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Ocean Boundaries and Petroleum Resources

National-international ocean boundaries are discussed in relation to petroleum resources.

Hollis D. Hedberg

During the last decades, the focus of world interest and activity in exploration for petroleum has been moving more and more into the oceans. In the highly competitive petroleum industry, rewards have traditionally gone to those who were willing and able to be the first to brave the hazards of strange and forbidding environments in order to preempt the choice petroleum areas they might contain. Thus, exploration has advanced through the mountains, the deserts, the jungles, the swamps, and the arctic tundras on land, and is already widespread in the coastal waters of the seas and oceans.

The entry to each new environment has been made possible only as specialized equipment and technology could be developed to meet the special problems of each. The complexities of resource extraction offshore once seemed completely prohibitive, but the development of marine geophysical prospecting and various types of marine drilling installations suited to various water depths has now made exploration and production in shallow and moderately deep offshore waters of the continental shelf entirely feasible and, in some respects, less difficult than in some land areas. Currently, there are hundreds of offshore fields producing oil and gas in the world; 17 percent of U.S. production and 18 percent of world production in 1973 came from these offshore sources (*1*).

Progress into deeper waters of the outer shelf, the slope, and beyond still presents formidable obstacles. However, exploration holes for petroleum now have been drilled in water depths of as much as 655 meters (2150 feet), and production has been established in water depths of more than 125 meters (about 400 feet). The latest record of the Joint Oceanographic Institutions for Deep Earth Sampling Deep Sea Drilling Program is a hole penetrating 1411 meters (4656 feet) below the ocean floor in a water depth of 4975 meters (16,417 feet).

Costs of offshore petroleum drilling and production operations are extremely high, and in waters as deep as 1000 meters or more would be fantastically so. However, there is now little doubt that drilling and production at these and greater depths can and will be accomplished eventually if the prospective returns are great enough.

Political-Economic Setting

Apart from matters of technology, two factors during the last few years have drastically altered the situation with respect to petroleum from the deep offshore waters. (i) The recent multifold increase in the price of crude oil on world markets and the recent emphasis on an inevitable future shortage of supplies of hydrocarbon energy have escalated the values attributed to potential offshore petroleum properties. (ii) The wave of nationalization of the petroleum industry, together with the increased prices of crude oil and the energy crisis, has stimulated a keener sense of national proprietorship in the ocean beds by those countries with ocean coastlines. In contrast with this latter point has been the appeal so eloquently voiced by U.N. Ambassador Pardo from Malta in 1967 and endorsed in word if not in spirit by many others since—the doctrine that the oceans are the heritage of all mankind and that the resources of the deep-ocean floor belong to the community of nations rather than simply to those nations who happen to control coastlines adjacent to them.

National-International Boundary

The result of the interplay of these factors has been the impasse at meetings of the U.N. Committee on the Peaceful Uses of the Seabed and the Ocean Floor Beyond the Limits of National Jurisdiction, starting in New York in 1968 and most recently held in Geneva during the spring of 1975, on the question of to whom the ocean floors belong. Another meeting is scheduled for March 1976 in New York but a solution satisfactory to the various parties concerned is dubious.

Nearly everyone recognizes that there should be an outer limit to the areal extent of a coastal state's jurisdiction over the ocean floor extending outward from its shores. Also, it is generally agreed that the great central regions of the deep ocean floor should be under international jurisdiction. The big problem is just how far out the boundary between national and international domains should be drawn.

It is critically important that the position of this boundary be decided promptly. It is equally important that it be decided wisely. Once petroleum exploration drilling has progressed out to water depths which may bring it close to this boundary, and the position of particularly attractive areas for petroleum development begins to be known, the problem of attaining any boundary agreement based on principle rather than on self-interest, greed, or military power will have become infinitely more difficult.

Various boundaries based on depth of water or distance from shore, or a combination of the two, have been proposed but none have been adopted. At the moment, the proposal which is said to have the most support is that of a national-inter-

The author is professor emeritus of geology at Princeton University, Princeton, New Jersey 08540.

national boundary 200 nautical miles (1 nautical mile = 1852 meters) from shore. However, for subocean resources this proposal lacks any basis in nature or logic; it is largely an inheritance from the fishing claims of certain South American countries. As applied to petroleum (and other mineral resources) such a boundary would be unacceptable to many countries who would lose much potentially valuable territory naturally pertaining to them, whereas others would needlessly be given huge tracts of ultra-deep ocean bed which would more appropriately have been assigned to an international oceanic regime.

Moreover, although the 200-mile boundary superficially has a simple and definite sound, there appears to be little realization of the many problems involved in its practical implementation. One of these is the lack of any uniform rule among nations for determining the coastal base lines from which the 200-mile distance would be measured. Another is the unsettled question of whether the 200 miles should be measured from the mainland coast only, or whether any or all of the myriad reefs, islets, and islands of the continental shelves, far from shore but belonging to coastal nations, might also be used to extend their 200-mile limits farther seaward. Furthermore, probably few have considered how difficult accurate definition on the ocean floor of 200-mile limits measured off from an irregular coastline might be, although the time might come when such precise and detailed definition of the national-international boundary would be of the greatest economic and political consequence.

Requirements for Boundary

Any plan for a boundary between national and international jurisdiction that could, in the long run, prove acceptable to the nations of the world would be so in proportion as it satisfied the following conditions.

1) It should be a plan with a logical or natural reason behind it rather than one that is purely artificial.

2) As a minimum, it should give to each nation what appears to be the natural prolongation of its land mass—continental or insular—beneath the oceans.

3) It should allow each coastal nation a substantial maritime zone of ocean bottom adjacent to its shores, regardless of the narrowness of its shelf or the steepness of its slope.

4) It should be a plan which it would be equitable to impose uniformly on all nations without exception or special modification for any.

5) It should be a plan that provides for the boundary problems of islands, whether on the shelf or in the deep sea and whether isolated or in archipelagos.

6) It is desirable that it allow each coastal nation to be represented in the fixing of its own precise boundary, which should be defined by coordinates of latitude and longitude within internationally agreed guidelines.

7) It should be a plan which can accomplish uniformly for all nations whatever turns out to be the agreed wishes of the nations with respect to a national-international division of the ocean bottom out beyond the minimum coastal state limits.

8) Finally, it should be a plan which, while recognizing the natural oceanward extent of the coastal state domain, at the same time leaves some substantial part of the potentially valuable resources of the ocean bottom to the international domain.

Continental Margin Boundary Guide

In contrast to the many artificial distance boundaries and the even more artificial and impractical water-depth boundaries that have been proposed, there is one obvious, natural, and logical guide to a division between national and international jurisdiction over the ocean floor. This is based on the difference between the topographically high-standing continental and island blocks of the earth's surface—the traditional domain of mankind and the nations—and the topographically low-lying deep-ocean floor which has been conventionally international territory (*2*).

