UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

HYDROCARBON POTENTIAL, GEOLOGIC HAZARDS, AND INFRASTRUCTURE FOR EXPLORATION AND DEVELOPMENT OF THE LOWER COOK INLET, ALASKA

By

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OPEN-FILE REPORT
76-449

This report is preliminary and has not been edited or reviewed for conformity with Geological Survey standards and nomenclature.

Menlo Park, California
August 1976

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SUMMARY

The lower Cook Inlet Outer Continental Shelf (OCS) includes 9,100 square kilometres (3,500 sq. mi.) of submerged land in less than 200 metres (660 ft.) of water 150 to 350 kilometres (95 to 220 mi.) southwest of Anchorage, Alaska. This area could contain from 0.3 to 1.4 billion barrels of oil and from 0.6 to 2.7 trillion cubic feet of natural gas depending upon the statistical confidence level indicated.

The geology of this submerged area is extrapolated from onshore data. The exposed sedimentary rocks are as old as Late Paleozoic-Triassic and as young as Quaternary. Late Paleozoic through Early Jurassic rocks form the basal complex and include volcanics, volcaniclastics, and marine clastic sediments. Middle Jurassic through Cretaceous strata consist of marine sedimentary rocks. Tertiary rocks, from which the oil and gas in upper Cook Inlet are produced, consist of nonmarine conglomerate, sandstone, siltstone, and coal. The potential objective section for oil and gas in the lower Cook Inlet OCS area ranges in age from Middle Jurassic through the Tertiary.

The present structural configuration of this area is a northeast-trending trough filled with Tertiary sedimentary rocks. The trough

is flanked by two major faults, the Bruin Bay fault on the northwest and the Border Ranges fault on the southeast. Between these faults is the OCS area containing anticlinal structures and faults which are potential traps for hydrocarbons.

Potential geologic hazards are present in this area. It is an area of intense tectonism expressed as seismic activity (earthquakes) and volcanic eruptions which produce many natural disturbances including tsunamis. The distribution of soft sediment and other submarine features which relate to geologic hazards are only generally known.

The technology required for exploration and development in the lower Cook Inlet is available, having been demonstrated by offshore oil-and gas-producing operations in the upper Cook Inlet and recent developments in the North Sea and other offshore areas. Procedures for analyzing seismic forces and for designing offshore structures to withstand earthquakes are available. New techniques for measuring and predicting maximum environmental forces are improving overall capability and reliability for design of offshore equipment.

Exploratory drilling in the lower Cook Inlet can be accomplished by jack-up rigs as well as drillships and semi-submersible vessels. Only three or four mobile drilling vessels are presently located in Alaska or on the West Coast of the United States. Mobile drilling units must be obtained from the Gulf of Mexico, North Sea, or other parts of the world. Moving times will be long and costs high.

The reservoir of available skilled manpower in the Alaska area is relatively small due to the low population density and distance from significant industrial centers. Skilled manpower and manpower available for training is available in the Pacific Northwest and California.

The time frame for significant development will be relatively long due to high costs and environmental conditions. It is estimated that it will be 1-2 years after a lease sale until substantial exploratory drilling will occur, 4-8 years until initial production, and 6-10 years until maximum production.

INTRODUCTION

Purpose

This report is a summary of the geologic framework, petroleum geology, oil and gas resources, environmental geology, and operational considerations of the lower Cook Inlet Outer Continental Shelf (OCS) area. The report also provides a preliminary assessment of the technology availability of drilling units and manpower, the time frame for possible oil and gas development of the lower Cook Inlet area, and comments on capital, manpower, and infrastructures necessary for the development of this area as requested by the Director, Bureau of Land Management.

Operations in the lower Cook Inlet will be influenced to a great degree by environmental conditions such as relatively harsh climate, severe weather and sea conditions, and possible seismic disturbances. In addition, a shortage of exploration drilling units and skilled manpower and the remoteness from industrial areas and supply centers could contribute to delays in the time frame for development and to increasing capital layout. This report is meant principally to aid the Bureau of Land Management (BLM) in preparation of the Draft Environmental Impact Statement (DES) for the lower Cook Inlet OCS sale.

