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GEOLOGICAL SURVEY CIRCULAR 619

Subsea Mineral Resources and Problems Related to Their Development

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By V. E. McKelvey, J. I. Tracey, Jr., George E. Stoertz, and John G. Vedder

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Statements made by United States representatives before the Economic and Technical Subcommittee of the United Nations Committee on the Peaceful Uses of the Seabed and Ocean Floor Beyond the Limits of National Jurisdiction during its March 1969 meeting

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V. E. McKelvey, *Director*

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FOREWORD

In December 1967, the United Nations General Assembly adopted a resolution establishing an ad hoc committee to study the peaceful uses of the seabed and the ocean floor beyond the limits of national jurisdiction. It thus began the complex and difficult task of trying to lay the groundwork for international arrangements regarding the peaceful exploration and exploitation of seabed resources.

The ad hoc committee, composed of 35 member nations, formed two working groups—the Economic and Technical Subcommittee and the Legal Subcommittee—that included representatives of all the member nations and that met in working sessions in New York from June 17 to July 9, and in Rio de Janeiro from August 19 to August 30, 1968. In these meetings, the Economic and Technical Subcommittee reviewed the extent of seabottom mineral resources, the outlook for their economic development, possible repercussions of the exploitation of mineral resources on other uses of the sea, the prospects for international cooperation in the exploration of the sea floor, and related problems. The Legal Subcommittee considered principles that might govern the exploration and exploitation of the seabeds. The full committee considered the need for a long term program of scientific research and exploration and the desirability of reserving the deep ocean floor for peaceful purposes, and it tried to reach agreement on a statement of principles that would be submitted to the General Assembly. The ad hoc committee failed to agree on a statement of principles, but all members of the committee seemed to agree that there is an area of the seabed and ocean floor that is beyond the limits of national jurisdiction. The ad hoc committee report (U.N. Doc. A/7230) usefully identifies the salient problems and their complexities and indicates something of the range of views expressed in the meetings.

Recognizing the need for a continuing focal point for the consideration of all of these problems, the General Assembly in December 1968 appointed a standing committee on the Peaceful Uses of the Seabed and the Ocean Floor Beyond the Limits of National Jurisdiction; this committee was composed of 42 member states. The new committee was instructed to study legal principles that would promote international cooperation in the exploration and use of the seabed and ocean floor for the benefit of mankind, economic and other requirements which such a regime should satisfy, means of promoting international cooperation, and measures to prevent marine pollution stemming from exploitation of seabed resources. At its organization meeting in February 1969, the committee again formed legal and economic and technical subcommittees and held its first substantive sessions in New York from March 11 to March 27, 1969.

Members of the U.S. Geological Survey have served as United States representatives at meetings of the Economic and Technical Subcommittee of both the ad hoc and the new standing committees. In the sessions thus far, our principal purpose has been to help provide a base of understanding concerning the character, distribution, and potential of seabed mineral resources and the problems related to their development. This has been done mainly through statements and discussion at the meetings themselves.

At its March meeting the Economic and Technical Subcommittee considered two agenda items—progress in seabed mineral resource exploration and exploitation, and the ways and means of promoting the exploitation and use of mineral resources beyond the limits of national jurisdiction. In essence, the latter item is interpreted as the economic and technical requirements that must be met by a regime governing the development of seabed resources beyond the limits of national jurisdiction, regardless of its structure or political affinity. The statements presented on these topics by the representatives of the United States are reproduced here because of their interest to those concerned with the seabed juridical issues and with other aspects of subsea resource development.

W. T. Pecora,
Director.

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SUBSEA PHYSIOGRAPHIC PROVINCES AND THEIR MINERAL POTENTIAL

By V. E. McKelvey, George E. Stoertz, and John G. Vedder

[Statement distributed informally to the Economic and Technical Subcommittee of the United Nations Committee on the Peaceful Uses of the Seabed and Ocean Floor Beyond the Limits of National Jurisdiction in March 1969]

The oceans and adjacent seas cover an area of 362 million square kilometers or about 72 percent of the earth's surface. The sea bottom over this vast area is by no means uniform in geologic composition and resource potential, and its physiography, including both the configuration of the sea bottom and that of the land-sea boundary, is complex also.

To help provide a background of understanding that will aid the Economic and Technical Subcommittee in its deliberations, the physiography and geology of the sea bottom are briefly reviewed here with particular reference to their bearing on the mineral potential of the various subsea provinces.

CONTINENTS AND OCEAN BASINS

Seen as a dry surface, with surface waters drained off, the earth's surface consists of two major physiographic features—the continents and ocean basins (fig. 1). The boundaries between these two features, as they would be seen in hemispheric perspective, are abrupt, with the continental blocks rising to mean heights of about 4,300 to 5,800 meters above the floor of the ocean basins and to maximum heights of 6,200 to 13,000 meters. These physiographic features reflect profound differences in the geology of the underlying crust, for the continental crust is lighter in density, thicker, richer in silica, alumina, and the alkalis and poorer in iron and magnesia than the oceanic crust. The compositions of the continental and oceanic crusts are sometimes described as granitic and basaltic, respectively, after the common igneous rocks that characterize them, and both rest on mantle that is even richer

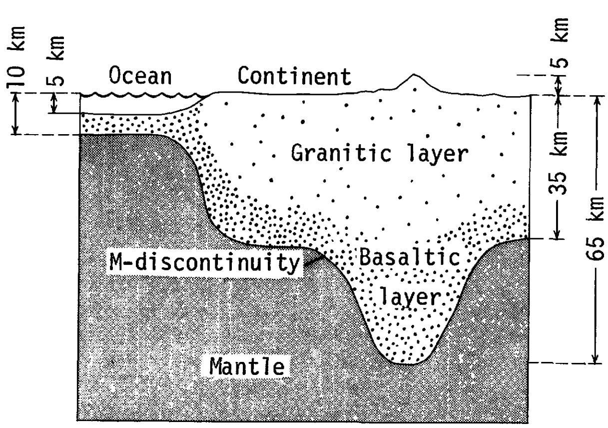


Figure 1.—Idealized cross section showing the floatational equilibrium between oceanic and continental crust (modified from Takeuchi and others, (1968).

in magnesia and poorer in alumina than the basaltic crust. The continental crust averages about 35 km (kilometers) in thickness compared to about 5 km for the oceanic crust. Like icebergs, with only part of their mass showing, the continents rise above the ocean basins because they are lighter in density and they are in floatational equilibrium with the oceanic crust on the underlying mantle.

The ocean basins, of course, are not dry but are filled with water. They are more than filled, in fact, for the ocean everywhere laps over the margins of the continents a distance ranging from a few kilometers to many hundreds of kilometers. The margins of the continents in many places have been planed off by wave erosion or prograded by deposition of marine sediments so that part of their surface in most parts of the world forms a nearly flat or gently dipping shelf, the seaward edge of which lies at depths ranging from 50 to 550 meters below present sea level. Beyond the shelf, the surface of the continental margin slopes more steeply to the floor of the ocean basins (fig. 2). Its edge, however, is in many places concealed beneath the surface by an apron of erosional debris—the surface of which is called the continental rise—derived from the adjacent continent.

Neither world sea level nor its local position have been constant during the past. For example, the melting of the ice caps since their maximum development during the Pleistocene has gradually raised world sea level from 135 to 160 meters. Coastal erosion, sedimentation, and tectonic movements of the crust also lead to change in the location of shorelines. As a result of such changes in the location of the shoreline, at many times in the past the sea has covered much larger parts of the continents than it does now. At one time or another, in fact, all parts of the continents have been submerged for long periods, and marine sedimentary rocks are widespread on the continents (fig. 3).

While the continents and ocean basins are grossly different from each other, they also display great differences and variations in their internal physiography and geology (fig. 4). The continents, for example, may be broadly described in terms of three kinds of geologic provinces:

1. Mountain chains composed of highly folded and faulted sedimentary rocks, several tens of thousands of feet in thickness, and intrusive and extrusive igneous rocks; the island arcs that lie along the northern and western border of the Pacific Ocean basin are continuations of such mountain chains.

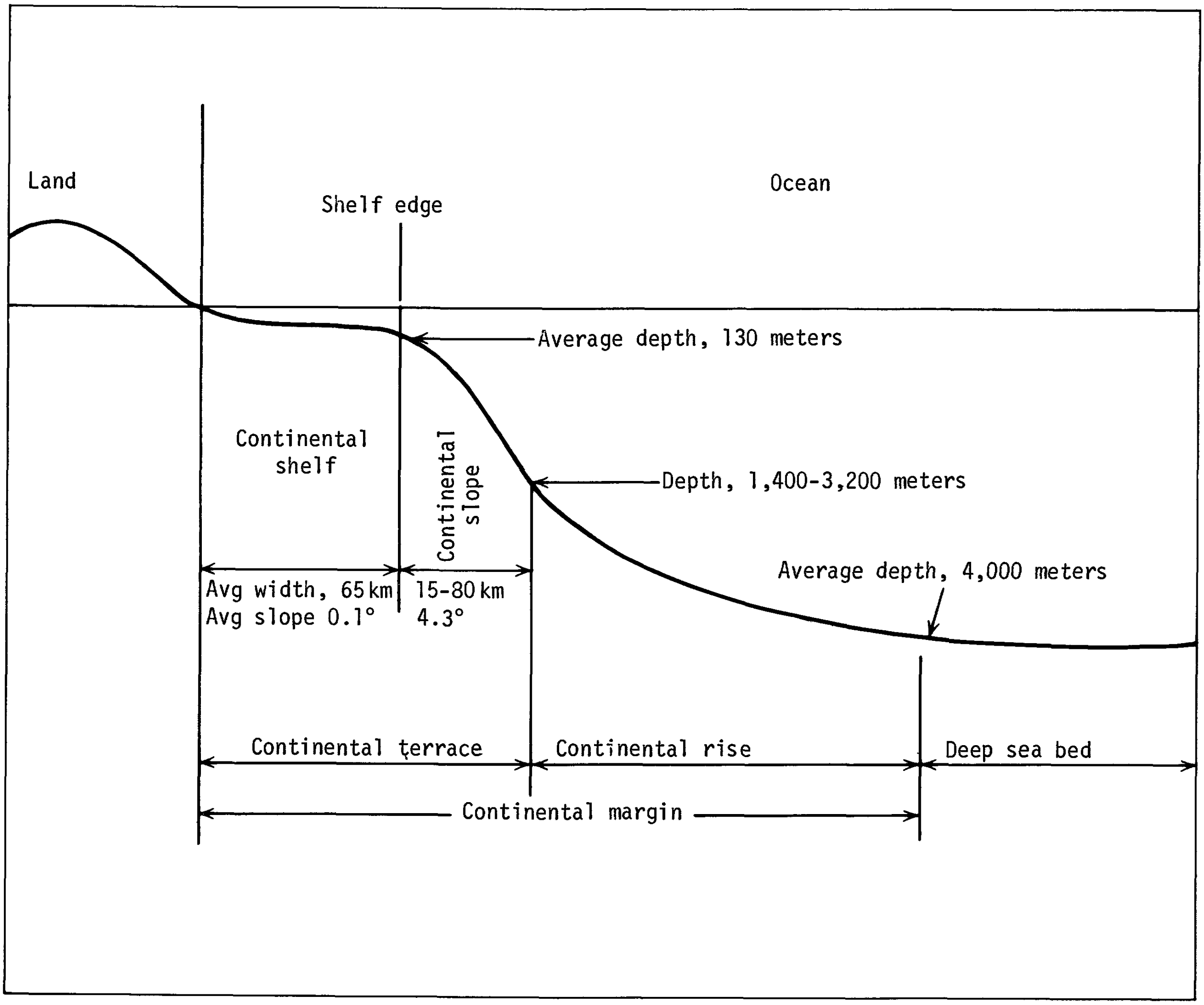


Figure 2.—Diagrammatic profile of continental margin showing average widths and depths and terminology (modified from Heselton, 1969).

2. Shield areas underlain by ancient and generally highly deformed and metamorphosed sedimentary and igneous rocks.
3. Ancient basins, embayments, and platforms, in which a few thousand to a few tens of thousands of feet of sediments accumulated from epicontinental seas that spread over ancient shields; they are now generally areas of low relief underlain by flat lying or gently dipping sedimentary rocks.

These provinces reflect a complex geologic history during which the processes of subaerial weathering, crustal movement, photosynthesis and other biologic activities, sedimentation in shallow marine environments, and rock heating, compression and melting at depth have contributed to the differentiation of the material from which the continental crust was originally derived into a great variety of rock and mineral types. Thus, petroleum, coal, sulfur, phosphate rock, limestone, potash, salt and other salines, and many other minerals are typically concentrated by biologic and sedimentary processes in sedimentary rocks. Copper, lead, zinc, gold, silver, mercury, fluorspar, beryllium, tungsten, tin, and many other metallic and nonmetallic minerals are concentrated as part of the igneous and related hydrothermal processes that operate within the continental crust. And many minable concentrations of iron, alumina, manganese, gold, tin, and other minerals are formed as the result of weathering processes. Although several minerals are already being mined from the seabed, it is significant that all of the 130 or so minerals and fuels currently produced and used by man have commercial continental sources, and that it is the continents, including their submerged margins, that, on the basis of our present knowledge, are the only likely sources of many of them.

