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A SUMMARY OF PETROLEUM POTENTIAL, ENVIRONMENTAL GEOLOGY, AND THE TECHNOLOGY, TIME FRAME, AND INFRASTRUCTURE FOR EXPLORATION AND DEVELOPMENT OF THE WESTERN GULF OF ALASKA

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CONTENTS

ILLUSTRATIONS

[All illustrations are at end of report]

TABLES

A SUMMARY OF PETROLEUM POTENTIAL, ENVIRONMENTAL GEOLOGY, AND THE TECHNOLOGY, TIME FRAME, AND INFRASTRUCTURE FOR EXPLORATION AND DEVELOPMENT OF THE WESTERN GULF OF ALASKA

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SUMMARY

The Kodiak Tertiary Province is in a very early stage of oil and gas exploration. Although a great deal of industry geophysical work has been conducted in the area, no drilling has been done to sample the rocks that might contain commercial quantities of oil and gas. The most prospective sites are concentrated in an area about 660 km long and 100 km wide that has a thick sedimentary sequence in conjunction with large structures which may have trapped oil and gas. However, this is also a rich commercial fisheries area which poses problems of multiple use. Early identification of potential geologic hazards and the measures needed to insure minimal environmental impact could ameliorate the problems of multiple use.

The Kodiak Tertiary province has three main sedimentary basins. The largest, Albatross Basin, has several lesser subbasins separated by broad arches. Tugidak and Portlock Basins are smaller and have a simpler configuration and internal structure. The sedimentary sections in Albatross and Tugidak basins are over 6km thick, whereas Portlock Basin probably has a thinner sediment sequence.

Scanty onland exposures of rocks along the fringes of Albatross and Tugidak Basin indicate most potential hydrocarbon source rocks to be of Miocene age or younger. Older sedimentary rocks onshore are altered; however, the older section offshore might be less deformed and might also be a source rock. Rocks onshore on the landward side of the prospective area, and sediments from

deep sea cores on the seaward side of the prospective area, suggest that sand favorable for reservoir rock is present in the Kodiak Tertiary Province, but this is highly inferential. Potential hydrocarbon traps are anticlinal structures and stratigraphic traps; the anticlines in Albatross Basin are the most interesting initial targets for exploration. Stratigraphic traps are inferred from seismic data in Tugidak Basin and these possible traps could be targets. Portlock Basin appears to be of the least interest for exploration.

The undiscovered recoverable resources in the Kodiak Tertiary Province are estimated, at 5% and 95% probability levels, to be from 0 to 1.2 billion barrels of oil and from 0 to 3.5 trillion cubic feet of gas, respectively. Because these estimates have been made prior to any exploratory drilling, they are highly speculative. Therefore, a resource estimate of 0 indicates that there is less than 95% probability of commercial quantities being present.

The regional environmental geologic problems of major concern are (1) location of the most likely areas where contaminants will accumulate and form high concentrations of pollutants, (2) areas of unstable sediment, and (3) major earthquakes and accompanying hazards. Site-specific environmental geologic data will be acquired in systematic surveys during later stages of leasing procedures to address potential hazards in localized areas.

The possible repositories of contaminants that could become incorporated into sediments coincide with areas of modern sediment accumulation. In the Kodiak area, the pathways of modern sediment are former glacial channels. During times of glaciation and low sea level, glaciers from the Kodiak group of islands and the Kenai Peninsula merged in the present coastal zone and extended across the continental shelf. Channels formed by the glaciers and the intervening plateaus and banks remain as prominent physiographic features. Modern sediment collects mainly in fiords; the relatively small amount that escapes to the continental shelf plus material from adjacent plateaus and banks is probably transported and deposited in these channels. Therefore, most of the thick accumulations of unconsolidated modern sediment and the long-term repositories for contaminants are found in the glacial channels.

The glacial channels are also potential areas of sediment instability since the channel banks have relatively steep slopes (3° to 5°). The seaward edge of the continental slopes is another possible area of slumping but only one has been identified in 15 erosions of the slope. The unconsolidated sediments in the channel floors may possibly be more hazardous than on the slopes as they could have very low strength.

Present estimates of major earthquake recurrence in the Gulf of Alaska range from 35 to 800 years. The estimated minimum interval is less than the lifetime of a productive oil field. Shaking caused by earthquakes can be particularly destructive in areas of thick unconsolidated sediment and therefore might be a potential problem in the channel floors. A more serious potential hazard may be surface rupture along active faults in a narrow zone along Kodiak Island and from there northeast to Montague Island. Fault scarps have also been noted on Albatross Bank. During the 1964 earthquake, both of these areas were subjected to the regional warping that affected most of the Kodiak Tertiary Province; maximum uplift and subsidence was 15 m and 2.5m, respectively.

In the coastal zone, environmental problems are more complex. The harbors of Seward and Kodiak are the closest staging areas for exploration and development activities. Both harbors were inundated by the regional tsunami accompanying the 1964 earthquake. In addition, Seward was subjected to local tsunamis generated by failure of large sections of the delta on which the town is built. Docks and rail facilities along the water front slid into the water and severe damage occurred throughout the city.

The technology for exploration and development in the western Gulf of Alaska has been demonstrated recently in the North Sea. Several mobile drilling rigs capable of operating in the Gulf of Alaska are presently under construction on the Pacific coast and in Japan. Until these are completed, rigs must be obtained from the North Sea or other parts of the world. There are few skilled workers in the Alaska area but trained personnel are available in the Pacific Northwest and California.

The time required for significant development will be relatively long and the costs will be high. Substantial exploratory drilling will occur 2-3 years after a lease sale, initial production in 7-8 years, and maximum production in 10-11 years, assuming that producible discoveries are made.

Preliminary estimates of peak production and facilities necessary for development are difficult to make without knowledge of the quantity of oil and gas in potential anticlinal traps. The high cost of operations in the western Gulf of Alaska will restrict development to giant fields that have large recoverable reserves.

INTRODUCTION

This summary of the regional geology, petroleum potential, geologic hazards and time frame for exploration of the western Gulf of Alaska has been written to aid the Bureau of Land Management in preparing the Draft Environmental Impact Statement. A preliminary version was written in Sept., 1975. (von Huene and others, 1975) in support of the Call for Nominations, Proposed OCS Oil and Gas Lease Sale #46. Since that time, there has been a substantial increase in information as the result of a two-month examination of recent studies of the adjacent Gulf of Alaska Tertiary Province and a preliminary interpretation of some publicly available common depth point (CDP) seismic reflection data recently acquired by the U.S. Geological Survey. The main source of geologic and geophysical data used in the preparation of this summary is published and unpublished information of the U.S. Geological Survey (Plafker and others, 1975, Bruns and Plafker, 1975; Carlson, Bruns and Molnia, 1975; Carlson and Molnia, 1975; Core, Mattick, and Bayer, 1975; Molnia and Carlson, 1975 a & b; von Huene and others, 1975). Prior to 1975, data were gatherd mainly for purposes other than for assessment of oil and gas resources and of the environmental consequences of exploration and development. A systematic survey for such an assessment is planned for the summer of 1976 and, therefore, this summary is tentative. Although the major problems and regional setting are discussed in this paper, a great deal more specific data and interpretations will begin to become available in about one year.

In this summary we consider the geology of a broad region on the continental shelf off the Kodiak group of islands and the Kenai Peninsula. We will concentrate on the area proposed for leasing in Sale #46. The area lies between about 56°N latitude and 60°N latitude (Fig. 1), and it measures approximately 660 km x 100 km. Water depths are generally less than 200 m.

GENERAL GEOLOGY

GENERAL CONSIDERATIONS

The western Gulf of Alaska continental shelf (Kodiak Shelf) extends roughly from Montague Island on the northeast to Chirikof Island on the southwest (Fig. 1). It contains lithologic sequences that are extensions of those in the Aleutian Island Arc as well as extensions of sequences in the eastern Gulf of Alaska. The continental shelf contains three newly identified basins, the largest of these being Albatross Basin which trends parallel to, and is roughly between, the shelf edge and Kodiak Island. The two smaller basins flank Kodiak Island to the southwest and northeast, respectively.

The landward edges of the basins are uplifted on portions of the Kodiak group of islands and incomplete Tertiary outcrop sections are about 12,000 m thick (Moore, 1969). The Tertiary rocks are chiefly clastic, with subordinate lava and tuff near the base and thin coal beds in the middle. Rocks older than middle Oligocene contain graded beds throughout, and probably formed in a deep-water environment. Rocks younger than middle Oligocene are shallow-marine and deltaic.

STRATIGRAPHY AND LITHOLOGY

Basement Rocks

The arcuate lithologic sequences of the western Gulf of Alaska margin are underlain by basement rocks of different ages that are inferred to have originated as separate blocks of oceanic crust and are accreted to the continental margin. The Cook Inlet basin, for example, is underlain by bedded Jurassic and older rocks that may contribute to the petroleum potential of that belt. Pre-Jurassic chert, pillow lava, and ultramafic rocks, which crop out on the upper plate of a major thrust fault on the northwest side of Kodiak Island, are inferred to mark a seaward limit beyond which no early Mesozoic or older strata are present (Fig. 2).

On the landward side of the Kodiak Tertiary Province, Tertiary sediments were deposited on a very thick section of contorted Upper Cretaceous flysch that has been metamorphosed to slate grade (Fig. 2). The Tertiary sediments are named the Valdez Group on the Kenai Peninsula, the Kodiak Formation on Kodiak Island, and the Shumagin Formation on the Shumagin Islands (Plafker, 1971; Moore, 1969; Burk, 1965).

On Kodiak Island, the Kodiak batholith has intruded the metamorphosed Cretaceous rocks. Nearby stocks that are presumed to have been emplaced at approximately the same time have intruded lowermost Tertiary rocks. A potassium-argon date of 58.1 m.y. (Paleocene) has been published for the Kodiak batholith (Karlstrom, 1969).

Lower Tertiary Strata

The Cretaceous flysch of Kodiak Island is overlain by the Tertiary rocks of the Kodiak Tertiary Province. Lowermost Tertiary rocks onshore consist of a sequence of nonfoliated, strongly indurated rocks of Paleocene and Eocene age that at some levels contain pillow lavas and volcaniclastic debris. They are generally at the zeolite grade of metamorphism, and thin hornfels aureoles occur where they have been intruded by Paleocene plutons. This sequence is called the Orca Group on the Kenai Peninsula, the Ghost Rocks Formation on Kodiak Island, and the Tolstoi Formation along the Alaska Peninsula.

The Ghost Rocks Formation (Fig. 2 & 3) is overlain by tightly folded Eocene and Oligocene flysch of the Sitkalidak Formation that is estimated to be approximately 3,000 m thick (Moore, 1969). The lower part of the Sitkalidak Formation is nearly as altered and as cemented as the underlying Ghost Rocks Formation. Induration is less near the top, where the formation is conformably overlain by shoreline facies of the Sitkinak Formation. The Sitkinak Formation of Oligocene age is about 1,500 m thick and consists of siltstone, sandstone, and deltaic conglomerate. It contains fossil redwood needles and thin coal beds. At the type locality of Sitkinak Island, the formation is conformably overlain by about 150 m of mollusk-bearing Miocene siltstone assigned to the Narrow Cape Formation. On Chirikof Island, a marine unit 6,000 m thick has been tentatively assigned to the Sitkinak Formation because it contains coal pebbles and thick submarine fanglomerate beds that have clasts similar to those of the deltaic Sitkinak Formation.

The Oligocene rocks of the Kodiak Tertiary Province are age equivalents of the organic-rich beds associated with oil and gas seeps in the eastern Gulf of Alaska (Plafker and others, 1975). During the deposition of graded beds of the Sitkalidak Formation, the shoreline lay shoreward from Kodiak Island near the lithologic belt that includes Cook Inlet. Later in the Oligocene, during deposition of the Sitkinak Formation, a flood of granitic and chert clasts occurred, indicating that Kodiak Island had then become established as a land mass.

Upper Tertiary Strata

In outcrops at the type locality of Kodiak Island, the Narrow Cape Formation is about 700 m thick and unconformably overlies lower Oligocene and Eocene rocks. It contains molluscan fossils of middle Miocene age and consists of fairly well sorted conglomerate, sandstone, and siltstone. At the only other outcrop of the Narrow Cape Formation, 150 km to the southwest on Sitkinak Island, siltstone of the Narrow Cape Formation conformably overlies Oligocene coal-bearing rocks of the Sitkinak Formation and contains mollusks of early Miocene age.

The youngest Tertiary formation cropping out on the Kodiak group of islands is the Tugidak Formation of Pliocene age. The full section is not exposed. On Chirikof Island, it overlies Oligocene rocks unconformably. On Tugidak Island, where the exposed thickness is 1,500 m, the base is not exposed. The Tugidak Formation consists of interbedded sandstone and siltstone containing mulluscan fossils and abundant ice-rafted dropstones.

Offshore Tertiary and Quaternary Strata

Within the offshore part of the Kodiak Tertiary Province, a section of probable upper Tertiary sedimentary rocks occurs in a series of basins (von Huene, 1972). The rocks in these basins are virtually unsampled. Their age and properties are inferred from the few dredged samples, from rocks of presumed equivalent age on the islands, from the character of reflectors in seismic records, from acoustic velocities, and from cores recovered in the deep ocean on Leg 18 of the Deep Sea Drilling Project. These rocks may be the most promising source rock for oil and gas and may have the best reservoir potential because they are not metamorphosed, although nonmetamorphosed rocks of Oligocene and Eocene age might also be present in the offshore basins.

On southern Albatross Bank, near the edge of the continental shelf off Kodiak Island, several samples were recovered at a dredge station. The samples consist of Miocene and Pliocene siltstone containing assemblages of Foraminifera that indicate deposition in a bathyal environment prior to uplift (von Huene, unpub. data). The trend of some reflections in the seismic reflection data suggests that certain intervals are thicker under the continental slope, and that the depocenter was on the slope and has now been uplifted and eroded.

The geologic age of strata that appear as the upper sequence of good reflections in seismic records can be estimated by reflections projected from seismic lines to outcrop areas on Tugidak Island. Gently dipping Pliocene beds more than 1,500 m thick on Tugidak Island appear to be correlative with horizontal strata about 2,900 m thick at the end of a seismic reflection record 14 km offshore. On Chirikof Island, correlative beds of the Tugidak Formation unconformably overlie steeply dipping Oligocene rocks of the Sitkinak Formation; this relation is not seen offshore in the seismic data. On the basis of this evidence, the stratified deposits recorded in seismic surveys across Tugidak basin are inferred to be largely Pliocene, and younger sediments.

The upper highly reflective sequence in Albatross Basin is inferred to be of Miocene and Pliocene age from the single dredge station on Albatross Bank where rocks of this age were recovered. At the dredge station the reflective sequence crops out near the crest of an arch that is deeply eroded; however, the bottom of the sequence is not exposed. Therefore, the section in Albatross Basin is probably at least as old as Miocene.

Some inferences based on this sparse information can be made about the lithology of the Tertiary section of the continental shelf near Kodiak. Although the pre-Oligocene section is generally metamorphosed where exposed on land and is therefore considered to have a poor potential for petroleum, the post-Oligocene section contains some sand in outcrops and in three drill sites seaward of the continental shelf. The presence of sand on the continental slope and adjacent abyssal sea floor indicates that large enough quantities of well sorted sands were present to bypass the continental shelf; therefore, sand with reservoir characteristics may also have been deposited in suitable environments now under the shelf.

STRUCTURE

GENERAL CONSIDERATIONS

Within the proposed lease area, three basins are named informally for this report (Fig. 4). The largest, named Albatross Basin after Albatross Bank, is on the outer continental shelf. Two smaller basins at the northeast and southwest ends of Kodiak Island are on the inner continental shelf. The northeast basin is named Portlock Basin after Portlock Bank and the southwest basin is named Tugidak Basin after Tugidak Island. Publicly available geologic and geophysical data are generally insufficient to define the configuration of the basins, but they are sufficient to describe their general geologic character.

In outcrops on Kodiak and adjacent islands, the intensity of deformation seems to gradually decrease with decreasing geologic age (Fig. 3). Paleocene rocks consist of flysch and are intensely fractured; Eocene rocks are overturned in isoclinal folds; Oligocene rocks occur in close folds, which are occasionally overturned; Miocene rocks occur in tilted beds dipping 30°; and Pliocene rocks dip 10° or less. The belt of Tertiary rocks along the southeast coast of Kodiak Island, both onshore and offshore, is a locus of particularly intense late Cenozoic faulting (Moore, 1967; von Huene, 1972). This narrow zone of deformed rocks, which allows observations of the tightly folded and steeply tilted bedding, provides the only outcrops where geologic structure can be studied by conventional surface geologic methods. Such structures cannot be defined on the available marine geophysical data, on which most of the subsequent discussion is based. The zone of deformed rocks appears to mark a major change in crustal structure (Shor and von Huene, 1972) along which Kodiak Island was uplifted in Oligocene time. Therefore, the post Oligocene sediments deposited nearshore that are now exposed may not accurately represent the time equivalent sediments deposited further offshore.

ALBATROSS BASIN

Albatross Basin is about 40-60 km in width and extends about 600 km along the outer continental shelf from near Sitkinak Island to the area of Middleton Island (Fig. 4). The basin is a depressed area between a ridge at the edge of the continental shelf and the major fault zone along the southeast coast of Kodiak Island. This general configuration is shown in a cross-section based on seismic refraction data (Fig. 5) outlining the basic relation of the basin to deeper crustal layers (Shor and von Huene, 1972; von Huene, 1972; von Huene, Shor and Malloy, 1972). A relatively uncomplicated cross section of the basin is shown in the seismic reflection data recorded on line 509 (Fig. 6). Here the shelf break structural high is an arch that corresponds to the topographic high of Albatross Bank. On its landward side is the stratified sequence in Albatross Basin that has been uplifted, gently folded, and deeply eroded; on its seaward side nearly flat strata cover steeper tilted strata of the continental slope. Below the broadly arched sequence of reflections is a core of folded stratified rocks seen only as weak reflectors. Albatross

Bank is a topographic high that probably underwent renewed uplift during the 1964 Alaska Earthquake (von Huene, Shor, and Malloy, 1972), indicating continued deformation to the present.

The structure of the deformed zone forming the western limit of Albatross Basin is unclear because the steeply dipping and tightly folded lower Tertiary strata, seen on land and probably present offshore, are beyond the limits of resolution of the available seismic data. However, along line 509 (Fig. 6), offset reflectors indicate steeply dipping faults in the first 2 seconds of record, and the stratified sequence of Albatross Basin appears to butt against some faults and be draped across others.

Line 509 displays a basic framework which can be recognized in the more complex structures of seismic records to the northeast. For instance, along line 508 (Fig. 6), folding and faulting occur within the basin; the seaward structural high at Albatross Bank broadens and consists of two distinct arches, and is not as deeply eroded; the shoreward deformed zone along Kodiak Island appears less distinct but it has fault scarps at the ocean floor. Similar complex structures are seen along line 505 (Fig. 6) and other multichannel records not illustrated here. These records, along with older single channel seismic reflection records and topography data, suggest that Albatross Basin consists of several subbasins separated by broad low structural highs. The central parts of some subbasins contain broad folds and occasional faults, especially off the northeastern end of the Kodiak group of islands.

The shelf break structural high forming the Albatross Bank has a variability and a discontinuity similar to that found in the basin (von Huene, Shor, and Malloy, 1972). Along Albatross Bank this structural zone is composed of a series of arches. Northeast of the bank, the arches are more deeply buried and often have little surface expression. Opposite Amatuli Trough the structure is inferred only from gravity data, but its presumed continuation is strongly expressed at the Middleton Island platform where Albatross Basin ends. Thus, the seaward flank of the basin consists of a series of arches with strong surface expression along Albatross Bank followed by moderate to deeply buried arches along the segment opposite Portlock Bank and Amatuli Trough, and by a deeply eroded arch at the Middleton Island Platform.

