from 14 to 90 days' duration can be expected, depending upon the time of year and the success in locating fish near California or Mexico.

The continued increasing demand for tuna, and the relatively high productivity of men and equipment on American vessels, has enabled them to remain competitive with foreign imported fish. During the 1950s, modern tuna clippers of wood and steel, 125 to 130 feet in length, utilizing the pole-and-bait fishing method, were being constructed in California. In 1958 through 1961, 75 per cent of these vessels were converted to purse seiners, with an acknowledged increase in productivity. Estimates of catch per vessel just prior to and after conversion indicated a substantial increase in catch could be attained. This was due to the more effective catch rate of net as compared with pole fishing

techniques and the increased fishing time which was otherwise required to obtain live bait. Since that time, no new pole-fishing vessels have been constructed, and a number of military and commercial craft of all types have been converted to purse seine fishing for tuna. Despite increased productivity, the annual American tuna catch is declining, indicating a strong probability that we have passed the point of maximum sustained yield. Once it became apparent that purse seine fishing can be conducted from larger than the 105-foot San Pedro boats, there seemed to be no limit to the size of vessel being considered for this service.

The essential changes which have taken place in vessels have been a result of the change of fishing method from pole to purse seining. The pole-fishing technique required men to fish from racks alongside the vessel, only slightly above the water line. Since the fish must be hauled on board manually, low freeboard was essential to the operation. The typical freeboard of a tuna clipper at sea was alarming to most mariners, and was deemed to be the cause of a number of vessel losses. The conversion of these clippers to purse seiners was accomplished by removing the bait tank from the stern deck and installing a large mast and boom, equipping the vessel with a purse seine winch, Power Block, and auxiliary winches, and mounting a heavy wooden table on the stern approximately two feet above the deck, onto which the net could be stacked. A 30- by 15-foot wood open-powered skiff with 150 hp diesel engine was added to assist in setting and supporting the net and towing the big vessel into position during pursing and net-hauling. These vessels, weighing seven tons, are carried on top of the 12-ton net when the vessel is traveling. The skiff is launched over the stern and towed behind while the vessel is on the fishing grounds. Little was done in the majority of bait boat conversions to increase the freeboard of the vessels, and in fact the weights were often equal or heavier, with the addition of net, rigging, skiff, and winch gear, than with the bait tank.

Until 1965, a majority of the conversions and all of the new vessels followed the traditional conversion arrangement, with the fishing conducted on the main deck slightly avove or below the water line, as the sea conditions dictated. All types of vessels 125 to 200 feet in length have been converted to refrigerated purse seiners. Figs. 6 and 7 show one of the largest, a vessel which was formerly a coastal mine layer. A totally different and unconventional arrangement of purse seining, on the CLIPPERTON, can be seen in Fig. 8. A few of the notable conversions, and all of the new vessels in the past two years, have enclosed the main deck amidships to the net platform. The pursing, net handling, and brailing take place from the upper deck, approximately eight feet above the load water line (Fig. 9). The enclosed main deck area is utilized for distribution of the fish to the various brine wells (usually ten in number). Fish are passed through a funnel and flume arrangement from the upper deck to the well hatches on the main deck in this 'tween-deck space. These vessels have demonstrated superior fishing ability and seaworthiness, although the center of gravity is higher due to the additional deck superstructure and higher weight of the winch gear. At the present time, all of the vessels now under construction are utilizing this arrangement.

The present purse seine fishing method is highly mechanized, with all loads of the net and the fish handling accomplished by machinery from a centralized control. Extensive development has resulted in the most advanced fishing equipment for this purpose. Additional small boats are also carried on new vessels for herding porpoise from the net and otherwise assisting in the fishing operation.

The fish are stored in refrigerated wells, through which a concentrated salt brine solution at 14 degrees F. is circulated until the fish are completely frozen. The brine is then pumped from these wells and the fish are held at 5 degrees with coils in each well. This is the only method presently available which is capable of handling the sporadic large catches, which sometimes exceed 100 tons in a day. Fish are unloaded from these wells at canneries, in a frozen state, with buckets.

The recent trends show no signs of limitation on vessel size. Presently three vessels of 200-foot length are under construction in Canada, and, if successful, they could undoubtedly lead to larger vessel construction here in the United States. On these large vessels, further effort is being devoted to increasing the quality of frozen fish by freezing in a single brine freezer, after which the fish are removed, glazed, and re-stored in a cold dry storage hold. Fish are transferred in these vessels on conveyor belts, and a mechanized system of unloading with conveyors and bucket elevators is to be adapted.

In the future, it is expected that further mechanization of the loading process from the net, the possible use of horizontal thrust units in the bow and stern of the large vessel, better refrigerating techniques, and possibly a modified purse seine fishing system over the stern of the vessel rather than the side, are all in the realm of possibility.

Presently five subsidy applications are being processed for 150-foot vessels, which will cost $1,300,000 or more. These vessels will also be capable of trawling, with only slight modification, should tuna fishing become unproductive.

NORTH PACIFIC COMBINATION BOATS

Although king crab fishing has a major share of the interest for investors in new fishing vessels in the Northwest, consideration is also given to multiple uses for this vessel as the season, prices, and availability of fish dictate. The western Canadian fishing industry has led in the development of new vessels for this purpose. A score of new vessels, from 60 to 100 feet in length, have been launched in the past two years in British Columbia. These vessels are built under subsidy of the Canadian Government, and are operating as herring seiners, trawlers, and halibut-long line vessels. Most all of these ships are equipped with refrigeration for maintaining cold temperatures in fish hold space, and winches for multi-purpose fishing.