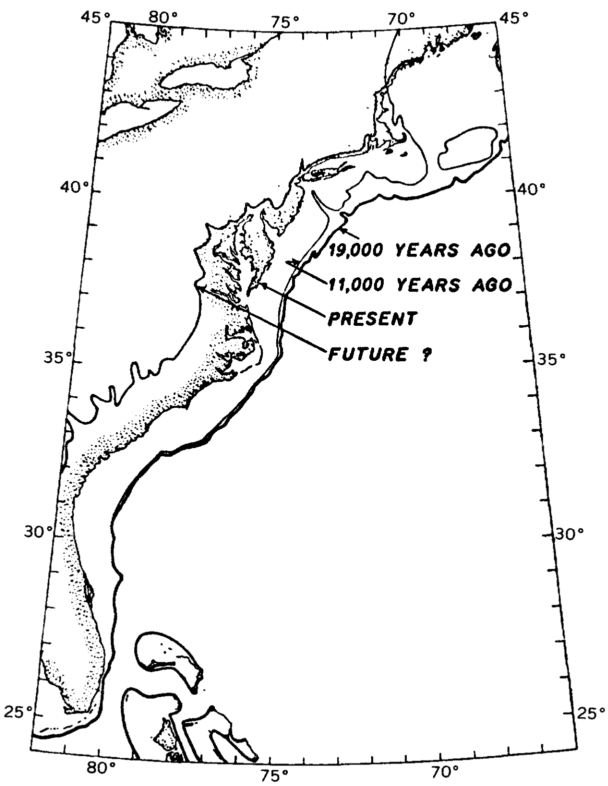


Figure 3.—Past, present, and future(?) shoreline positions along the Atlantic Coast resulting from melting of the ice caps (modified from Emery, 1967a).

The physiography of the large ocean basins beyond the continental margin and rise is also varied, but it is dominated by a few kinds of provinces:

1. Oceanic ridge and rise—often called the midoceanic ridge and rise, although it does not everywhere occur in midocean. The oceanic ridge and rise is essentially a worldwide mountain chain with many branches—in all, it is some 75,000 miles long (fig. 5). A rift valley along the crest of the ridge is a prominent feature in many places, as are volcanoes and volcanic fields, many of which are islands, such as Iceland.
2. Abyssal plains and hills, lying on both sides of the oceanic rise; both the oceanic ridge and rise and the abyssal plains and hills provinces are cut by fracture zones and faults that in places produce an extremely rugged topography.
3. Individual volcanoes or composite volcanic ridges formed by overlapping volcanoes that are scattered over the ocean basin but are often clustered to form groups of islands or seamounts.
4. Trenches and associated ridges which where present generally occur along island arcs or young mountain chains at the periphery of the large ocean basins.

Small ocean basins in places lie between two continents or between the continents and adjacent island arcs. Characteristically, they have an abyssal plain below a depth of 2,000 meters and a few also have trenches along the concave sides of bordering island arcs. Geologically, many of them are more closely allied to the continent than to the ocean basin.

These physiographic features also have a geologic base, primarily in the igneous origin of the ocean floor and the process of ocean floor spreading. Thus, basaltic igneous rock is brought to the surface along the oceanic ridge at the junction of giant convection cells in the mantle, which may be likened to two adjoining conveyor belts moving in opposite directions (fig. 6). New oceanic crust forms along the ridge as these conveyor beltlike convection currents carry the entire floor away from the ridge at the rate of a few centimeters a year; old crust is buckled in ridges or forced down in trenches along the junction of convection cells where currents move toward each other and bring the overlying crusts under compression at the juncture. Much is still to be learned about the behavior and history of this process, but it appears that the continents have split apart and drifted away from each other along

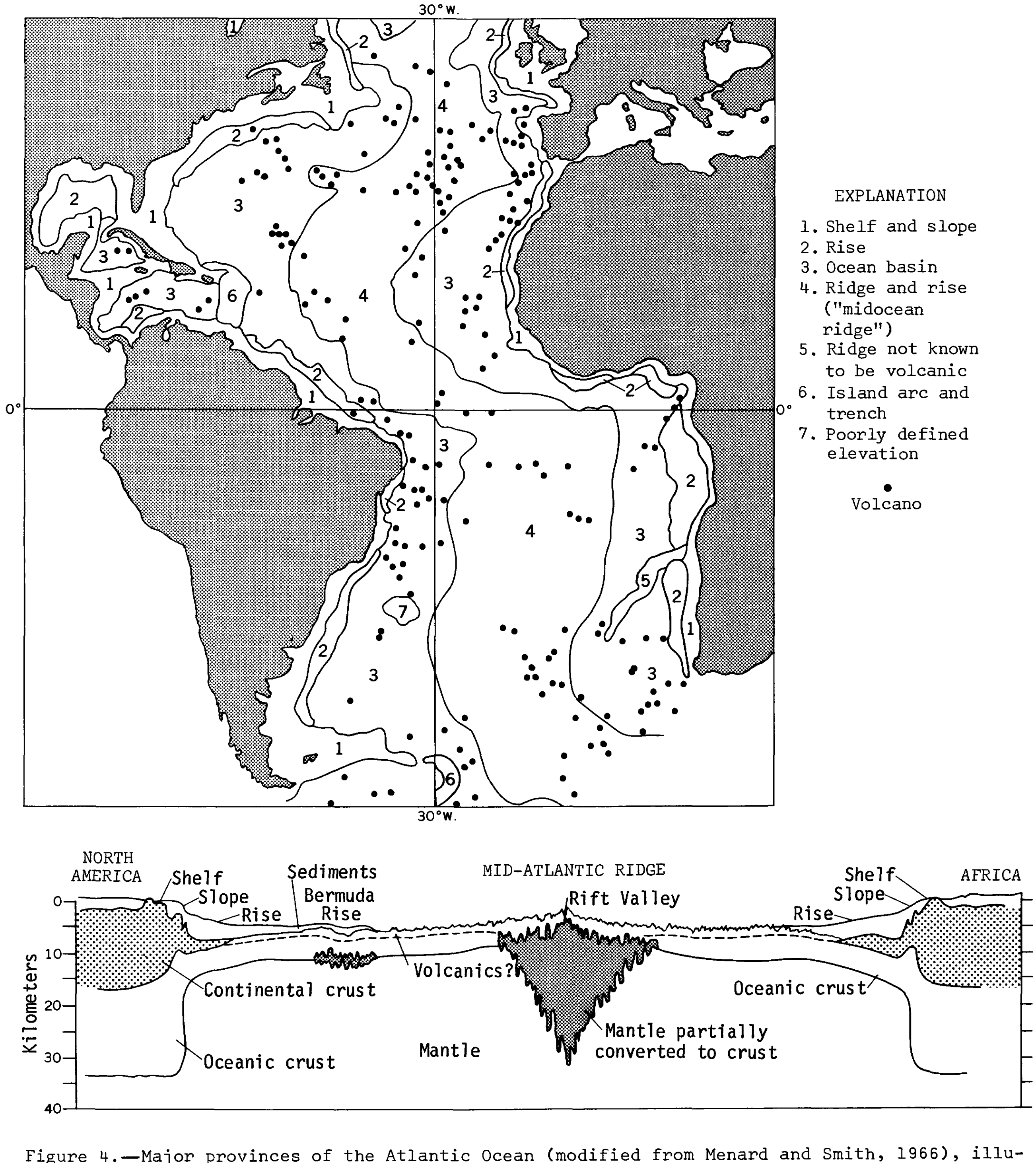


Figure 4.—Major provinces of the Atlantic Ocean (modified from Menard and Smith, 1966), illustrated by a diagrammatic profile across the North Atlantic (modified from Heezen, 1962).

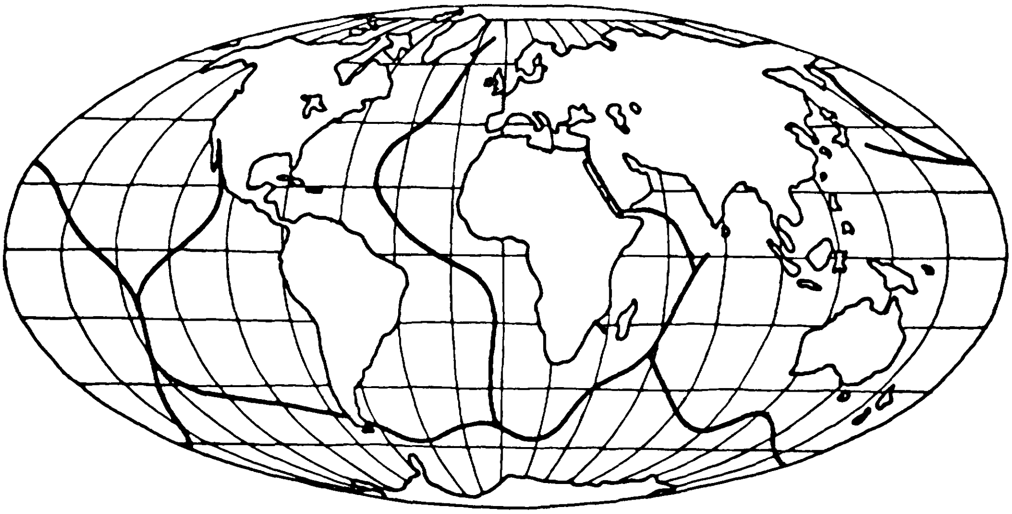


Figure 5.—World oceanic ridge system (Takeuchi and others, 1968, from Runcorn, 1962).

what are now ocean ridges in the Atlantic and Indian Oceans (fig. 7) and that the continental mass is still in the process of separation in the Gulf of California, the Red Sea, and along the African rift valley system.

In contrast to continental crust, oceanic crust is thin and relatively uniform in composition. Basalt bedrock lies at or near the surface over much of the ridge and rise province and although sediments increase in thickness toward the edge of the ocean basin (reflecting the longer time available for their accumulation), they probably do not attain a thickness of more than a few hundred meters, except in some of the small ocean basins and trenches. Although there is some evidence to suggest that deposits of a few metals may occur in the oceanic ridges, some of the processes that operate to differentiate rocks and minerals in continental crust have much limited play in the deep ocean. On the basis of present knowledge, therefore, the large ocean basins are not likely to contain the wide variety of minerals found in continental crust. The manganese nodules, in fact, are the only likely potential resource over much of the large ocean basins, although it is possible that petroleum may occur in some areas where sediments have accumulated in exceptional thicknesses. The trenches and the small ocean basins have somewhat better prospects, as is indicated below.

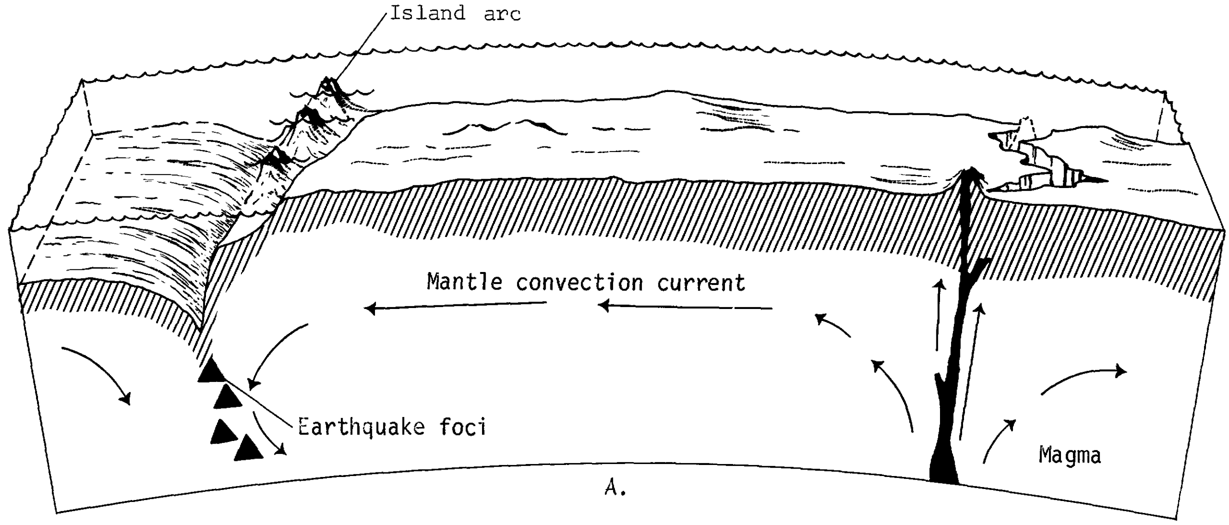
AREA OF SUBSEA PHYSIOGRAPHIC PROVINCES

The total world areas of the major subsea physiographic provinces, including the submerged parts of the continents, are summarized in the following table, drawn from Menard and Smith (1966), Menard (1967), and James (1968).

Province	Area (millions of sq km)	Percentage of total area	Approximate median depth (km)
Continental shelf and slope----------	55.4	15.3	1
Continental rise-----	19.2	5.3	2.5
Abyssal plains and hills--------------	151.5	41.8	5
Trenches and associated ridges----	6.1	1.7	4
Oceanic rise and ridge--------------	118.6	32.7	4
Volcanic ridges and cones and other features-----------	11.2	3.2	---
Total------------	362.0	100.0	
Small ocean basins (included above in "Continental rise" and "Abyssal plains and hills")--------	7.5	2.1	2

The abyssal plains and hills and the oceanic rise and ridge are thus far the largest subsea physiographic provinces. Even though they may be smaller percentagewise, however, the total areas of each of the other provinces are large indeed. Thus, the small ocean basins, excluding the shelf and slope on their margins, are nearly as large in total area as the conterminous United States.