The landward flank of the basin formed by the zone of deformation has a corresponding variability. Along the Kodiak group of islands this zone is characterized by deformed rocks cut by a system of steep faults that separate the uplifted older metamorphosed rocks of the islands from the subsiding Albatross Basin. Across Portlock Bank and possibly Amatuli Trough, the zone may have a discontinuous surface expression. It then becomes well defined by faults southwest of Montague Island where large fault displacements occurred during the 1964 earthquake. The apparent discontinunity of strong surface faulting raises questions about the origin of the fault zone and its relationship to underthrusting of the continental margin. Plafker

(1969) suggests that the part of the zone near Montague Island is secondary to the major zone of underthrusting between the Pacific and North American plates along which the 1964 earthquake is thought to have occurred. Yet the deformed zone corresponds to the area of maximum aftershock strain release accompaning the 1964 event, to an abrupt change in crustal structure, and locally to maximum regional uplift in 1964 as well as the separation of the uplift of the Kodiak group of islands from the subsidence of Albatross Basin. Thus the deformed zone is a major crustal boundary, but further study is needed. to clarify its nature and origin.

The depth of sediment in Albatross Basin is somewhat uncertain from seismic data alone. Seismic reflection records show no consistent strong reflectons defining acoustic basement and coherent reflections generally become weak from deeper layers. This is due in part to the nature of the sedimentary rocks and the limits of the seismic reflection method to resolve highly deformed bedding. On some structural ridges, weak discontinuous reflections, possibly indicating greater deformation of the rocks, is seen below the upper stratified sequence depicted in figure 6. Basin depths derived from the seismic reflection velocities are shown in figure 6; these are significant in that they represent the minimum thickness of the upper stratified sequence in the deeper parts of the basin. The refraction data suggest that a sedimentary section with relatively high acoustic velocity (4.4 km/sec) underlies this upper stratified sequence. Therefore economic or sedimentary basement can only be defined in a rather arbitrary way, and what appears as the floor of Albatross Basin is probably a transition from a less deformed younger sequence to a more deformed and compact older sedimentary sequence.

TUGIDAK BASIN

Tugidak Basin lies between Tugidak and Chirikof Islands, and between Shelikof Strait and the edge of the continental shelf (Fig. 4). The basin is roughly equidimensional, about 70 km across, and in its central part strong reflections occur to a depth of approximately 6 km (Fig. 6). Much of this section is exposed in an arch between Tugidak and Chirikof Islands along the seaward part of the basin (Fig. 3). The thickness of this section was previously reported as 4 km (von Huene, Shor, and Malloy, 1972) but approaches 7 km based on the multichannel seismic reflection work.

Tugidak Basin is similar to Albatross Basin in that it also appears to be underlain by more deformed older sedimentary rock. The upper sequence of strata produced strong coherent reflections in Tugidak Basin and only weak reflections are seen below the upper sequence. Therefore, Tugidak Basin is also thought to be a depressed area in older deformed sedimentary rocks filled by a relatively undeformed younger sequence. The upper sequence in Tugidak yields more regular and continuous reflections than the sequence in Albatross Basin.

There is locally a very pronounced lensing of strata against the basin flanks (line 514-516, Fig. D). Broad folds occur at shallow to intermediate depths along the basin's flank. In general, Tugidak Basin is considerably less deformed than Albatross Basin, and has a more regularly stratified sedimentary fill.

PORTLOCK BASIN

Very little data is available for Portlock Basin, and its extent is inferred primarily from the gravity minima, or low, associated with it (Barnes, 1967). The basin seems to correspond to the topographic low roughly between Portlock Bank and the Kenai Peninsula (Fig. 4). It is separated from lower Cook Inlet by the submarine extension of the Kenai Peninsula that surfaces along the Barren Islands, and from Albatross Basin by the structural high associated with the zone of deformation (von Huene, Shor, and Malloy, 1972) (see NW end of line 505, Fig. 6). A refraction station (unreversed) on the south flank of the basin indicates about 1 km of uncompacted sediment (V = 2.17 km/sec) overlying sedimentary rock with a much higher velocity (V = 4.04 km/sec) (Fig. 5) (Shor and von Huene, 1971). Single channel seismic reflection records (von Huene, Shor, and Malloy, 1972) show up to 0.3 seconds of penetration (one way time) also indicating a section more than 0.5 km thick.

Portlock Basin lies along a transverse alignment of breaks in the regional structural trend. These breaks include a jog in the Alaska Peninsula and the Aleutian volcanic chain; the straits between Kodiak Island and the Kenai Peninsula; the Amatuli Trough and Portlock Bank; a striking change in topography of the continental slope; and an oceanic fracture zone. The significance of alignments will remain obscure until more is known about the ages and relations between these features; however, it may express a fundamental break in the structure of the continental margin.

PETROLEUM GEOLOGY

GENERAL CONSIDERATIONS

The Kodiak Tertiary Province is within a zone of subduction; that is to say that it is between the Aleutian trench and Aleutian volcanic arc and over a well defined Benioff zone. If the structure of this zone is generally consistent with the structure diagramatically shown in models of subduction zones, then Albatross Basin would be underlain by sedimentary rocks formed from material originating in bathyl or abyssal oceanic environments that are now accreted onto the continent. These accreted sedimentary rocks may therefore underly the reflective sediments of Albatross Basin and form the core of Albatross Bank. The structure and history of the Kodiak Tertiary Province may have its best analog in other converging continental margins.

Until recent years, few of the world's petroleum test wells had been drilled on continental shelves above active subduction zones. Although areas seaward of volcanic arcs do contain oil fields as, for example the large La Brea-Parinas Field of coastal Peru, nonmetamorphosed Mesozoic strata generally underlie the Tertiary rocks of such fields. Hence, these fields occupy a structural setting landward from that of the Kodiak Tertiary Province and more analogous to the Cook Inlet basin.

An oil field that has a geologic environment much like that of the Kodiak Tertiary Province is the recently discovered Woodbourne Field of Barbados. Production from rocks of Eocene age occur in folds parallel with the nearby Antilles Trench; also, a zone of earthquake foci similar to that below the Kodiak Shelf decends beneath the island. This commercial accumulation of oil is in a geologic setting that forms a very close analog to the Kodiak Tertiary Province.

Commercial accumulation of hydrocarbons requires (a) source rocks, (b) reservoir rocks, (c) large traps. Each of these parameters will be discussed on the basis of the preceding information.

SOURCE ROCKS

In the Kodiak Tertiary Province the only exposed rocks which appear to be potential source beds are the strata of Miocene age and younger that crop out along the southeast coast of Kodiak Island. Older rocks on the islands have been altered enough to have destroyed any oil and serve as an effective economic basement. However, this alteration may not be typical of the rocks in the offshore basins which may be less deformed and farther from known magmatism. The fact that these younger onshore Tertiary strata are exposed in or near the zone of deformation that defines a geologic boundary, suggests that they may be more or less atypical.

The presumed upper Tertiary section offshore, which is equivalent to the upper sequence of reflective strata in seismic records, is thick enough to provide an environment for maturation of hydrocarbons. Relatively high rates of deposition suggest that the organic components may not have been completely oxidized prior to burial. Another potential source of hydrocarbons may be the possible abyssal sedimentary rocks that form the structural floor of the basins. Mature hydrocarbons have been observed in an abyssal environment as, for example, in a Pliocene-Pleistocene sample from the landward wall of the Aleutian Trench (von Huene and Kulm 1973). However, proof that abyssal sediments are a hydrocarbon source rock is lacking.

Sedimentary structures and stratigraphic characteristics of the Kodiak Tertiary section closely resemble those of the Tertiary section of the central Gulf of Alaska where oil occurs on land in fractured Oligocene and Miocene rocks (Plafker, 1971). No similar oil seeps, however, have been reported in the Kodiak Tertiary Province.

RESERVOIR ROCKS

Sandstone with intergranular porosity and permeability will probably be the reservoir rock for any commercial accumulations of oil or gas in the Kodiak Tertiary Province. Sandstone suitable for reservoirs is contained in rocks which have been found onshore on the fringes of the basins; but their offshore extent is not known. Samples from the deep ocean indicate that sand was carried across the continental shelf into the deeper waters. Therefore, sufficient sources of sand may have been available to form reservoirs on the continental shelf; until more samples have been obtained, this supposition remains untested.

TRAPS

Initial exploration will probably be on anticlinal structures rather than on stratigraphic traps, which are most difficult to find. Both types of traps are evident, however, on the seismic reflection records. For example, a fold 15 km broad in Albatross Basin, is seen on the records illustrated in Fig. 6. However, the data are insufficient to accurately determine amount and extent of closure on this structure. If the other dimension of this fold proves to be equally great, it may form an attractive target. Albatross Bank may contain large discontinuous traps, but it has been locally breached by erosion and may therefore have a diminished potential.

The smaller anticlines in Tugidak and Portlock basins seem less promising, favorable opportunities for stratigraphic traps were noted in the seismic records across Tugidak Basin.

OIL AND GAS RESOURCE POTENTIAL

The resource potential of the Kodiak Tertiary Province was evaluated recently in a U.S. Geological Survey study of U.S. oil and gas resources (Miller and others, 1975). This estimate and the effects of new geologic information on the estimate are presented in this section. The volumetric analog method is described briefly and is more completely described in Miller and others (1975).

To arrive at an estimate of oil and gas potential, publicly available data were summarized with particular attention being given to calculations of volumes of geologic units and the selection of areas analogous to the Kodiak Tertiary Province. Of the total province, a 71,500 square km area was assumed to have favorable oil and gas potential, with the thickness of rocks in this area estimated to average about 2 km. The estimated volume of rock is conservative because only presumed Neogene rocks are included. Because Paleogene rocks may not be as altered offshore as they are onshore, some of them may be source rocks. Furthermore, a minimal area was assumed for Tugidak and Portlock Basins, and the depths of sediment from multichannel reflection data are greater than those from the refraction data available to Miller and others.

The most nearly analogous basins were considered to be the adjoining Eastern Gulf of Alaska Tertiary Province and westernmost Oregon-Washington, including the offshore. However, neither area has commercial production, because both are at an early state of exploration. The lack of productive analogs make these calculations particularly uncertain.

The Resource Appraisal Group made final estimates of undiscovered recoverable resources by a subjective probability technique that involved the following categories:

1. A low resource estimate with a 95 percent probability of occurrence.

2. A high resource estimate with a 5 percent probability of occurrence.

3. A modal estimate of the resources with the highest expectation of occurrence.

In the initial resource appraisal, the assumption was made that oil and gas exists in commerical quantities. This assumption is tenuous in the Kodiak Tertiary Province where no petroleum has been discovered. The probability of finding no oil and gas in commercial quantities (marginal probability) was estimated to be 60 percent.

The low, high, modal estimate, and marginal probability were then fit to a lognormal distribution to compute the probability distribution (Kaufman, 1962) for the Kodiak Tertiary Province. These curves are for the full range of probability values (Fig. 7) and can provide estimates of undiscovered recoverable resources at any chosen probability.

The estimates of oil and gas potential for the Kodiak Tertiary Province made by Miller and others, (1975), are summarized as follows:

Undiscovered Recoverable Resources

	95 Percent Probability	5 Percent Probability	Statistical Mean
Oil (billions of barrels)	0	1.2	0.2
Gas (trillions of cubic feet)	0	3.5	0.7

Additional hydrocarbons, occurring as natural gas liquids, might be anticipated if quantities of natural gas were to be discovered. There is no way to estimate these liquids directly, however, on a national basis, the NGL/gas production ratio is approximately 33

Table 1

Calculated "Recoverable'

(based on discovered volumes, 1975)

Area	Analog	Oil (billions barrels)	Gas (trillions cubic feet)
	Oregon-Washington British Columbia	0 (no production)	0 (no production)
KODIAK TERTIARY PROVINCE	Sacramento basin, CA	0.1	6.8
	Cook Inlet, AK	1.4	14.6
	San Joaquin, CA	11.0	12.4

barrels of NGL for each million cubic feet of gas produced.

The analogs used give a pessimistic estimate because they are areas without production. When productive basins are used as analogs, the estimates of resources are considerably larger (table 1). Caution should be exercised in use of these analogs because even though the resource potential may fall within the wider limits in Table 1, the areas also have geologic settings different from the Kodiak Tertiary Province in one or more aspects. They are smaller basins with somewhat different geologic settings, and they are not areas where the cost of production is as high as in the Gulf of Alaska.

The uncertainties of analog selection and the volume of rock make the estimate of oil and gas resources highly conjectural until frame exploratory drilling has been done. Onshore exploration in the central Gulf of Alaska has largely been unsuccessful. Although the possibility of significant oil and gas accumulation may improve offshore, there are as yet no compelling reasons to make this assumption.

ENVIRONMENTAL GEOLOGY

GENERAL CONSIDERATIONS

There are two major environmental geologic concerns in OCS resource development. First are hazards such as faults and sea floor instability which may affect resource development by causing accidents. Second are the affects of an activity on the environment, such as incorporation of spilled contaminants into bottom sediments where they may affect benthic life.

The geologic data on which to base an environmental geologic assessment of the Kodiak Tertiary Province are presently limited to a few published reports and some unpublished USGS data. These data were acquired prior to any program for OCS resource development. No systematic environmental geologic study has been conducted and therefore this preliminary analysis must draw on analogies with studies in similar environmental geologic settings where more is known.

The Kodiak Tertiary Province was subjected to profound erosion and deposition from glacial processes. This imprint was superimposed on the continually evolving features resulting from tectonic processes. Glaciation is obvious from the fiord indented coastline and the bathymetry of the shelf. Glacial periods were separated by interglacial periods (von Huene and others, 1973, 1976) when non-glacial processes predominated. Since glacial and inter-glacial environments each left an imprint on the sea floor, a great deal can be inferred about the surficial geology from an analysis of physiography.

In this section, the physiographic analysis is presented first. Then the types of environmental geologic problems important to OCS exploration and development which can be anticipated in this area are discussed.

PHYSIOGRAPHY AND BATHYMETRY

The physiography of the Kodiak Tertiary Province is marked on various charts by relatively flat areas that are cut by transverse valleys. Gershanovich (1970) and Gershanovich, Kotenev, and Novihov (1964) subdivided the shelf into three morphologic units: (1) the nearshore, (2) plateau-like surfaces, and (3) sea valleys.

The nearshore area fringes the coastline, ranging from 5 to 8 km in width and reaching depths of 30-50 m except in fiords. Fiords, associated deep inlets, and their seaward extensions are also characteristic of the nearshore area.

Plateaus cover the major part of the shelf. They have gradients of 1-5 minutes and are in water depths of 80-120 m. Local banks and shoals protrude from the sea floor, some having small steep scarps and small reefs. The shoals, as well as the shelf edge banks and scarps, represent tectonic uplifts, as described in the previous sections on structure.

Sea valleys cut the plateau areas and are of two general types. Shelikof Strait trends more or less parallel to the shelf edge and has a broad, flat floor and has sides which slope 1 to 3 degrees. A second type includes the smaller valleys extending offshore from bays and inlets in a direction transverse to the shelf. They have broad, flat floors and gently sloping sides (2-3°). In longitudinal profile they commonly show deepening in their outer course followed by shoaling, which is typical of glacially formed channels.

Figure 8 summarizes the sea floor morphology of the Kodiak area, outlining the major physiographic features. To relate the text more conveniently to this figure, a number of names have been informally introduced for the major banks and troughs.

A major trough - Hinchinbrook Seavalley - is located off Prince William Sound, just east of Montague Island. von Huene and Shor (1969) indicate that it is flanked by sides that are at least 100 m high. Molnia and Carlson (1975b) have found that one of the sides, formed by Tarr Bank, and Middleton Island Platform is composed of Tertiary and Pleistocene strata.

Between Resurrection Bay and Montague Strait, several fiords converge. Bathymetric data suggest that the glaciers, following the fiords during low stands of sea level, converged into two major glaciers. The one occupying Bainbridge Trough moved southeast around the end of Montague Island. The other one, occupying Resurrection Trough, extended in a more southerly direction. Both troughs become shallower in the lower part of their course, indicating the possible presence of end moraines.

The topographic high between Bainbridge and Resurrection troughs may be morainal material, or an erosional remnant of a former plateau with a morainal cover. The complex bathymetry of this area indicates tectonism as well as glaciation.

Resurrection Trough terminates along the northern bank of Amatuli Trough and the terminal deposits of glaciers in the former is thought to have formed the northern bank of the latter (von Huene, 1966). The southern bank of Amatuli Trough is formed by the northern end of Portlock Bank. Since Portlock Bank is an uplifted, deformed, and eroded area (von Huene and others, 1972), the southern flank of Amatuli Trough is largely a tectonic feature.

Off the Kenai Peninsula, the troughs probably contain fine sediment, much like that found in the trough extending seaward from Naka Bay (von Huene, 1966), consisting mainly of fine grained terrigenous muds from streams and glacial melt water. Hinchinbrook Seavalley contains more than 50 m of Holocene silty clays and clayey silts (Carlson and Molnia, 1975).

Between Kenai Peninsula and the Kodiak group of islands, there are two straits named Kennedy Entrance and Stevenson Entrance which are separated by the Barren Islands. The southeast continuation of both straits is not known, but Portlock Bank divides them. The source of a former glacier in Stevenson Trough was most likely Cook Inlet; however, there is no clearly defined connection across

Barren Deep between Stevenson Trough and the Stevenson or Kennedy entrances.

Immediately southwest of Portlock Bank is Albatross Bank which is divided into three parts by Chiniak Trough and Kiliuda Trough. This bank has a rough topography and as discussed previously; the bank is an eroded anticline with several fault scarps on the sea floor.

Both Chiniak Trough and Kiliuda Trough were originally formed by glaciers during low stands of sea level. Chiniak Trough is relatively straight and uniform with steep sides, axial depressions, but no end moraine (Fig. 8 and 9). Kiliuda Trough is wider than Chiniak and seems to have been an area of glacial convergence directly off Kodiak Island. Kiliuda Trough contains a large depression near its seaward end that appears to be closed off by a high end moraine.

There are enough data to reconstruct the area of glacial convergence at the head of Kiliuda Trough. Ugak Bay, about midway between the heads of Kiliuda and Chiniak Troughs, has a short relatively steep slope at its mouth that continues in a southerly direction. This suggests that the Ugak Bay glacier joined the Kiliuda Trough glacier along with the glaciers from Kiliuda Bay and Sitkalidak Strait.

Figure 9 shows bathymetric cross sections through two troughs and one over southern Albatross Bank. The vertical exaggeration emphasizes detail.

Physiography also reveals fault scarps, such as the major scarp of Ugak Island (Fig. 10). (A number of cross sections show a steep slope facing seaward marked by arrows on this figure). This fault scarp corresponds with a fault defined by seismic records (von Huene, Shor and Malloy, 1972) off Kodiak Island.

Sitkinak Trough, near the southern end of the area, is a broad embayment at the edge of the continental shelf. According to von Huene, Shor and Malloy (1972) and von Huene (unpublished data) this feature is mainly tectonic and not erosional.

The Kodiak shelf physiography is mainly relict, developed during times of intense glaciation. This physiography does not reflect the present sedimentary processes well. The glaciers eroded channels across tectonically uplifted banks. The tops of the banks were probably eroded by wave action during the times of lowered sea level that accompanied glaciation. During glacial retreat, coarse debris was probably left along the channels, particularly along their sides and in other physiographically low areas as well. Some of this material may have also been affected by melt water, and wave action. During interglacial periods deposition and erosion also occurred, but at a greatly reduced rate and mostly finer grained material was deposited. On Tarr Bank in the central Gulf of Alaska, currents appear to be sweeping the fine-grained material away, allowing carbonate-building organisms to collect (Molnia, in press). In the topographic lows, on the other hand, the conditions are favorable for deposition of fine grained sediments.

BOTTOM SEDIMENTS

The bottom sediments in the western gulf have received relatively little study. Notations from the C & G S Boat Sheets are used to construct a generalized bottom sediment map (Fig. 11). The notations on the C & G S Boat Sheets were not made by geoscientists but by persons concerned with depth measurements for ship lanes and anchorages. Certain terms, like "rocky," are therefore imprecise for a geologic analysis and not specific enough for an environmental geologic assessment. The only other sources of published information are by Gershanovich (1970) and Gershanovich, Kotenev and Novihov (1964). Since these authors do not present their basic data, their information is difficult to substantiate and reinterpret in an environmental geologic context.