The line of division between the two is at the continental margin (or insular margin), and the boundary problem should have been approached from the very beginning with the recognition that the margin is the natural reference base or guide for any boundary between coastal state and international jurisdiction.

The term "continental margin," as used here, is simply the now-submerged *edge* of the continent, as the word margin itself implies. Its position and breadth depend entirely on how sharply one defines that edge.

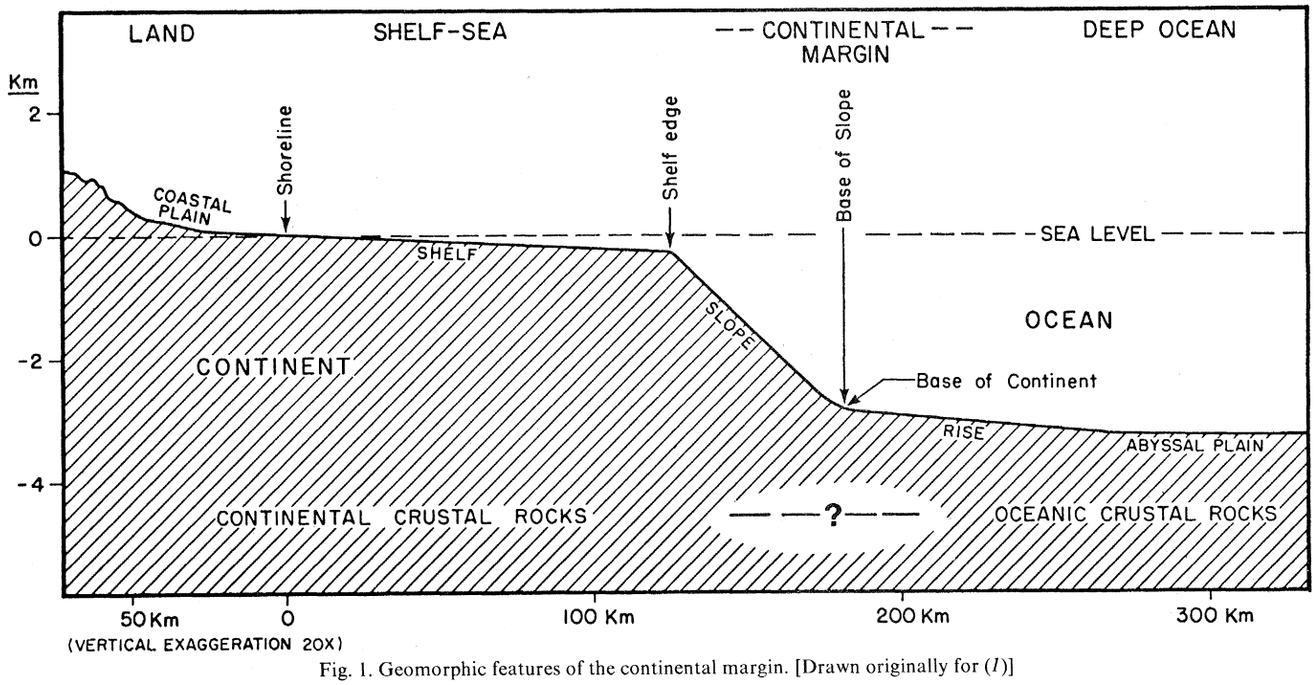

Fig. 1. Geomorphic features of the continental margin. [Drawn originally for (*1*)]

The edge may be considered to be the frontal face of the submerged continental mass (or insular mass) as it faces the deep oceans; and as such it is the continental slope (or the insular slope). Most exactly, however, it is the *base* of that slope that marks the outer limit or base of the continent (or island). (The true inclination of the margin features is far more gentle than the exaggerated scale in Fig. 1 might suggest.)

The continental margin as thus defined coincides in a very general way with a geological change from a relatively light but thick continental crust to a relatively dense but thin oceanic crust—a change that is probably fundamentally responsible for the difference in elevation between the continents and the deep-ocean floors. The continental masses of relatively low-density rock tend to float high in the heavier oceanic crust. However, this geologic change, although scientifically important, is too ill-defined and uncertain in position to be of much help in drawing a political boundary.

The most practical basis for the definition of the outer limits of continent and island masses is not geologic but geomorphic. It is based on the simply and directly observable surface form of these earth features and is readily identifiable by anyone at least in a general way. This outer geomorphic limit of the continents and islands—the boundary separating these high-standing masses from the intervening vast and deep ocean basins—is the most natural and most logical guide to where the political boundary between national and international jurisdiction over the resources beneath the ocean floor should lie.

Base-of-Slope Boundary Zone Plan

The only boundary scheme that appears to meet closely the eight requirements listed above is one which calls for the base of the continental slope (or the insular slope) to serve as a general guide to an internationally prescribed boundary zone, within which the exact position of the boundary between national and international jurisdiction over mineral resources beneath the ocean floor would be designated by the coastal state itself.

The continental slope is probably the single most impressive and most extensive feature of the earth's surface, with a linear extent of 300,000 kilometers on the ocean floor and a height of as much as several kilometers. The slopes of islands are almost equally impressive. However, although the base of the slope is a remarkably widespread and distinctive feature well suited to serve as a general guide to a boundary, it is not definable sharply enough to serve as the boundary itself. Hence an essential feature of any proposed plan that uses the base of slope as a guide is the creation of a boundary zone that would extend oceanward from the approximate position of the base of the slope for an internationally agreed distance within which the precise boundary would be drawn by the coastal state itself (Figs. 2 and 3). It would seem impracticable for the standard width of the boundary zone to be less than 100 kilometers (54 nautical miles), although it might be as much wider as the consensus of nations considered desirable.

The principal reasons for the boundary zone are to take care of uncertainties in precise identification of the base of the slope, as well as to guarantee to all coastal nations as a minimum the submerged part of the continental or island mass adjacent to their shores and naturally pertaining to them and to allow them uniformly such additional area as the nations in joint consultation might agree to be desirable. An additional advantage of the boundary zone scheme is that it would allow the final designation of the precise boundary to be made by the coastal country itself, although within internationally agreed