Prominent among the various proposals concerning the location of boundaries of national jurisdiction over seabed resources are the 200 meter and 2,500 meter isobath, often taken to be the average depth of the shelf edge and the toe of the continental slope, respectively. According to Menard and Smith (1966), the total world seabottom area within the 200 meter isobath is 27.1 million square kilometers or about half that shown



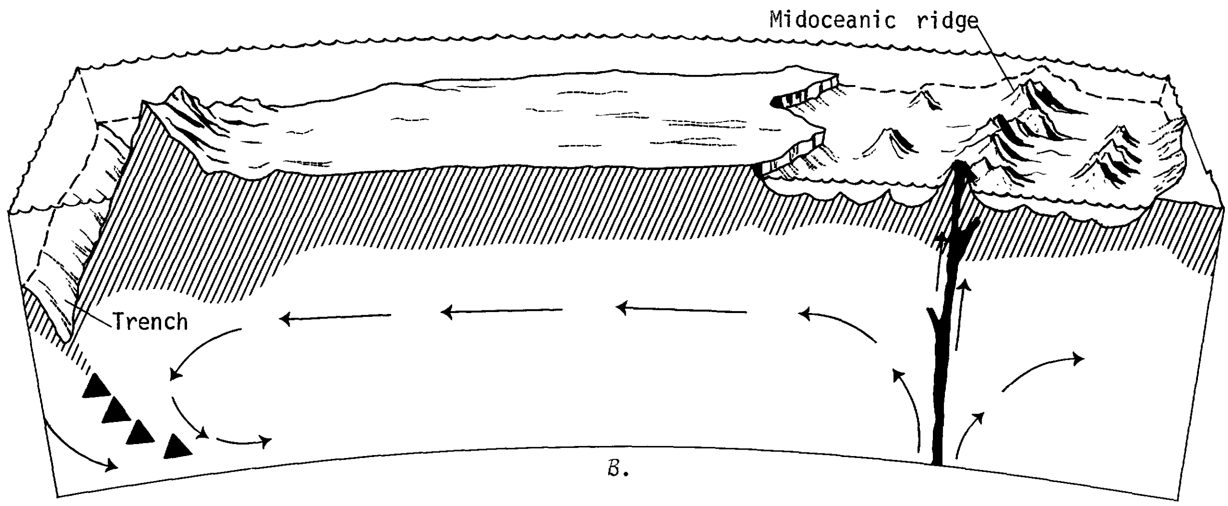


Figure 6.—Schematic crustal sections showing in successive stages the formation of midoceanic ridges and continental drift by mantle convection currents (modified from Wilson, 1963).

above for the shelf and slope combined, and the area within the 2,500 meter isobath is 74.3 million square kilometers,[1] which is nearly that shown above the continental shelf, slope, and rise.

The physiography, geology, and resource potential of these provinces are discussed more fully below.

PHYSIOGRAPHY, GEOLOGY, AND RESOURCE POTENTIAL OF SUBSEA PHYSIOGRAPHIC PROVINCES

Continental Shelf and Slope

The continental shelf and slope, together called the continental terrace, are part of the continental margin, which in most places extends some distance beyond the toe of the slope beneath the continental rise. Whereas the continental margin is a geologic province, the shelf and slope are physiographic provinces within a geologic one and are defined by the configuration of their surface. But although the continental shelf is a part of the continent, a shelf in the physiographic sense may also occur around oceanic islands as a result of wave cutting or sedimentation; such shelves, however, are generally narrow—they are a few miles in width at the most. Included as part of the continental terrace are the floor of many large seas that are partly or almost entirely surrounded by land—for example, the North Sea, Baltic Sea, Irish Sea, Adriatic Sea, Barents Sea, Kara Sea, Chukchi Sea, Hudson Bay, Yellow Sea, East China Sea, Java Sea, Timor Sea, Arafura Sea, Gulf of Carpentaria, Gulf of Siam, and the Persian

[1]Obtained by interpolation from estimates given by Menard and Smith (1966) for the areas to the 2,000 and 3,000 meter isobaths.

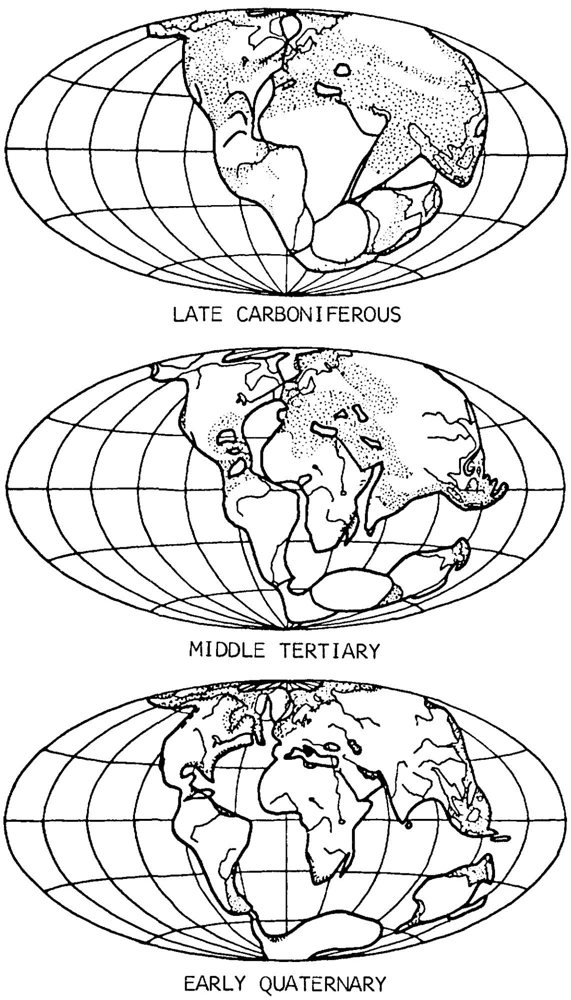


Figure 7.—Reconstructions of the map of the world showing the separation and drift of the continents since Late Carboniferous time. Dotted areas represent shallow seas (modified from Wegener, 1922).

Gulf. The seabed beneath the straits and channels that separate most offshore islands from the mainland—Base Straits, the Santa Barbara Channel, and the English Channel, for example—is also part of the continental terrace.

Although the continental shelf in many places is the nearly flat or gently dipping surface that the name implies, in some places the bottom adjacent to the coast is irregular and consists of ridges or banks, separated by troughs or basins, much like the hilly or mountainous terrain adjacent to many coasts. Such provinces are sometimes called borderlands. In other areas, a deep channel may separate a shallow bank from the mainland. The narrow trench that reaches a depth of about 800 meters along the Norwegian coast of the relatively shallow North Sea is an example. Where a well-defined shelf is present, its surface is in many places uneven. The steepening of the declivity marking the shelf edge is not sharp but may take place over a distance of less than 1 km or more than 10 km, and locally, two or more separate zones of steepening may be present. Although the shelf edge is considered to lie at an average water depth of 200 meters, its depth may range from 50 meters to more than 550 meters. Submarine canyons similar in configuration to subaerial canyons, locally dissect the margins of the continental shelves and borderlands and add to the bathymetric irregularity. The shelf is also variable in width, for although its width is considered to average about 100 km, it ranges from less than a mile to more than 1,300 km.

The limits of the continental slope are also variable and difficult to define, not only at the upper limit but at the lower limit also. For convenience, the slope has sometimes been defined to end where the gradient decreases below a ratio of 1:40. If this definition is applied, the width generally ranges from 15 to 30 km, but the depth at which the lower boundary occurs ranges from 1,000 to more than 4,000 meters (Emery, 1967a).

Geologically, the continental terrace is underlain by continental crust, including older sedimentary and igneous rocks and even shields in some areas, such as along the coast of New England, where these have been planed off by wave action or glaciation. Commonly, however, the continental terrace contains a thick sequence of young sedimentary rocks that were deposited in the same terrace environment in which they are now found and that reflect a seaward growth of the continents (Emery, 1968). Sediment traps, formed by dams created by fault blocks, reefs, or mud or salt intrusions, play an important part in the accumulation of sediments on some terraces.

These accumulations of sediments beneath the continental terrace have already been shown to be rich in petroleum in many areas, and they have also yielded sulfur and salt; placer minerals such as gold, tin, diamonds, rutile, ilmenite, and magnetite; and sand, gravel, lime mud, and shells. Phosphorite also occurs in surficial sediments and bedrock, although it has not yet been mined from the terrace. Older rocks beneath the shelf have been mined for coal, tin, copper, and other minerals in underground mines entered from artificial islands or the adjacent land. It is not profitable yet to mine minerals from the bedrock far from land, but without doubt the rocks of the continental terrace are potential sources of nearly all the minerals now produced on land and they have by far the greatest potential mineral value of all subsea provinces (McKelvey, 1968).

Continental Rise

The continental rise is the gently sloping surface that extends from the toe of the slope to the abyssal plain. Its seaward boundary is also indefinite and has sometimes been defined arbitrarily to be where the slope becomes less than 1:1,000. Under this definition it may occur at depths ranging from 1,000 to 5,000 meters. Its width may be as great as 1,000 km, but in some regions it is extremely narrow or is absent altogether, particularly where trenches are present. As with the continental terrace, some extensive areas of continental rise lie in bays or seas, partly surrounded by a few coastal states; large areas of rise in the Arabian Sea and the Bay of Bengal are examples.

The continental rise is a depositional feature, for it is underlain by sediments that were transported from the continents by bottom currents, gravitational creep, and turbid flow down submarine canyons. In many areas, the sediments of the continental rise are as much as 3,000 meters thick, and in the aggregate they make up the largest volume of sediments on earth (Emery, 1967b). Their petroleum potential is therefore perhaps even greater than that of the continental terrace, although because of the greater water depth its profitable exploitation will require considerable advance in technology over that available now.

Small Ocean Basins

The small ocean basins that are between or are nearly surrounded by continents, such as the Mediterranean Sea and the Gulf of Mexico, or are protected by island arcs, such as the Caribbean Sea and the Sea of Okhotsk, have extensive areas deeper than 2,000 meters. Other examples include basins in the Bering Sea, Sea of Japan, South China Sea, Sulu Sea, Celebes Sea, Banda Sea, Andaman Sea, Black Sea, and the Red Sea. Those basins that receive the drainage from large land areas may contain sequences of sedimentary rocks that are as thick as 10,000 meters or more. Except for the fact that they lie in enclosed basins, the sediments of some of the small ocean basins resemble those of the continental rise, and in total geologic aspect many of these basins are more continental than oceanic.

Because of their very large volume of sediments, the petroleum resource potential of the small ocean basins is large, and it probably approaches that of the continental rise and is probably far larger than that of the abyssal plains and hills and oceanic ridge and rise. Sulfur and a considerable variety of other minerals are also very likely potential resources. The metal-bearing muds recently discovered at depths of about 2,000 meters in the Red Sea, for example, contain small amounts of copper and zinc. Because of their water depth, these resources of the small ocean basins cannot be exploited profitably now, but their potential value for the future is large.

Trenches and Associated Ridges

The deep ocean trenches, and the complex of low ridges and swales that in some places are associated with them, are located adjacent to the convex sides of island arcs or along tectonically active coastal mountain ranges. Most trenches lie around the margin of the Pacific Ocean, but a few, such as the Puerto Rico and Sunda trenches, are on the edges of the Atlantic and Indian Oceans. The trenches include the deepest parts of the sea floor and their floors are generally at depths greater than 6,000 meters. The slopes of their walls are generally in the range of 4° to 16°, although steeper slopes occur locally. Some of them may contain considerable thickness of sediment, and thus they have some petroleum potential and may also have a wider variety of other minerals than do the adjacent abyssal plains. Except in areas of shallow water, however, where some of the trenches pass into island arcs, these minerals are not likely to be exploited within the next few decades.

Abyssal Plains and Hills

The abyssal plains and hills lie at depths of about 3,000 to 5,500 meters and at an average depth of about 5,000 meters. They consist of relatively flat to rolling and hilly plains, studded with seamounts largely of volcanic origin, but in some areas their surface is rugged as the result of extensive fracture zones and faults. The cover of unconsolidated sediment is generally less than 1 km in thickness; because the area is enormous, thicker accumulations may be found locally in areas favorably situated to trap sediment transported from the continental terrace by turbidity currents. Underlying rocks consist predominantly of basalt.

Manganese nodules, averaging about 24 percent manganese, 14 percent iron, 1 percent nickel, 0.5 percent copper, and somewhat less than 0.5 percent cobalt, are abundant in many areas of the abyssal plains and hills. Improved mining and beneficiation techniques must be developed before these deposits can be produced profitably, and because land sources of these metals are adequate for the foreseeable future, it is possible that the nodules may not be exploited for several decades. However, one company, Deepsea Ventures, Inc., recently announced its initiation of a program of exploration and research, which it believes will result in the production of metals within five years. If breakthroughs in mining and extraction technology are achieved, the outlook for exploitation of the nodules could change. In any case, the aggregate amount of metals concentrated in the nodules is so large that they constitute an important resource for the future.

With the possible exception of local areas in which sediments may exceed 1 km in thickness, most of the abyssal plains and hills province probably contains little petroleum, and because of its great depth, as well as the availability of petroleum from other sources, what petroleum is present is not likely to be recovered for many years. Except for deposits of siliceous and calcareous ooze and red clay, which are of no prospective value for the foreseeable future, resources of other minerals are very likely sparse, if not absent altogether, in the abyssal plains and hills. Although this conclusion is supported not only by the sea floor samples and other data already in hand but by broader knowledge of the character of oceanic crust and the processes that operate within and above it, at this early stage of sea floor exploration, allowance must be made for the unknown and the surprises it may hold. The ocean floor is a big place, ore deposits are small features (the huge porphyry copper deposits, for example, generally underlie an area less than a square mile in size), and most of them are geologic accidents, some of which may occur in unexpected places. Even allowing for discoveries not now anticipated, however, the resource potential of the abyssal plains and hills of the large ocean basins appears to be much less than that of the continental terrace, rise, and small ocean basins.

Ocean Rise and Ridge

The oceanic mountain ridges and slopes rise 1,000 to 3,000 meters above the adjoining abyssal plains and reach the surface in places in volcanic islands. Commonly a rift valley is present at the ridge crest, bordered by high ridges offset along numerous transverse fractures or faults, which also cut the adjacent slopes. Although most of the ridges and oceanic rise are underlain by bare rock, largely basalt, a thin veneer of sediment such as red clay or ooze is present in some areas and thin sequences of older sedimentary rocks also occur in places along the flanks of the oceanic rise.

The possibility that petroleum exists on the oceanic ridges and rises is remote but perhaps cannot be ruled out altogether. Concentrations of chromium, platinum, copper, and related metals may exist in the ridge, where some of the rocks with which these minerals are associated elsewhere have already been found in a few places. The Red Sea metal-bearing muds are forming in a young rift zone and although the muds and associated brines show evidence of continental influence (James, 1968), it is possible that similar deposits may be found in closed basins in some places in the rift zone of the oceanic ridge. Manganese nodules also occur in places on the ocean rise, although they are not as abundant as they are on the abyssal plain. More likely as a source of mineral production in the near future than any of these metals are the more prosaic shell deposits, such as those already being mined off Iceland, and coral, which may provide lime not available on most of the volcanic islands on the ocean ridge.