Unconsolidated sediment typically forms a thin veneer on the banks and is less than 50 to 100 metres thick in most of the lower areas. This sediment is largely of terrigenous origin and was transported by glacial or glacially associated processes during Pleistocene low stands of sea level. Other sediments include volcanic debris and biogenic materials (Hayes and Ninkovich, 1970; Gershanovich, 1970; Gershanovich, Kotenev and Novihov, 1964; Sharma, pers. comm.).

The majority of the veneer consists of coarse grained deposits including sandy sediment with pebbles and shell material. Off the Kenai Peninsula, however, the Boat Sheets indicate a relatively large area of muds with local pebbles. Similar muddy sediments also occur beyond the shelf break at water depths over 150 - 200 m.

Since no major sediment sources similar to the Copper River exists in the area off Kodiak or the Kenai Peninsula and since the circulation patterns are different from those found in the eastern Gulf of Alaska, the sedimentary environments may differ between the eastern and western Gulf (Molnia and Carlson, 1975b; Reimnitz, 1966). The weak counterclockwise Alaska Current and Alaska Stream may move muds discharged from the numerous fiord along the Kenai Peninsula. Tidal currents are probably also weak in the offshore region. But the relatively sparse discharge of coarse sediment beyond the fiords adjacent to the Kodiak Shelf, and the channeling of sediments from Cook Inlet through Shelikof Strait, suggest that very little deposition presently occurs on this shelf. The lack of clastic deposition gives biogenic sediments an opportunity to form.

The above statements are general and tentative. A high resolution seismic survey and sampling program will be conducted during the summer of 1976 from which a modern bottom sediment distribution map will be constructed.

ENVIRONMENTAL GEOLOGIC CONSIDERATIONS

Some of the principal geologic factors of concern for OCS resource development in the Kodiak Tertiary Province are sediment dispersal, sediment stability, seismicity, and volcanism.

SEDIMENT DISPERSAL

No major post-glacial sediment accumulations are likely to exist on the Kodiak shelf since the major coarse sediment from the Kodiak group of islands and the Kenai Peninsula is presently trapped in deep fiords. Some fine material is probably carried seaward from fiords; such material is likely to be transported through the troughs and also to be deposited in them. According to Sharma (pers. comm.) very little sediment escapes the fiords on Kodiak because of tidally influenced circulation that also traps finer material within the fiords. Since offshore accumulation rates of fine grained detritus are unmeasured, the rate of sediment accumulation in possible depositories of pollutants is unknown. Most pollutants are adsorbed to individual fine particles, primarily clay minerals and organic debris, and can reside for long periods of time in sediment. If bottom-living organisms feed on such materials, a magnification of pollutants throughout the food chain could result. However, it seems unlikely that significant quantities of pollutants will be concentrated on the offshore banks which are the major fishing grounds because most sediment is concentrated in the glacial channels.

SEDIMENT STABILITY

Unstable sediments are most likely to occur where thick, unconsolidated, saturated accumulations of sediment are located. Because thick sediment accumulation probably does not occur on the continental shelf in the western Gulf of Alaska, the only potential areas of sediment failure are the slopes of the glacial troughs, inside fiords, and on the continental slope. In the few seismic records available no slides or slumps have been detected on the shelf.

If a comparison between the shelf off Prince William Sound and the one off Kodiak is valid, the consolidated deposits representing Tertiary and Pleistocene stratified units or glacial debris are generally stable. Hinchinbrook Seavalley represents a good example (Molnia and Carlson, 1975a & b; Molnia, in press; Carlson, in press). The upper surface of the glacial deposits in the valley and along the banks is very irregular with local steep slopes. There is no indication on the seismic records that slumping has occurred in these strata. The finer-grained overlying sediment, sometimes ponding in former depressions and at other times draping over the old topography, reveals occasional slumping, as well as minor deformation resulting from differential compaction. The stability of this fine grained sediment can only be inferred until geotechnical measurements can be made.

SEISMICITY

The Gulf of Alaska - Aleutian area is one of the most seismically active on earth, accounting for about 7% of the world-wide release of seismic energy annually. Most of this energy release is associated with large earthquakes (greater than magnitude 6). Since 1902, at least 95 potentially destructive earthquakes (m>6) have occurred in the vicinity of the western Gulf of Alaska, (Fig. 12, Table 2).

Recurrence intervals of major earthquakes (greater than m 7.5) within a given area along the Gulf of Alaska-Aleutian system have been estimated by various geoscientists. A maximum average recurrence interval of about 800 years has been estimated from geologic evidence and the uplift sequence of Middleton Island (Plafker, 1971). On the basis of historic seismic patterns recorded over the past 75 years, Sykes (1971) estimated a minimum interval of 33 years. The minimum recurrence interval will likely be exceeded by the lifetime of a major oil-producing province because the last major earthquake to affect the western Gulf of Alaska area occurred on March 27, 1964.

The western Gulf of Alaska is included in seismic risk zone 3 defined as an area susceptible to earthquakes of magnitude 6.0 - 8.8 and where major structural damage could occur (Fig. 13)(Evans and others, 1972). Damage can be produced either directly by ground shaking, fault displacement, and surface warping, or indirectly by seismic sea waves (tsunamis), ground failure, and consolidation of sediments.

Damage from ground shaking is likely to be greatest in areas underlain by thick accumulations of saturated, unconsolidated sediment, rather than in areas underlain by solid bedrock. This is especially true if the frequency of seismic waves is equal to the resonant frequency of the sediment. Furthermore, ground shaking weakens sediment and thereby can trigger other types of instability such as landsliding and ground fissuring.

Plateaus and banks in the offshore lease area are apparently covered with a thin veneer of unconsolidated sediments, less than a few metres thick. Lack of subsurface geotechnical and stratigraphic data precludes identification of specific dangerous areas, but the glacial troughs, fiords, and the continental slope might contain accumulations of unconsolidated sediment sufficient to amplify seismic shaking.

The coastal areas of Kodiak and Seward sustained relatively little damage directly from shaking during the 1964 earthquake, although Homer and Anchorage were affected significantly. Kodiak was particularly stable because it is predominantly underlain by solid bedrock.

A reconnaissance study of the distribution of active surface faulting in the Kodiak shelf region was made in connection with the 1964 Alaska earthquake. Surface rupturing along faults during 1964 was documented off the southwest end of Montague Island (Malloy and Merrill, 1972; Plafker, 1969) within a major fault zone that has been active during geologically recent time. A similar zone extends along and off the southeast coast of Kodiak Island (von Huene, Shor, and Malloy, 1972; see Fig. 4) but here the time of formation of fault scarps could not be determined.

Closely spaced high-resolution seismic reflection lines are needed to determine the precise distribution and extent of active faults, particularly in the zone of deformation from Kodiak to Montague Island, and also in the remainder of the lease area. Possibly active faults have been noted on Albatross Bank (von Huene, 1972); the fact that this bank is a structural and topographic ridge suggests active uplift.

Surface deformation in the form of regional warping accompanied the 1964 earthquake and affected an area of about 280,000 sq. km of land and sea floor. This was documented off Montague and Middleton Islands and along Albatross Bank (Malloy and Merril, 1972; von Huene, Shor and Malloy, 1972). The remainder of the outer continental shelf probably underwent similar deformation, but the data to substantiate this are lacking. Maximum observed uplift was 15 m, maximum subsidence was 2.5 m and maximum horizontal displacement was 19.5 m on land. These measurements suggest the possible magnitude of regional deformation that could accompany a large earthquake. Offshore tectonic deformation can produce problems when shallow navigation channels are uplifted, requiring recharting and perhaps dredging.

Along the coastline, tectonic subsidence can cause inundation of facilities originally above the high-tide line. This occurred at the Kodiak Naval Air Station due to 1.7 m of subsidence in 1964. Kodiak also experienced accelerated coastal erosion above the high-tide line because of subsidence (Plafker and Kachadoorian, 1967). Coastal areas of Seward were inundated as a result of 1.1 m of subsidence. Moreover, these areas were made more susceptible to damage by seismic sea waves because of subsidence.

Several types of water waves can be associated with seismic activity. Seismic sea waves (tsunamis) can be generated when large volumes of sea water are displaced, either by tectonic displacement of the sea floor (regional tsunamis) or by large rockfalls or landslides (local tsunamis). Standing waves (seiches) can be set up in partially or completely enclosed water bodies, such as bays, fiords, and lakes, by seismic acceleration and tilting.

Regional tsunamis occur as a train of long-period waves that radiate energy in a pattern that is controlled by the geometry of the source disturbance. They travel great distances, covering the entire ocean basin in which they originate, and are seldom detectable in the open ocean but can build up to significant, destructive heights close to and along the shoreline. They can run up along the coastline repeatedly for several hours, and their run up is greatest if the waves reach the shoreline at or near the time of high tide.

A regional tsunami was generated in the 1964 Alaska earthquake, with the most intense radiation of energy directed toward the seaward-facing coastal areas of the Kodiak Islands and the Kenai Peninsula. These areas, including the towns of Kodiak and Seward, had subsided during the earthquake and received extensive damage (Lemke, 1967, Kachadoorian and Plafker, 1967).

Tsunamis do not occur with most submarine earthquakes, and their prediction is not yet certain. The Seismic Sea Wave Warning System (SSWWS), set up by the U. S. Coast and Geodetic Survey in 1948, issues advance notice of tsunamis to Pacific coastal areas. It was operative during the 1964 event and issued warnings of the tsunami throughout the Pacific. Improved tsunami warning systems have been installed in Alaska since 1964 to rapidly provide warnings to areas close to the source of a tsunami (Spaeth and Berkman, 1972; Cox and Steward, 1972).

Destructive waves other than regional tsunamis can be expected to accompany major seismic activity in coastal areas. Local tsunamis, produced when water masses are displaced by large rock falls or submarine slumps, are likely to occur within the steep-walled fiords common to the coastline of the gulf. Deltas constructed of rapidly deposited sediment exist in the heads of many of these embayments, and such sediment is especially susceptible to failure during earthquakes.

In 1964, Seward, which is built on a delta, experienced major damage from local waves generated by massive coastal sliding. The waves destroyed many of the port facilities (Lemke, 1967).

Most of the damage caused by locally generated waves is usually confined to the embayments within which they originate. These waves are particularly dangerous because they occur without warning, during or shortly after an earthquake. Local waves caused the greatest loss of life during the 1964 earthquake.

Seismic seiches, which generally are much lower than the local waves, may be generated in the epicentral region by rapid tectonic accelerations, or may be produced up to great distances from the epicenter by seismic surface waves (von Huene and Cox, 1972; McGarr and Vorhis, 1972). Seiche waves are believed to have occurred in Resurrection Bay in 1964, contributing to coastal damage of Seward. The regional and local tsunami waves at Seward, in combination with the seiche waves, produced a maximum run up nearly 10 m above mean lower low water.

Coastal areas, both on land and underwater, that are underlain by thick, unconsolidated sediment are vulnerable to various types of ground failure typically associated with large earthquakes. The types of failure include liquefaction, block sliding along weak subsurface strata, rotational slumps, earth flow and avalanches, ground fissures, and consolidated subsidence. The alluvial deltas at the heads of many Alaska fiords are most prone to ground failure. The deltas are appealing sites for construction because they commonly are the only extensive flat ground along the coast, but most of them are composed of weak water-saturated material that fails easily.

Resurrection Bay experienced major coastal and submarine sliding during the 1964 earthquake (Lemke, 1967). At Seward, a slide mass 15-120 m wide, along with docks and harbor facilities, moved into the bay. Extensive ground fissuring occurred for a few hundred metres behind the slide scarps. Additional fissuring, unrelated to major slide activity, occurred at the Forest Lakes subdivision and on the alluvial plain of the Resurrection River valley. Sand extrusion accompanied this fissuring. Sewer and water lines were ruptured and the foundations of some homes were heavily damaged by the fissuring.

Submarine slopes off Seward are now steeper in some places than they were before the sliding occurred. Additional sliding is predicted in the event of another severe earthquake. However, no major sliding is expected under static conditions.

Underwater dispersal of slide sediment also can occur in the western Gulf of Alaska area. The sediment may travel a few miles from the origin of the slide, perhaps as a turbidity current, and cause burial or physical damage to installations on the sea floor.

The offshore shelf sediment in the gulf, away from the deltas, may fail during earthquakes, but whether this will occur is presently unclear. Most of the sediment probably is normally consolidated as a result of slow deposition and reworking by currents and is therefore relatively stable. The possibility of earthquake-induced sliding in areas of steep slopes and of localized liquefaction cannot be overlooked, however. Large-scale slumping, probably earthquake induced, has been identified in the areas of high sedimentation rates and sloping sea floor in the nearby eastern Gulf of Alaska in U. S. Geological Survey high-resolution seismic profiles (Carlson and Molnia, 1975; Carlson, Bruns and Molnia, 1975). No slumps have been identified in the existing seismic records off the Kodiak Shelf.

Consolidation of sediment and the resulting ground subsidence without actual sliding are also seismic-related phenomena. For example, consolidation of sediment on Homer spit contributed to the temporary closing of port facilities there after the 1964 earthquake (Waller, 1966). Consolidation subsidence of offshore shelf sediment is possible in areas underlain at depth by loosely packed sediment.

VOLCANISM

Active volcanoes in Alaska occur in a narrow, arcuate zone extending from the Aleutian Islands, along the Alaska Peninsula, and up to northwest side of Cook Inlet (Fig. 14). The volcanoes are part of the much larger circum-Pacific seismic and volcanic belt. Alaskan volcanoes are andesitic and typically have relatively violent eruptions compared to the basaltic volcanoes of ocean basins. At least 60 Alaskan volcanoes have been active in the last 10,000 years (table 3).

Most volcanic effects are local, but ash falls can deposit significant thicknesses of ejecta up to 160 km from the eruptive center. This depends on the direction and strength of the wind as evidenced by deposits of 1/3 m on Kodiak Island from the 1912 Katmai event. Ash fallout from Mt. Spurr in 1953 damaged aircraft and required extensive cleanup in Anchorage.

Mt. Augustine in lower Cook Inlet is considered to be the most active volcano in the western Gulf area and is under continuous seismic surveillance. Its most recent eruptive activity, involving ash, steam and minor lava flows, began on January 23, 1976. Because of its marine setting, there is a remote chance that Mt. Augustine could produce a Krakatoan-type eruption; this type has large explosions which are probably caused by the simultaneous inrush of sea water into the lower part of the volcano as melt moves into it. Installations or persons near Mt. Augustine would be in danger from such an eruption.

TECHNOLOGY, TIME FRAME, AND INFRASTRUCTURE NEEDED FOR EXPLORATION AND DEVELOPMENT

Technology and operations in the western Gulf of Alaska are principly influenced by the harsh climate, sea conditions, and possible seismic disturbances. A shortage of exploration drilling units and skilled manpower in the area, combined with the remoteness of the Gulf of Alaska from industrial areas and supply centers, will, also contribute to longer development time.

TECHNOLOGY NEEDED

The following are some of the more important considerations for technology and operational activities in oil and gas development.

1. Climatic conditions will be a major consideration in the design of offshore exploration, production, and transportation facilities. Fall and winter storms have extreme winds of 120 mph (193 kmph) and waves of 60 feet (18 m) (Searby, 1969). The monthly variation of probable wind speeds and recurrence interval of winds in the Gulf of Alaska are indicated in figure 15 and figure 16. The seasonal variation of wave heights and the recurrence interval of waves in the Gulf of Alaska are indicated in figure 17 and figure 18.

2. Potential seismic loading and earthquake effects must also be considered in design criteria for offshore and onshore structures in the western Gulf of Alaska area. Potential damage and hazards may arise from various causes, including ground motion (vibration), fault displacement, surface deformation, tsunamis, and ground failure. Local tsunamis or sea waves, resulting from earthquake-caused landslides, are particularly hazardous nearshore.

3. Areas which appear favorable for oil and gas exploration are between 12 miles (19.3 km) and 90 miles (145 km) from shore in water depths ranging from 120 feet (36.6 m) to in excess of 1,000 feet (305 m).

4. The western Gulf of Alaska is remote from major population centers, industrial areas and oil supply centers. The closest significant industrial complex is Seattle, Washington. The area is relatively undeveloped and would require local onshore supply bases, transportation facilities, living areas for workers and families as well as onshore terminals, storage facilities, and other industrial complexes. Seward and Kodiak are the two deep water ports in the area. These are now primarily involved in support of the fishing industry but would probably be utilized for oil exploration and development in the proposed lease sale area.

5. Sea ice is not a problem in the western Gulf of Alaska except in isolated bays near glaciers. Ice loading due to surface or superstructure icing (freezing spray) may occur under certain conditions during the coldest months.

6. The shelf area of the western Gulf of Alaska supports abundant marine life including a wide variety of fish, shellfish, mammals and sea birds. The Kodiak shelf is one of the most important fisheries of the United States and is also important to foreign fishing fleets. Kodiak is one of the top ranked fishing ports of the nation in annual volume and value of fish and shellfish landed. Because of the abundant marine life and fishing activity, special operating procedures and equipment may be necessary for protection of the marine habitat and compatible multiple use of certain areas.

AVAILABILITY OF TECHNOLOGY

The developing technology for offshore oil and gas exploration and production has permitted a progression from activity in shallow water and in moderate climates to work in deeper water and more hostile environments. Figure 19 shows the present water depth capability of mobile drilling and underwater well completion systems, underwater production and manifold systems, and fixed platforms, with a projection of the capability to drill and produce in deeper water. A summary of present and projected water depths, in which drilling and production are possible in various U. S. offshore areas, including the Gulf of Alaska, is shown on Table 4.

The North Sea has a severe environment comparable to the Gulf of Alaska (Fig. 20) and oil operations have been possible in deeper water through the use of newly developed technology. This technology may be generally adapted to use in the Gulf of Alaska. In the North Sea, drilling has been successfully conducted in water depths exceeding 660 feet (200 m); drilling and production platforms have been placed in 410 feet (125 m) of water at the Brent Field north of 61° latitude in the North Sea. Pipelines, 32 inch (18 cm) in diameter have been installed successfully in water depths of 480 feet (146 m) and new equipment under construction will extend that capability (Rainey, 1974). Planned offshore storage facilities include a concrete storage facility with a one-million barrel capacity to be placed on the ocean floor in 230 feet (70 m) of water at the Ekofisk field. Floating storage facilities attached to the ocean floor include Shell Oil's SPAR system for Brent Field, Hamilton Brother's floating platform for the Auk Field, and concrete gravity-base production platforms storing up to one million barrels of oil in the Brent and Beryl Fields (Geer, 1974). Recent developments in platform technology include a tension leg platform (a permanently moored floating platform), and a guyed platform (a bottom-fixed structure supported by special anchors) which are currently being tested with prototype models for possible use in deep water areas.

Between 1960 and 1975, 252 subsea wells were completed worldwide in water depths of 50-375 feet (15-114 m). Several subsea production systems are being tested for use in water depths of 300-1500 feet (91-456 m) and are being developed for use with fixed platforms or without platforms. Some of these systems are being put to use in the Gulf of Mexico and the North Sea.

The type of development in the Gulf of Alaska will depend upon the water depth, distance from shore, the type of oil or gas deposit to be developed, and the environmental factors at the discovery location. Shallow water development will probably use the conventional fixed steel platforms with pipelines to shore, similar to those found in the Cook Inlet fields. Deep water development may involve: 1) conventional fixed steel platforms as in shallow water or 2) a combination of fixed steel or concrete structures with subsea wells and production systems and pipelines to shore or 3) one of the above-mentioned production systems, with sea floor or floating storage and offshore tanker loading capability.

The trend in new drilling ships and semi-submersible vessels allows drilling in deeper water and in harsher climates than before. Most drilling ships and semi-submersibles constructed in recent years, and nearly all of those under construction or planned, are of the type designed for extended operations in the rigorous environments of the North Sea, offshore Eastern Canada and the Gulf of Alaska. The semi-submersible rigs are designed for stability whereas the drilling ships are designed for maximum mobility and self-sufficiency. Both semi-submersible and drilling ships are capable of drilling in water depths of 1,000 feet (305 m) using chain anchor systems. Drilling ships with dynamic positioning systems can be used in deeper water. Drilling in the Gulf of Alaska will probably be reduced during the stormy fall and winter season even though the newer rigs are designed for year-round operations.