The first American subsidy vessel in this area is now under construction, following closely the standard Canadian design (Fig. 16). This vessel, and others under construction for crab fishing, have stimulated the interest in new vessel construction, which in the next five years should closely parallel that which has taken place in British Columbia. Thus we can predict that vessels of 75 to 110 feet in length, of the multi-purpose type, will be the most prevalent.

KING CRAB VESSELS

This fishery is the focal point for most new vessel construction and most conversions from other types of fishing in the Pacific Northwest during the past few years. In 1965, more than 100,000,000 pounds of king crab was landed by an estimated 220 vessels, whereas 15 years ago this fishery was virtually unknown. Vessels handling 35 to 100 large steel traps operate from Kodiak west along the Aleutian chain, carrying their catch in circulating sea-water tanks to shore-based plants or factory ships stationed in the bays and harbors. A surprising number of vessels have been lost in this service, which can be explained by the loading conditions and severe weather normally experienced in this area.

The typical vessel has been converted from sardine and herring seiners 70 to 80 feet in length. Sea-water tanks of wood with fiberglass lining, or steel or aluminum, have been sized for maximum loading and a minimum acceptable freeboard. Such loads have placed severe strains on the older vessels converted to this service. Modifications to a typical West Coast herring seiner vary from the mere installation of a circulating sea-water tank to a complete redesign of the deck house and upper pilot house structure, for enclosed steering so necessary in winter fishing. Fig. 10 shows a complete conversion of such a vessel.

The major criteria for a good crab vessel are large carrying capacity and adequate deck space to carry a maximum number of 8-foot square by $3\frac{1}{2}$-foot deep pots. This is not a strict requirement for a fishing vessel, and as a result a number of various types of ships have been successfully converted. Some of the successful conversions are: 88-foot power scows, a 157-foot LCI landing craft, a 182-foot tanker, and a 167-foot FS-type freighter (Fig. 11). It is interesting to note that although some of these vessels have four times the carrying capacity of others, the crew remains virtually the same. The vessel shown in Fig. 11 is now operating with a total ship's complement of five men.

Equipment for these vessels consists of a hydraulic pot-hauling device, and cargo gear to swing the pots on board and stack them on deck (Fig. 12). In order to keep these crabs alive, a circulating water system which completely changes the fish hold each 20 to 30 minutes is required.

It is interesting to note that so long as conversion hulls are available, the fishermen have preferred to adapt them to this service rather than invest in new construction. During 1965, the first new vessel designed as a combination crab-trawling boat was launched (Fig. 13). This 99-foot by 28-foot raised-deck vessel has a 6,000-cubic foot hold of circulating sea-water tanks. This design is typical of the latest combination vessels for the west coast of Canada, and is acknowledged to be a most versatile fishing vessel, capable of trawling, seining, and long-line fishing as well as crabbing.

Now, three totally different concepts of crab boats, Fig. 14, are under contract in Seattle. This twin-screw, 88-foot power scow with flat bottom has proven to be a very effective crab vessel. The broad beam of 26 feet provides a stable platform and substantial pot-stacking area at a modest cost.

In the king crab fishery, six factory ships are employed for canning and freezing of crab meat and legs (Fig. 15). Since a number of larger commercial vessels are available for conversion, no new construction of factory ships is contemplated at this time.

In the future we can expect to see considerable emphasis placed on conversion of larger vessels, possibly up to and even over 200 feet, as the exploration of the crab grounds in the Bering Sea progresses. In new construction, we can anticipate vessels 100 to 125 feet, of the same general type as Figs. 13 and 14. These vessels may be equipped with mechanized unloading equipment, and more effective pot-handling and stowing gear. Operators considering such vessels as new construction would undoubtedly allow space for refrigeration systems so that these vessels could be converted to other fisheries should the occasion demand.

Conclusion

The United States Government is now making a direct investment in our fishing industry through subsidy. The industry is by no means 100 per cent receptive to this funding and the resultant control. One can say as a basic premise that this industry is still profit-motivated to the extent that further developments in fishing vessels and equipment and fishing methods will come into common usage only as they can be applied profitably commensurate with the risk and within the financial capabilities of the fishing companies or fishermen-boat owners. Without a change in motivation, we are not going to see the radical changes in fishing vessels that will enable us to answer the foreign challenge on our fishing grounds with vessels of equal size and capabilities.

There are several alternatives to this course of development. Some of these are:

1) Direct government intervention in the industry, as recently proposed by Representative Stanley R. Tupper (R., Maine), who proposed a Factory Fishing Vessel Bill. This plan of action has already met with considerable disapproval from the industry, as such vessels would be directly competitive not only with foreign imports of fish into the United States but with our own fishing vessels as well.

2) Increase tariffs on foreign fisheries products so as to provide a higher price, enabling a greater share of domestic production to enter the market. If enacted, this would undoubtedly improve the picture for the industry, but would have reciprocal reactions in other phases of the national economy.

3) A brighter and more constructive development is in the field of changing technology, enabling American fishing vessels to land higher quality products faster, or to land refined products of higher value. Fish-handling and -processing methods which can be accomplished on small vessels with relatively little increase in manpower offer one of the greatest challenges to fisheries technologists. Mechanized processing, cleaning, gutting, cooking, inexpensive and rapid freezing of whole fish, breaded fish, fillets, and the cheap reduction of waste and scrap fish (irradiation).