Location

The lower Cook Inlet Outer Continental Shelf (OCS) area is located between north latitudes 58° 50' and 60° 20' and between west longitudes 151° 45' and 153° 35' (fig. 1). Major geographic features on the perimeter of the area are: 1) The Aleutian Range on the northwest; 2) Kalgin Island on the northeast; 3) the Kenai Peninsula and Kachemak Bay to the east; 4) the Barren Islands on the southeast, and 5) the north end of the Alaska Peninsula on the southwest where the Katmai National Monument is located. Augustine Island, a prominent active composite volcano, lies 24 kilometres (15 mi.) north of the Alaska Peninsula in the southwest part of lower Cook Inlet.

Lower Cook Inlet is a bay nearly surrounded on all sides by mountains except on the south where it opens into the Gulf of Alaska and Shelikof Strait (fig. 2). The water depth in the OCS area is less than 200 metres (660 ft.) except for a small area around the Barren Islands. More than half the area is less than 100 metres (330 ft.) deep. The Inlet gradually deepens to the south.

Anchorage, the largest city in Alaska, lies 320 kilometres (200 mi.) northeast of Cape Douglas, the southernmost point in this OCS area. Production, pipeline, refining, and other related facilities are available in the upper Cook Inlet around Anchorage.

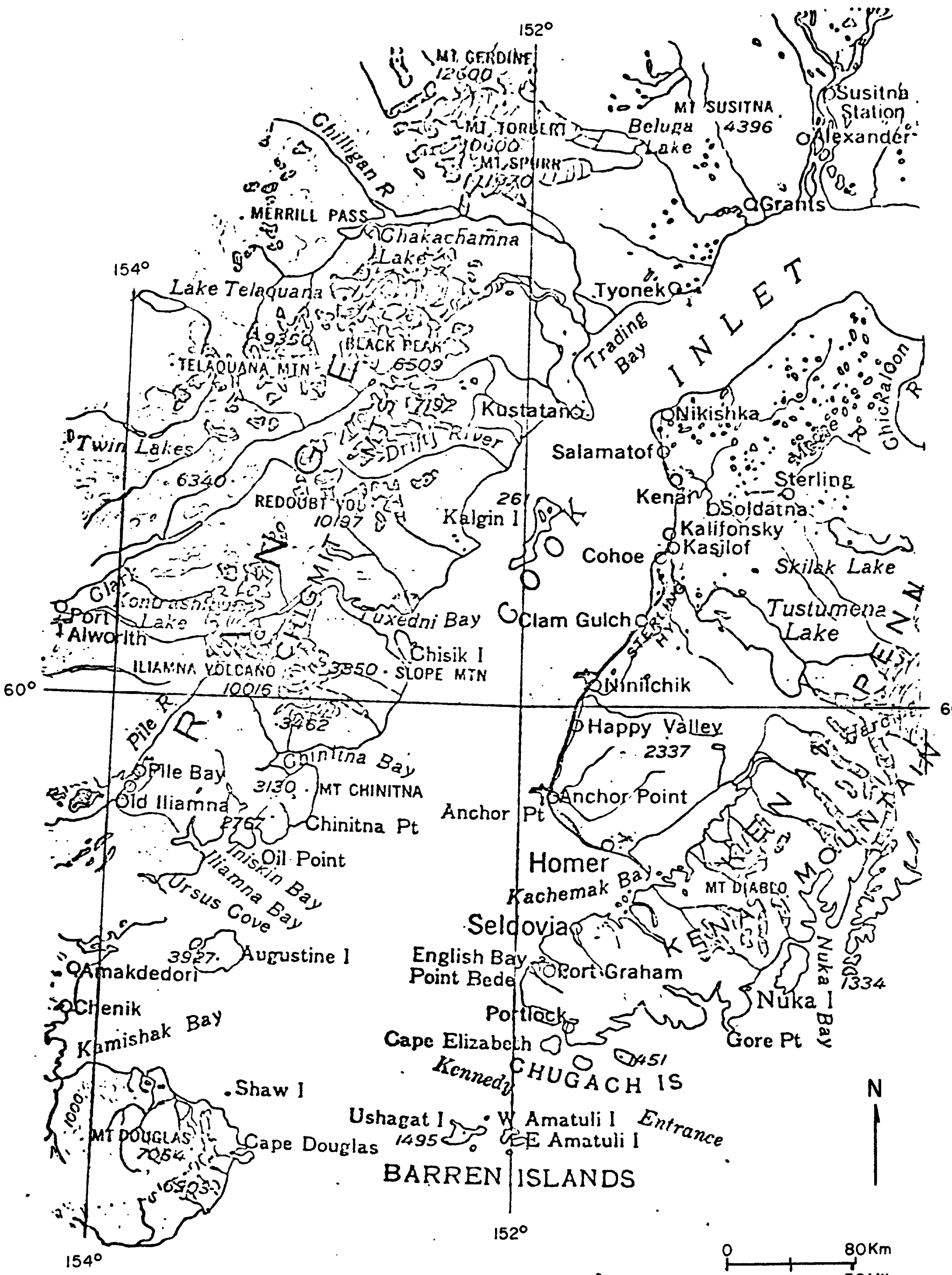


Figure 1 --Map of Cook Inlet area showing named features.

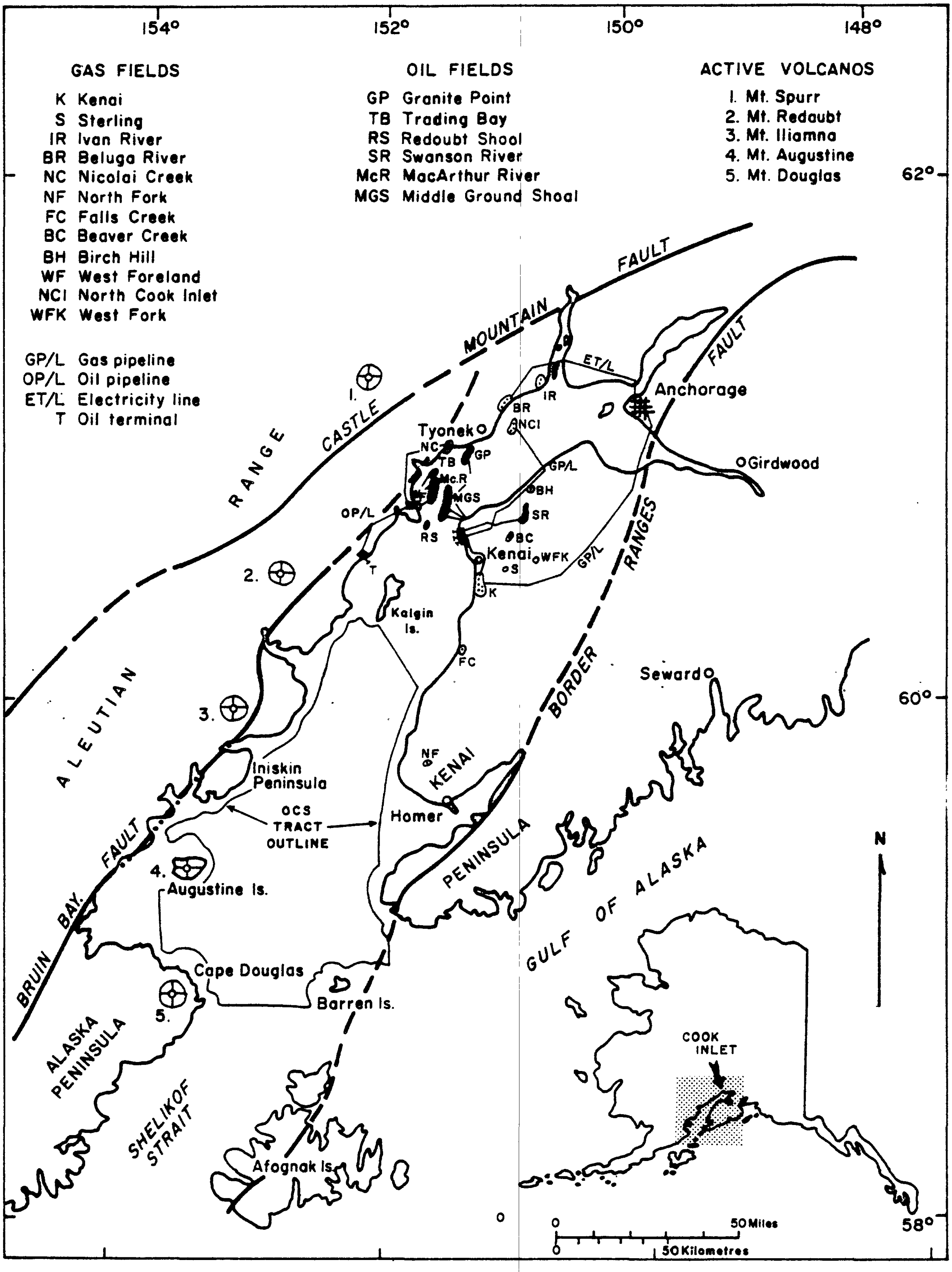


Figure 2. Cook Inlet area index map.