The Tenneco Oil Company Middleton Island State No. 1 well has been drilled offshore in the Gulf of Alaska in approximately 80 feet (24 m) of water utilizing the J. C. MARTHENS, a jack-up rig owned by Sun Marine Drilling Company. Jack-up rigs may be used in water depths of 300 feet or less (91 m) in the Gulf of Alaska where there is a satisfactory foundation. The rig is designed to withstand environmental conditions, including seismic hazards, at the site.

Until design criteria are fully established (Hasselman et al, 1975; Kallaby and Millman, 1975; API, 1976), conservative standards will be required to assure an adequate margin of safety. Minimum design criteria for offshore structures will include:

1) No significant structural damage from ground motion during the maximum magnitude earthquake that might occur during the life of the structure.

2) Installation of motion-sensing devices on platforms and automatic shut-down of wells and facilities if ground shaking impairs safe operation.

The physical properties of the sea floor can influence the local intensity of seismic forces and detailed site investigations are required to determine geotechnical factors for optimum facility siting and foundation design. Prior to permitting exploration or production platforms, site specific geophysical surveys and soil analysis will help avoid placement of installation where they could be endangered by surface faulting or soil movement and assure adequate foundation and structural design for fixed structures.

DRILLING UNIT AVAILABILITY

A recent count of offshore mobile rigs showed 298 total units in operation worldwide. Eighty-three are floating drilling ships or barges, 130 are jack-up, and 76 are semi-submersible. An additional 139 units are under construction or are planned, including 33 drill ships, 55 jack-ups and 51 semi-submersibles (Offshore Rig Data Service, 1975). Table 5 indicates mobile offshore rigs under construction with a breakdown of completion dates through 1977 by rig type.

Only one offshore drilling vessel, is located in Alaska. It is the GEORGE FERRIS, a jack-up rig owned by Sun Marine Drilling Co., which is presently sitting idle in Kachemak Bay. There are only a few mobile drilling vessels on the Pacific Coast of the United States which are suited for operation in the Gulf of Alaska. However, over twenty semi-submersible drilling vessels and drilling ships are under construction, or scheduled for construction, on the west coast of the United States and in the Far East which could drill in the Gulf of Alaska. Three of the semi-submersible drilling vessels may be used for operations in the Gulf of Alaska or on the West Coast of the United States are:

RIG OWNER	SHIPYARD	DELIVERY DATE	CONTRACT
Exxon	Mitsiubushi, Japan	March 1977	Exxon, W. Coast and Gulf of Alaska
SEDCO, INC.	Kaiser Steel, Oakland, CA.	March 1976	Shell, ARCO, Mobil Grp. Gulf of Alaska, 2 years
SEDCO, INC.	Kaiser Steel, Oakland, CA	Nov. 1976	Sun, Gulf of Alaska, 2 years

Mobile offshore drilling vessels for Alaska that must be obtained from other parts of the world require considerable transit time since most units are working in the Gulf of Mexico or in Europe and the Far East. The cost of mobilization and moving a drilling unit from the North Sea to the Gulf of Alaska area is estimated to be between 1.5-5 million dollars, depending upon the type of rig.

Although mobile drilling vessels for the Gulf of Alaska must be transported from distant areas, it appears that there will be a good supply of the appropriate type vessels available on a worldwide basis. While it is difficult to predict future availability, there has been a recent weakening in the demand for such equipment, indicating a possible change from the shortage of offshore drilling vessels over the past few years.

MANPOWER

Like the drilling units, most of the skilled manpower for exploratory drilling will have to come from other areas. The number of workers, available for drilling, development, and production, is relatively small due to the low population density in Alaska and the lack of previous large scale petroleum development in the Gulf of Alaska area.

Some of the skilled workers may be available in Alaska, depending on the stage of construction of the Trans-Alaska or other pipelines, of the Prudhoe Bay oil field, or of exploration and development of previously leased offshore areas (possibly Gulf of Alaska and Lower Cook Inlet). As the energy shortage continues, many predict that skilled manpower for the oil and gas and related industries will probably be in short supply.

A large potential supply of workers available for training exists in the Pacific Northwest and California. The real availability will depend on the state of the national economy and also on finding a sufficient number of individuals willing to work far from home in a harsh climate for long periods of time.

DEVELOPMENT SCHEDULE

Estimates of the time needed for development and production from a new area are conjectural at best. Factors which can affect development include the availability of needed equipment and material, water depth, reservoir and hydrocarbon character, the economy, labor disputes, environmental hearings, but most importantly the discovery of oil and gas in commercial quantities.

Table 6 shows the most probable schedule for platform development in the Gulf of Alaska. This was prepared by a subcommittee of the Gulf of Alaska Operators Committee and presented to the Council of Environmental Quality at hearings in September 1973. This projection indicates that two to three years will elapse after a lease sale before substantial exploratory drilling will occur; this is due to the time necessary to acquire and mobilize the drilling vessels. The first production will not occur until seven to eight years after the sale, and about 10 years will be needed to achieve maximum production. This schedule could be accelerated in nearshore areas in shallow water as these may be drilled and developed with less difficulty than anticipated. Production from deep water areas could be delayed because of the time needed to design and construct special deep water equipment and facilities.

The high cost of operations and equipment in the Gulf of Alaska will probably restrict development to shallow water areas and only to those deep water areas which have very large recoverable reserves. The climate will influence the timing of many construction-related activities to the milder seasons. Transportation of platform jackets and other facilities from west coast construction sites, installation of platforms, pipeline construction and other activities will generally be conducted only during the "weather window" of the summer season.

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Table 2. Large earthquakes in the western Gulf of Alaska area, 1902 to 1975.

Day	Date Month	Year	Origin Time GMT Hr/Min	Latitude (Degrees N)	Longitude (Degrees W)	Depth (Kilometers)	Magnitude
01	01	02	0520	55.00	165.00	25	7.80
02	06	03	1317	57.00	156.00	100	8.30
22	08	07	2224	57.00	161.00	120	6.50
19	09	09	2100	60.00	150.00		7.40
13	05	10	1758	57.00	160.00	100	6.75
22	09	11	0501	60.50	149.00	60	6.90
31	01	12	2011	61.00	147.50	80	7.25
07	06	12	0955	59.00	153.00		6.40
10	06	12	1606	59.00	153.00		7.00
07	11	12	0740	57.50	155.00	90	7.50
05	12	12	1227	57.50	154.00	90	7.00
04	05	23	1626	55.50	156.50		7.10
21	06	28	1627	60.00	146.50		7.00
24	12	31	0340	60.00	152.00	100	6.25
14	09	32	0843	61.00	148.00	50	6.25
30	10	32	2046	55.00	159.75		6.75
04	01	33	0359	61.00	148.00		6.25
04	05	34	0436	61.25	147.50	80	7.20
14	05	34	2212	57.75	152.25	60	6.50
[illegible]2	06	34	1645	61.25	147.00		6.25
18	06	34	0913	60.50	151.00	80	6.75
28	07	34	2136	55.50	156.75		6.75
02	08	34	0713	61.50	147.50		6.00
10	11	38	2018	55.50	158.00	25	8.50
17	11	38	0354	55.50	158.50		7.20
12	02	40	0917	55.00	161.50		6.75
11	10	40	0753	59.50	152.00		6.00
01	04	41	1040	56.00	153.50		6.50
06	08	41	0615	55.75	163.00	150	6.75
28	09	41	0534	56.50	157.50	100	6.75
05	12	42	1428	59.50	152.00	100	6.50
03	11	43	1432	61.75	151.00		7.30
03	11	45	2209	58.50	151.00	50	6.75
12	01	46	2025	59.25	147.25	50	7.20
26	05	48	0916	56.00	156.00		6.00
27	09	49	1530	59.75	149.00	50	7.10
13	02	51	2212	56.00	156.00		7.00
08	11	51	1345	55.60	160.40		6.60
29	11	52	2346	56.30	153.80		6.90
25	02	53	2116	56.00	156.20		6.75
15	06	53	1747	56.30	153.80		6.50
03	10	54	1118	60.50	151.00	100	6.70
17	06	54	0142	56.00	154.50		6.50

Table 2. (continued)

Day	Date Month	Year	Origin Hr/Min	Time GMT	Latitude (Degrees N)	Longtidue (Degrees W)	Depth (Kilometers)	Magnitude
19	07	55	2352		56.50	153.00		6.00
26	07	55	0404		56.50	153.00		6.00
27	07	55	1819		56.50	153.00		6.25
15	11	55	1006		55.40	155.60		6.50
04	04	57	0013		58.17	155.04	89	6.00
10	04	57	1130		55.96	153.86		7.10
24	01	58	2317		60.00	152.00	60	6.38
19	04	59	1503		58.00	152.50		6.25
26	12	59	1819		59.76	151.38		6.25
13	05	60	1607		55.00	161.50		6.25
01	09	60	1537		56.30	153.70	24	6.13
20	01	61	1709		56.60	152.30	46	6.38
31	01	61	0048		56.00	153.90	26	6.38
10	05	62	0003		62.00	150.10	72	6.00
12	05	63	1205		57.30	154.00	60	6.10
24	06	63	0426		59.50	151.70	52	6.80
06	02	64	1307		55.70	155.80	33	6.75
28	03	64	0336		61.00	147.80	33	8.50
28	03	64	0454		59.80	149.40	25	6.10
28	03	64	0643		58.30	151.30	25	6.10
28	03	64	0710		58.80	149.50	20	6.10
28	03	64	0901		56.50	152.00	20	6.00
28	03	64	1035		57.20	152.40	33	6.10
28	03	64	1220		56.50	154.00	25	6.00
28	03	64	1447		60.40	146.50	10	6.10
28	03	64	1449		60.40	147.10	10	6.10
28	03	64	2029		59.80	148.70	40	6.60
30	03	64	0709		59.90	145.70	15	6.00
03	04	64	2233		61.60	147.60	40	6.20
20	04	64	1155		61.40	147.30	30	6.60
21	04	64	0501		61.50	147.40	40	6.00
06	02	65	0140		53.20	161.90	33	6.40
06	02	65	1650		53.30	161.80	33	6.10
04	09	65	1432		58.20	152.70	10	6.20
22	12	65	1941		58.40	153.10	51	6.50
23	04	68	2029		58.70	150.00	23	6.30
15	11	68	0007		58.32	150.36	26	6.38
17	12	68	1202		60.17	152.84	86	6.50
24	11	69	2251		56.20	153.56	33	6.00
16	01	70	0805		60.31	152.72	91	6.00
11	03	70	2238		57.46	153.91	29	6.50
18	08	70	1752		60.70	145.38	16	6.00
24	03	72	0338		56.14	157.18	69	6.00
06	04	74	0356		55.12	160.44	40	6.00
02	08	75	1018		54.10	161.78	60	6.20

Table 3. Volcanoes of the western Gulf of Alaska area. (From University of Alaska, 1974, and Evans, et al, 1972).

Name	Last Eruption	Comments
Pavlof	1973	Active in 1970, 1892, 1880. Numerous smoke and ash eruptions in historic time.
Pavlof Sister	1786	Active 1762-1786.
Veniaminof	1944	Numerous smoke and ash eruptions in historic time.
Amiakchak	1931	
Chiginagak	1929	Smoke and steaming in 1852.
Peulik	1852	Ash eruption in 1814.
Martin	1960	Intermittent steaming since 1912.
Mageik	1946	Active in 1929, several ash eruptions since 1912.
Novarupta	1912	One of main sources of ash and province in Valley of 10,000 smokes.
Katmai	1931	Caldera collapse with vast province and ash deposits in 1912.
Douglas	None in historic time	Presently quiescent.
Augustine	1963-64, 1976	January 23, 1976 eruption
Iliamna	None in recent years	Active but quiescent.
Redoubt	1966	Active and potentially eruptive.
Mt. Spurr	1953	Active but quiescent.

PRESENT AND FUTURE WATER DEPTH CAPABILITIES AND EARLIEST DATES FOR EXPLORATION DRILLING AND PRODUCTION FOR UNITED STATES OUTER CONTINENTAL SHELF AREAS

Area Province	Maximum Water Depth Capabilities		Earliest Date	
	Exploration Drilling	Production	Exploration Drilling	Production
Cook Inlet Southern Aleutian Shelf Gulf of Alaska Bristol Bay S. of 55° Lat.	Jack-ups 300-350 feet. Drillships and semi-submersibles 1,200 - 1,500 feet.	Platforms 600 feet for ice-free areas. For seasonal ice areas such as Bristol Bay and Lower Cook Inlet, platforms to 200 feet feasible.	Now	At present fixed 24 well platform for ice-free areas in 600 feet ready for production 4½ to 6 years after field discovery and delineation, in 200 feet ready for production 4 to 5 years. Earthquake zones require special surveys and engineering considerations that could cause delays. Satellite UWC could extend depth 100-200 feet in most areas. In the future, production in ice-free areas in 1,500 feet feasible 1980-1985. Production in seasonal ice areas beyond 200 feet feasible 1980-1985.

Source: National Petroleum Council, 1975.

Table 4

Mobile Rigs Under Construction as of August 1975

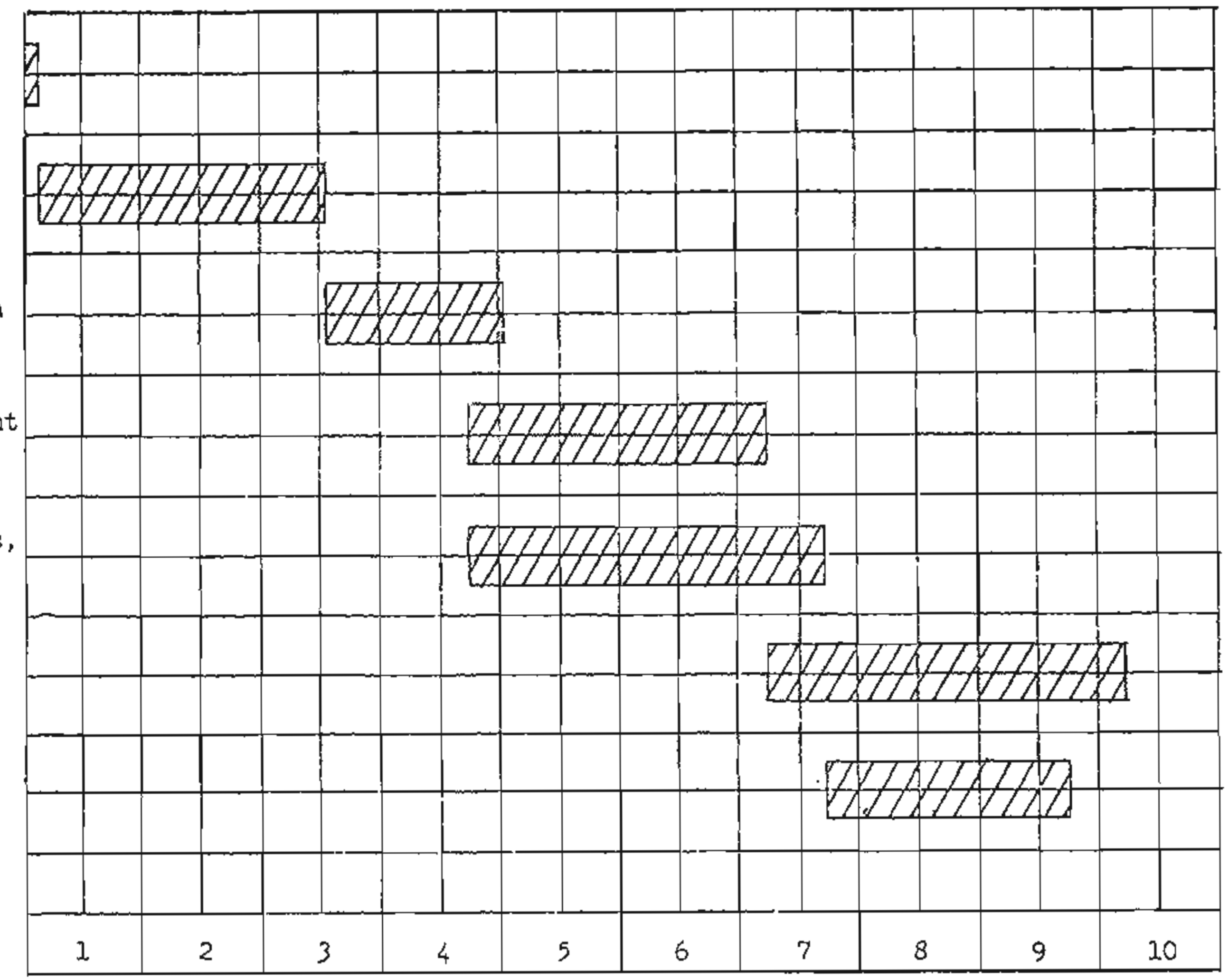
Rig Type	Total Number	Completion Rate 1975	1976	1977 or later
Semi-submersibles	51	14	33	4
Jackups	55	15	31	9
Drillships	33	9	18	6
Total	139	38	82	19

Source: Offshore Rig Data Service, 1975.

Table 5

MOST PROBABLE TIME FRAME FOR PLATFORM DEVELOPMENT
GULF OF ALASKA

1. Lease Sale
2. Acquire & Mobilize Exploratory Drilling Vessels
3. Exploratory Drilling Program Including Discovery, Confirmation & Reservoir Delineation Wells
4. Build, Move & Install Development Drilling/Producing Platforms
5. Design, Build, Move & Install Production Facilities, Pipelines, Onshore Facilities, Tanker Terminals, Etc.
6. Development Drilling Program
7. First Production to Full Scale Production



Source: Gulf of Alaska Operators, Oceanographic Survey Technical Committee, 1973.