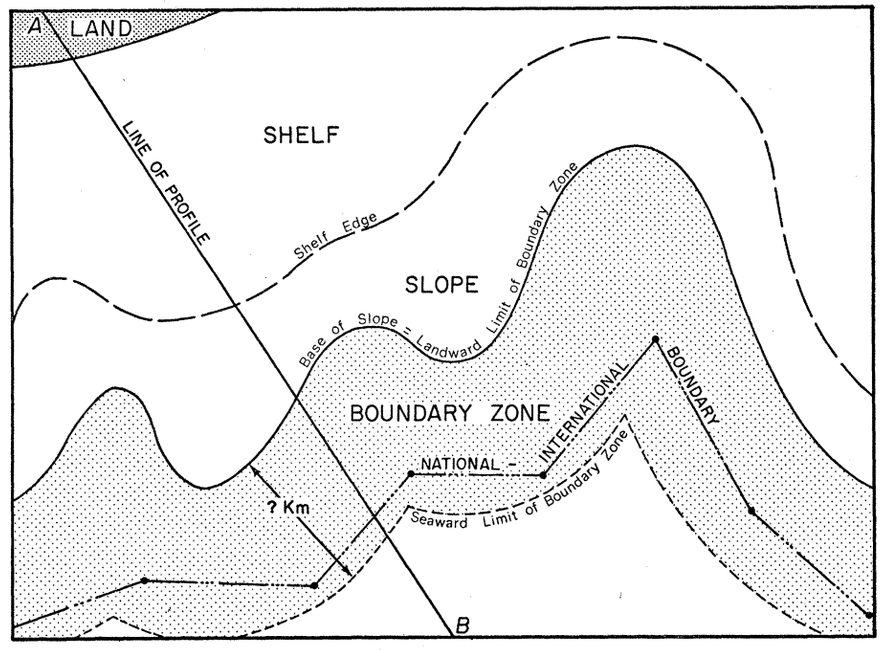

Fig. 2. Base of slope, boundary zone, and national-international boundary. [Drawn originally for (*1*)]

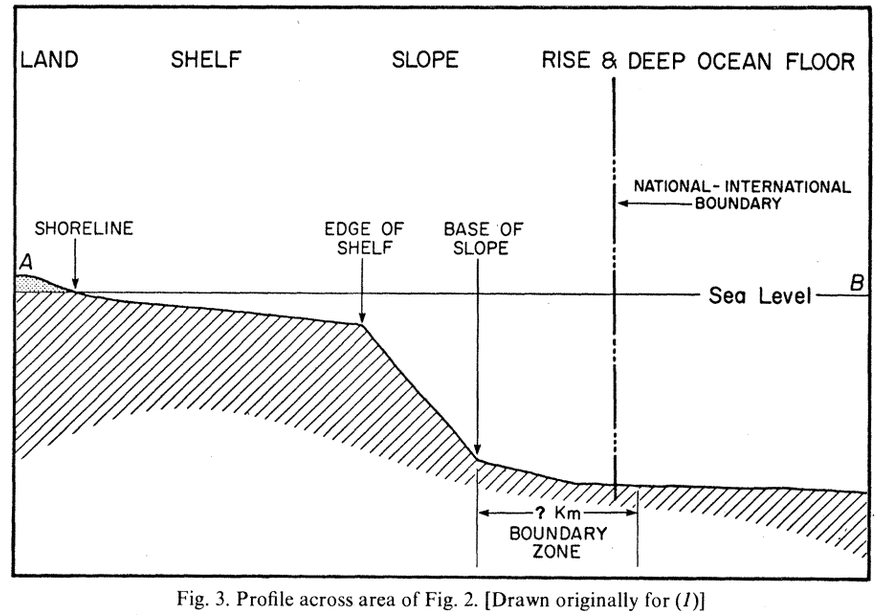

Fig. 3. Profile across area of Fig. 2. [Drawn originally for (*1*)]

boundary zone limits. Finally, the boundary zone concept carries the added advantage of allowing the final boundary to be drawn by simple straight lines connecting fixed points of latitude and longitude, which makes it a practical, precise, and readily determined boundary—a feature quite lacking in a 200-mile-from-shore boundary.

As must be the case with respect to the application of any boundary formula, the establishment of an international boundary commission with qualified technical personnel would be necessary to make certain that the precise boundaries drawn by the coastal states fell within the internationally prescribed limits. This body, working in conjunction with individual advisory national oceanographic committees, would determine in advance the approximate position of the base of the slope (or its reasonable projection through areas of uncertainty) for each coastal state. Based on this approximate base-of-slope line and the standard distance adopted by the nations-in-concert for the width of the boundary zone, the coastal state would itself proceed to draw its own precise boundary. This would then be submitted to the international boundary commission for approval, for linking with the boundaries proposed by adjacent countries, and for recommendation for acceptance by the nations-in-concert.

This, in essence, is what seems to be the simplest, most equitable, and most practical procedure for choosing and defining boundaries between coastal state and international jurisdiction over the mineral resources beneath the ocean floor. Details of the scheme have been explained elsewhere (*2*). Some years ago, using the best bathymetric maps available to me, I tentatively tried out the feasibility of drawing an approximate base-of-slope line around most of the continental and insular areas of the world, and believe that it could be done quite satisfactorily by a group of experienced oceanographers working for the international boundary commission. Some examples showing the approximate position of the base-of-slope line in various parts of the world, boundary zones of alternative widths of 100, 200, and 300 kilometers, and supporting profiles were published in 1973 in order to illustrate the method and its feasibility (*2*, attachments 1–8). Further experience and information indicate that some of these initial attempts require modification.

It should be stressed that the proposed plan is recommended only for a national-international division of jurisdiction for *mineral resources* beneath the oceans. It is not a plan for a division of jurisdiction over oceanic waters for navigational purposes, nor is it necessarily a plan for division of fishing rights. These purposes involve other factors and should be settled accordingly. It might not even be a plan for minerals *on* the ocean floor (such as manganese nodules), although it could be. It is rather a plan that concerns only mineral resources *beneath* the ocean floor requiring drilling or mining and fixed ocean floor installations for their recovery—principally petroleum resources.

Defects of 200-Mile Boundary Scheme

Some of the practical difficulties in application of a 200-mile-from-shore boundary formula have been mentioned above. However, in view of the publicity that has been given to the 200-mile proposal, it may be well to consider also some of its more fundamental defects.

Just as there is no logical or natural basis for an arbitrary 200-mile-from-shore limit, so also the distribution of mineral resources is much less related to the very superficial feature of the present shoreline than to the more fundamental base of slope, or base of continent. The world's great thicknesses of sediments with promising petroleum prospects are more closely related to the base of the slope than to some fixed distance from shoreline.

Adoption of a 200-mile-from-shore formula would cause many "wide-margin" countries to lose large potential petroleum-bearing areas situated on the natural seaward projection of their lands. These would be countries whose base-of-slope line is more than 200 miles from shore, such as Argentina, Australia, Canada, People's Republic of China, Ireland, Great Britain, the United States, and the Soviet Union. At the same time, many countries with narrow shelves and slopes would by the 200-mile formula be given vast tracts of deep-ocean bottom of little or no value to them and in no way an apparent prolongation of their lands beneath the sea. Examples are such countries as Chile, Peru, Portugal, Liberia, and Malagasy.

In contrast, the base-of-slope formula would assure to all countries all adjacent ocean floor naturally pertaining to them, and only so much more as the nations agreed to allot uniformly to all coastal states. If the extent given by the 200-mile formula were considered a desirable minimum, this could be attained by making the standard width of the boundary zone great enough (for example, 300 kilometers, or 162 nautical miles) to always allow the drawing of a boundary at least 200 miles from shore. Moreover, this could be done without robbing the wide-margin countries of their natural rights or without the complication of having to establish different formulas for wide-margin countries than for narrow-margin countries. Conversely, the international oceanic domain could be adjusted readily to whatever size the nations-in-concert might wish, simply through the standard width assigned to the boundary zone.