4) Probably the major factor which has affected the development of new fishing vessels, and will have the greatest future effect, is the development of new fishing grounds and the exploitation of different species of fish which are not now caught. Certainly the whole Alaska king crab industry, into which a major capital investment in vessels has been made during the last six years, is developed strictly on the demand for a new product. Estimates prepared by the U. S. Fish and Wildlife Service indicate that we in the United States are only catching 25 per cent of the fish available to us in our coastal waters.

5) The matter of international agreements on limited fishing and extention of territorial waters may have a long term favorable effect on our fisheries. However, in those fisheries such as North Pacific halibut where such agreement has been in existence for many years, the development of new vessels has been noticably lacking.

So long as the American fishing industry is a free enterprise, capital will be applied to new vessels when the risks are rewarding and when no less costly alternative is available to fill the demand for fish. No, it really isn't the demand for fish, it is the demand for capital. It is surprising, in Seattle where I live, to see the investments that individual fishermen-boatowners are making in apartment houses and property as compared with new vessels.

RELATIONSHIP OF U. S. POPULATION TO FOOD FISH CATCH AND IMPORTS, 1945-64

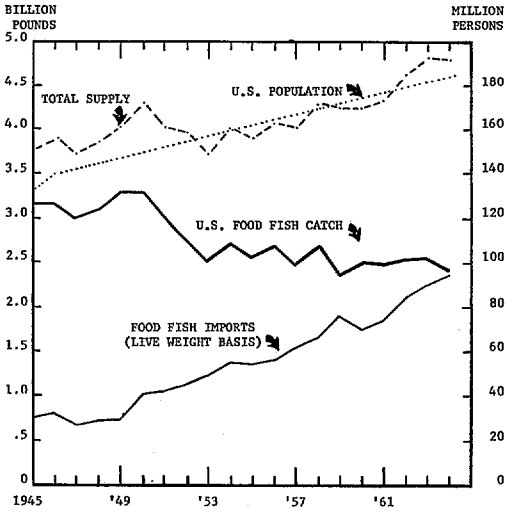


FIG. I

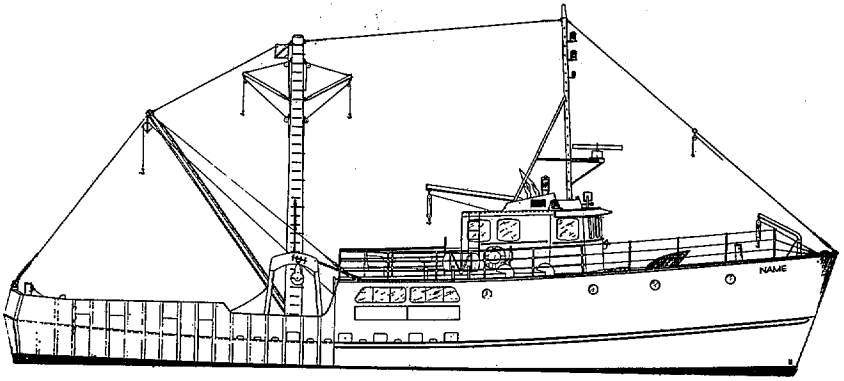


FIG. II

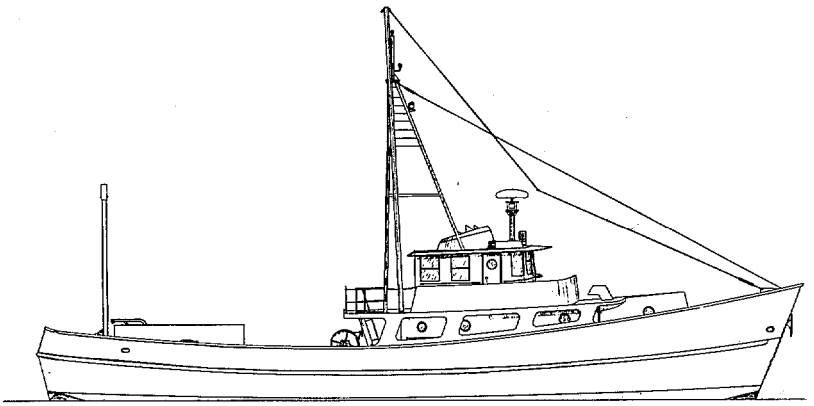
New England modern stern fishing scallop dragger, 95-ft. Designed by J. W. Gilbert Associates, Boston, and being built under subsidy for the Ellingsen Fishing Corp., New Bedford.

FIG. III

Modern refrigerated menhaden carrier with 350 tons aboard. The two purse boats for setting the net are carried in the davits aft.

FIG. IV

Mechanized net hauling with the Puretic Power Block in American menhaden fishing.