Table 6

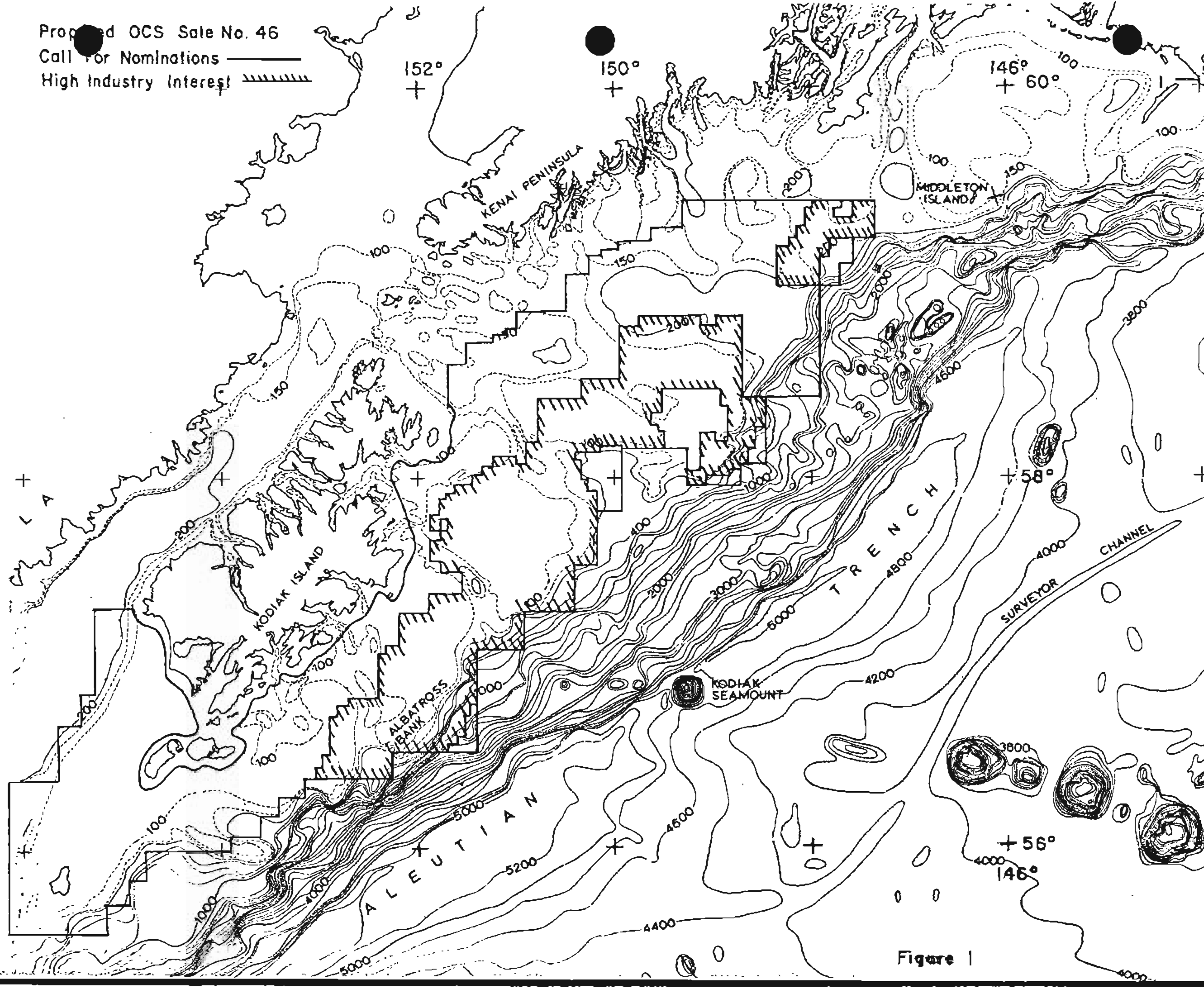

Proposed OCS Sale No. 46
Call For Nominations
High Industry Interest
152°
150°
146°
60°
58°
56°
KENAI PENINSULA
MIDDLETON ISLAND
KODIAK ISLAND
ALBATROSS BANK
KODIAK SEAMOUNT
ALEUTIAN TRENCH
SURVEYOR CHANNEL
100
150
200
1000
2000
3000
3800
4000
4200
4400
4600
4800
5000
5200
6000

Figure 1

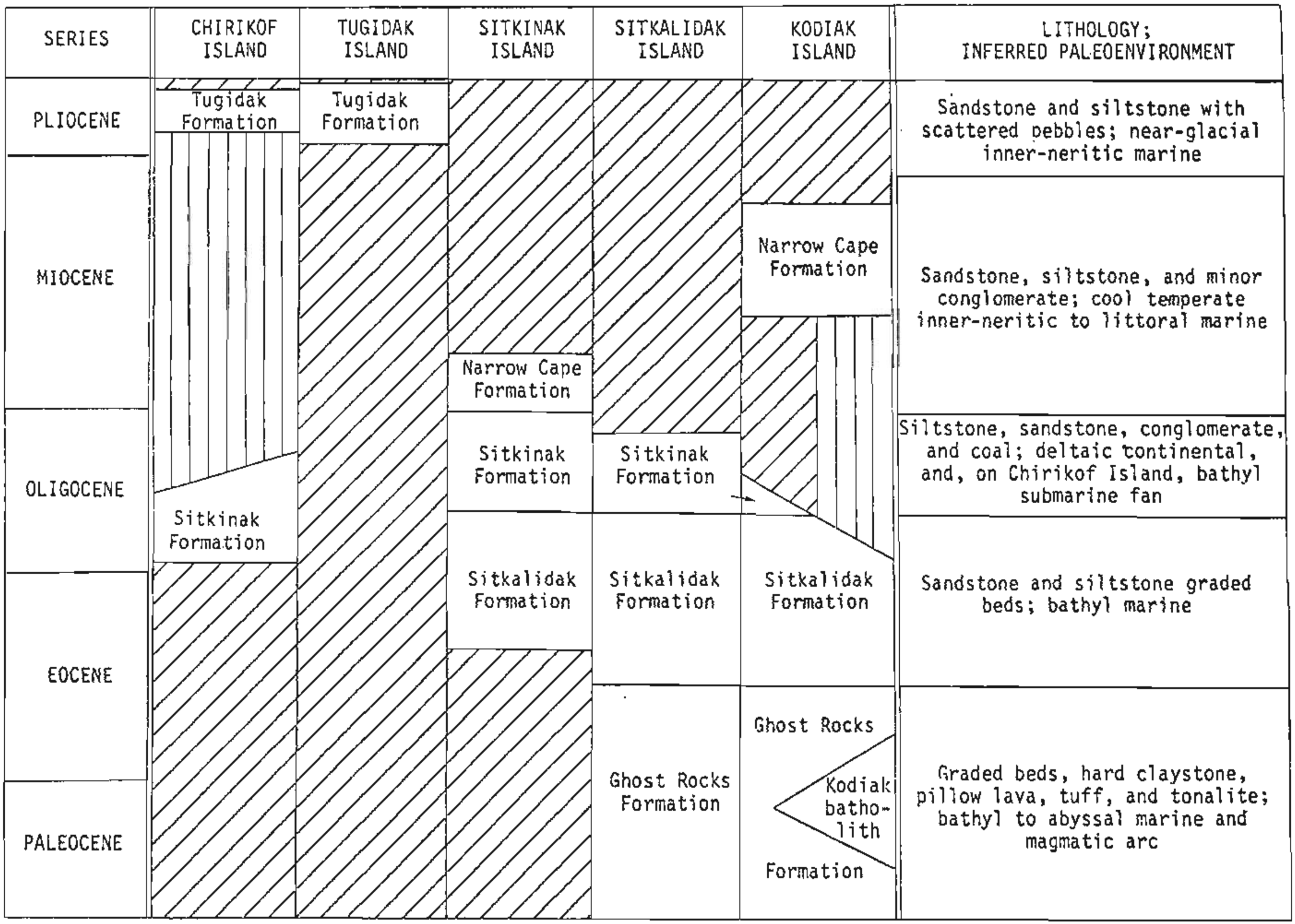


Figure 2. Tertiary rock units on islands in the western Gulf of Alaska. Vertical ruling represents missing strata at unconformity; diagonal ruling indicates no data.

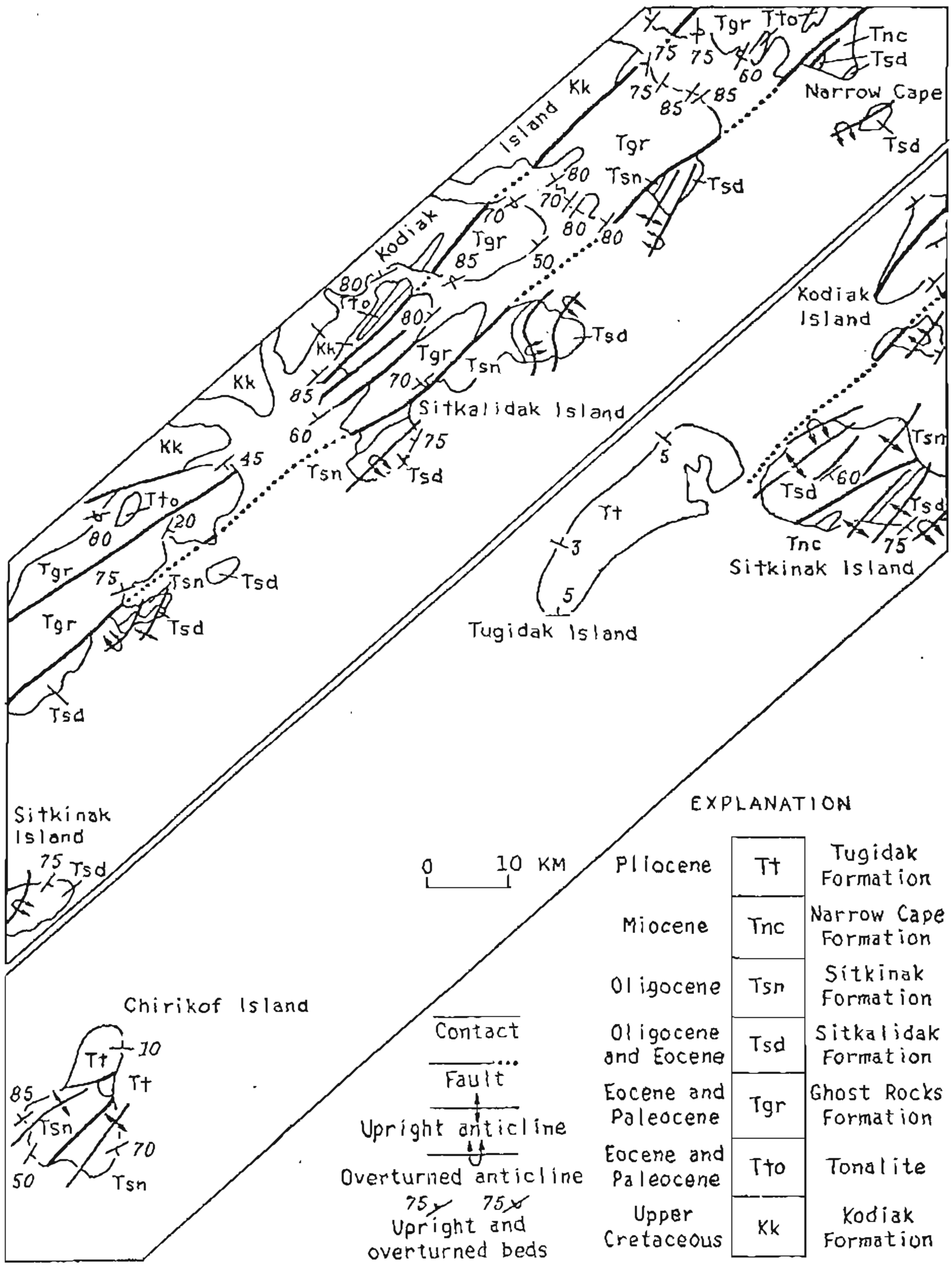
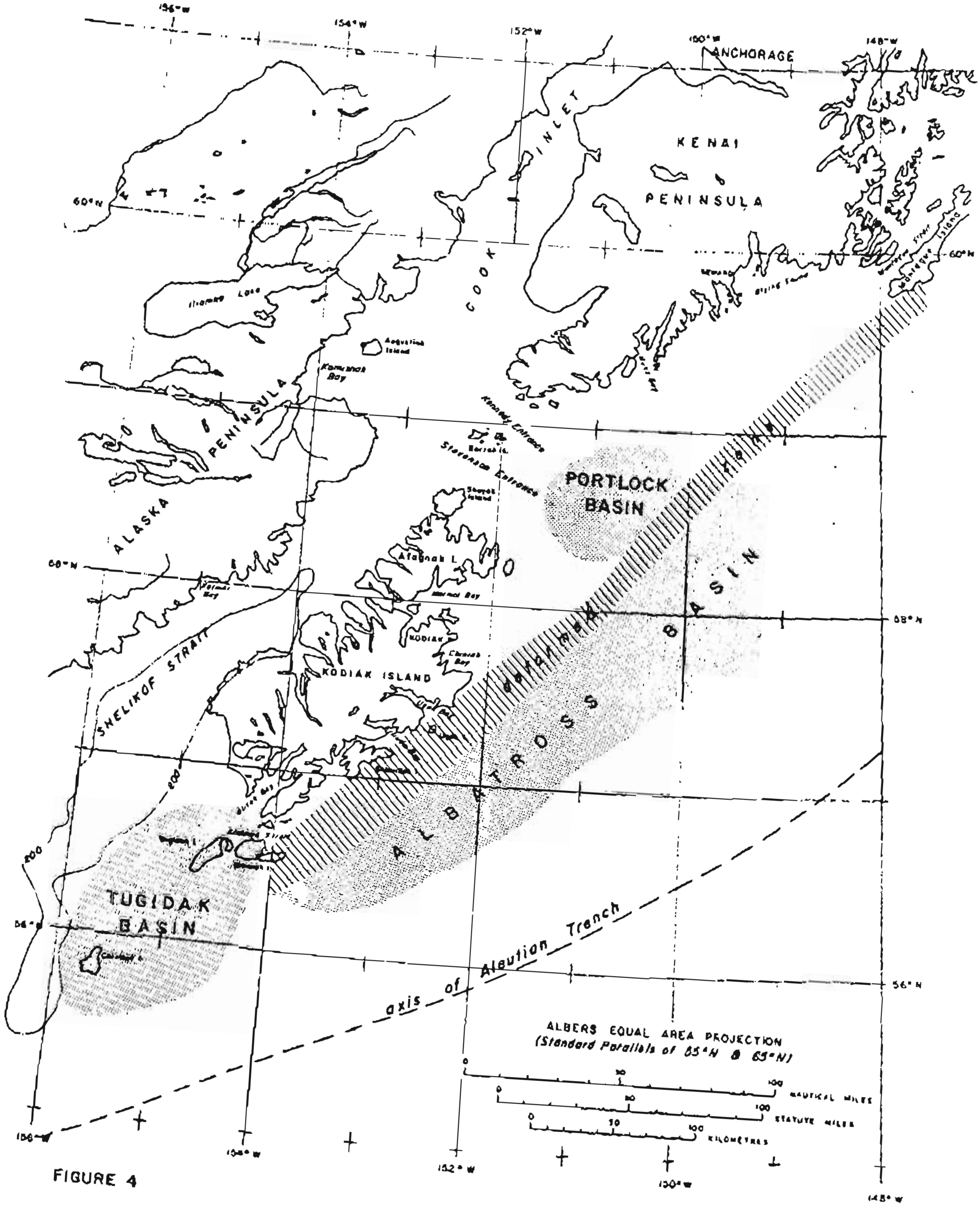


Figure 3. Tertiary outcrops on Kodiak and adjacent islands, Alaska (after Moore, 1967).



ANCHORAGE
KENAI
PENINSULA
COOK
INLET
ALASKA
PENINSULA
SHELIKOF STRAIT
KODIAK ISLAND
KODIAK
Afognak I.
PORTLOCK
BASIN
ALBATROSS
BASIN
TUGIDAK
BASIN
axis of Aleutian Trench
ALBERS EQUAL AREA PROJECTION
(Standard Parallels of 55°N & 65°N)
NAUTICAL MILES
STATUTE MILES
KILOMETRES
60°N
58°N
56°N
156°W
154°W
152°W
150°W
148°W

FIGURE 4

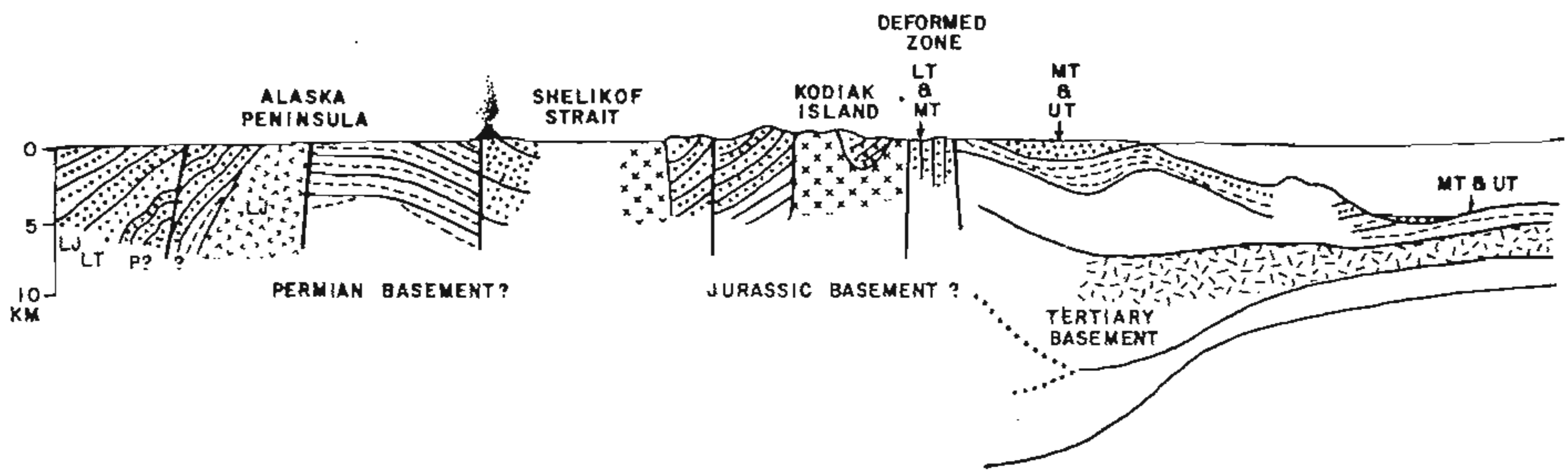


Figure 5

Idealized geologic cross section through Alaska Peninsula, Aleutian Trench, and Kodiak Island

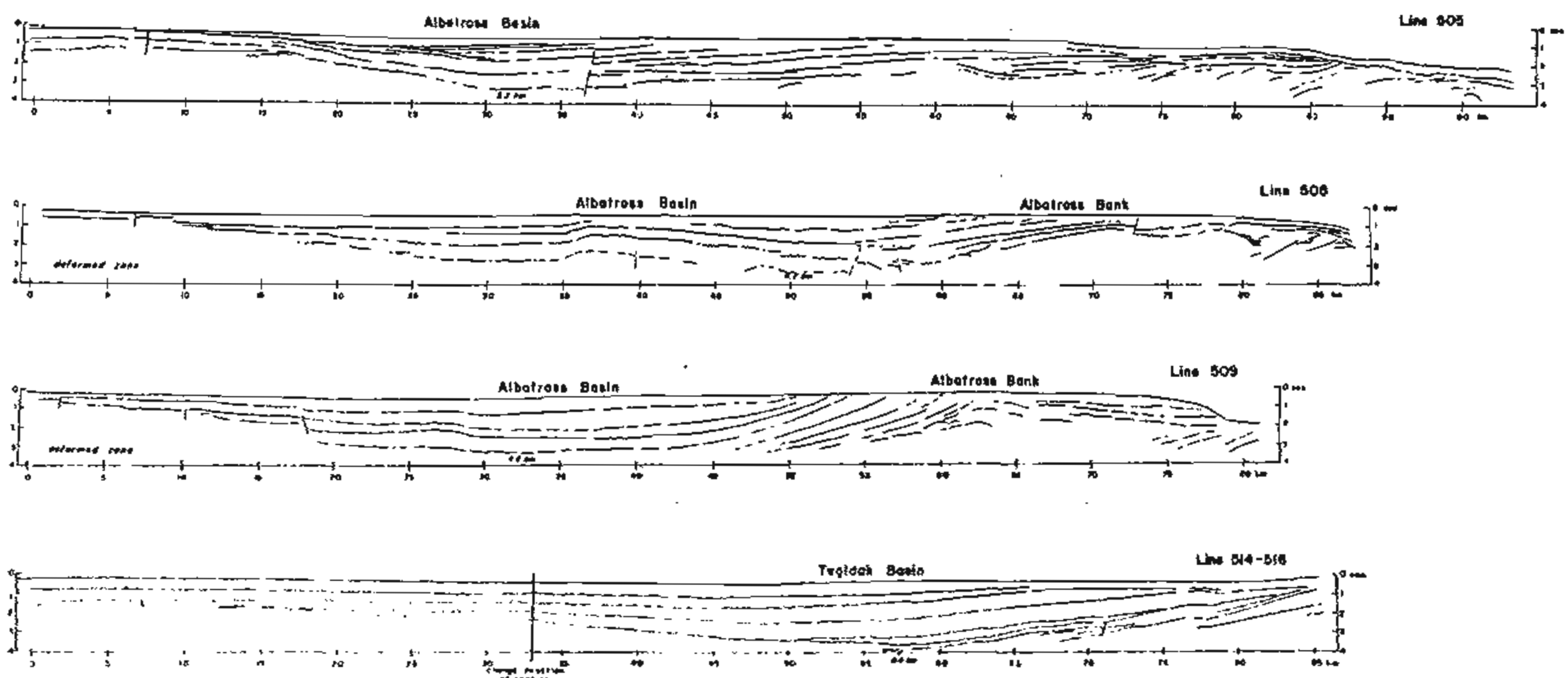
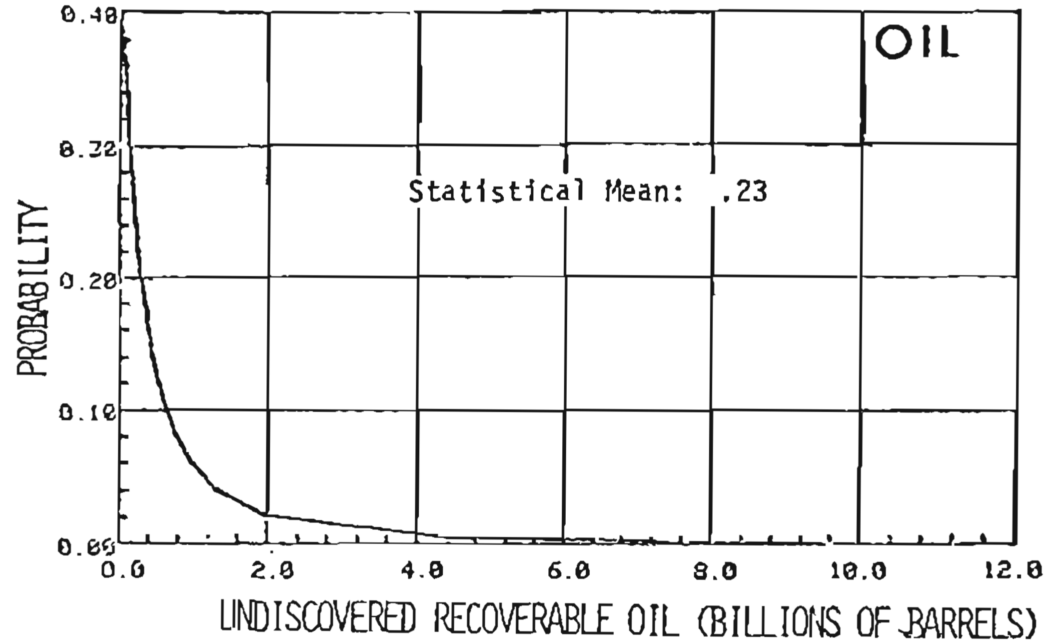