The base-of-slope formula, as compared with the 200-mile formula, provides a much readier means of expressing the wishes of the nations-in-concert and relating them to essential issues, foremost of which is the wish of each nation to be assured of the sub–ocean bottom minerals that it feels naturally belong to it.

Petroleum Prospects Beneath Oceans

Critical to any wise decision on jurisdiction over the mineral resources beneath the ocean floor is a proper understanding of the nature of their occurrence. Aside from manganese nodules, phosphate deposits, and other surface deposits on the ocean floor, it seems clear that petroleum is by far the most important sub–ocean bottom resource to be considered. It also seems clear that thoughts of petroleum resources have been a dominating factor in the attitude of the nations with respect to proposed boundaries between national and international jurisdiction.

We know from the geology of existing oil-field areas that marine geological environments of the type that we can associate with the continental margins constitute some of the world's most favorable settings for the genesis and accumulation of petroleum. This is in part because of the abundant supply of organic matter there, which is derived from both terrestrial and marine sources by drainage from the land and from marine life fed by upwelling, nutrient-rich waters from the ocean depths. In part, it is because of the restricted bottom circulation and rapid sedimentation rate of many of the margin seas which have been conducive to the preservation of organic matter. And in part, it is because the extraordinary crustal mobility of these margin belts adjacent to the continents has allowed the thick accumulation of a variety of sediments, the gradual cooking of the organic matter under sedimentary overburden, the collection of the generated hydrocarbons in reservoir beds, and the development of abundant trapping features through folding, faulting, unconformities, and stratigraphic changes.

Although a very substantial part of the world's petroleum is already coming from accumulations beneath the ocean floor, almost all is from the landward, relatively shallow waters near shore on the continen-

tal shelves. We still know little or nothing directly from actual drilling for petroleum about the prospects of strata beneath the deeper waters adjacent to the margin—those of the continental slope and beyond the base of the slope.

Such information as we have suggests that much of this deeper water area associated with the margins may also have a good petroleum potential. Geophysical surveys and the very limited amount of deep-sea drilling and sampling done for scientific purposes indicate that under much of this deep water lie sequences of sediments deposited, not under bathyal conditions as might offhand have been expected, but under all the favorable shallow-water sedimentary and structural environments of the sediments of the known oil-field areas of the present coastal plains and continental shelves.

However, about as far as we can justifiably go in appraising the prospects of this deep-ocean floor is to recognize that in general it has petroleum potential and that much of it is worthy of drilling exploration for petroleum when the need and incentive are great enough to compensate for the tremendous costs involved in operations in deep, open oceanic waters far from shore bases. Furthermore, in considering the prospects of entirely undrilled ocean areas, it should be recognized that they are truly unknowns. At this stage we can only speculate as to how well they may meet the geological requirements that experience and the progress of the science have shown are necessary for the creation of commercial petroleum accumulations.

The principal requirements for the development of a geological setting favorable to petroleum prospects may be summarized briefly as follows.

1) There must be a rich source of organic matter of the right kind.

2) Conditions must be favorable for the preservation of the organic matter until it can be buried by sediments.

3) Conditions must be favorable for the thermochemical conversion of the organic matter in the sediments to fluid petroleum (oil or gas). This requires an adequate thickness of blanketing sediments (1000 meters or more) so that, with the local geothermal gradient, favorable generating temperatures (50° to 150°C) may have been attained in the buried sediments, but not exceeded to such point as would have destroyed the fluid petroleum generated.

4) Conditions must be favorable for the movement of petroleum from source rocks to carrier beds. This presupposes the presence, in or adjacent to the fine-grained, organic-rich source rock sediments, of porous and permeable rock layers into which the newly generated petroleum can migrate in response to compaction pressure and other expulsive forces, and along which it can move to accumulation centers.

5) Accumulation traps must be present. These are structural or stratigraphic features where petroleum moving along carrier beds might be concentrated to form commercial accumulations.

6) There must be impermeable cover rocks to prevent the escape of petroleum and its dissipation at the surface. Thick shales and evaporites in the section are commonly effective cover rocks.

7) Proper timing in the development of the various conditions mentioned above is necessary; for example, traps formed after the petroleum has departed are of course worthless.

The more nearly an area promises to qualify with respect to the factors listed above, the better are its prospects. However, failure in any one factor may nullify promise in all the others, and until extensive drilling is done in an area it is rarely possible to evaluate all of the critical factors with assurance.

In some ways it is much easier to eliminate areas of little or no prospects than it is to determine how good are those with some prospects. One factor stands out as essential to the fulfillment of almost every one of the requirements listed, and that is the presence of an adequate thickness of sediments. Of course, mere thickness of sediments does not necessarily mean favorable petroleum prospects, but the lack of an adequate thickness to give temperatures sufficient to convert organic matter into petroleum, or to give pressures necessary to have caused its migration to accumulation centers, is sufficient in itself to condemn the prospects of many areas.

Geophysical surveys have already effectively eliminated vast areas of the ocean floor from serious consideration for petroleum by showing that they have only a few hundred meters of sediment. They have also shown that particularly thick sections of sediments commonly exist along the margins of the continents (and in associated seas and small ocean basins) and in some regions extend far out beyond the base of the slope. A thickness of about 1000 meters has commonly been used to separate areas of no promise from those that may have some promise, depending on the character of the rocks. Figure 4 shows estimated thicknesses of sediments above basement in the Atlantic Ocean as interpreted from seismic surveys (*3*).

Unfortunately, there is no reliable answer to the demand for quantitative estimates of the magnitude of petroleum resources in unknown and undrilled areas such as those beneath the deep oceans. Many persons have yielded to the pleas of the public, governments, or the United Nations and have come out with figures. This is perhaps good, because there is a variety in these estimates which tells its own story and because, taken as a whole and in application to large enough regions, such estimates probably do give a worthwhile order of magnitude answer. However, the truth is that the estimators do not know, nor does anyone know before drilling. Quantitative estimates of petroleum resources in new undrilled areas should probably be prefaced by a zero so that a true impression of the estimator's justified assurance may be given (*4*).

Relation of Boundary to Petroleum

The margins of continents and islands appear to have constituted a generally favorable environment for petroleum accumulation. Abundant petroleum production already comes from the landward edge of the margin—the near-shore continental shelf—and even most of the production from petroleum fields on land comes from uplifted sediments which were once deposited in close association with the continental margins of past geologic time.

A dividing line between national and international jurisdiction drawn at today's base of continental slope would leave a large share of this promising belt of potential petroleum-bearing sediments on either side. The landward side of course has the better-known potential, is in shallower water, and is more accessible. However, some of the thickest sedimentary deposits known lie just seaward of the base-of-slope line and constitute the so-called continental rises—huge sediment-filled sumps which, although somewhat questionable as regards adequate reservoirs and traps, must certainly have been good generators of petroleum. The oceanward side of the base of slope may thus have a high petroleum potential although it has the disadvantages of its remoteness from land and the great depths of water in which any operations would have to be carried out.