Volcanoes and Volcanic Ridges

Islands, banks, ridges, guyots, and seamounts composed of basalt of volcanic origin are common in the ocean basin, and in fact most islands in the ocean basin are of this origin. More than 1,400 seamounts are known in the Pacific Ocean alone. Some of the seamounts are capped by a smooth platform on which manganese nodules or lime deposits may occur, and coral reefs fringe some of the volcanic islands. Guano and phosphatized rock derived from it occur on some of these islands and it would not be surprising to find some subsea phosphorites on seamounts in the zone of equatorial upwelling. The shallow depth of some of these seamounts might permit early production of such deposits if they occur in suitable concentrations. Other kinds of minerals are not likely to occur in this environment.

CONCLUSIONS

The continental shelf, slope, and rise and the small ocean basins have by far the greatest potential mineral value of the subsea provinces. Most of this is in the form of petroleum, but a variety of other minerals occur in these provinces, some of which are already being produced near shore and others of which may come within technologic and economic reach in the future. The resource potential of the remaining area of the seabed—nearly 80 percent of the total—is largely restricted to the manganese, copper, nickel, and other metals in the manganese nodules. Although the tonnages of metals in these nodules are so enormous that they may attract enough interest in research to yield the breakthroughs in mining and extraction technology necessary to make them competitive with other sources, the odds are that the deep sea nodules will not be exploitable for many years. Metal-bearing muds of the Red Sea type and petroleum may be present in some places in the large ocean basins, but the prospects for exploitable deposits are not bright. As judged from available knowledge, therefore, the exploitable mineral wealth of the seabed in the near future is largely confined to the submerged parts of the continents and the debris piles in the continental rise and small ocean basins that have been derived from them. But as James (1968) put it, after reaching a similar conclusion, "This appraisal of the resource potential of the deep ocean is based almost entirely on inferences drawn from existing knowledge and theory. These inferences seem reasonable—in fact inescapable—but it must be remembered that the area of the oceans is enormous and that the amount of specific information on the underlying rocks is minute in comparison."

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PROGRESS IN THE EXPLORATION AND EXPLOITATION OF SUBSEA PETROLEUM RESOURCES AND ITS IMPLICATIONS FOR DEVELOPMENT BEYOND THE LIMITS OF NATIONAL JURISDICTION

By V. E. McKelvey

[Statement by United States Representative before the Economic and Technical Subcommittee of the United Nations Committee on the Peaceful Uses of the Seabed and the Ocean Floor Beyond the Limits of National Jurisdiction, March 12, 1969]

In the year since the ad hoc committee on seabeds resources convened its first meeting, much progress has been achieved in the exploration and exploitation of subsea petroleum resources. On the whole, these developments do not change any of the conclusions reached by the ad hoc committee, but they do add justification for its "cautious optimism" concerning the future exploitation of the resources of the ocean floor beyond the limits of national jurisdiction.

Some of the more notable of these advances of the past year in the exploration and exploitation of seabed petroleum are summarized here, along with their economic implications.

RECENT DEVELOPMENTS

Progress in offshore petroleum exploration and exploitation was significant on every front—in the development of exploration methods prior to drilling, in extending the capability for drilling to greater depths, in adding new producing provinces, in increasing production, and in improving facilities for storage and transfer of petroleum at sea. These advances provide a basis for continued optimism concerning the future development of seabed petroleum resources, but incidents such as the *Torrey Canyon* and Santa Barbara oil spills are an uncomfortable reminder that exploitation of seabed resources involves some serious hazards and underscore the need to further improve offshore technology and its practice.

Reflection seismic surveys have for many years been the principal means of identifying possible oil-bearing structures at depth. The energy used to create the seismic waves was dynamite—an expensive source and one sometimes dangerous to marine life. In recent years, tools and methods employing nonexplosive energy sources have been steadily improved and have been brought to the point now where they virtually eliminate the need for dynamite as an energy source. This not only reduces the damage to fish and other living resources, but also the cost and the time required. It also makes possible continuous recording, which yields a more detailed seismic profile than is obtainable from widely spaced explosions. Moreover, digital recording of the data permits computerized analysis, which not only speeds up the process but more importantly allows for the use of a wider array of interpretative procedures. Developments during the past year have been of an incremental rather than a revolutionary nature, but they have added to both the speed and sensitivity of the method.

Perhaps the most dramatic of the achievements of the past year were those of the drilling ship, the *Glomar Challenger*, sponsored by the National Science Foundation. You may recall that, while our Rio meeting was in progress last August, we received and reported to you the exciting news that a hole drilled by the *Glomar Challenger* in the Sigsbee Knolls in the Gulf of Mexico, in water 11,720 feet deep, penetrated the caprock of a salt dome and found a show of oil, gas, and sulfur. Since then, the ship set a record for the deepest penetration into the deep ocean floor and the longest drill string ever suspended from a floating platform. Both records were set in a hole drilled 2,759 feet below the sea floor in water 16,316 feet deep in the North Atlantic. The total length of the drill string was thus 19,075 feet. It is hard to imagine, you know, a string of drilling pipe nearly 4 miles long being powered into the ocean floor from a floating vessel. To help his friends visualize it, one marine engineer scaled down the size and strength of such a drill string to a single strand of spaghetti dangling a thousand feet to the street from the top of the Empire State Building. The technology for drilling in such water depths does not yet include reentry capability, although that may be developed soon, or the capability to test adequately for oil and gas, or to produce them, and hence we do not know for certain that petroleum occurs in recoverable quantities beneath the deep ocean floor. Nevertheless, the direct observation of petroleum at these depths is highly significant.

We are distributing a brief statement about the Deep Sea Drilling Project, of which the work of the *Glomar Challenger* is a part, but I may just say here, Mr. Chairman, that the ship is now on the fourth and last leg of its Atlantic track, and that it will begin its Pacific track soon. Its results are being published and a descriptive catalog of the cores collected on its first leg will be ready for distribution during the coming summer. Samples of the cores will be made available to qualified scientists from many countries. The international cooperation that characterizes this project is also shown in the shipboard participation of scientists of other countries. Scientists from Canada, Italy, Switzerland, and Brazil have already shared in the work aboard ship. Scientists from many other countries are also expected to participate.

Although, as the *Glomar Challenger* work so dramatically shows, it is now possible to obtain core samples in deep water, the depth limit for exploratory well drilling—that is holes that can be reentered to make the tests necessary to determine whether or not producible petroleum is present—is still rather shallow. The record water depth of 640 feet for exploratory petroleum well drilling held at the time of the last meeting of the ad hoc committee, however, was broken by drilling in the Santa Barbara Channel, first by a hole in 990 feet of water and then by one in 1,350 feet. A drilling ship is being outfitted now to drill in 1,600 feet of water and new kinds of systems are under consideration and design to permit well drilling and production in still deeper water. One of these designed to operate at depths of 2,000 feet, and perhaps greater later on, plans an occupiable cylinder moored to the sea floor and surrounded by a ring of automatically operated wellheads. This "satellite" would contain equipment and controls activated by a surface station. It would be serviced by a submersible, however, and would be occupied intermittently.

Several new deep submersibles and work vehicles were completed during the year, and the technology for undersea habitats and work units is being advanced by the Sealab program, Tektite, and other projects.

Petroleum exploration is now underway offshore in nearly 40 countries, including several in which it has just begun during the year. Important new discoveries have been made off many areas, including the United States, Mexico, Trinidad, Brazil, Norway, Dahomey, Nigeria, Cabinda (Angola), and Australia, and geophysical exploration and exploratory drilling is underway in many other favorable areas.

In recent years, offshore petroleum production has been increasing at the rate of about 10 percent per year, and it now supplies about 5 million barrels per day or 16 percent of the total output of non-Communist nations. Private investment in offshore exploration and production has been increasing at the rate of about 18 percent per year and amounted to about $2.3 billion in 1968. The cumulative total is now nearly $13 billion.

Important new developments have also taken place in the construction of offshore storage and loading facilities. A 500,000-barrel undersea storage tank, for example, is being installed in 150 feet of water 65 miles off the coast of Dubai on the Persian Gulf. Such units not only reduce the probability of storm damage but solve the loading problem for supertankers unable to use conventional port facilities.

IMPACT AND OUTLOOK

The developments during the past year bring much new ground within the reach of economic exploitation—laterally in new areas of the shelves now shown by exploration to be productive or promising and vertically in deeper waters that advancing technology has made accessible to exploratory drilling. The results of the *Glomar Challenger's* deep tests do not extend the depth range of petroleum exploration and production capability, but they substitute evidence for what heretofore has been largely speculation as to the occurrence of petroleum in parts of the deep ocean floor.

World demand for fluid hydrocarbons certainly will continue to increase. How much of it will be met by synthetic fuels—derived from tar sands, oil shales, and coal—how much from land sources of petroleum, and how much from offshore petroleum is difficult to predict; for the amount that will come from each of these sources depends on future discoveries, on the future development of technology—including, in the case of offshore production, that relating to the prevention and control of pollution—and on the economic and political policies set by governments.

One of the largest elements of uncertainty in the extent to which offshore production will share in future growth of the world market stems from the recent huge discovery of oil on the Arctic Slope of Alaska and from others that may come there and elsewhere in the future. Offshore costs are generally higher than onshore costs under comparable conditions of drilling depth and field size. For example, according to figures recently released by Shell, drilling costs for a 14-well, 120,000-barrel-per-day oil field would be about $11.5 million offshore in water of moderate depth, compared with $4 million onshore, and development costs would be about $13.5 million offshore compared with $4.7 million onshore. In spite of these costs, of course, offshore exploration has increased because the virgin offshore ground offers a better opportunity to find giant fields, producible at costs low enough to offset increased exploration and development costs, than does much of the already partly explored onshore. But important new discoveries are still possible onshore and their rate and magnitude will influence the rate and magnitude of offshore petroleum development.

Synthetic hydrocarbons from oil shale or coal are not expected to make significant inroads on the market for petroleum during the next decade or so, but because their costs are not much above those of natural petroleum, a breakthrough in oil shale or coal conversion technology could make them competitive earlier. In the meantime, they serve to set a ceiling on the price of petroleum at a figure not much higher than it is now in the United States and many other areas, for with a modest increase in price these large sources of fluid hydrocarbons would become competitive.

Fuels in many of their uses are interchangeable. Thus it does not matter to a boiler whether the heat comes from coal, gas, oil, or nuclear fission, and even water power is exchangeable with other forms of energy through the medium of electricity. Therefore, technologic developments that influence the availability, cost, and use of sources of energy other than hydrocarbons also will affect the overall demand for petroleum. The development of an efficient electric automobile and a low-cost electric heating system, for example, could markedly reduce the rate of increase in the demand for petroleum.

The Santa Barbara incident has brought to the fore another factor that may influence the rate of offshore development—namely, public concern about the potentially disastrous effects of an oil-well blowout, no matter how rare it may be. Without doubt, improved safety technology will develop as a consequence of the Santa Barbara accident and will much reduce the hazard from this source. But in the meantime, caution may somewhat retard the rate of growth of the offshore industry, and added safety measures may add to cost and thus narrow the area in which offshore production is competitive.

The economic and political policies established by governments also effect the competitive position of various fuels and their component sources, and because they are subject to change, they add an important element of uncertainty about the competitiveness of individual fuel sources in the future. In the United States, for example, a change in State or Federal production control policies or import controls could, depending on the direction of the change, act to stimulate or retard the development of the offshore industry. In the same way, the decisions and arrangements that come to govern the development of seabed petroleum resources beyond the limits of national jurisdiction can also act to aid or hinder petroleum exploration and development.

Recognizing then, that such uncertainties may invalidate any projection made now, present trends suggest that offshore production will supply something of the order of 30–35 percent of the world market by 1980. Very likely, nearly all of this will be produced from water depths of less than 2,000 feet, not only because it will take time to develop the new drilling systems that will be required and to reduce their cost to a competitive level, but also because the less expensive onshore and shallower offshore sources are ample to meet the demand to and some years beyond 1980.

[Following is additional statement on the National Science Foundation's Deep Sea Drilling Project distributed to the Economic and Technical Subcommittee March 12, 1969]

The deep sea drilling project of the National Science Foundation's National Ocean Sediment Coring Program is being carried out under a contract with the Scripps Institution of Oceanography. Scientific planning and guidance for the program is provided by the members of the Joint Oceanographic Institution for Deep Earth Sampling (JOIDES), which include the Scripps Institution of Oceanography, Woods Hole Oceanographic Institution, Lamont-Doherty Geological Observatory of Columbia University, the Institute of Marine Sciences at the University of Miami and the University of Washington.

The project involves an 18-month program to core-drill deep ocean sediments in water depths of as much as 20,000 feet in the Atlantic and Pacific Oceans. Global Marine Incorporated designed and constructed a special drilling ship, the *Glomar Challenger* to carry out under a subcontract from Scripps the drilling operations at sea. Many of her features are unique and represent breakthroughs in oceanographic engineering and drilling. She has a dynamic positioning system, employing tunnel thrusters which, with the ship's own screws, enable her to remain on station. While drilling is in progress, a computerized system automatically controls both thrusters and propulsion to maintain her position with reference to a sonar beacon system on the ocean floor. She is the first commercial ship to utilize satellite navigation.

The *Glomar Challenger* is now on the fourth and last leg of her Atlantic track. Already she has set a record for the deepest penetration into the ocean floor and the longest drill string ever suspended from a floating platform. Both records were set in a hole drilled 2,759 feet below the sea floor in water 16,316 feet deep in the North Atlantic. A hole drilled in the Sigsbee Knolls in the Gulf of Mexico, in water 11,720 feet deep, penetrated the caprock of the salt dome and found a show of oil, gas, and sulfur.

The preliminary core descriptions of the Deep Sea Drilling Project are being published for the benefit of the world scientific community as they are completed. A descriptive catalog of the cores collected on the first leg of the Atlantic cruise will be ready for distribution during the coming summer. Catalogs describing cores from subsequent legs will be published at 3-month intervals thereafter. Samples of the cores will be made available to qualified scientists from many countries. Scientists from Canada, Italy, Switzerland, and Brazil have already shared in the work aboard ship. Scientists from many other countries are expected to participate during the drilling operation and in the subsequent studies and analyses of the cores.