FIGURE 6 - TRACINGS OF MULTICHANNEL SEISMIC RECORDS


OIL
Statistical Mean: .23
PROBABILITY
0.40
0.32
0.20
0.10
0.00
0.0
2.0
4.0
6.0
8.0
10.0
12.0
UNDISCOVERED RECOVERABLE OIL (BILLIONS OF BARRELS)

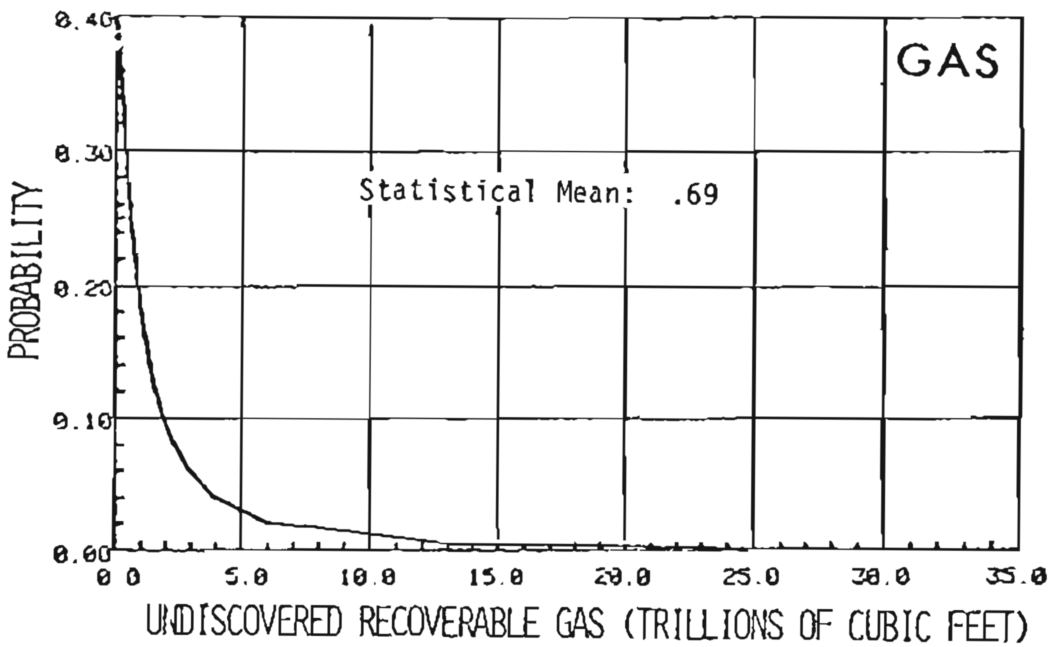
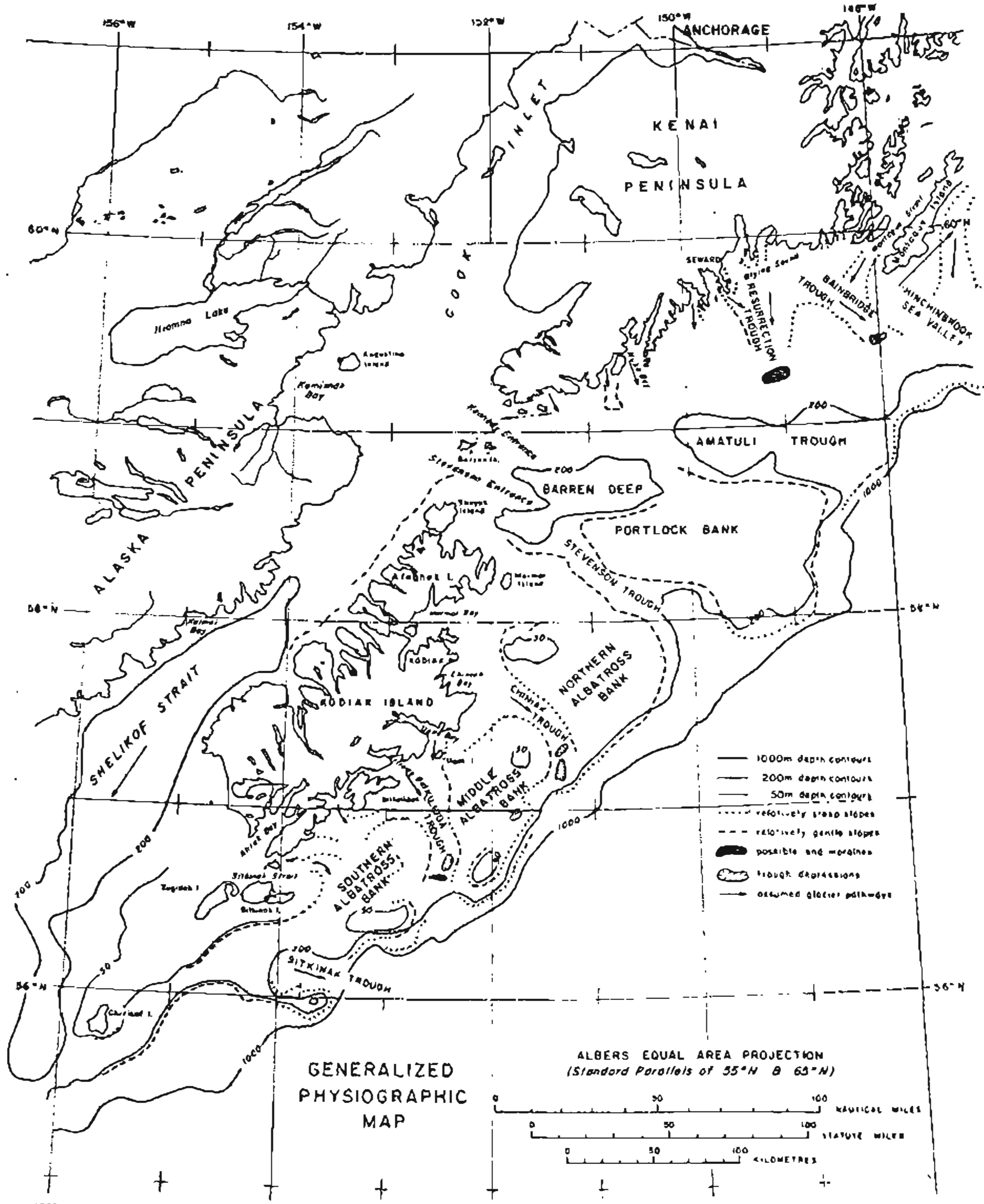

GAS
Statistical Mean: .69
PROBABILITY
0.40
0.30
0.20
0.10
0.00
0.0
5.0
10.0
15.0
20.0
25.0
30.0
35.0
UNDISCOVERED RECOVERABLE GAS (TRILLIONS OF CUBIC FEET)

Figure 7



156° W
154° W
152° W
150° W
148° W
60° N
58° N
56° N
ANCHORAGE
KENAI
PENINSULA
COOK
INLET
Iliamna Lake
Augustine Island
Kamishak Bay
ALASKA
PENINSULA
SEWARD
RESURRECTION TROUGH
BAINBRIDGE TROUGH
HINCHINBROOK SEA VALLEY
AMATULI TROUGH
Barren Is.
BARREN DEEP
Stevenson Entrance
Shuyak Island
PORTLOCK BANK
STEVENSON TROUGH
Afognak I.
Marmot Island
Kodiak
Chiniak Bay
NORTHERN ALBATROSS BANK
KODIAK ISLAND
SHELIKOF STRAIT
Chiniak Trough
Ugak I.
MIDDLE ALBATROSS BANK
Sitkalidak
KILUDA TROUGH
SOUTHERN ALBATROSS BANK
Sitkinak Strait
Tugidak I.
Sitkinak I.
SITKINAK TROUGH
Chirikof I.
200
1000
50
1000m depth contours
200m depth contours
50m depth contours
relatively steep slopes
relatively gentle slopes
possible end moraines
trough depressions
assumed glacier pathways
GENERALIZED
PHYSIOGRAPHIC
MAP
ALBERS EQUAL AREA PROJECTION
(Standard Parallels of 55° N & 65° N)
0 50 100 NAUTICAL MILES
0 50 100 STATUTE MILES
0 50 100 KILOMETRES

FIGURE 8

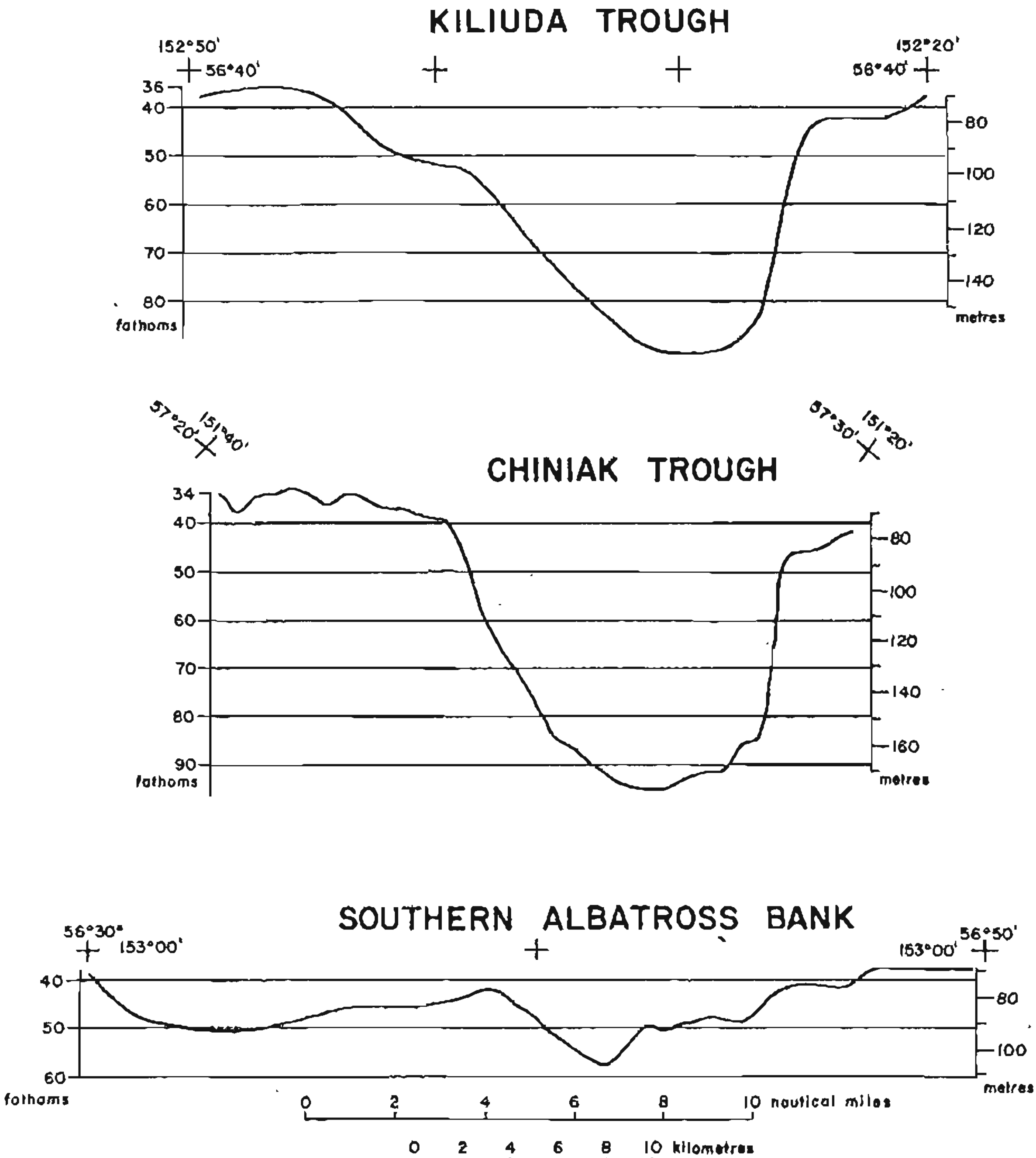


FIGURE 9. BATHYMETRIC PROFILES

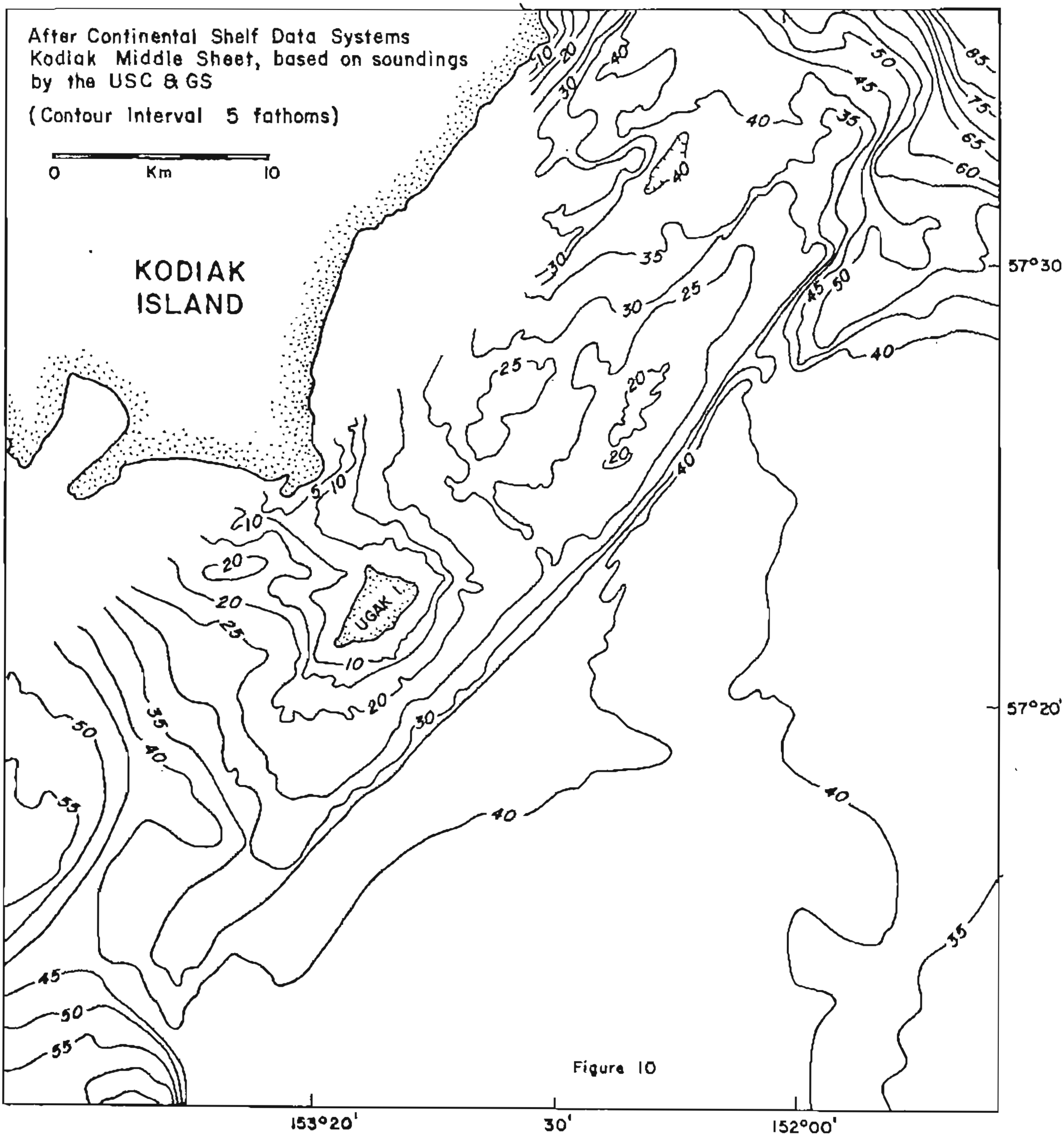

After Continental Shelf Data Systems
Kodiak Middle Sheet, based on soundings
by the USC & GS
(Contour Interval 5 fathoms)
0 Km 10
KODIAK ISLAND
UGAK I.
57°30
57°20'
153°20'
30'
152°00'