However, it is not the base of the slope itself but a boundary zone adjacent on its oceanward side that is recommended as the site for the national-international boundary. Thus, the width adopted as standard for this boundary zone would be of critical importance. A boundary drawn near the outer edge of a boundary zone of minimum width (100 kilometers) would still leave much of the areas of thick sediment in the international zone, although in very deep water. On the other hand, the nations-in-concert might decide that a wider boundary zone was desirable—200 or 300 kilometers, perhaps—expressly in order to give

the coastal states more of the possible petroleum resources of the so-called rises, or perhaps in order to give complete continuity to the sea floor areas between the islands of archipelagic countries like Indonesia, Philippines, or Mauritius, or to completely divide up the very promising seas and small ocean basins, such as the Gulf of Mexico, the Bering Sea, or the Black Sea, among the adjacent bordering states.

Obviously, any increases in the width of the boundary zone would leave less and less to the international regime and give more and more to the coastal states. However, even with a boundary 300 kilometers oceanward from the base of the slope there would still be some large ocean floor areas with more than 1 kilometer of sediment thickness left in the international zone (for example, off of Argentina, Canada, India, the United States, and the Soviet Union,

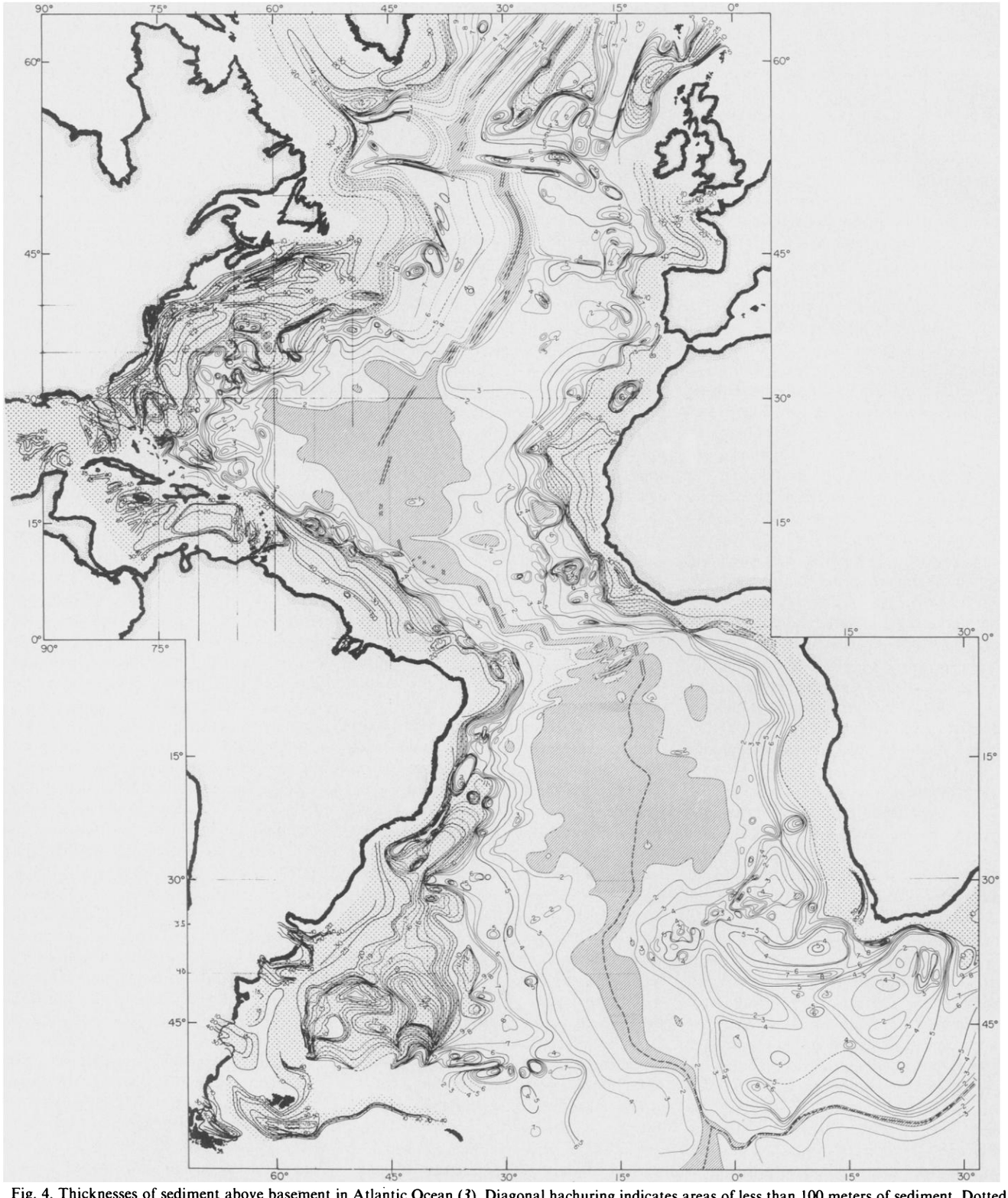

Fig. 4. Thicknesses of sediment above basement in Atlantic Ocean (*3*). Diagonal hachuring indicates areas of less than 100 meters of sediment. Dotted pattern indicates areas of more than 1000 meters of sediment. Numbered contour lines show thicknesses of sediment in hundreds of meters.

among others). The boundary zone concept leaves a flexibility in decision to the nations-in-concert as to how much of the world's prospective petroleum territory they wish to make international, while at the same time guaranteeing by the base-of-slope guideline that the coastal nations shall have at a minimum all that naturally belongs to them.

I am optimistic about the eventual petroleum production prospects of the outer continental margins, but certainly with a boundary beyond the base of slope the ocean territory that would go to the international regime would have little prospect of early petroleum development regardless of how good its ultimate potential might be.

The problems of drilling and development in the extreme water depths and remote locations of the outer margin may be so great and the costs so overwhelming that many of these areas may never even be given a chance to yield actual production. Certainly, only extremely lush reservoirs in this environment could be economic in the near future. And certainly, any areas beyond the base of the slope could not be a great source of international revenue in the next few years, as many seem to have hoped.

Moreover, the plan, once envisioned by some, to immediately benefit the developing countries through the proceeds of petroleum production beyond a national-international ocean floor boundary can no longer practically be carried out, because firm coastal state claims have already preempted the sea bottom out beyond any water depths that will be attractive for petroleum development for many years to come.

If it is the serious will of the nations to assign some part of the world's sea floor resources for the benefit of developing nations, a much more expeditious and practical procedure would be for the nations-in-concert to agree to dedicate to this purpose a certain percentage of coastal state government revenue from all ocean installations actually producing petroleum from water depths greater than a specified number of meters or at distances from shore greater than a specified number of kilometers. Accurate determination of such depths or distances could readily be carried out for each producing installation. International revenue from such sources, however, should of course come entirely from the coastal government's share and not from private entrepreneurs, because the development of even moderately deep and distant water areas will require maximum financial incentives, not additional tax burdens, in order to stimulate interest and compensate for the huge financial risks involved.