PROGRESS IN THE EXPLORATION AND EXPLOITATION OF HARD MINERALS FROM THE SEABED

By V. E. McKelvey

[Statement by United States Representative before the Economic and Technical Subcommittee of the United Nations Committee on the Peaceful Uses of the Seabed and the Ocean Floor Beyond the Limits of National Jurisdiction, March 13, 1969]

Continuing our review of the progress and exploitation of seabed resources since the report of the ad hoc committee was completed, we can say, as we did for petroleum, that while the advances of the past year in the field of hard-mineral seabed mining have been encouraging, they do not change any of the conclusions reached last year. Nevertheless, it may be worthwhile to briefly review some of the highlights of the recent achievements in this area.

RECENT DEVELOPMENTS

Advances in offshore mining of hard minerals have not been nearly as rapid as those relating to petroleum. Progress in solving the difficult problem of prospecting for and evaluating seabed mineral deposits has come in recent years through the development of a detached "boomerang" corer, which is brought to the surface by a float after it has taken its sample; a series of such corers can therefore be dropped from a moving ship on traverse and picked up on its return. A sediment analysis pod has also been developed that will transmit a digitized signal by cable to the surface, giving data on acoustic velocity, bearing strength, temperature, and bulk density. Another new device is a radioisotope-powered acoustic pinger that has a 5-year life, is usable in water as deep as 6,000 feet, and will precisely mark undersea locations, a fundamental need in both mineral evaluation and mining. The advances in geophysical exploration, submersibles, undersea work vehicles and habitats, and deep-drilling techniques already mentioned also contribute to the development of subsea hard-minerals technology.

Mining is in progress in waters less than 200 feet offshore in many countries—sulfur in the Gulf of Mexico; sand, gravel, and shell off the United States, Japan, Iceland, and Great Britain; lime mud off the Bahamas; magnetite off Japan; tin off Indonesia and Thailand; diamonds off the southwestern coast of Africa; and rutile and ilmenite off Australia. Exploration underway in other areas includes that for gold and platinum in Norton Sound and the Bering Sea; gold off northern California, the Gulf of Alaska, Nova Scotia, and British Columbia; gold, chromite, and magnetite off the Philippines; gold off the Soviet Union in the Laptev Sea and the Sea of Japan; gold and tungsten off Australia; tin off Malaysia, Borneo, Solomon Islands, and Great Britain; metal-rich mud in the Red Sea; and phosphorite off the United States, Palau, and Mexico. Interest continues in the manganese nodules, particularly for their content of nickel and copper, and research is underway on mining systems that will make their economic recovery feasible. Most of the companies who have investigated the manganese nodules have found the prospects for their development in the next decade or so discouraging. One American company, Deepsea Ventures, Inc., recently announced plans, however, to begin research on the recovery of the nodules, has a vessel equipped to prospect and appraise certain deposits, and believes it will reach production of metals within 5 years.

IMPACT AND OUTLOOK

The exploration in progress may lead to the development of offshore mining in new areas, but none of the developments of the past year constitute breakthroughs that substantially enlarge the scope of marine mining in the near future or that will speed economic access to the sea-floor minerals in deep water.

The drag on the development of hard minerals in deep water has several origins. Ore-finding technology, particularly for bedrock minerals beneath the floor, is poorly developed—as indeed it is for wholly concealed deposits on land—and knowledge of the regional and local geology necessary to guide prospecting is as yet fragmentary. Evaluation technology for most subsea minerals is both weak and expensive. Low-cost systems for deep-sea mining are not much beyond the conceptual stage, and each of the major surficial deposits—the manganese nodules, the phosphorites, and the sulfide muds—poses difficult beneficiation or extraction problems. On the economic side, low-cost onshore sources of most seabed minerals are ample for the foreseeable future, and this dampens the incentive to press the research and development necessary to speed development. They do not kill it, however, and even though the advance of deep-sea-mining technology may be slow, it seems certain to come eventually. And, of course, a real breakthrough that would reduce mining and extraction cost to competitive levels would have a substantial impact on world supplies in the case of the manganese nodules and perhaps also the sulfide muds and an important impact on regional supplies in the case of the phosphorites.

POTENTIAL ILL EFFECTS OF SUBSEA MINERAL EXPLOITATION AND MEASURES TO PREVENT THEM

By V. E. McKelvey

[Statement by United States Representative before the Economic and Technical Subcommittee of the United Nations Committee on the Peaceful Uses of the Seabed and the Ocean Floor Beyond the Limits of National Jurisdiction, March 17, 1969]

Subsea mineral exploitation inevitably carries the potential to create hazards to other uses of the sea and to damage other marine resources. The nature of some of these dangers is already known from experience gained in coastal waters, but others, particularly as viewed with respect to the deep-sea floor far from land, are as yet poorly understood. Experience thus far indicates that the hazards and damages stemming from subsea mineral exploitation can be largely avoided if it is properly managed, but at this stage it is essential to recognize that some of the problems to be faced and overcome are as yet unknown and that the dimensions of others are as yet not defined.

The potential ill effects of subsea mineral exploitation relate to (1) safety of personnel, (2) damage to living resources, beaches, and other installations from pollution, (3) interference with navigation and fishing, and (4) aesthetic and recreational values. These ill effects may be associated with each phase of the exploration-exploitation process. In areas under national jurisdiction, government should establish procedures and practices governing the exploitation and extraction of the subsea mineral resources so as to insure, to the extent feasible, that the operations are at all times safe, do not interfere with the other uses of the sea, and do not in any way damage the other resource values. Under any international arrangements agreed to relating to the seabed beyond the limits of national jurisdiction, it will be necessary to insure that seabed operations there are conducted in a manner that will avoid damage to other values.

At this stage in our deliberations, it may be helpful to review the nature of the potential ill effects of subsea mineral operations and the approaches taken to prevent them by regulatory authorities. Most of what is known of these topics comes from experience with petroleum exploration and production. It is this experience in U.S. waters and the U.S. regulatory procedures that govern these operations that form the primary basis for the following review. Several other governments represented here also have procedures to cope with these problems, and we hope they will report their experience also.

HUMAN SAFETY

Subsea mineral exploration and exploitation undertaken from floating vessels combine the hazards to the safety of operating personnel related to shipping and fishing and those associated with onshore drilling or dredging. In U.S. waters and vessels the U.S. Coast Guard, advised by a Merchant Marine Council, maintains a Merchant Marine Safety Program, providing for safety inspection and regulation of vessels, their construction, repair, and their equipment, and for the investigation and review of marine casualties and acts of incompetency and misconduct. The Coast Guard also maintains a search and rescue program to provide assistance to ships at sea. Experience in these activities is sufficient to form the basis for safety regulations and practices, which nevertheless deserve continuing review and improvement.

Marine operations undertaken from submersibles and from platforms attached to the bottom introduce some hazards not encountered in vessels. The submersibles that might be used in conjunction with subsea mineral exploration, evaluation, and exploitation are almost entirely in the experimental stage, and much research will be required in several fields—e.g., in materials and structural engineering, in physiology and medicine, and in oceanography—to make them operational under acceptable licensing, and operation of submersibles and the training and licensing of pilots are currently under consideration by the Congress of the United States.

Fixed platforms are also undergoing continual changes in design, and entirely new types are in the design or construction phase. An excellent safety record has been achieved by those already in use, but nevertheless several have toppled over or have been otherwise destroyed during hurricanes and other storms. The danger comes not only from the direct force of high winds and heavy seas, but also from the effects of scouring on the sea bottom. The experience gained thus far about these effects is being taken account of in new designs and modification of older structures. Another danger to operating personnel in petroleum exploration, whether undertaken from a fixed or mobile platform, comes from fire, particularly that resulting from gas or oil blowouts, such as that which destroyed the Little Bob rig offshore Louisiana last summer and took 10 lives. In U.S. waters, State agencies have regulatory authority over fixed platforms in State waters, and the U.S. Geological Survey is responsible for design approval and inspection in Federal waters.

The millions of tons of ordnance explosives that have been dumped in the sea constitute a hazard to subsea mining that may prevent it altogether in some areas (a phosphorite lease off southern California was cancelled for this reason) and may be an uncertain threat elsewhere.

POLLUTION

Pollution stemming from subsea mineral exploitation may be of three types: (1) oil, gas, brines, or fluids released directly from the well, from production or storage facilities, and from pipelines, (2) particulate matter stirred up from the sea bottom in mining or discharge as waste in the course of onsite beneficiation, and (3) human waste and refuse. The last of these is readily controllable and needs no further discussion.

Not enough is known yet about the effects of seabed mining to assess adequately the hazards stemming from the release of particulate matter even in shallow water (the U.S. Bureau of Mines is beginning an investigation of the effects of dredging that will define the problem in coastal waters), much less in deep water far from shore. Locally, dredging in such waters may be expected to pose some hazard to marine life, but on the whole particulate matter released in the course of deep-sea mining should have no ill effects on other resources or the environment. In fact, over much of the ocean beyond the limits of national jurisdiction, the capacity of the sea to receive locally generated solid waste without producing any harmful effects may well prove to be a valuable advantage compared to mining either in coastal waters or on land.

Pollution from offshore petroleum exploration and production in the past has resulted from blowouts during drilling, from rupture of well casing as the result of hurricanes or of ship collisions, from spillage of oil in storage at the surface, and from pipeline leaks. Earthquakes are a potential source of rupture of well casing and pipelines, although thus far no offshore spills are traceable to them.

The procedures and equipment to prevent release of oil and gas from all of these sources are already available. Drilling technology, for example, already provides for control of unexpected oil or gas pressure through the use of heavy drilling mud, well casing, and automatic blowout preventers. Storm chokes close the well automatically if wellheads are broken by storms or ship collision. Valves in surface lines shut off flow when loss in pressure signifies a leak. Electronic navigational devices are used to guide ships through shipping lanes in which oil and gas operations are not permitted, offshore platforms are equipped with navigational devices to warn ships that for one reason or another ply the water around producing fields, and navigation charts are periodically updated to show the location of new installations. Weather services are employed to provide advance storm warnings and thus allow exercise of safety precautions and evacuation of personnel if necessary. The surprise and the unexpected elements in many of the events leading to release of oil and gas set the stage for the "accident," but in view of the state of development of both prevention procedures and equipment, the accident itself must be attributed to human error or equipment failure or a combination of the two.

Parallel in importance to procedures and equipment to prevent unwanted release of oil and gas are those necessary to regain control of the flow and dissipate and clean up that already released. As shown by the Santa Barbara incident, the technology for stopping the flow also is available. Means to dissipate and clean up a large spill are as yet poorly developed, but many valuable lessons have been learned as a result of the *Torrey Canyon* and Santa Barbara incidents.

In the United States, State agencies are responsible for the supervision of exploration, drilling, and production offshore, and the Secretary of the Interior, and under his direction the Geological Survey, are responsible for operations on the outer continental shelf. On the outer continental shelf, regulations governing procedures have been further supplemented by specific orders issued by the Regional Oil and Gas Supervisors of the Geological Survey, who must also approve proposed plans for exploration, production, and related operations and who also inspect operations in progress. That the regulations, procedures, and practices generally have been effective in preventing pollution is shown by its very low incidence in offshore operations over the years, but the entire process requires further improvement.

Although government, of course, bears the responsibility of insuring that safe procedures and practices are followed at all times in offshore operations, the public purpose in the prevention of offshore pollution is also served by industry, which is largely responsible for the development of the highly effective safety technology already in use and which is continuing to improve both the technology and its practice.

INTERFERENCE WITH NAVIGATION AND FISHING

As already indicated, the establishment of sealanes and use of modern aids to navigation have largely eliminated interference with navigation by offshore mineral operations in coastal waters, and the hazard should be diminished further in waters beyond the limits of national jurisdiction. There is no denying, however, that the increase in the number of fixed or stationary installations increases the number of obstacles shipping must face and calls for increasing attention and vigilance on the part of both shipping crews and authorities. In the U.S. waters the Corps of Engineers is responsible for the delineation of sealanes and for preventing obstruction to navigation, and the Coast Guard is responsible for other aids to navigation.

In addition to the damage that may be done to marine life by pollution, mineral exploration and extraction may interfere with fishing. The use of dynamite as an energy source in seismic exploration may kill fish locally, and obstructions in the form of gear or debris piles not visible from the surface may cause damage or loss of fishing gear. The development in recent years of seismic methods of exploration that utilize nonexplosive energy sources, however, has nearly eliminated the use of dynamite, and in water below a depth of several hundred meters, it seems unlikely that other mineral operations still interfere much with fishing.

The 1958 Geneva Convention on the Continental Shelf recognizes the need for multiple use and provides for it in several specific terms in Articles 4 and 5. In the United States, the Fish and Wildlife Service advises the Geological Survey on the issuance of exploration permits and other problems related to fishing and, through State agencies and the Department of the Army, reviews proposals and plans for marine undertakings that affect fisheries and other values. The Geological Survey requires operators to remove all litter and obstructions from the sea bottom on the abandonment of a well site.

RECREATION AND AESTHETIC VALUES

Near-shore mineral operations may adversely affect sports, fishing, and boating, and it may damage aesthetic values as well, although the sign on the balance sheet is by no means clearly negative on either point. Many fishermen are of the opinion that oil and gas platforms attract fish, others find that they serve as navigational aids and emergency ports, and the number of boats that visit platforms on a summer weekend suggest that they offer some attraction to sportsmen. Be this as it may, coastal preserves have been set aside in certain areas, and in certain other areas in U.S. waters the Geological Survey requires that the platforms be camouflaged and that as many well as possible (20 or more) be drilled from a single platform to reduce their number.

In waters beyond the limits of national jurisdiction, the damage to recreational and aesthetic values will be negligible in most areas.

CONCLUSIONS

All of the ill effects that may result from subsea mineral exploitation in coastal waters seem at this stage to be subject to satisfactory control. Technologic improvements in both prevention of cause and remedy of effect are necessary in many areas and will come, but of equal if not greater importance is improvement in the practice of prevention procedures, particularly fail-safe procedures that guard against human and equipment failures.