Figure 10

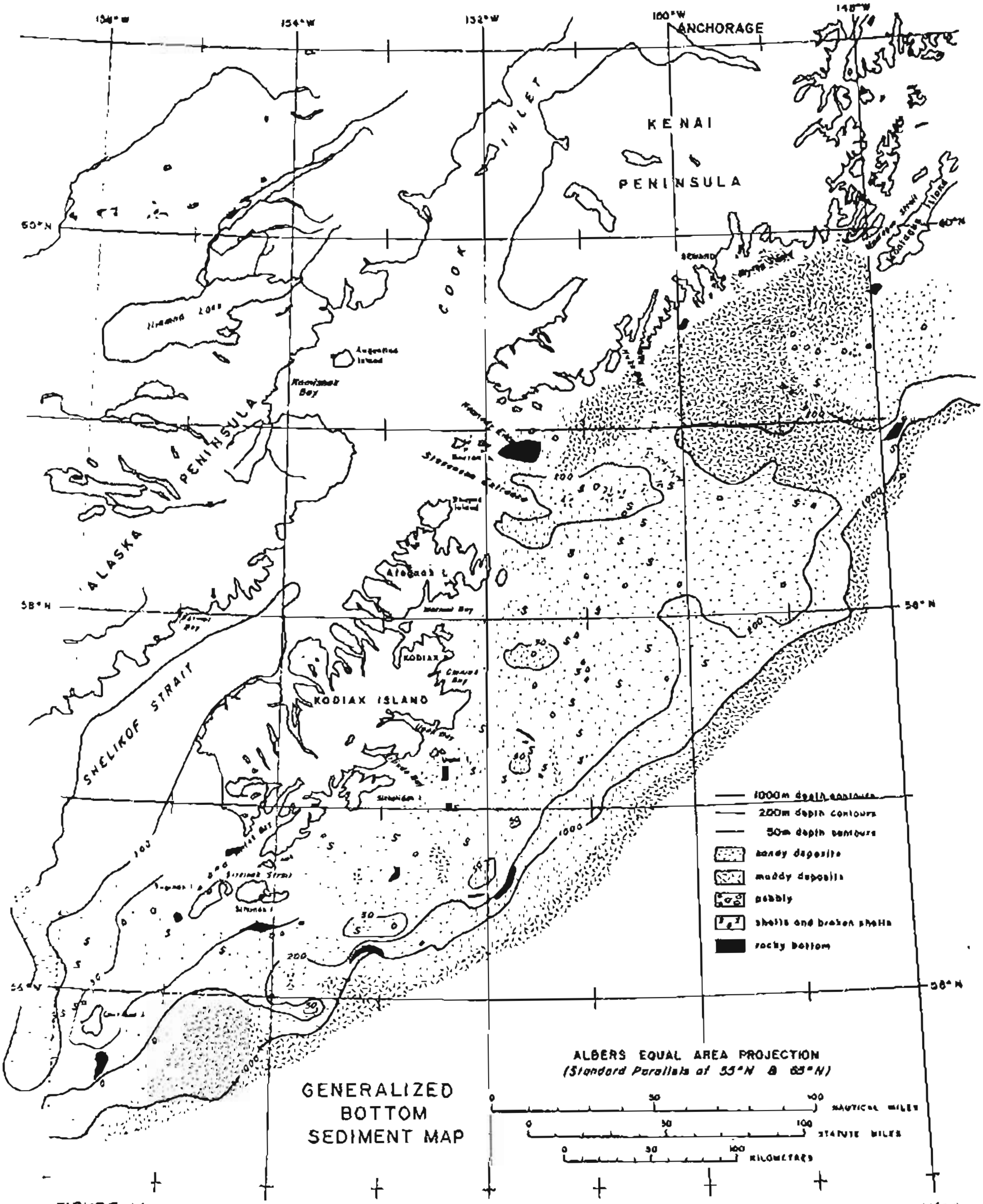

ANCHORAGE
KENAI
PENINSULA
COOK
INLET
ALASKA
PENINSULA
SHELIKOF STRAIT
KODIAK ISLAND
KODIAK
1000m depth contours
200m depth contours
50m depth contours
sandy deposits
muddy deposits
pebbly
shells and broken shells
rocky bottom
ALBERS EQUAL AREA PROJECTION
(Standard Parallels at 55°N & 65°N)
GENERALIZED
BOTTOM
SEDIMENT MAP
NAUTICAL MILES
STATUTE MILES
KILOMETERS

FIGURE 11

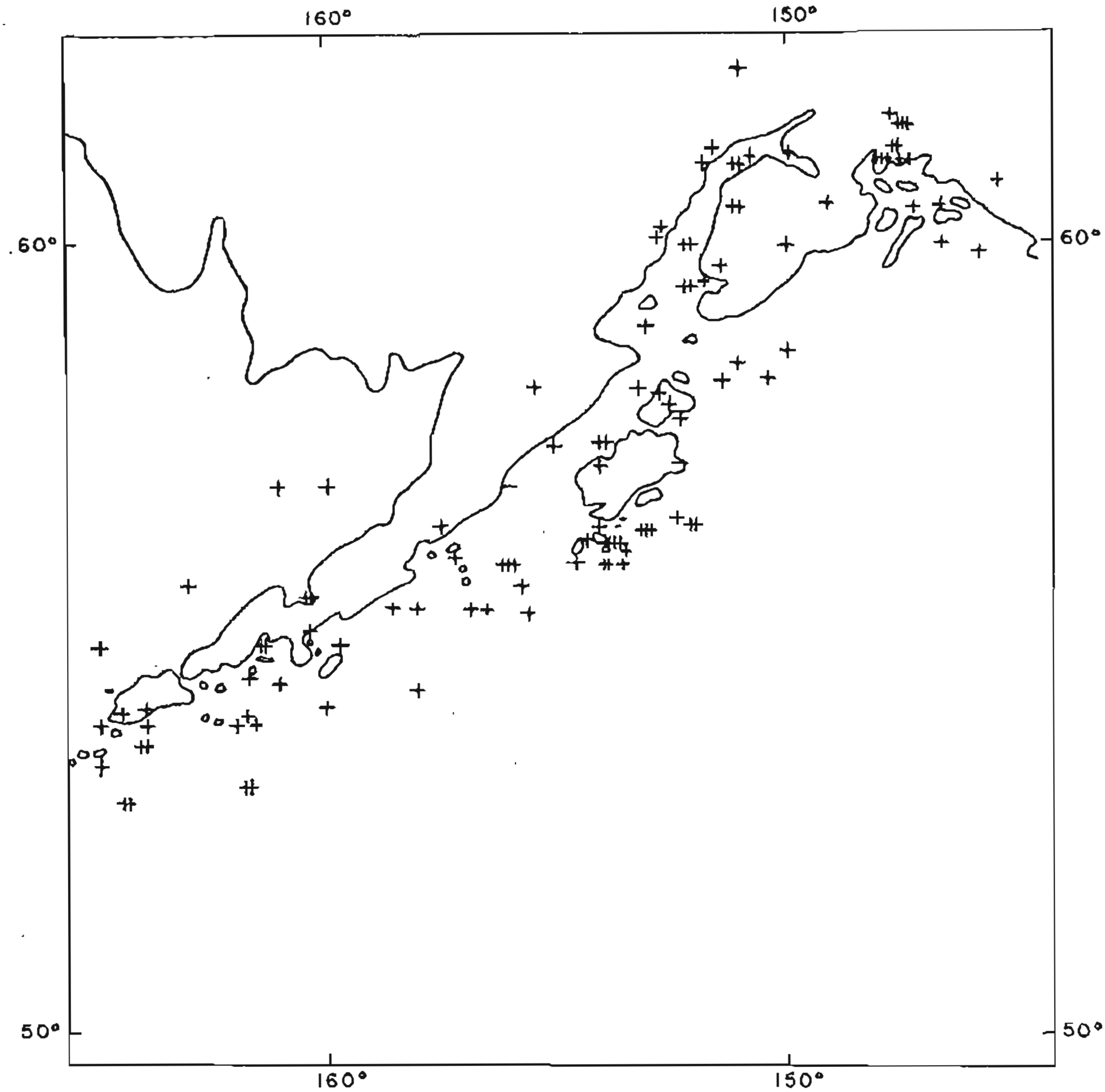


FIGURE 12– Distribution of earthquake epicenters, greater than magnitude 6.0, western Gulf of Alaska region. Data from Table 2.

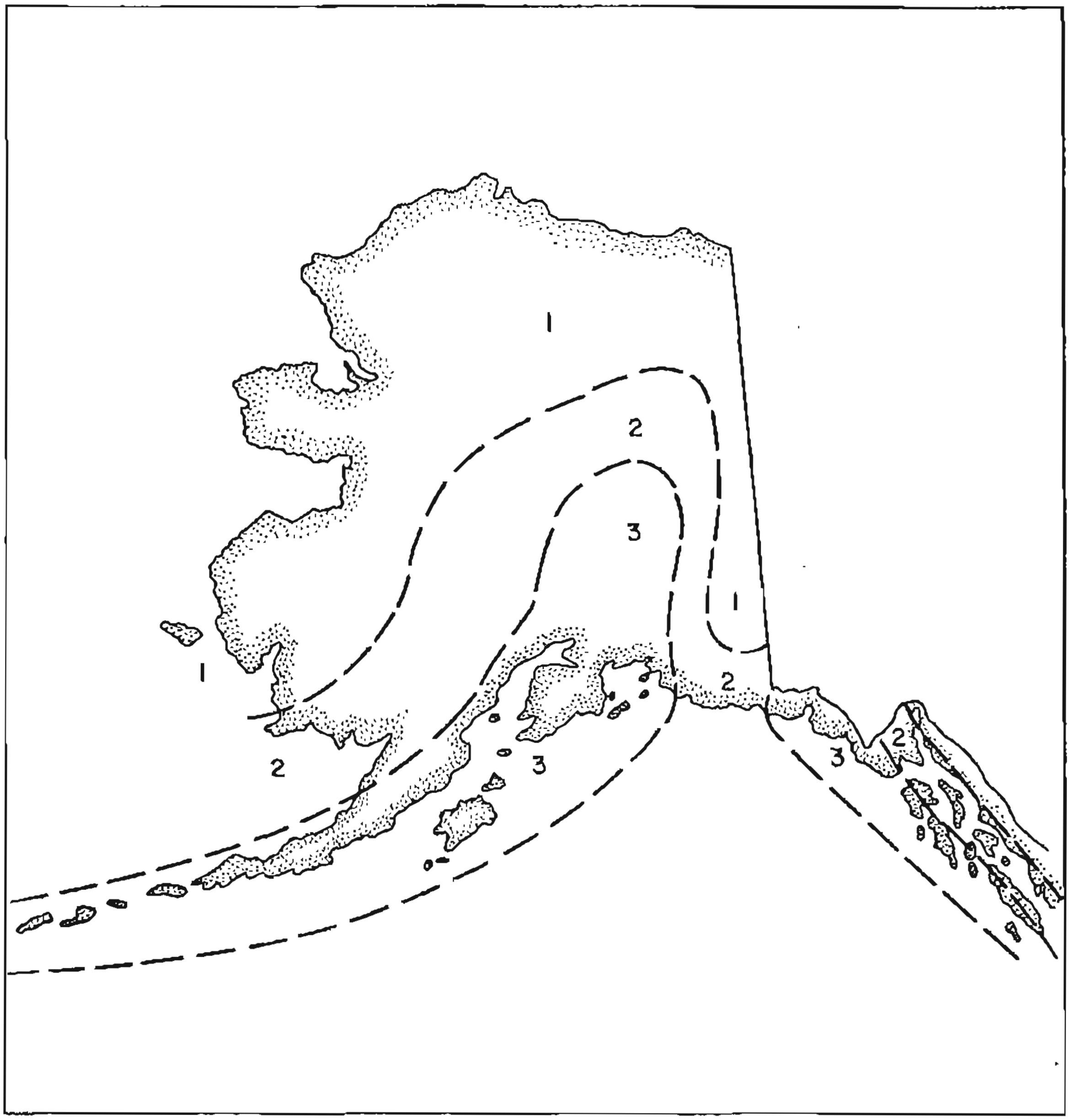


FIGURE 13. Seismic zones in Alaska
1-Minor structural damage (magnitude 3.0-4.5)
2-Moderate structural damage (magnitude 4.5-6.0)
3-Major structural damage (magnitude 6.0-8.8)

From Evans et al, 1972

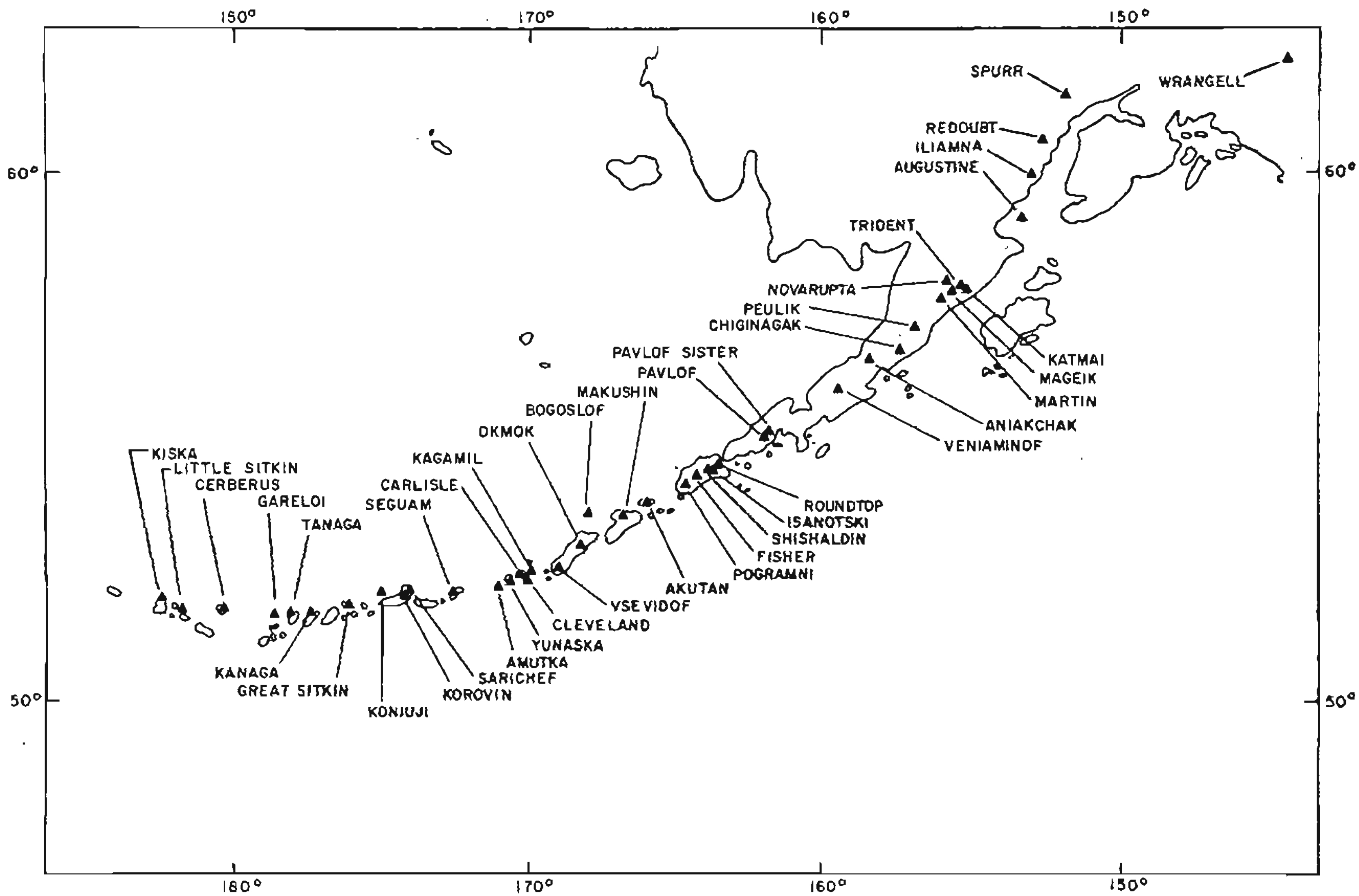
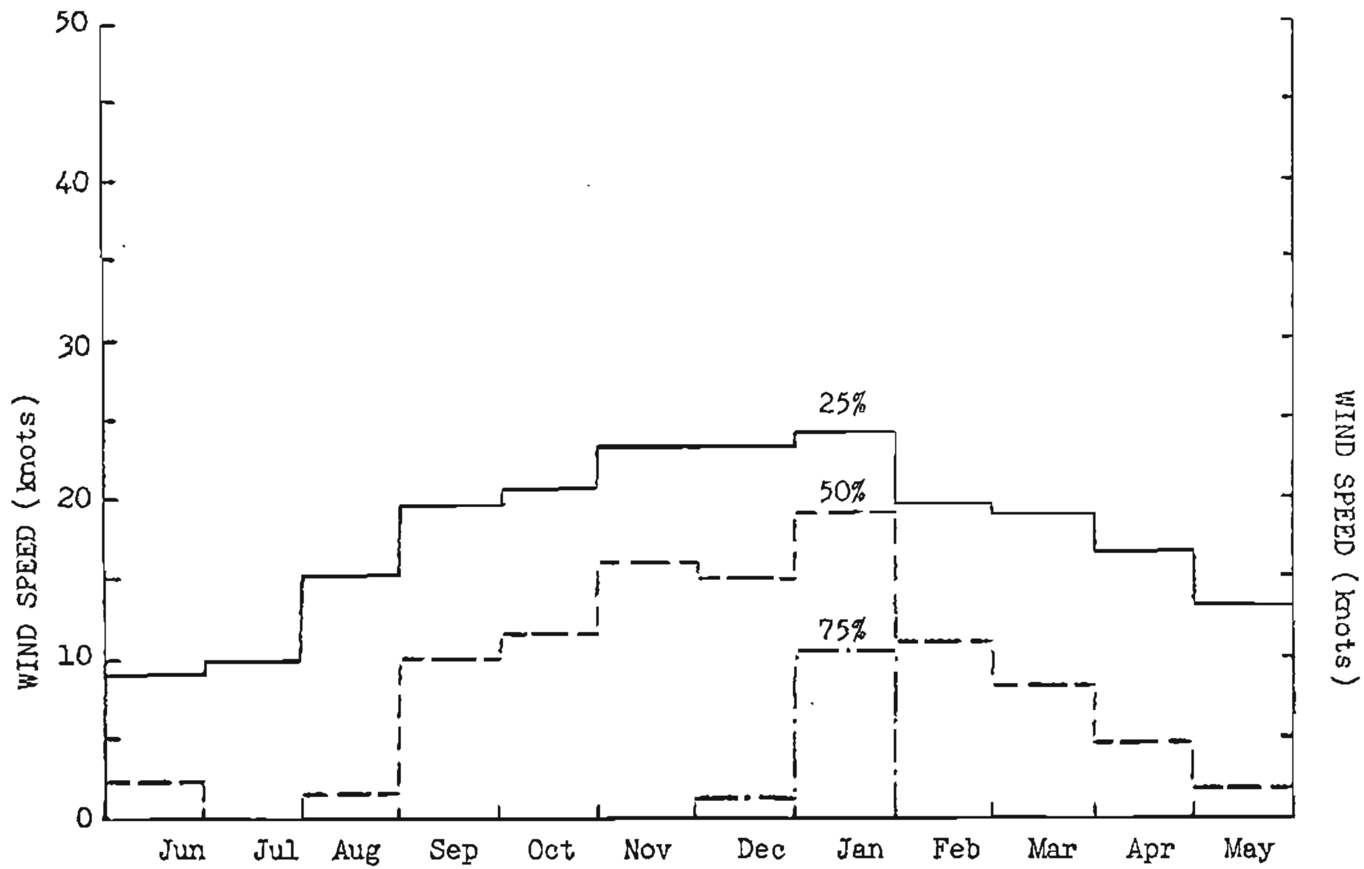


FIGURE 14- Active volcanoes in Alaska. From Evans, et al, 1972

MONTHLY VARIATION OF WIND SPEEDS

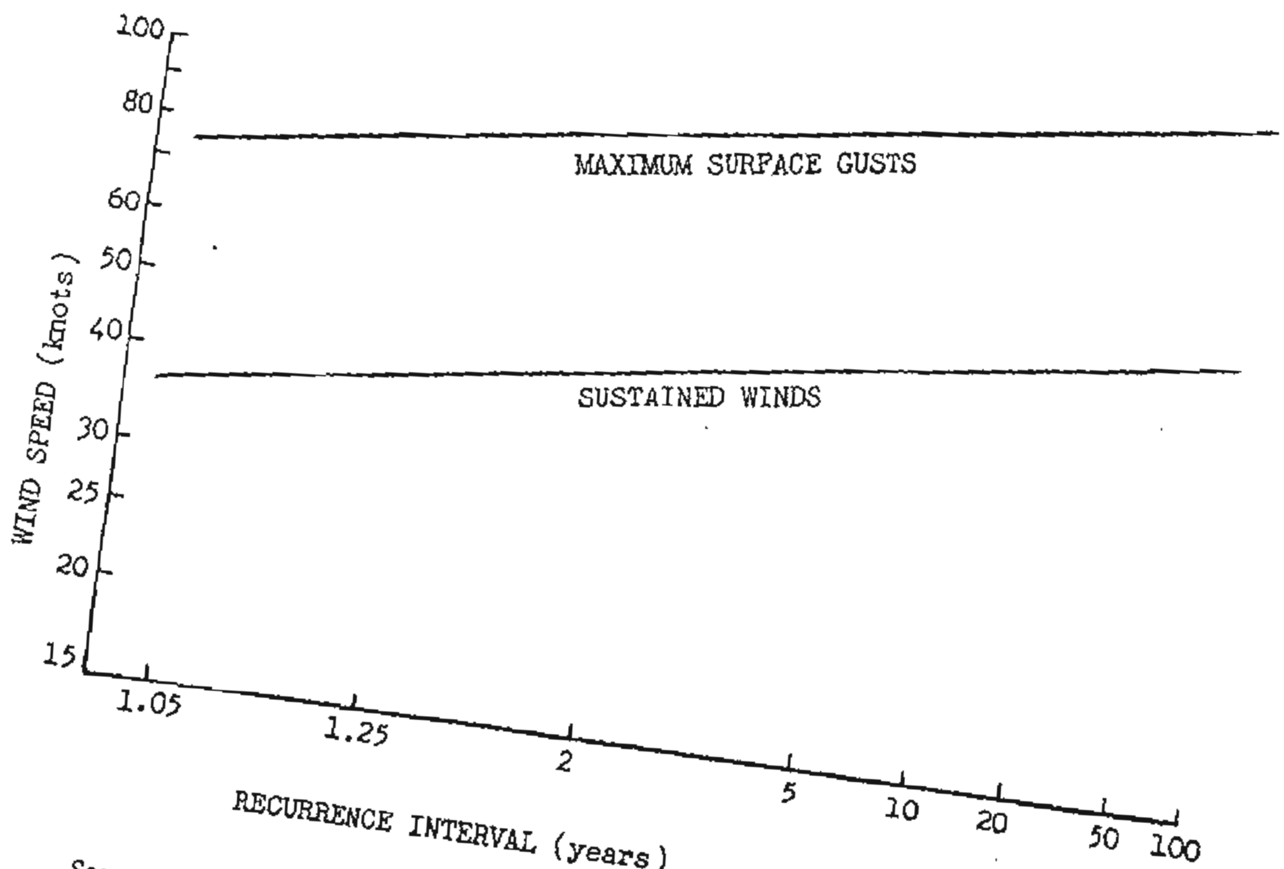


Probability of Wind Speeds ≥ Indicated Value

Source: Horrer, 1975.