Proposed Boundary off Eastern United States

Figure 5 is a bathymetric map of the ocean floor off the eastern (Atlantic) coast of the United States, including adjacent offshores of Bahamas, Bermuda, and Canada (*5*). The base-of-slope boundary guide and alternative zones, as well as the 200-mile-from-shore line, are shown. The base-of-slope line does not coincide with the conventional boundary between slope and rise provinces off eastern United States but has been drawn farther offshore to make it correspond approximately with the outermost principal flattening of the seaward gradient of the ocean floor at the continental edge. More detailed or revised bathymetry might change its position somewhat, but to have used the conventional slope-rise boundary would have put the base-of-slope line at a water depth of about 2000 meters, high up on the edge of the geomorphic continent rather than at its base.

Thicknesses of sediments (in kilometers) from the isopach map of Fig. 4 (*3*) have been transposed roughly to Fig. 5 where they are shown as numbers. However, more recent investigations have indicated that maximum thicknesses of sediment near the axis of the sediment-filled trough adjacent to the continent are somewhat greater than previously supposed and in several areas exceed 10 kilometers.

Assuming that a sediment column of a minimum thickness of 1 kilometer is necessary to make petroleum prospects interesting, it is evident that all of the offshore area out to the base-of-slope line qualifies in that respect. The 100-kilometer boundary zone beyond the base of slope also appears to have an adequate sedimentary thickness for petroleum prospects. Boundary zones of 200 and 300 kilometers would include successively less interesting thicknesses of sediment but even a 300-kilometer boundary zone would leave some sediment thicknesses greater than 1 kilometer on its oceanward side.

Figure 5 illustrates differences that would result from the proposed 200-mile-from-shore boundary between national and international jurisdiction as compared with a boundary related to the base of slope.

North of latitude 38°, the 200-mile line would coincide quite closely with the base of slope if the 200 nautical miles were measured from the mainland of Nova Scotia. However, if the position of the 200-mile line were also influenced by Sable Island (a small Canadian island at the edge of the shelf southeast of Nova Scotia), a quite different boundary would result. Both possibilities are shown in Fig. 5. This is an example of one of the problems with the 200-mile scheme—the question of how small shelf islands should be treated in determining a base from which the 200 nautical miles should be measured. In contrast, using the base-of-slope guide there would be no such ambiguity.

Between latitudes 34° and 38°N, there is a large divergence between the 200-mile line and the base-of-slope line. The 200-mile line fails to include for the United States most of a broad terrace area which is underlain by a substantial sediment thickness. Likewise, between 29° and 32°N, the 200-mile line fails to include in national territory the interesting Blake Ridge, which has thick sediments and has already shown evidence of gas hydrates (*6*). South of latitude 30°N the 200-mile line is not shown because it is uncertain how it might be measured in this area of both United States and Bahama islands shorelines.

Petroleum Prospects off Eastern United States

In evaluating the significance of proposed national-international boundaries to ownership of petroleum resources off the East Coast of the United States, three cautions need to be emphasized. They are: (i) the unreliability of attempts at quantitative estimates of the petroleum resources of this area; (ii) the tremendous costs of any drilling and production operations in the remote deep waters beyond the edge of the continental shelf; and (iii) the remoteness in time when technology and economics might unite to make such areas practically commercial.

There have been many estimates of the petroleum resources off the Atlantic Coast of the United States during the last few years. Some have been very sanguine, others less so; all have one thing in common—they are necessarily based on little or no drilling knowledge and so are of little quantitative reliability. Such estimates, with the false impressions of accuracy which they too often give, may actually be a hindrance to good planning and may impede realization of our true need—the need to find out.

Probably the best (and most conservative) job of appraisal (*7*) is that which, however, applies to the offshore only out to a water depth of 200 meters. This estimate is based on the coordinated studies of a large group of specialists and is given as a range from 0 to 9 billion barrels plotted against a scale of probabilities (for example, 75 percent probability that there will be more than 1.5 billion barrels, 25 percent probability that there will be more than 4 billion barrels, and so on). However, even with this estimate, perhaps another

probability factor needs to be applied—the probability that any estimate in a previously undrilled region will not be even close to the truth. What group of specialists, however skilled, would have come close to estimating the petroleum resources of the North Slope of Alaska before Prudhoe Bay, even with the most thorough study and after several wells had been drilled?

The important initial task is not a quantitative estimate but a careful and thorough appraisal of all geological, geochemical, geophysical, and economic data available, with the purpose of answering the