ACKNOWLEDGMENTS

The responsibility for specific subjects is as follows: Magoon and Adkison, introduction, framework geology, petroleum geology; Fisher, reflection seismic, magnetics, gravity; Dolton and Sable, resource-appraisal estimate; Hampton, geologic hazards; Smith and Chmelik, technology, drilling-unit availability, manpower, and time frame for development.

John S. Kelley mapped the Seldovia area. Robert L. Detterman made significant contributions on the geology from Tuxedni Bay to Chenik Lake. Jack Wolfe collected fossil-leaf localities and provided information that has clarified many Tertiary stratigraphic problems. David L. Jones identified the Middle Jurassic through Cretaceous marine fossils. The micropaleontology work was done by William V. Sliter.

FRAMEWORK GEOLOGY

Available Public Data

The literature that describes the onshore geology dates back to the turn of the century. The subsurface geology of the upper Cook Inlet and the Kenai Lowland is generally known from exploratory and development wells. Three of five exploratory wells on the Iniskin Peninsula (fig. 2) were drilled recently enough to have information available (Detterman and Hartsock, 1966). Kirschner and Lyon (1973) wrote the most recent summary which emphasized the stratigraphy and structure of the upper Cook Inlet petroleum province. A bibliography of geological literature on Cook Inlet was published by Maher and Trollman (1969). Selected references are listed at the end of this paper.

Little, if any, data exists that pertain directly to offshore lower Cook Inlet. However, much of the onshore geology can be extended offshore using geological and geophysical techniques. In the summer of 1975, 485 kilometres (300 mi.) of 3600% common depth point (CDP) seismic data was acquired, and two onshore areas (Cape Douglas and Seldovia) were mapped geologically with the express purpose of extending this control offshore into the OCS area. Some of the new data is incorporated in this report.

Forearc Basin Model

Lower Cook Inlet is part of a belt of Mesozoic-Tertiary sedimentary rocks that extends northeast into upper Cook Inlet and southwest down the Alaskan Peninsula and Shelikof Strait (fig. 3). Along this belt marine Mesozoic rocks locally exceed 6,100 metres (20,000 ft.) in thickness and continental Tertiary rocks are as much as 7,600 metres (25,000 ft.) thick. The lenticular geometry of this belt, the lack of tectonic deformation compared to the Chugach terrane, proximity of these rocks to an active arc, the Aleutian-Alaskan Range, and the apparent accretion of sedimentary rocks from the Kenai Peninsula to the present Aleutian trench suggest that lower Cook Inlet is a forearc basin that developed in conjunction with the arc-trench system. Major lineaments that flank this forearc basin are the Bruin Bay and Border Ranges faults (fig. 2).

Projection of the forearc basin model into the Triassic provides a basis for discussion of the evolution of this area. This dynamic plate tectonic model dictates that structures grow and sedimentary rocks accumulate in an interrelated manner. The order of discussion