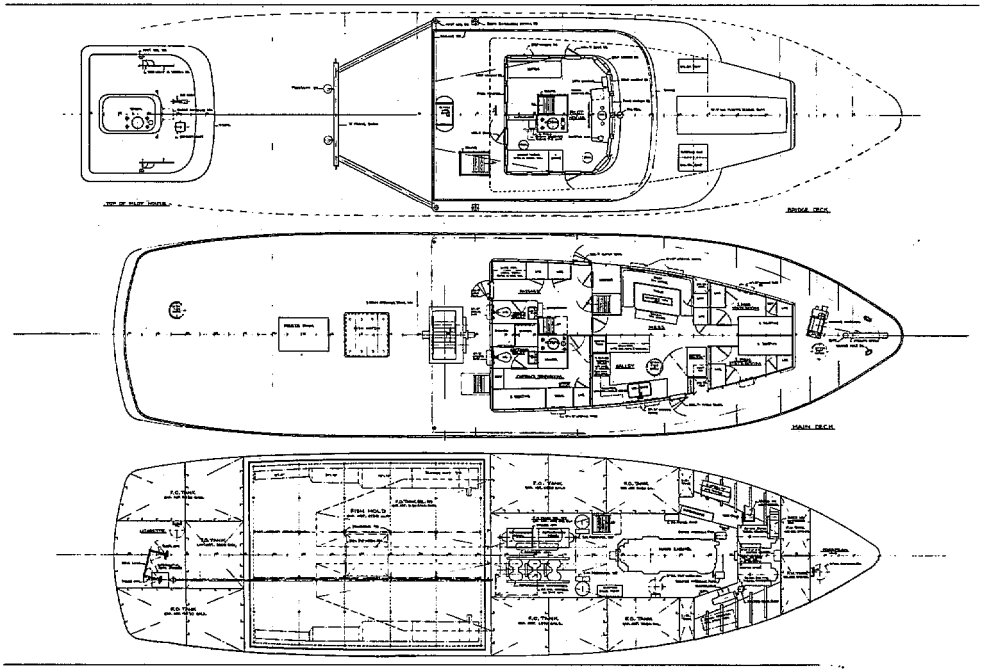


Fig. 5. Latest design of refrigerated shrimp trawler, to be constructed under subsidy by John W. Gilbert Associates, Inc., Boston, Massachusetts.

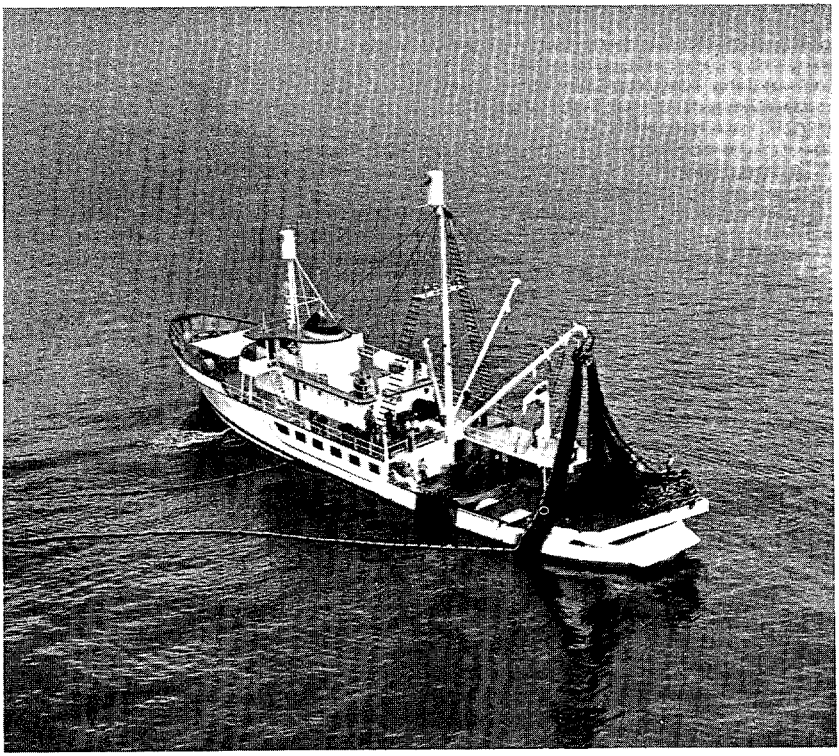


FIG. VI

Largest American tuna purse seiner conversion carries 1,000 tons of fish. (Pacific Fisherman photo)