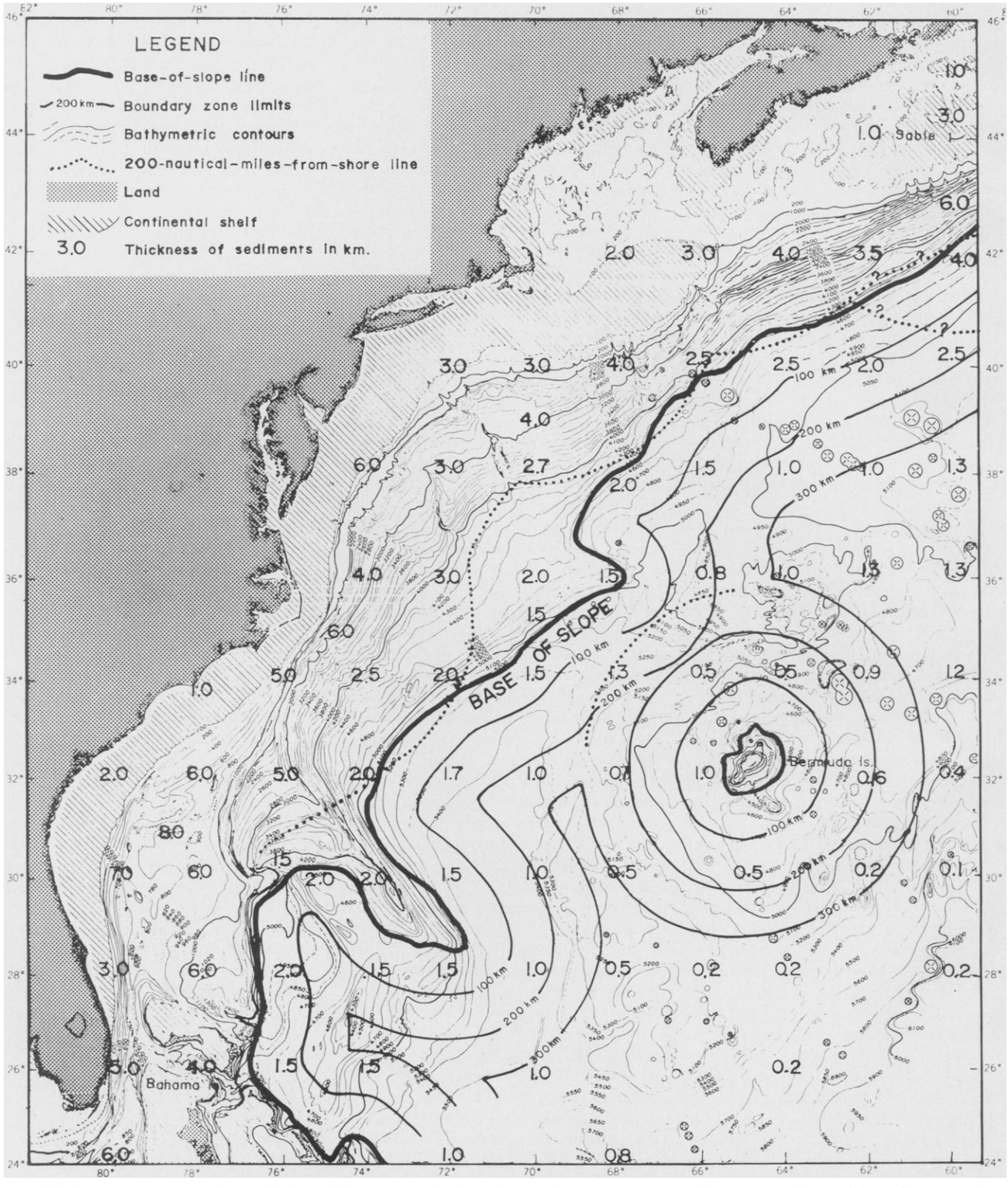

Fig. 5. Bathymetry (meters), sediment thickness (kilometers), and effect of various boundary proposals off the Atlantic Coast of the United States. The approximate base-of-slope boundary guide is shown with three alternative boundary zones on its oceanward side (black lines to right of and parallel to base-of-slope line). These lines indicate possible zone widths of 100 kilometers (54 nautical miles), 200 kilometers (108 nautical miles), and 300 kilometers (162 nautical miles). The thickness (in kilometers) of sediments is measured above acoustic basement (*3*).

only pertinent and practical question at this stage, which is: Do the prospects of the region, in the light of all the knowns and unknowns, reasonably justify exploratory drilling? In the case of the Atlantic offshore, the answer is Yes. The sooner we get on with the job of drilling exploration the better, regardless of quantitative estimates, optimistic or pessimistic (*8*).

To some extent the concern shown about the division of petroleum resources under the deep-ocean waters far from shore may seem a tempest in a teapot, so far removed is their utilization from present reality. With the tremendous costs and marginal economics of many current offshore petroleum exploration and development projects even at very moderate water depths, it may be completely impractical to think of ever producing oil and gas from deep-ocean environments. It may also seem only a barren academic exercise to argue about schemes for national-international boundaries in these remote areas that are so difficult to exploit.

However, the same things were once said about shallow-water offshore drilling; yet in only a few decades this has become commonplace. Offshore oil and gas now occupy an important position in our world economy. With inevitable progress toward the exhaustion of our petroleum reserves on land and in shallow coastal waters, the already steady march of exploratory drilling into deeper and deeper waters farther from land may see no limits as far out as geological possibilities of petroleum accumulations exist. It seems true that if the productive possibilities are good enough, there is scarcely a place on the earth where either technology or economics will be allowed to be a permanent barrier.

In view of this trend, the prudent time to settle matters of jurisdiction is *now*, before actual discoveries in the far offshore make it more and more difficult to peaceably establish boundaries on the basis of uniform and equitable principles without the complicating factor of selfish interest in acquiring specific local areas. The principle on which the boundary is to be established should be decided now, even if, locally, implementation into precise and definitely defined boundaries is delayed somewhat by needs for more accurate bathymetric data.

Even assuming that deep water and remoteness from land may not be permanent barriers to petroleum exploration and development, realistically it is still necessary to recognize that petroleum resources near the base of the slope are resources only for the far future. Many years of improving technology and increasing demand must intervene before such resources can be utilized. Moreover, the chimera of a rapid and enormous payoff from an internationally owned and sponsored petroleum development, to be used for the benefit of developing nations, must be abandoned, even in only moderately deep waters. A much more effective alternative was suggested above, but perhaps it should be considered whether a more practical way for all to benefit from petroleum resources under the deep oceans may not be simply to create stable conditions of national ownership of the ocean floor naturally pertaining to each coastal state so that these