The potential ill effects of mineral exploitation in waters beyond the limits of national jurisdiction are much less well understood at this stage and will require both further study and caution. The danger to operating personnel may prove to be greater in certain deep-sea undertakings than it is in coastal waters, but the ill effects from pollution and the hazard to navigation, fishing, recreation, and aesthetics very likely will be less in deep water far from land than they are near shore.

Marine industries and operators can be counted on to pursue aggressively the development of safe practices and equipment—accidents are costly in terms of both life and capital and they work hard to avoid them. Nevertheless, it is government's responsibility to set and enforce safety standards, and this function must be provided for in mineral exploitation beyond the limits of national jurisdiction.

TOPOGRAPHIC AND GEOLOGIC MAPPING OF THE SEA BOTTOM

By J. I. Tracey, Jr.

[Statement by United States Representative before the Economic and Technical Subcommittee of the United Nations Committee on the Peaceful Uses of the Seabed and the Ocean Floor Beyond the Limits of National Jurisdiction, March 19, 1969]

It is evident from the statements of other speakers that everyone is aware of the complexity of the problems we face in considering the development of the resources of the seabed and ocean floor beyond the limits of national jurisdiction in the interest of mankind.

The kinds of basic information that are needed before exploitation of the resources can take place are put under the general heading of basic documents in the excellent paper prepared by the Secretariat for this meeting. Basic documents, especially regional topographic and geologic maps, lay the groundwork for identifying areas favorable for the occurrence of various minerals and for an appraisal of their potential resources. They also help to define the physical and chemical properties of the bottom sediments and underlying bedrock. These properties must be known in order to determine the stability of the bottom sediments when designing large structures to be placed on the bottom, to predict the hazards that might exist to bottom operations from slides or slumps, and to predict the effects caused by the disturbance of sediments by large-scale mining or dredging operations. The uses of such basic data are thus many, and their availability is essential as a base for many of the uses to be made of the seabed. It is worth emphasizing, however, that although such basic maps and data serve many purposes, they are not sufficient in themselves to guide exploration for specific mineral deposits or to evaluate them. Far more detailed studies are necessary for those purposes.

It may be helpful to review briefly the kinds of maps that need to be prepared, the procedures for preparing them, and the magnitude of the effort involved, illustrated by our own experience in U.S. waters. Three principal kinds of maps are needed as a base for seabed development: (1) accurate topographic or bathymetric base maps that show bottom depth and shape of features by contours and are used as base maps for geologic and other studies, (2) surficial- or bottom-sediment maps that show the kinds, distribution and thickness of the sediments that lie at the surface of the sea bottom, and (3) geologic maps of the bedrock beneath the sea bottom that show the distribution, thickness, and structural relations of rock units underlying the sea floor and that make possible three-dimensional analysis of potential oil- and mineral-bearing structures.

Topographic maps are now made from depth information obtained by fathometers that record depth profiles along the ship trackline. The depths plotted from many parallel or intersecting tracks over an area are contoured to show the depth and bottom shape. Precise navigational systems are required for accurate maps, especially for those far from shore, and because such systems have become available only in the last decade or so, most older maps have very low reliability.

The information required for bottom-sediment maps is obtained from several sampling techniques—gravity or piston corers that are dropped to the bottom and retrieved by a line from the ship; detached or boomerang corers that are dropped free, take a core sample by gravity, and float to the surface to be picked up by the ship; grab samplers of several kinds, some of which will take as much as 1-cubic-meter sample; and dredges towed over the bottom to take very large samples or to break samples off hard rock outcrops on the sea bottom.

Three-dimensional structural maps are made primarily from geophysical information—from magnetic, gravity, and seismic surveys. Continuous seismic profiling using various gas or electrical energy sources is now both an effective and widely used approach to obtain information on either shallow or deep rock layers, depending on the kind of equipment used. The geophysical information so obtained is interpreted geologically from information obtained by sampling of rock layers on the bottom or from drill holes.

The maps that are produced by these bathymetric, geophysical, and geological surveys may be made on regional or reconnaissance scales to show general features and relations over large areas, or they may be made on more detailed scales to show intricate local relations. The investigations must be planned to accomplish the scale of mapping desired, for this determines the spacing of ship tracks and to some extent the number of samples that must be obtained.

Dr. Ewing, in his talk yesterday on the deep ocean drilling by the *Glomar Challenger*, presented a slide showing the thousands of kilometers of seismic-profiling tracklines across all the oceans by ships from the Lamont-Doherty Geological Observatory. This worldwide reconnaissance and the 40 holes to be drilled at sites selected on the basis of the reconnaissance will enable geologists to define the geologic character and the sedimentary history of many major provinces of the oceans. Ship traverses such as these constitute a pioneering effort that could be likened, in our country, to the knowledge gained by the geological traverses across our western interior—the Rocky Mountains and Great Basin—by the early Government surveys of King, Powell, Hayden, and Wheeler a century ago.

Much is still to be gained from such widely spaced traverses, but we are approaching the time when it will be desirable to choose specific areas to investigate in more detail.

A scale of 1:1,000,000—that is, 10 kilometers on the ground equals 1 cm on the map—is a reasonable scale for reconnaissance mapping of moderately large areas. An area of 1,000,000 square kilometers—1,000 kilometers on a side—would be represented on a map 1-meter square at such a scale. To obtain the information necessary to make a bathymetric map showing detail suitable to this scale would require at least 200,000 kilometers of ship trackline. These tracks would be 5 kilometers apart—obviously too widely spaced to reveal all the bathymetric detail but adequate for this scale. Furthermore, although some geophysical measurements can be obtained at the same time, the geological sampling and coring and other geophysical measurements would require at least an equal additional amount of ship time. It probably will not be necessary to map many areas in such detail, but until we have tried we will not know the degree of detail that will be justified. Inasmuch as the area of the ocean is 362 million square kilometers, it has the areal equivalent of 362 maps of this size and scale. Plainly, even for most fundamental mapping—and the easiest and cheapest to prepare—we face an enormous undertaking in the acquisition of basic information on the configuration and character of the surface of the sea bottom.

As an example of the kind of investigations needed to arrive at a regional or reconnaissance understanding of the geology of a large region, I would like to discuss a part of the present program of geologic mapping of the U.S. continental margin by the U.S. Geological Survey. The shelves off each coast of the United States differ greatly in size and geologic complexity. I shall speak only of the investigations off the Atlantic Coast, for these have been carried out for the longest time and the field work for the reconnaissance phase is virtually complete.

The investigations began in 1962 when the Geological Survey started a joint program with the Woods Hole Oceanographic Institution under a research contract. The program was directed by Dr. K. O. Emery of Woods Hole and has been carried out by about a dozen geologists from the Geological Survey and from Woods Hole. The purpose of the investigation was to obtain a regional understanding of the Atlantic continental margin—an area that is relatively well known among the margins of the continents because of the many previous hydrographic surveys of the U.S. Coast and Geodetic Survey, extensive oceanographic and geophysical work already undertaken by oceanographic institutions, and previous biological work of academic institutions and of the Bureau of Commercial Fisheries.

Because of the wealth of hydrographic information available, it was possible to prepare base maps—topographic or bathymetric maps—of the entire region at a scale of 1:1,000,000 without additional surveys. Three large sheets show the Atlantic continental margin from Nova Scotia to Florida.

About 20,000 kilometers of continuous seismic profiling was undertaken on widely spaced tracks to show the sediment thickness and shallow structure of the rock formations of the shelf. More than 2,000 sediments samples were collected using a large grab sampler. The sampler contained a camera that took a picture of the bottom area before taking the sample. The samples were taken on a rectangular grid pattern using a spacing of about 18 kilometers, or one sample for every 324 square kilometers. Outcropping rocks in critical areas such as submarine canyons down the continental slope, were sampled by dredging and were observed and sampled from submersibles such as the *Alvin*. Much valuable information was obtained from six core holes drilled across the Florida shelf and the Blake Plateau to a maximum depth of 1,000 feet below the sea floor by a small drilling ship, the *Caldrill*. This drilling, sponsored by the National Science Foundation, was the first project of the ocean-coring program that is now being carried on in the deep oceans by the *Glomar Challenger*.

More than a hundred scientific papers and reports have been published on the physiography, the sediment size, mineralogy, fossils, biologic fauna, structure, and other aspects of the geology of the Atlantic Continental Shelf as a result of this investigation, but analyses and preparation of final reports are continuing. We now have a reasonable understanding of the geology of the Atlantic continental margin at a reconnaissance scale, although much remains to be done in achieving a synthesis of recent work by scientists in many agencies and institutions. We know the parts of this region that have the most potential for petroleum, although exploratory drilling for it has not yet begun; we know where pavements and nodules of manganese and phosphate are to be found off the Southeastern United States, although we do not yet know their economic significance; and we know large supplies of sand and gravel occur off the Northeastern United States, though we do not as yet know their thickness and quality.

I should like to emphasize a point raised at the beginning of this statement. The investigations described here have been general-purpose geologic studies aimed at finding all the geologic conditions and relations that might affect the use and conservation of all resources. They were not made solely to find economic sources of minerals. As an example of the general nature of the investigations, all living bottom-dwelling organisms collected from the sediment-sampling program are being classified and studied by biologists from the Bureau of Commercial Fisheries. Eventually the sediment studies, the bottom photographs showing bottom conditions, and the biological studies will provide a basis for ecologic studies relating to commercial fisheries. If the sand and gravel deposits off New York and New Jersey are exploited—and they will be needed before long, inasmuch as sand and gravel from land sources is becoming increasingly expensive in this built-up area—information will be available not only for locating the most favorable areas for dredging but also for predicting the effects resulting from disturbance of the sediment by large-scale dredging operations and for minimizing the effects of these activities on nearby fisheries.

Several areas in each of the major coastal regions of the United States are currently being investigated and mapped at an intermediate scale of 1:250,000—i.e., 1 cm on the map represents 2.5 km on the ground. The Coast and Geodetic Survey of the Environmental Science Services Administration (ESSA) has proposed a 15-year program to map the bathymetry, magnetics, gravity, and sediment thickness of the entire continental margin—an undertaking that will require 70 ship-years of work, and the Geological Survey has proposed a related 20-year program to investigate and map the geology of the entire region at this scale. I should point out, however, that on land, geologic studies at a scale of 1:250,000 are called regional or reconnaissance mapping, and most geologic mapping by government surveys of many countries is done at scales of 1:50,000 (1 cm represents 500 m) to 1:10,000 (1 cm represents 100 m).

Now, what conclusions may we draw from all this as applied to mapping of the seabed beyond the limits of national jurisdiction? Some of the bathymetric mapping of the deep ocean floor that has already been published has been at a scale of approximately 1:1,000,000, nearly the same as we have been using for the U.S. margin, and this scale should be considered for universal coverage, although it is possible that many areas will not need to be mapped at this scale. Thus far, the geologic mapping that has been undertaken in the deep oceans has been of a special-purpose type. Systematic geologic mapping has not yet gotten underway, and hence we have no direct experience from which to judge its complexity. We anticipate that the geology will be less complex than that of the coastal regions, however, and of course for a long time there will not be as much need for three-dimensional knowledge as there is on the margins. Even though the 1:1,000,000 scale might be used as the base map for plotting geologic observations, in many areas the observations themselves will be far more widely spaced than would ordinarily be called for at this scale. Initially, then, we would not attempt to obtain nearly as much detail as we need on the margins. The cost of deep-sea work per unit is certain to be greater than that in shallower water, of course, and because the area is so large, it is plain that the task of deep-sea mapping will be a long and expensive one.

This outlook actually is not much different than that for the land. The area is larger than that of the lands, it is far more difficult to investigate, and much less is known about it. But only a small part of the more complex land areas of the world have been mapped adequately, and we face an almost never-ending job in attempting to gain the knowledge necessary to develop and use our land resources wisely. The magnitude of the problem of deep ocean-floor mapping, therefore, should not discourage us. We know it is a big, a difficult, and a costly undertaking, but it is an exciting undertaking. We know how to begin it, and that is what is important.

It is also important to recognize that resource development need not await the completion of the kinds of mapping we have been discussing. Because systematic mapping provides the broad base of understanding needed for wise use and efficient development of the earth and its resources, it is important that it be undertaken. But the prospector and developer have often preceded the topographer and geologist on land and will do so at sea. In the long run, however, the base for the full and effective use of the seabed will be laid by systematic mapping, just as it is on land.

THE ORIGIN, INCIDENCE, EFFECTS, AND MEANS OF PREVENTION AND CONTROL OF OIL-WELL BLOWOUTS

By V. E. McKelvey

[Statement by United States Representative before the Economic and Technical Subcommittee of the United Nations Committee on the Peaceful Uses of the Seabed and the Ocean Floor Beyond the Limits of National Jurisdiction, March 20, 1969]

There is much public concern about the hazards of offshore petroleum exploitation. This concern is also held by the U.S. Government, and no doubt it is shared by other governments as well and particularly by those represented here who are trying to lay the framework for the exploitation of seabed resources for the benefit of all mankind. To help provide the delegates here with a basis for evaluating these hazards, I will describe briefly the origin, incidence, and effects of these kinds of accidents and the means for their prevention and control. Although we have already touched on this problem in considering the potential ill effects of subsea exploitation and measures to prevent them, the blowout problem is one generally encountered in petroleum exploitation and is in fact one of the principal concerns of governments in the exploration phase of the resource-development process. It is pertinent, therefore, to the exploration item of our agenda.

WHAT IS A BLOWOUT?

As applied to oil and gas wells, the term blowout has a much more literal meaning than it does in some of its other uses, for it describes the sudden, sometimes nearly explosive release of gas or oil from a well that has penetrated a stratum containing oil and (or) gas under high pressure. A more familiar term for an oil well blowout is a gusher—a term implying some admiration and envy on the part of those well removed from the scene, but one that does not describe the grim realities that face those who must try to bring it under control or that must endure its effects.

Ground water and geothermal steam are also contained within the earth under high pressure in some places, and their penetration by the drill also may result in the same kind of sudden and uncontrolled release. Although the blowouts of interest to us here are artificial in the sense that they are triggered by drilling, the phenomenon also occurs naturally when strata charged with fluids are breached by erosion or other natural processes. Many springs and oil seeps, in fact, are the result of natural surface discharge from underground strata under moderate pressure, and some of them begin with a blowout.