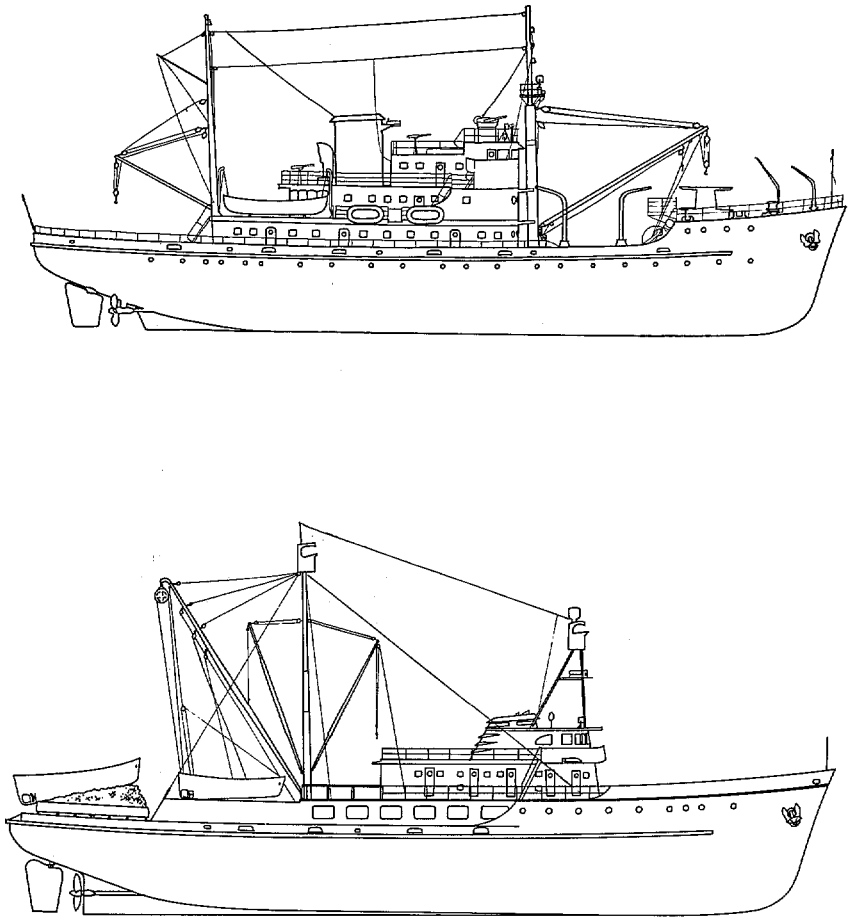


FIG. VII

The DAY ISLAND (see FIG. VI) before and after conversion from a coastal mine layer.

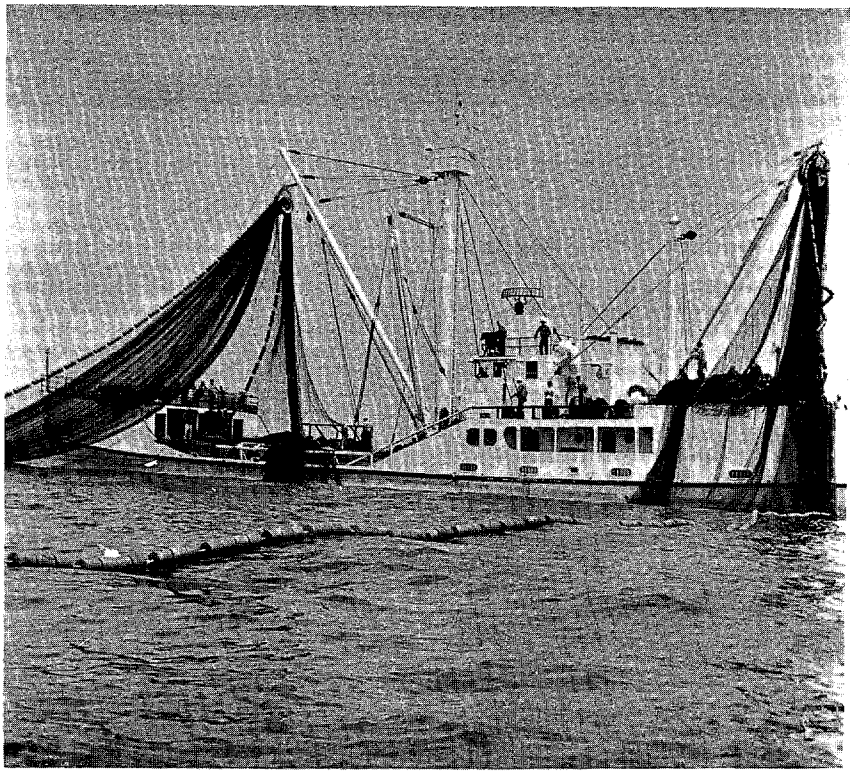


FIG. VIII

The CLIPPERTON, an unusual conversion to tuna purse seiner. (Pacific Fisherman photo)

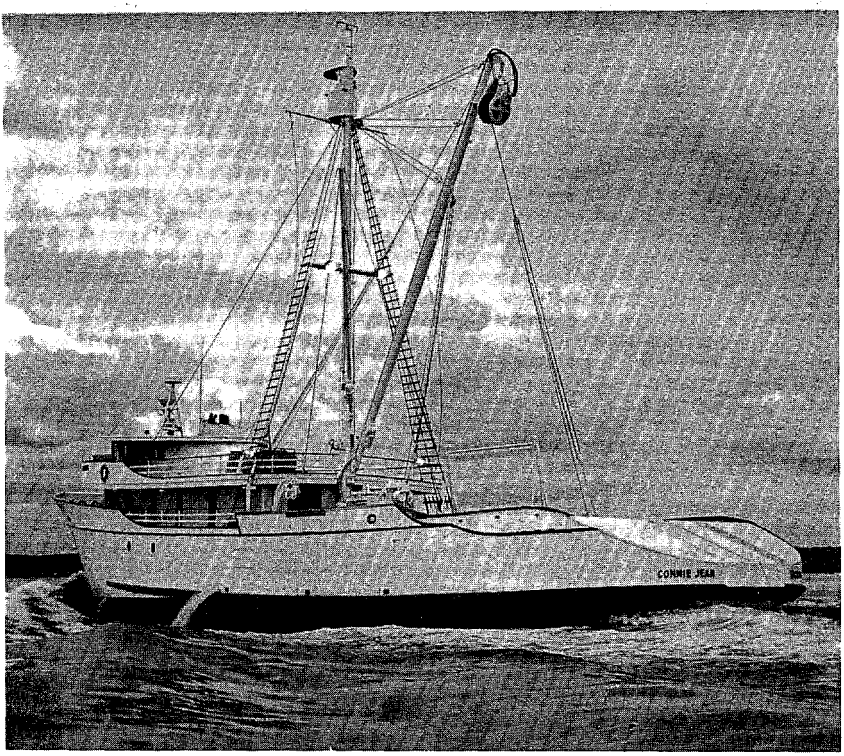


FIG. IX

CONNIE JEAN, newest American tuna purse seiner.