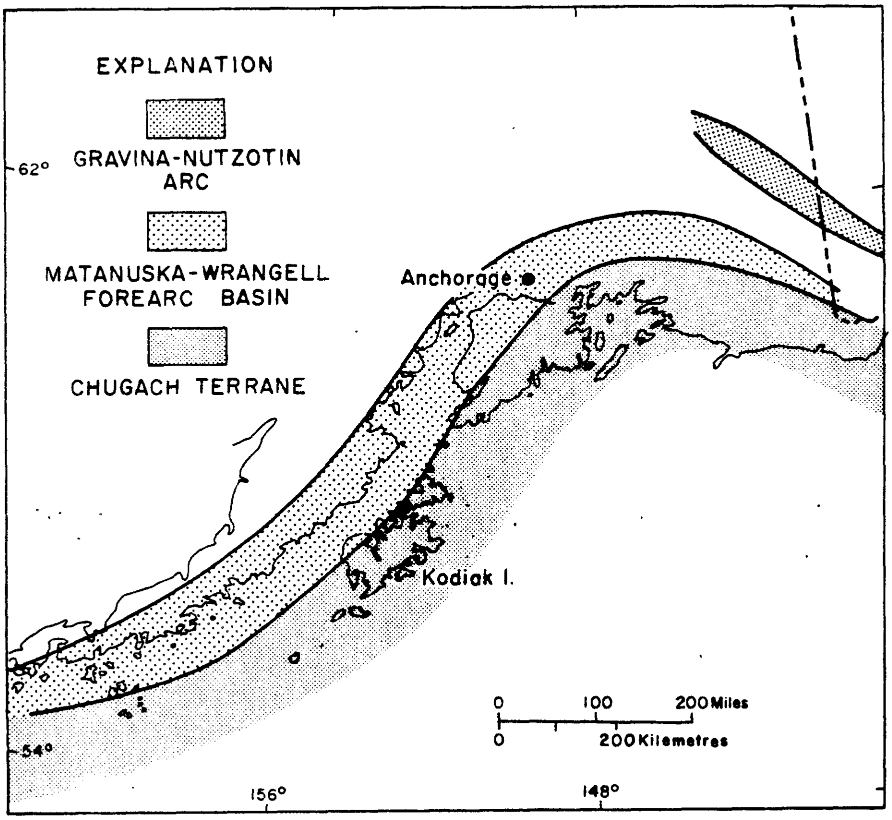


Figure 3. Matanuska-Wrangell Forearc basin (after Berg and others, 1972).

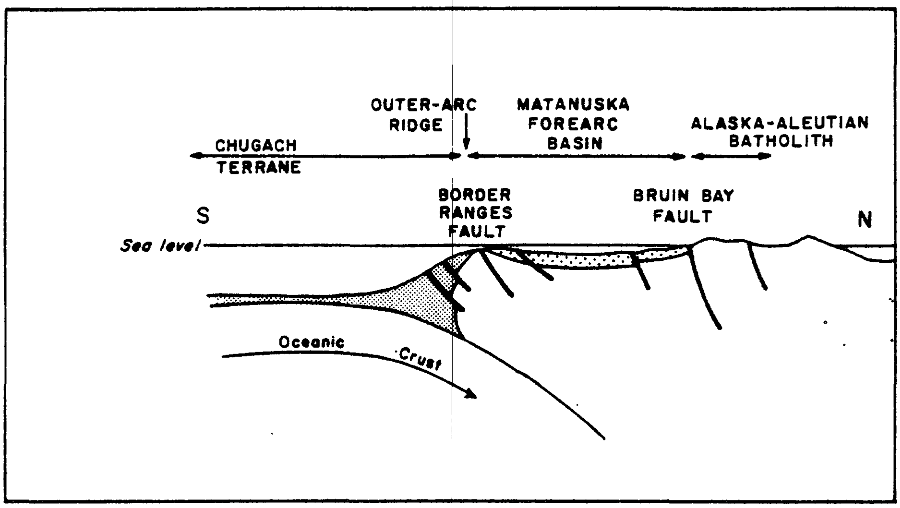


Figure 4. Nomenclature: forearc basin (modified from Berg and others, 1972).

progresses from the arc to the outer-arc ridge. The outer-arc ridge to trench sedimentary rocks in the Gulf of Alaska is not discussed. The elements, in order of discussion, are the Alaskan-Aleutian batholith, Bruin Bay fault, Matanuska terrane, Border Ranges fault, and Chugach terrane (fig. 4). The geologic evolution of these elements is considered last.

Alaska-Aleutian Range Batholith

The Alaska-Aleutian Range batholith is proposed by Reed and Lanphere (1974) as ". . . the roots of an early Mesozoic magmatic arc that probably formed above a descending oceanic plate." Among the lines of evidence suggested is that the K_2O content of the Jurassic plutons increases away from the trench. The relationship of K_2O in the Late Cretaceous and Tertiary plutons is not as clear but it is likely that they also could be formed in the same manner (Reed and Lanphere, 1974).

Potassium-argon age dates indicate five periods of plutonism in the Alaska-Aleutian Range batholith (Reed and Lanphere, 1969, 1972, 1973). The plutons get younger and smaller northward. The five periods of plutonism are: 1) 165-180 m.y., Middle Jurassic; 2) 72-84 m.y., Late Cretaceous (Senonian); 3) 50-65 m.y., Paleocene to early Eocene; 4) 34-40 m.y., late Eocene to early Oligocene; and 5) a minor event at 25-30 m.y., late Oligocene.