ORIGIN AND INCIDENCE

Although the occurrence of these fluids under high pressure is rather common, blowouts are comparatively rare. For example, of the 7,642 wells drilled by January 31, 1969, for oil and gas on the outer continental shelf of the United States, 4,215 of which were completed as producers, only 23 resulted in blowouts and only one—the Santa Barbara well—resulted in a serious oil spill. The reason blowouts are not more common is that the fluids encountered in drilling are put under reverse pressure by the weight of fluid kept in the well bore as the well is being drilled, partly to lubricate the bit and to raise the cuttings from the well but also for this very purpose of maintaining counter pressure on the formation fluids that may be encountered in drilling. To increase the hydrostatic pressure of the column of water in the well bore, specially mixed mud is generally used as the drilling fluid—mud that can be made to weigh twice as much or more than an equivalent volume of water—and it is kept under sufficient pressure by pumps at the wellhead to contain any high-pressure fluids that may be encountered in drilling. What happens when a blowout occurs is that for some reason, mud pressure is lost or reduced below the level of the pressure of the oil or gas in the wall of the well. This may be because the weight of the mud has been cut by gas, or because the hole was not kept full of fluid, perhaps because some of it drained off into underground cavities or fissures, or because of the swabbing or vacuum effect when the drill pipe is being withdrawn. Blowouts from these sources occur during drilling and most frequently when the drill pipe is being raised or lowered. Blowouts can occur later, however, if a shallow sand in weak ground is not cased off and is pressured by flow from a deep horizon, or if the casing in part of the well is defective.

PREVENTION

There are procedures to tell when all these things are about to happen, to prevent them from happening, and to stop them before the well goes out of control when they have happened nevertheless. For example, the density and gas content of the mud are frequently checked, its flow is watched constantly to keep the hole full of mud, blowout preventers are installed to close off the flow on a moment's notice, and drill crews are drilled in the procedures to follow at the first signs that pressure is building up. If, in spite of these precautions, the well does go out of control, procedures are available to stop the flow. Basically, the approach is to reenter the well—and remarkable procedures and devices have been developed to accomplish this even under adverse circumstances—or to drill another one aimed to come as close as possible to it at the critical depth. The purpose of both the reentry and the relief well is to pump mud under high pressure into the strata from which the fluids are coming and thus seal off their flow. These procedures are effective, but if they have to be taken—i.e., if the blowout preventers fail, or if the fluids break out of the well and the well does not seal itself, as sometimes happens—it may take days or weeks to bring the well under control.

EFFECTS

Most blowouts are of gas rather than oil. Of the 23 blowouts that have taken place on the U.S. outer continental shelves only three were of oil alone and two others, including the Santa Barbara well, were of both oil and gas. The most common hazard, therefore, is that of fire and consequent loss of life or injury to personnel. It was this kind of tragedy that befell the Little Bob drilling rig in Louisiana State waters in the Gulf of Mexico last August 22d when an explosion was followed by a fire that blazed wild for seven days. The blaze was finally extinguished with water from high-pressure hoses, after which the well was reentered through a specially installed tubing head, allowing mud to be pumped in through the tubing to kill the well.

Cratering beneath the rig is another hazard of blowouts and occurs when soil and rock are torn loose and carried out by what may amount to a jet stream. Development of such a crater may cause the rig to topple over or sink, leading both to loss of life and further loss of control of the well.

Oil pollution, whether it results from natural or human activities, is a hazard with which most people are familiar now, and rare as it is, its effects go a long way when it occurs, particularly in the offshore environment if the oil is not or cannot be consumed by fire. Of the techniques for combating the various phases and kinds of blowouts and their effects, those for preventing the spread of oil spills at sea and cleaning them up are possibly the least developed, perhaps precisely because they are so rare. The need for improved cleanup technology is clear, and we may reasonably expect to have much more efficient techniques for this in the future.

THE SANTA BARBARA BLOWOUT AND ITS EFFECTS

Turning now to the Santa Barbara blowout, it took place on January 28, 1969, in a well—No. A–21—being drilled by the Union Oil Company from a platform about 5 miles offshore in 188 feet of water. The drilling platform is designed to accommodate 56 wells, of which A–21 was the fifth to be drilled. Four other wells had been or were being completed, but not placed in production. None of them, nor any of the previous exploratory wells drilled on the same lease or the adjacent lease on the same geologic structure, had given any trouble.

Well A–21 had been drilled to its total planned depth of 3,479 feet but began to gush drilling mud and then a high-pressure stream of gaseous mist as the drill pipe was being pulled prior to logging, casing, and other steps that would be taken to complete the well. Attempts to cap the pipe by installing a high-pressure valve designed for this purpose and by reconnecting the pipe with the power- and mud-control assembly failed, and 13 minutes after the mudflow first began, the drill string was dropped back into the well to allow it to be closed off completely by the blowout preventer at the wellhead. The blowout preventer did shut off the flow from the well itself. Ordinarily that would have been the end of it, but within a few minutes the gas and oil apparently found passage outside the well wall and discharged at several points along a line extending about 800 feet eastward from the northeast leg of the platform. The exact nature of the leak may never be known, but the fluid is believed to have moved outward from the well into a porous formation and thence to the surface itself.

The amount of oil released cannot be measured, of course, but it was estimated to be between 200 and 500 barrels (or 8,000 to 21,000 gallons) a day. Offshore winds for the first few days prevented the oil from reaching the beaches, but with a change of wind and its development into a storm, the slick moved to shore on February 5 and eventually accumulated on beaches over a distance of about 30 miles along the channel shore.

Although the leak was brought under control on February 7, it has continued intermittently as oil bleeds from contaminated rocks. The leak now is estimated to be only about a barrel an hour, most of which is recovered by underwater vents or tents.

REMEDIAL ACTIONS

Actions to eliminate the effects of the well were directed at controlling the well itself and collecting or dissipating the oil. The basic approach to regaining control over the well was to seal off the oil- and gas-bearing strata by injecting heavy mud into them under pressure, as previously described. Both the reentry and relief-well procedures were followed at Santa Barbara. Attempts to alternately bleed off gas from the well and pump mud into it through a small line within the conductor casing with outlets below the blowout-preventer assembly were begun within minutes after the blowout preventer was closed. The next step was to run drill pipe through the hole through special wellhead equipment and stab and reconnect the drill pipe previously dropped into the hole. This was accomplished only to find that the bottom of the drill pipe was plugged and stuck, making it impossible to pump mud through it or to lift the stem. This problem was solved by milling out a valve within the pipe to allow a gun perforator to be lowered through the pipe. The pipe walls were then perforated near the bottom in the vicinity of the sand from which the flow was believed to originate, making it possible to pump mud into the walls and kill the flow. This series of operations took about 7 days, and because of bad weather and heavy seas, 3 more days were required to assemble the auxiliary pumping equipment and supplies necessary for the massive injection of mud into the well that brought it under control on February 7. In all, about 13,000 barrels of mud were pumped into the well at rates of up to 30 barrels per minute, equivalent to 43,000 barrels a day. The well was finally cemented and plugged to the surface.

While these operations were in progress, a drilling barge was brought in to drill a relief well, which was begun on February 2 from a point about 1,000 feet of well A–21. Drilling was discontinued when the reentry procedures succeeded, but it would have been used to intersect and kill A–21 with mud had it not been possible to reenter A–21.

On the recommendation of the President's panel of experts appointed to investigate the accident, all of the holes previously drilled from Platform A are being pumped to relieve the pressure in the hydrocarbon zones.

Control of the oil on the water took several forms—physical collection of the oil both at sea and on the beaches, laying log and plastic booms to contain the oil within a given area and prevent its entrance into marinas and the like, and degradation through the use of chemical dispersants and talc. Setting fire to the oil—a procedure sometimes used—was ruled out. All of the forms of control used at Santa Barbara had a degree of success. Fortunately, no lives were lost, as they might have been if the oil and gas had caught fire or if the platform had collapsed as a result of cratering, and the oil spill itself was not as large as it might have been. Thus, in total the spill probably amounts to only 3,000 to 6,000 barrels or so, but even if it had been ten times that it would have still been small compared to the potential spill from a supertanker. The *Torrey Canyon*, for example, carried some 700,000 barrels, and some of the tankers now under construction will have the capacity for 2 to 3 million barrels.

STORM OR COLLISION BREAKS

Storm breaks have taken place previously, particularly during the severe hurricanes in the Gulf of Mexico. As I mentioned on a previous day, this kind of accident generally involves the rupture of the casing at the wellhead itself as the result of a storm or a ship collision. Automatic storm chokes are required within the well and generally prevent any leakage, but failures sometime occur. The procedures for regaining control are similar to those described for blowouts, although because such wells are already cased, it is usually possible to cap or plug them without resorting to the mud techniques sometimes necessary to kill blowouts.

IMPLICATIONS FOR SUPERVISORY CONTROL AND FUTURE OFFSHORE DEVELOPMENT

In addressing itself to the Santa Barbara Channel incident the U.S. Government has initiated a comprehensive investigation of the accident itself as well as its regulations governing offshore drilling, and it is reviewing also the broader problem of offshore development of oil and gas. These various studies are in progress, and it would be premature to comment on their probable outcome. I may, however, briefly outline the procedures that have been followed and the changes already made and mention some of the general aspects of the problem for the future.

The Outer Continental Shelf Lands Act of 1953, and the regulations developed to implement it, vest authority for supervision of exploration, drilling, and production offshore in the Secretary of the Interior, and under his direction, the Geological Survey. The regulations governing drilling procedures have been further supplemented by specific orders issued from time to time by the Regional Oil and Gas Supervisors of the Geological Survey, who also must approve proposed plans for exploration, production, and related operations and who also inspect operations in progress. That the regulations, procedures, and practices have generally been effective in preventing blowouts is shown by their very low incidence in offshore operations over the years.

Secretary of the Interior Walter J. Hickel has already increased the weight of responsibility on the operators to insure that the phenomenon of the blowout is reduced from the rare accident that it is now to a completely controlled threat.

Basically, the accidents we are dealing with here are similar to other accidents—fire, airplane and other vehicle crashes, structural failures of dams, buildings and so on—in that they are the result of either human error or equipment failure or both, for the procedures and equipment necessary to prevent them have been adequate. The elements of the unexpected, the so-rare-as-to-be-forgotten, and even the familiarity-which-breeds-contempt for danger are common sources of human error that each of us must acknowledge in the small "accidents" that beset us daily, and our problem is compounded by the faith we have come to place in mechanical devices.

Recognizing the human propensity to err and the weakness that may develop undetected in equipment, perhaps we cannot hope to eliminate these or other kinds of accidents completely. Even rare accidents, however, can do damage, and we must reexamine our safety technology in exploration to improve our procedures and our practice of them and extend our knowledge of the terrain in which we are working to better understand the hazards that may have to be faced in drilling.

The results of the studies of accidents in U.S. waters will, one day, be made public, and we hope they may help others in developing the safeguards needed to prevent such accidents, as called for by General Assembly Resolution 2467B.

IMPLICATIONS OF GEOLOGIC AND ECONOMIC FACTORS TO SEABED RESOURCE ALLOCATION, DEVELOPMENT, AND MANAGEMENT

By V. E. McKelvey

[Statement by United States Representative before the Economic and Technical Subcommittee of the United Nations Committee on the Peaceful Uses of the Seabed and the Ocean Floor Beyond the Limits of National Jurisdiction, March 24, 1969]

Many of the questions we have been considering in item 2 of our program of work on the ways and means of promoting the exploitation of seabed resources essentially relate to the requirements of a system for seabed resource allocation, development, and management, regardless of what might be the structure of such a system or its national or international affinity. We have been privileged to hear many cogent observations by several of our distinguished colleagues on what these requirements might be as they are expressed in the terms governing exploration and exploitation. The statements of the distinguished representatives of Australia and Canada, both of whom are experts in this field, are especially pertinent, for the Canadian and Australian systems have been designed to meet the very objective this committee is considering—namely to encourage seabed exploration and development in regions in which it is not already in progress.

In previous discussions of agenda item 2, our delegation has attempted to report relevant U.S. experience and procedures, not as a model by any means, but merely as a description of one set of working procedures. We would be glad to describe also our procedures and experience for resource allocation and development, but frankly neither are entirely relevant to the problem at hand. Our system for leasing on the outer continental shelf was designed in 1953 after offshore petroleum development had already gotten underway in the state waters in the Gulf of Mexico, where extensive exploration and development in the adjacent onshore area had already shown the existence of a most promising petroleum province, and had provided a wealth of information about the nature of occurrence of oil and gas in the gulf province. In the light of this background of interest and experience, our leasing system for oil and gas provided for geophysical exploration under a nonexclusive permit with no subsequent rights, followed by the sale of lease tracts, each not exceeding 9 squares miles in area, by competitive bidding in advance of drilling on a cash bonus with a fixed royalty of not less than one-eighth the value of production. These terms are much stiffer than those described for Australia and Canada. Nevertheless, the offshore industry in the Gulf of Mexico has flourished under them, for since 1954 when production of oil and gas began on the outer continental shelf there, outer continental shelf production has come to make up 7 percent of our national production. Our system has also encouraged exploration off southern California and in the Gulf of Alaska, both of which are extensions of adjacent onshore producing provinces. Other parts of our shelves not adjacent to onshore producing provinces, however, have not received nearly as much attention. No doubt there are several reasons for this, including the greater appeal of the producing provinces and the magnitude of the resource potential in their still unexplored parts. But when we look at the much greater amount of offshore exploration that is in progress on the Canadian Atlantic Shelf compared to that on the U.S. Atlantic Shelf, where the first exploratory well has yet to be drilled, we must recognize that one possible reason for the difference may be the more favorable terms offered under the Canadian system than under our own. Australia has also attracted exploration to areas with no existing onshore production, as have several other countries. At this stage, the systems in effect in those countries may therefore be more applicable than ours to the problem of encouraging seabed petroleum development beyond the limits of national jurisdiction. The same may be true also for nonpetroleum minerals, for except for sulfur we have had little or no offshore exploration for other minerals. Many of our leaders in the mining industry say that one of the reasons for this is that the terms governing exploration and development are unfavorable for such high risk ventures.