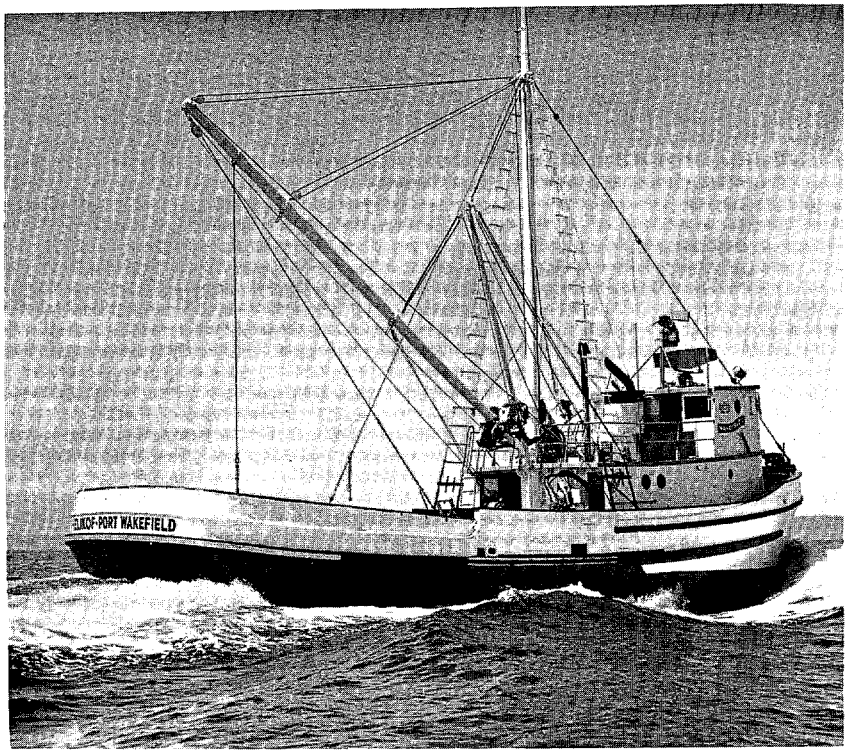


FIG. X

The SHELIKOF of Port Wakefield, Alaska when converted carries 5,000 live King Crab in circulating seawater tank. The new pilothouse is designed for winter operation in the North Pacific.

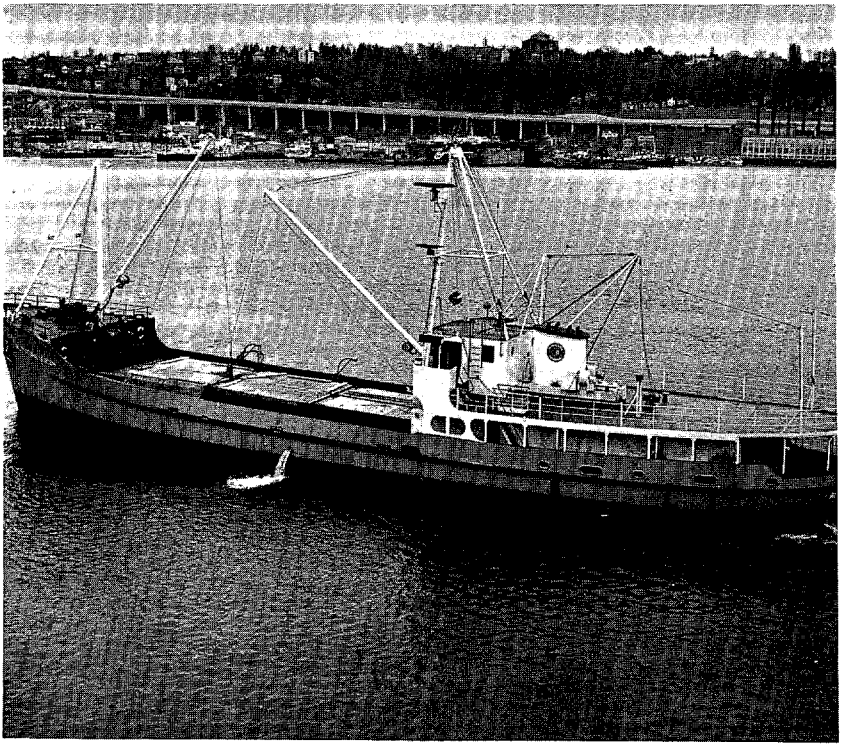


FIG. XI

ALEUTIAN QUEEN, one of the largest King Crab vessels, operates with a crew of five men and carries 35,000 live crabs in circulating water tanks.