Figure 15

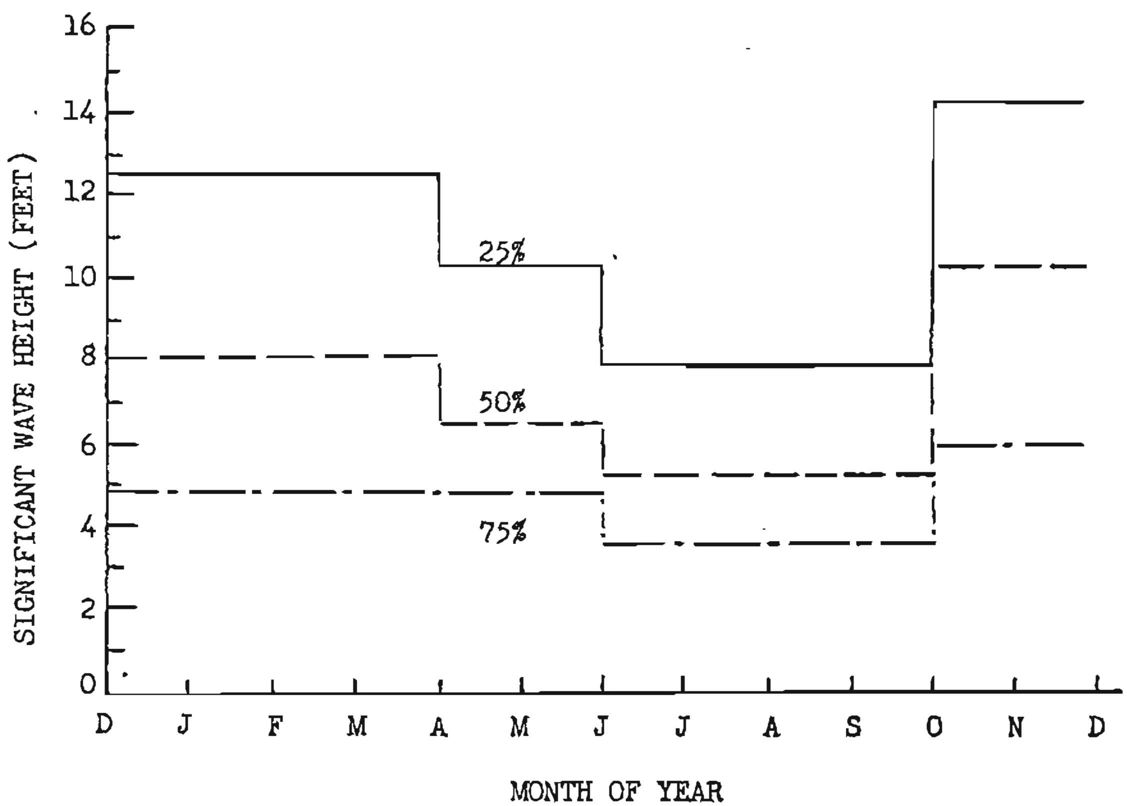
RECURRENCE INTERVAL OF WINDS



Source: Horrer, 1975.

Figure 16

SEASONAL VARIATION OF WAVE HEIGHTS

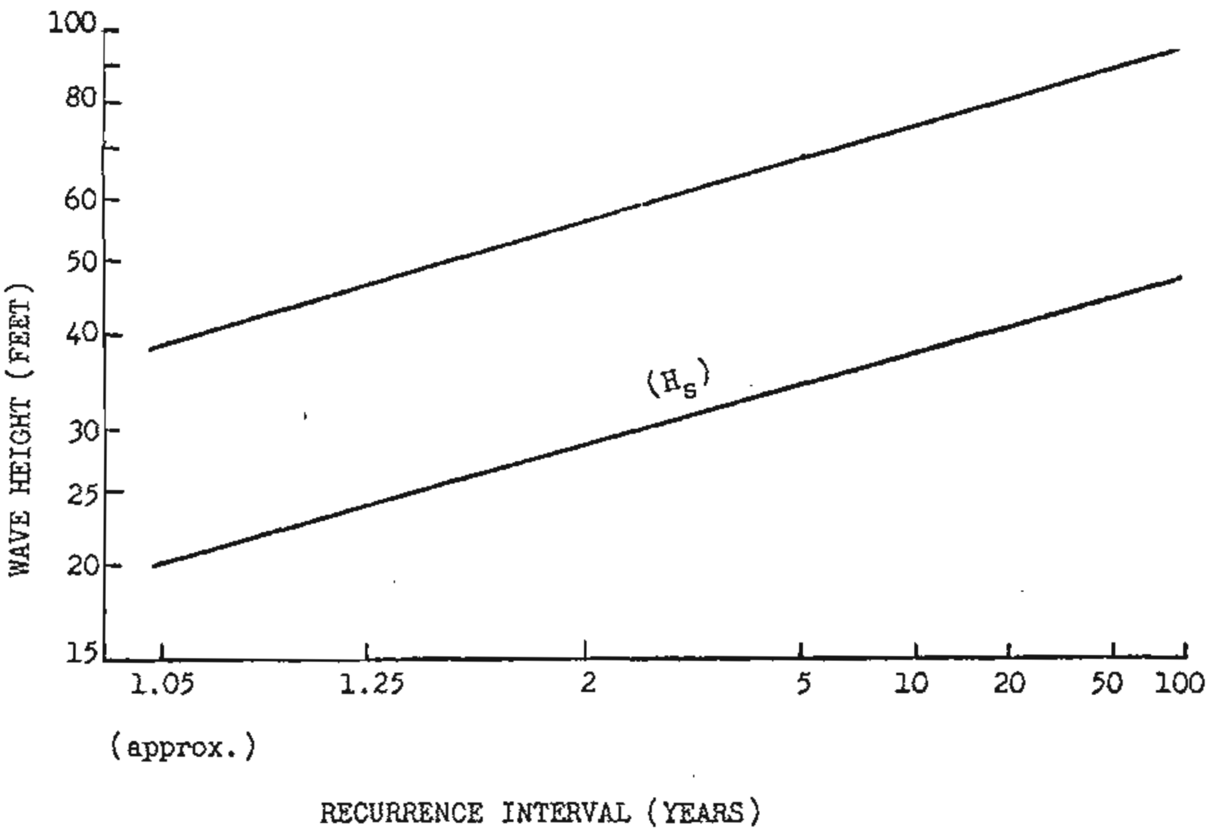


PROBABILITY OF WAVE HEIGHTS ≥ INDICATED VALUE

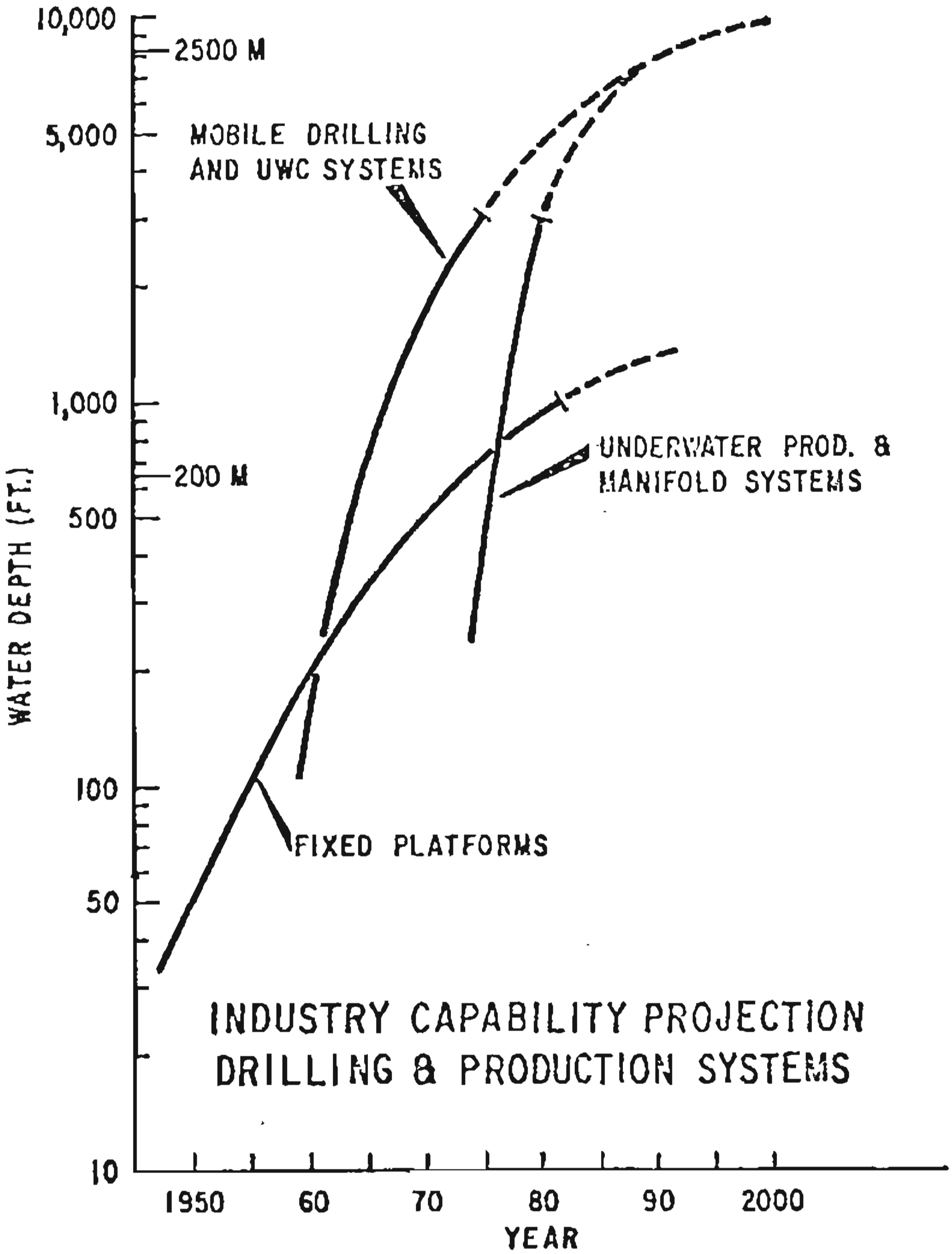
Source: Horrer, 1975.

Figure 17

RECURRENCE INTERVAL OF SIGNIFICANT WAVE HEIGHT (H_s) AND MAXIMUM WAVE HEIGHT (H_m)

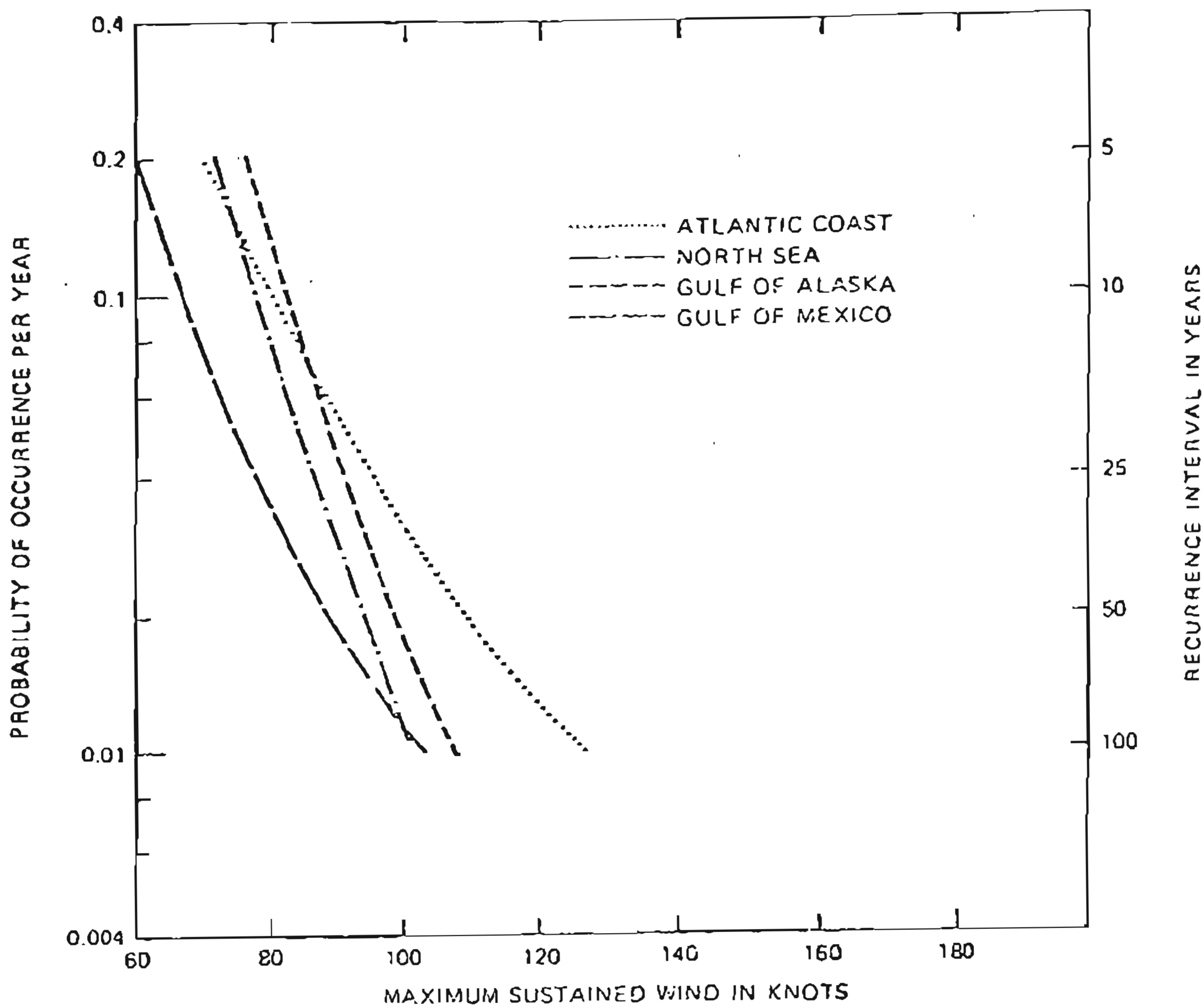


Source: Horrer, 1975.
Figure 18



Source: Geer, 1974.

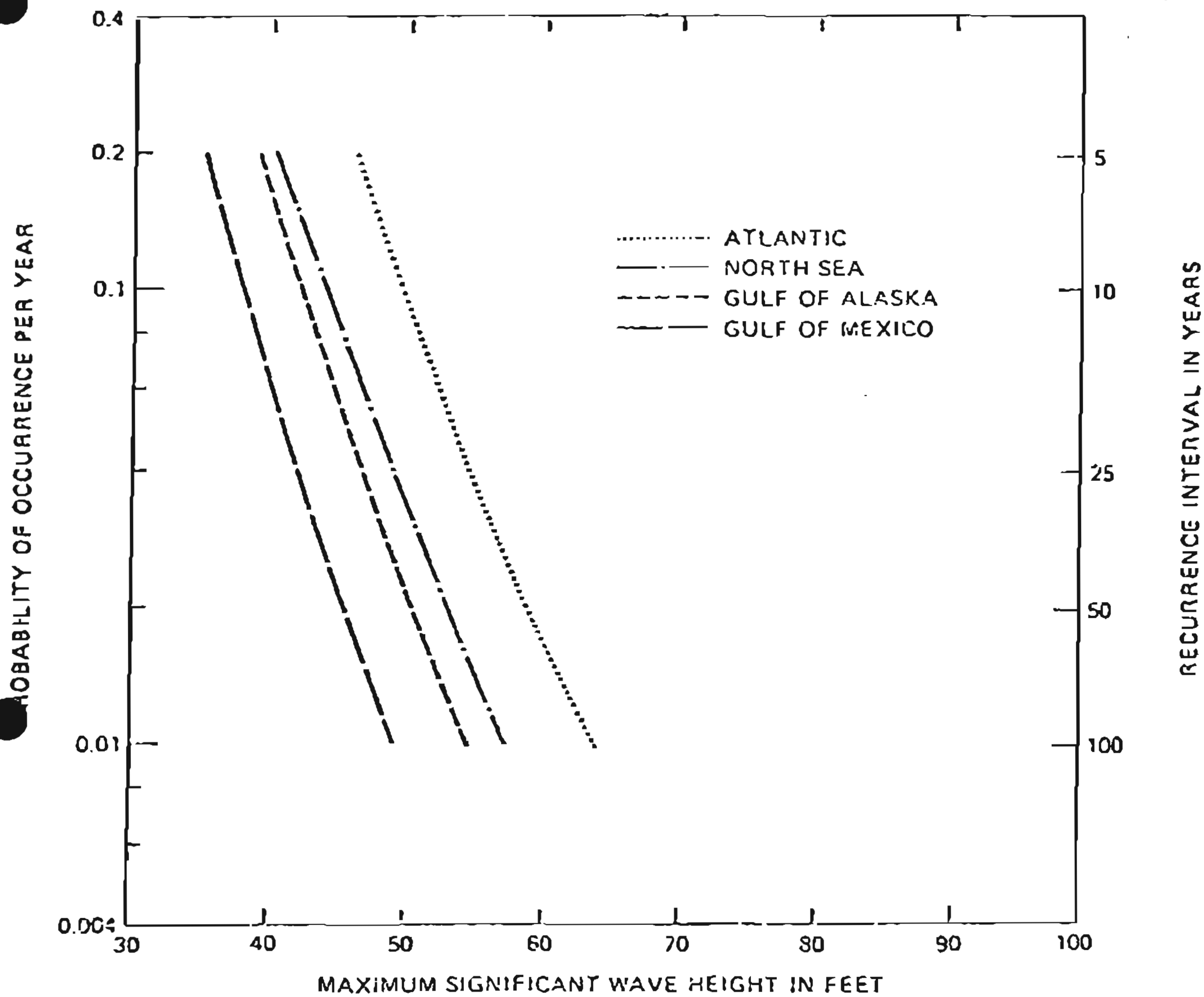
Figure 19



Maximum Sustained Winds for the Atlantic Coast, Gulf of Alaska, Gulf of Mexico, and North Sea.

Source: Tetra Tech, Inc., 1973.

Figure 20



Maximum Significant Wave Heights for the Atlantic Coast, Gulf of Alaska, Gulf of Mexico, and North Sea.

Source: Tetra Tech, Inc., 1973.

Figure 21

GPO 958-271