For these and other reasons, our policies governing offshore leasing have been undergoing review. These studies are not yet complete, but the fact that they are in progress makes a point that is significant for the deliberations of this committee, namely that the needs to be served by a resource allocation, development, and management system differ from place to place and change from time to time. In seeking the common denominators among existing resource allocation and development systems—several speakers have recommended that we do this—it is well to keep in mind that different systems may serve different purposes, and that widely differing terms may in fact be appropriate in the varied circumstances that will be encountered in the development of seabed resources beyond the limits of national jurisdiction.

It may be helpful at this stage, Mr. Chairman, to describe some of the geologic and economic factors that constitute the basic requirements that a resource allocation and development system must meet, for their identification may help to indicate the flexibility that such a system must provide.

GEOLOGIC FACTORS

Two geologic factors are particularly relevant to lease terms: One is that the size and mode of occurrence of mineral deposits vary greatly from one mineral or group of minerals to another. The other is that the presence of concealed deposits, such as oil and gas, can be established only by drilling or other means of underground exploration, and that the quality and recoverable quantity of minerals in individual deposits of nearly all minerals—exposed and unexposed alike—can be determined only by extensive sampling, whether done by drilling or other means, and perhaps even some production experience.

The differences in the characteristics of deposits of different minerals or groups of minerals affect the size of the area that an operator must prospect and hold to achieve an economically viable operation. For example, although some petroleum reservoirs underlie large areas, many producible petroleum reservoirs underlie areas of only a few square miles; the largest kinds of copper deposits—the porphyry coppers as they are called—generally underlie areas of a square mile or less; and many other workable hard minerals either occur in relatively small deposits or can be profitably mined from units a few square miles in size. Such deposits, however, may be widely scattered, so that even in provinces that are broadly favorable for their occurrence, a far larger area may need to be explored to find a deposit suitable for mining.

For the manganese nodules, however, even the area required to sustain a viable operation might be extremely large. For example, Chester Ensign, the Vice President for Exploration of the Copper Range Co., has calculated from John Mero's estimate that the manganese nodules at the surface of the sea floor in the better areas amount to 30,000 tons per square mile, that a normal large scale mining operation of 20,000 tons per day would mine out the nodules over an area of 235 square miles per year.

Differences in the characteristics of various minerals also influence the time required to bring them into production. Thus, where fixed installations are required, and where special mining systems of extractive processes have to be devised, several years or more may be required to bring a deposit into production after its existence and magnitude have been established.

The terms for resource allocation and development, therefore, must provide for prospecting and exploration over a far larger area than that in which production may take place; and they must take account of differing requirements for individual minerals or groups of minerals, both with regard to the area necessary for viable mining operations and the time required for development.

The facts that the presence of concealed deposits can be established only by drilling and that the quality and recoverable quantity of minerals in both exposed and unexposed deposits can be determined only by extensive sampling also bear on the terms for resource allocation and development, for they make it nearly impossible to appraise the value of seabed resources in advance of exploration, and perhaps even in advance of some production experience. In producing areas, experience may be sufficient to assign a probability factor to discovery that can be used in appraising value, much as one might do in establishing the value of the opportunities on a punchboard. For example, if experience shows that producible petroleum reservoirs in a partly explored area contain an average of about 10 million barrels of oil, and that one out of four structures identifiable from geophysical exploration usually contains oil, the value of a property believed to have such a structure might be estimated as 25 percent that of the in-place value of 10 million barrels of oil, discounted further to take account of the present value of money spent for something that will not be fully recovered for many years. If, however, there is no previous exploration and production experience to give an indication of the size, quality, and frequency of occurrence of mineral deposits in a given area, the chance of finding a producible deposit can hardly be assigned a numerical value. When investigations reach the stage when expensive forms of exploration are required to determine whether or not an economic operation is feasible, the operator, of course, needs an exclusive right to explore and to produce valuable deposits as they are found. Because the value of the deposit cannot be established in advance, particularly in unexplored and nonproducing provinces, the basis for payment for the resource produced should be one that is related to actual production rather than to a predetermined estimate of the value of an unexplored area.

As indicated by the distinguished representative of France, the right to explore need not be granted on an exclusive basis until the stage of expensive exploration is reached; in fact, there is much merit in giving wide opportunity for geophysical and other relatively low-cost means of exploration on a nonexclusive basis in order to encourage prospecting, as is permitted under the Canadian exploration license as well as our own permit for geophysical exploration.

ECONOMIC FACTORS

Now for some observations on the economic side of the problem. Four things are worth discussing here: (1) The sources and effects of risk in mineral exploration and development, (2) the concept of net resource value, (3) alternative means of resource allocation and payment to the resource owner, and (4) the kinds of benefits that result from mineral production.

Mining is well known to be a high-risk activity. Large sums of money may be spent in searching for a producible deposit and evaluating discoveries without any assurance that production will result or be sufficient to pay out the investment. The risk is not confined to the prospecting and evaluation stage, for mining and recovery problems may prove to be insurmountable, the mining process or natural forces such as storms may lead to costly accidents, and later developments in the market may reduce prices or demand and make it necessary to close down operations before the investment has paid off. To compensate for the high risk involved, it is necessary to have the opportunity for a higher rate of profit from mining investments than is expected from other kinds of enterprises. Thus, if only one out of 10 ventures is likely to be successful, profits received from the successful one must be sufficient to cover the losses on the other nine. Although several factors contribute to risk, its magnitude is generally reduced by increasing knowledge about the occurrence of recoverable minerals in a given area and by increasing experience in producing them. Thus, even though risk in petroleum exploration and exploitation in a producing province is high, it is much lower than it is in a nonproducing area, such as that beyond the limits of national jurisdiction, where there is little knowledge of the occurrence of specific minerals and no experience in production.

Let me speak now of net-resource value, which I will define as the surplus remaining after the mineral product has been sold and the costs of production plus a normal profit on risk investment have been paid. This value is sometimes referred to as economic rent—the amount earned by land as a factor of production over and above returns to all other production factors, that is, wages to labor, interest to capital, and profits to management—and it is the amount that the resource owner can hope to receive in return for the production of his resources. Because the price at which the product can be sold is generally established externally, its level is beyond the control of either the owner or the producer. The amount that remains as net-resource value at any given time is thus largely a function of production costs and the profit that must be returned to management and to risk investment. If exploration and production costs are high, if the risk of discovery and successful production is so high that the investor insists on a high rate of return on invested capital, and if prices are relatively low, net resource value may be zero; and if costs exceed prices, the operation would not be economic even if no payment needs to be made for the resource itself. These situations are the ones that often prevail at the outset of exploitation in unexplored provinces or in the exploitation of minerals in forms of environments from which they have yet to be produced economically, and it is these situations that may be expected to prevail for seabed resources beyond the limits of national jurisdiction in the early stages of their development. As exploration, however, shows the existence of workable deposits, as costs are reduced, and as accumulating knowledge and experience reduce risks, net resource value may increase, particularly if prices do not decrease.

Now a word about the means of allocating seabed resources and the terms of payment for them. As the distinguished representative of Australia pointed out, the means of allocation must be impartial. Among the systems now in operation, the means for achieving this have included competitive bidding, assignment by lottery, assignment to the first to file a claim, or assignment on the basis of a judgment of the qualification and the plans of the operator. As I mentioned earlier, the United States Government uses competitive bidding as the means of assigning title to offshore leases; although this has many advantages, it probably would not be applicable now to the seabed beyond the limits of national jurisdiction, for it involves a predrilling estimate of value. The question as to which of the other systems is most desirable may not be significant now, for the first to propose mining in this environment should be welcomed with open arms, but the question will have to be posed eventually.

The most commonly used forms of payment of net-resource value are a lump-sum cash payment made at the time title is assigned, royalty on production, and profit sharing. Each of these forms of payments has advantages and disadvantages. The advance cash payment is an incentive to prompt development, it does not add to marginal cost, and is easy to administrate. But it offers a high-capital barrier to entry, requires predrilling appraisal of value, and offers no means of sharing windfall gains and losses by the operator and the resource owner. It is most suitable for the payment for resources where the risk is comparatively low and conversely is least suitable where risks are likely to be extremely high as they are in mining on the deep ocean floor. The royalty payment reduces the capital barrier to entry and relates payment directly to production. It may invite irresponsible operators, however, who may later plead for a lower royalty rate in order to initiate or continue production, and it increases the marginal costs of production; if royalty is established at a fixed rate, it may therefore lead to premature abandonment of the property when these costs can no longer be borne by the operator. Profit sharing also reduces the capital barrier to entry and because it does not add to marginal cost it is less of a deterrent to recovery than is a fixed royalty. It is difficult to administer, however, because it requires close control of accounting procedures, and it does not assure that title will be assigned to the most efficient producer. In contrast to the advance cash payment, which is most suitable where the risk is relatively low, profit sharing is most applicable where the risk is extremely high. These systems of payment can be modified in various ways, including combinations with each other, to make them more suitable to individual situations, but the important thing to note is that each of them has advantages and disadvantages that determine its suitability for individual operations.

In examining these various forms of payment we all have a tendency to view them in terms of the revenue they are likely to yield to the resource owner. As the distinguished representative of Australia pointed out, however, the direct revenue from the development of seabed resources is only one of two general forms of benefit to mankind that may come from their exploitation. The other is the addition to the world's inventory of useable minerals. For the developed countries, this is now by far the most important form of contribution that mineral production makes to their economies. Built as they are on the extensive use of minerals and energy in machines, in industrialized agriculture, in housing and construction, in transportation and communications systems, and in manufactured and processed goods of nearly all kinds, it is the use of minerals and fuels that supports their economies and it is in their use that they benefit most from mineral production. The direct revenue that comes to them from the sale and production of minerals may not be insignificant, of course. For example, revenue to the United States from petroleum on the outer continental shelves has been both substantial and welcome, for it has already amounted to about $4.4 billion. But the value of the raw products, the production of which adds directly to gross national product, is four to five times that of the revenue to the Federal Government; the total economic activity surrounding production and stimulated directly by it may be 10 times this amount; and far greater value—100 times or more that of the direct revenue from production—is represented in the chain of activities beginning with the processing and manufacture of petroleum products and ending with their use. The value that comes from the use of minerals in an industrial society is thus far greater than those that come merely from their sale and production, and it is these greater values, as I emphasized to the ad hoc committee last year, that we hope the developing countries and the peoples of the world will eventually come to share. When we think of means to promote seabed exploitation in the long run, then, we must recognize the fundamental importance of encouraging production for the materials it will yield rather than merely for the direct revenue that may come from the sale of seabed resources.

RESOURCE MANAGEMENT

In addition to the problem relating to the selection of terms for allocating and developing seabed resources, there is the very important responsibility of government to supervise many aspects of the exploration and exploitation processes. Some of these aspects we have already discussed in connection with the prevention of ill effects from mineral exploration and exploitation, and because the time available for our discussion is now drawing to a close, I will not elaborate on the other problems involved in resource management. I may mention, however, that in addition to maintaining safe practices and preventing damage to other values and interference with other uses of the sea, it is necessary for government to concern itself with the problem of conservation to see that minerals are extracted with maximum ultimate recovery. The requirements here also depend on the kind of mineral that is being produced, the environment in which it is found, and the mining system that is being used. The responsibility on supervisory authority in this area is not only heavy, but requires superior technical competence in its execution.

SUMMARY

In summarizing the implications of geologic and economic factors to seabed allocation, development, and management, I may list the following points:

1. The terms appropriate for mineral resource allocation and development vary from place to place and time to time.

2. The geologic characteristics of minerals that may be exploited from the seabed differ from one mineral or group of minerals to another, and influence the size of the area required for viable operation and the time required to achieve production for various minerals. For nearly all minerals a far larger area may need to be explored to find a deposit suitable for mining than is finally selected for exploitation.
3. The presence of concealed deposits can be established only by drilling or other means of exploration, and the amount and quality of both exposed and unexposed deposits can be determined only by extensive and expensive forms of sampling and may even require some production experience. At the stage when such expensive forms of exploration are reached, the operator needs an exclusive right to explore and to produce if workable deposits are found. Because the value of such deposits cannot be determined in advance, particularly in wholly unexplored areas, the basis for payment for such right should be one that is related to actual production rather than a predetermined estimate of the value of an unexplored area.
4. The high investment risks characteristically associated with mining must be compensated for by the opportunity for higher profits than are acceptable in many other enterprises. The risks stem from uncertainty of discovery, uncertainties concerning the feasibility of mining and recovery systems, possibility of loss from mining accidents, storms, and so on, and from uncertainties concerning future prices, demand, and other externalities. Although the high risk in mining cannot be eliminated altogether, it tends to reduce with increasing knowledge about the occurrence of recoverable minerals in a given area and with increasing experience in producing them.
5. Net-resource value—the surplus remaining when the mineral has been sold and after production costs and profits on risk investment have been paid—is the amount the owner can hope to receive from the sale and production of his resources. Limited as it is on one side by production costs and the amount of risk involved and on the other by a price that is fixed externally, net-resource value varies considerably from place to place and time to time. At the outset of seabed exploitation, it may be nearly zero, but if exploration shows the existence of workable deposits, if production costs can be reduced, if environmental hazards can be controlled, and if prices do not decrease, net-resource value may increase over time.
6. Several alternatives exist in the methods of impartial allocation of resources and the means of payment of net-resource value, each of which has advantages and disadvantages that influence its suitability for individual operations.
7. Direct revenue from the production of minerals is welcome to all governments, and to developing countries it may be the principal benefit to be derived from production of seabed resources in the immediate future. The chief value of minerals, however, is in the chain of economic activities that surround their production and follow on their use, and in the future these benefits should come to be shared by all the people of the world. In the long run, therefore, our goal should be to encourage subsea production for the raw materials it will make available rather than merely for the direct revenue that may come from the sale of seabed resources.
8. Resource management entails not only responsibility to maintain safe practices and prevent damage to other resources and uses of the sea, but also for conservation in production to see that minerals are extracted with maximum ultimate recovery.

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