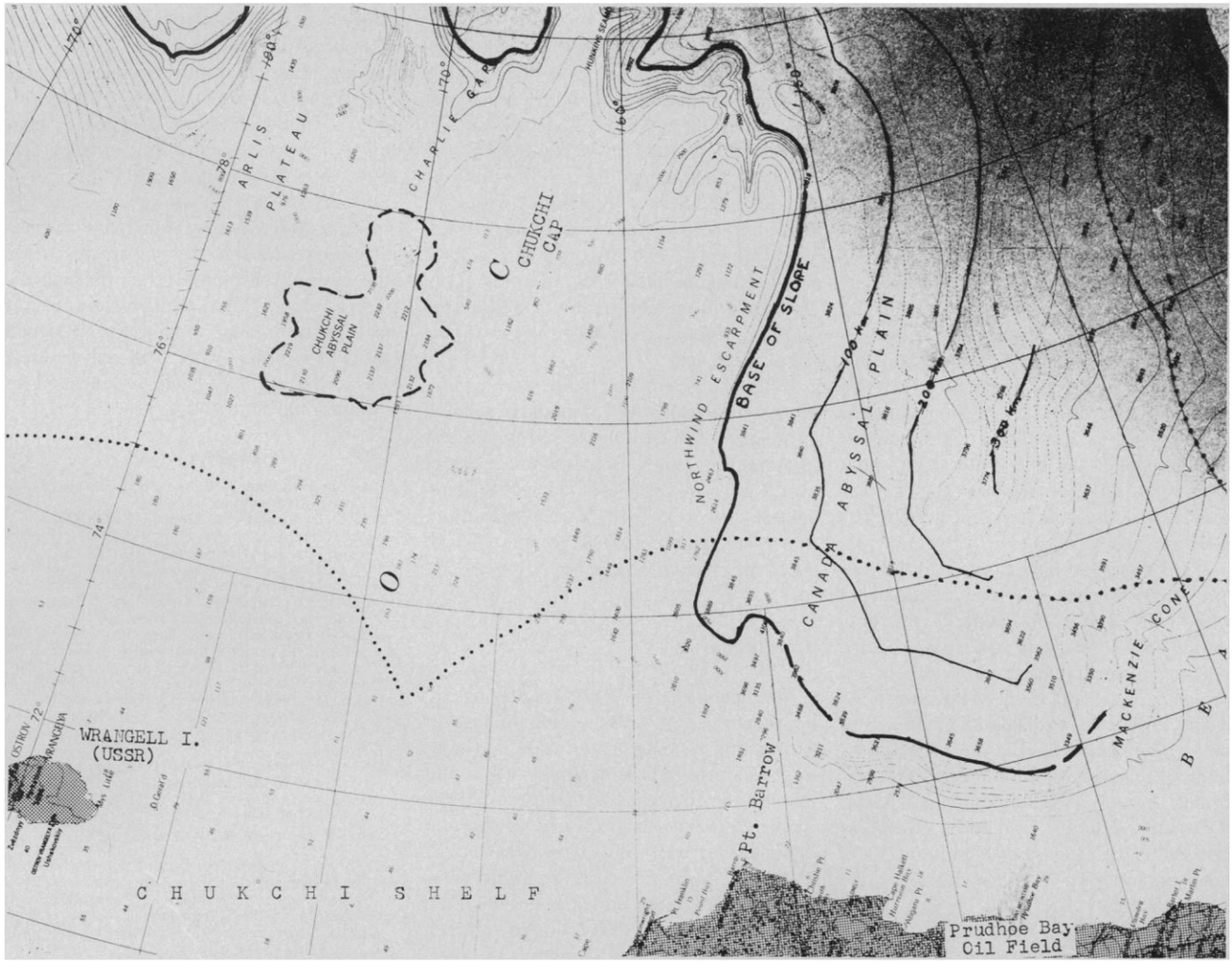

Fig. 6. Bathymetry (meters) and effect of various boundary proposals, Chukchi Shelf, north of Alaska (*9*) (conventions as for Fig. 5).

resources may be developed as rapidly and efficiently as possible, as the need for them arises, by those having the special skills, equipment, and geographic location to do so. A more abundant supply of petroleum more widely distributed among the coastal nations of the world would relieve present monopolies and inevitably work out to the advantage of all countries.

Boundaries off Other U.S. Coasts

The possible effect of proposed national-international boundaries on the U.S. petroleum position off the Atlantic shore has been discussed in detail. It may be of interest to briefly consider three other U.S. coasts similarly affected. It is also worth mentioning that the U.S. Pacific Coast, including Alaska, has a base of slope such that with a 100-kilometer boundary zone all areas of important petroleum promise would probably go to the United States. This would also be true for a 200-mile-from-shore boundary which would, however, result in the needless inclusion also of a broad band of deep-ocean bottom without petroleum prospects and with no other known subbottom values.

1) *Gulf of Mexico.* Geologically the whole Gulf of Mexico may be considered prospective petroleum territory. Extensive offshore production has long been established off the Louisiana, Texas, and Mexican coasts. The base of slope is quite clearly indicated or can be reasonably interpolated around most of the periphery of the Gulf and would serve to mark the limits of *minimum* areas to be assigned to the three bordering countries. With a 100-kilometer boundary zone a thin, elongate international zone would still be left in the middle of the Gulf, but with a boundary zone as wide as 200 kilometers this would be eliminated and the whole Gulf area would be divided between the United States, Mexico, and Cuba (*2*, attachment 3-B).

Use of the 200-mile-from-shore boundary would also leave a small central portion of the Gulf in the international zone, but again, the mode of application of this scheme would be uncertain because of the presence of several small Mexican reef islets at the edge of the shelf about 100 miles off the Yucatan shore. If the 200 nautical miles were measured from these islets rather than from the Yucatan mainland, Mexico's share of the Gulf would be greatly increased at the expense of the international zone and in part at the expense of the United States.

2) *Alaska: Bering Sea.* The Bering Sea not only has a thick sediment cover (locally as much as 10 kilometers) over its very broad shelf area, but also has thick sediments and petroleum potential thoughout its whole deep-water area beyond the base of the slope. A base-of-slope boundary would of course assure to the United States all of the broad eastern shelf of the Bering Sea, and the use of a 300-kilometer boundary zone would probably give essentially all of the deep-water sea floor to coastal state (United States and Soviet Union) jurisdiction.

A 200-mile limit measured from the mainland coast of Alaska and the Aleutian islands would leave much of the potential petroliferous area of the Bering basins, both on the shelf and in deeper water, under international jurisdiction. However, if the 200-mile distance were measured from the small U.S. shelf islands of St. Matthew, St. Paul, and St. George, far distant from the mainland, the United States could claim the entire eastern shelf area and also a substantial part of the deep-water area beyond the base of the slope under this boundary formula. Even so, it would lose much of the deep-sea, potentially petroliferous area that it would have received from the base-of-slope plan with a 300-kilometer boundary zone.

3) *Alaska: Arctic Coast.* Probably nowhere on U.S. coasts does the importance of the base-of-slope boundary stand out more than off the north coast of Alaska. Here the huge shallow-water areas of the Chukchi Shelf extend far out into the Arctic and are underlain by a thick (up to 6 kilometers) section of potentially petroliferous sediments. The situation with respect to the Chukchi Shelf is shown in Fig. 6 (*9*). The proximity of the great North Slope petroleum discoveries adds interest to the Chukchi region.

With a base-of-slope guide and a minimum (100-kilometer) boundary zone, a large part of this extensive and potentially petroliferous shallow to moderate water depth area would come under U.S. jurisdiction, whereas with a 200-mile-from-shore boundary, much of this part would go to the international zone.

Conclusions

In conclusion, the United States has everything to gain and nothing to lose by supporting a boundary formula that gives it its natural subsea territory out to the base of the adjacent continental slope, plus such additional selvage as may be provided by whatever width boundary zone the nations-in-concert decide is desirable. Conversely, the United States would definitely lose by accepting a 200-mile limit. In several places this would deprive it of potential petroleum territory which naturally should belong to it, while in other places it would give it an excess of deep-ocean bottom poor in sediments.

Similarly, for all coastal countries, the base-of-slope formula could give them as a minimum all the potential petroleum territory which they would receive by the 200-mile formula, without the unnecessary addition of inutile deep-ocean bottom better assignable to the international sphere, with the advantage to broad-shelf countries of giving them also all of their rightful petroleum resources beyond the 200-mile limit.

It is of course conceivable that the United States and other broad-margin countries may wish, for political or altruistic reasons, to go along with the 200-mile boundary proposal and donate what may be important potential petroleum resources of the far future to an international regime; but if so, they should know in advance what they are doing, and that they alone of the world's nations are doing it. Another alternative may be for the nations-in-concert to adopt one formula for the narrow-margin countries and another for the broad-margin countries (although differentiation between the two groups might be very difficult); or to adopt a combination of the two proposals, such as 200 nautical miles from shore or the outer edge of the margin, whichever is greater (although implementation of such a plan might be very complicated). Finally, perhaps, the United States and other countries may yet be willing to speak out for the simpler, more effective principle that gives all nations the sub-sea bottom resources that naturally belong to them through the natural prolongation of their land masses beneath the oceans, which treats all coastal states alike, and which still leaves some substantial areas of thick sediment in an international zone.

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