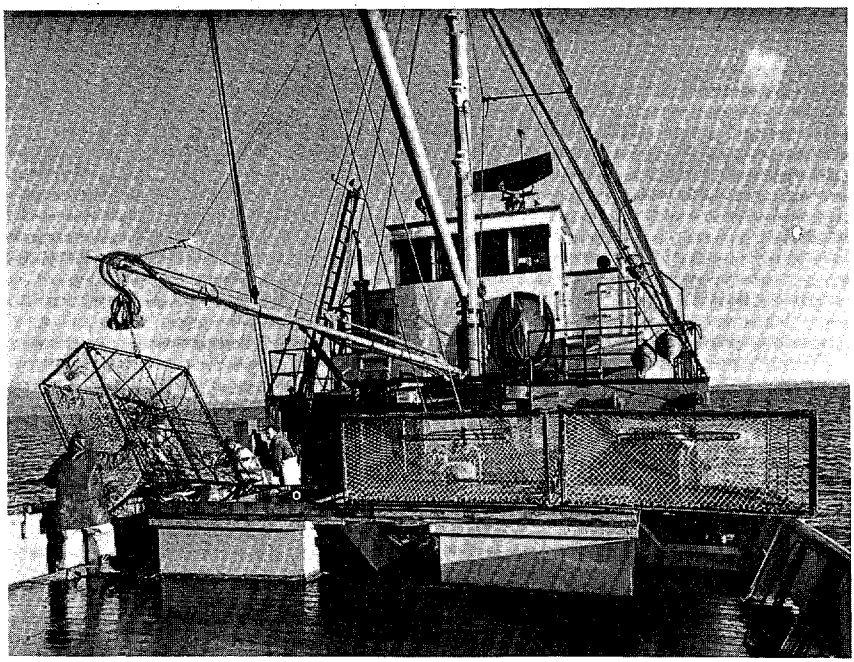


FIG. XII

Hydraulic power is applied to hauling King Crab pots on a power-scow type catcher vessel.

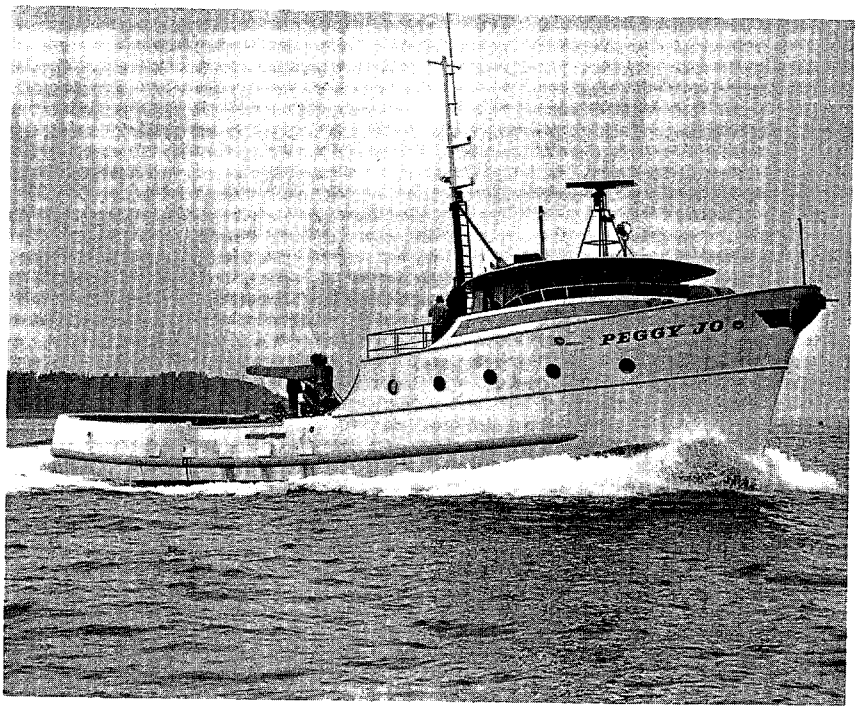


FIG. XIII

Newest 100-ft. King Crab vessel constructed in the Pacific Northwest. Consideration was also given to possible conversion to trawling in this design by B. F. Jensen & Associates, Seattle.

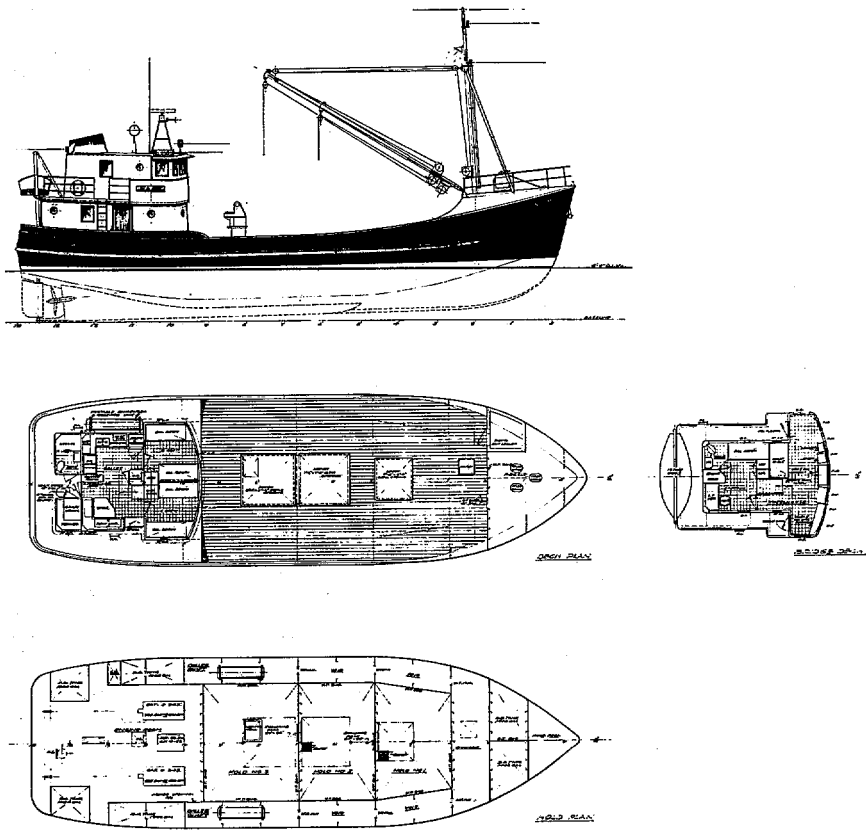


FIG. XIV

Steel 88 foot power scow type King Crab vessel designed so that refrigeration can be added for carrying salmon in the summer season. Designed by B. F. Jensen & Associates, Seattle.

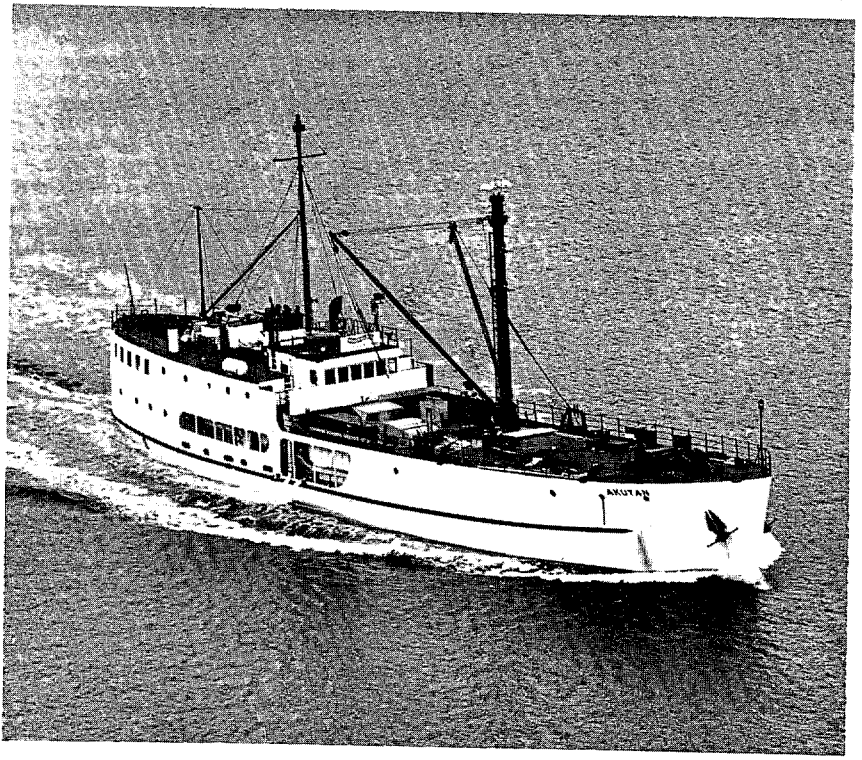


FIG. XV

King Crab processing ship AKUTAN cooks and freezes crab meat and whole legs, operating with five catcher boats in the Aleutian Islands.

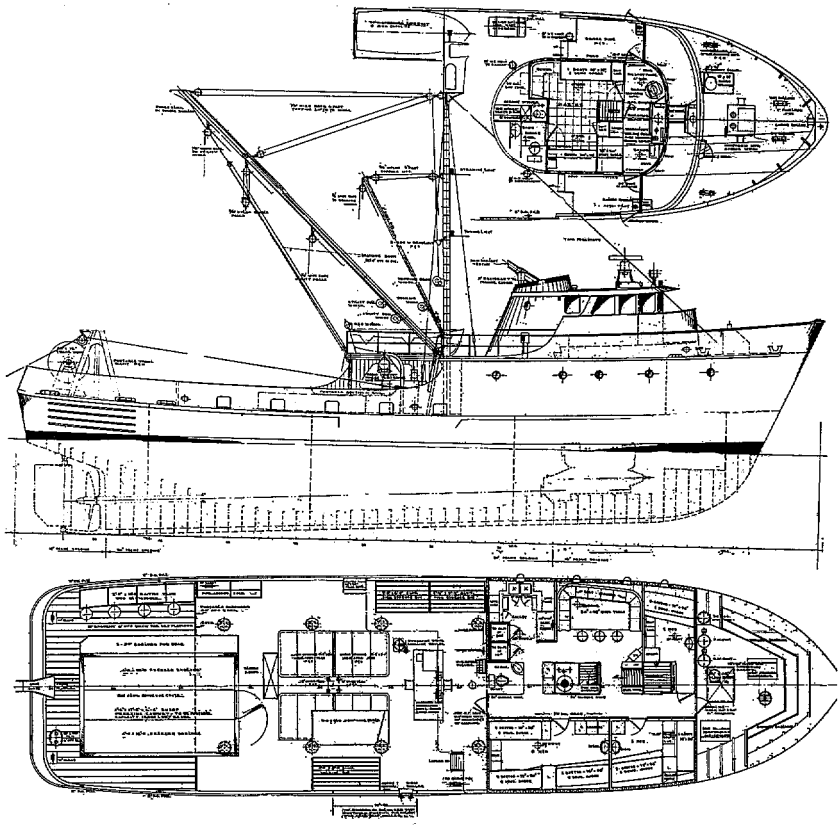


FIG. XVI

This is a 100-ft. combination longline - trawl - crab and seine vessel. First of its type constructed under Government subsidy for North Pacific fishing.

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