The Lower and Middle Jurassic plutons vary in composition from gabbro to granodiorite, but diorite and quartz diorite are the most common. The Lower Jurassic volcaniclastic sequence, the Talkeetna

Formation, is closely associated with these plutons for more than 800 kilometres (500 mi.) in a northeast-trending belt (Grantz and others, 1963; Reed and Lanphere, 1969, 1973). This volcaniclastic sequence is represented on the Kenai Peninsula between Point Bede and Seldovia Bay.

The Upper Cretaceous plutons are small bodies of granodiorite and quartz monzonite (Reed and Lanphere, 1973). There is no known recorded coeval volcanism in the forearc basin.

The Paleocene through lower Eocene plutons are generally granite to quartz diorite (Reed and Lanphere, 1973). Coeval volcanic activity is represented by the West Foreland Formation. The stratigraphic section at Capps Glacier best shows this activity as tuffaceous conglomerate and sandstone (Adkison and others, 1975a). The upper part of the conglomerate and sandstone sequence at Capps Glacier was formerly assigned to the Tyonek Formation (Adkison and others, 1975a); these rocks are here reassigned to the West Foreland Formation mainly because new leaf-fossil control suggests a late Paleocene and early Eocene age (Wolfe, J. A., oral commun., 1975).

The upper Eocene to lower Oligocene plutons are granitic and vented explosively, erupting lava and pyroclastic material on the northwest side of the Alaska batholith (Reed and Lanphere, 1973).

The upper Oligocene pluton is granitic (Reed and Lanphere, 1973). This small pluton intruded the Bruin Bay fault 10 kilometres (6 mi.) east of Kulik Lake. The pluton has not been broken by subsequent movement (Detterman, R. L., 1976, oral communication). The fault probably moved before, but not after, deposition of the upper Oligocene Hemlock Conglomerate.

Holocene (Recent) extrusive volcanic activity can be seen in the area as demonstrated by Mounts Augustine, Iliamna, Redoubt and Spurr. This activity can be related indirectly to the present Benioff zone that is about 115 kilometres (70 mi.) beneath these stratovolcanos (Lahr and others, 1974).

In summary, the Alaska-Aleutian batholith has a geochemical composition indicative of an arc sequence, and it represents plutonic activity which recurred in about the same belt from the Early Jurassic to the Holocene. The Holocene volcanic activity is clearly related to the Aleutian Benioff zone, so it is likely that the earlier magmatic events were related to the ancestral counterpart of this zone. The implacement of these plutons created topographic relief resulting in erosion of overlying sedimentary rocks and eventually the plutons.

Bruin Bay Fault

The Bruin Bay fault (fig. 2) is a high-angle reverse fault that juxtaposes granitic rock and Early Jurassic and older sedimentary rocks on the west side against Middle Jurassic and younger sedimentary strata to the east. The fault, or fault system, can be traced for 225 kilometres (140 mi.) from the intrusion east of Kulik Lake to Drift River. The plane of the fault dips 60 degrees northwest in the Kamishak Bay area. Rocks on the southeast or downthrown side of the fault are steeply dipping to overturned. An anticline is parallel to and near the fault trace between Chenik Lake and the Iniskin Peninsula.

Just north of Chinitna Bay, where rocks of the Talkeetna Formation are in juxtaposition with the Chinitna Formation, the stratigraphic throw is as much as 3,050 metres (10,000 ft.) (Detterman and Hartsock, 1966). Left-lateral strike-slip displacement of 19 kilometres (12 mi.) is possible along this fault, but most of the offset may be accounted for by vertical displacement (Detterman and Hartsock, 1966).

Evidence seems to suggest at least two major movements along the Bruin Bay fault system. The first occurred in Late Jurassic time just prior to the deposition of the Chisik Conglomerate Member of the Naknek Formation. Movement on the fault may have created the highland source area for this high-energy deposit. The second movement, marked by the intrusion west of Chenik Lake, occurred more than 25 million years ago and preceded deposition of the Hemlock Conglomerate. The Hemlock is a high-energy deposit that probably was derived from the Alaska-Aleutian batholith (Hartman and others, 1972). The Chisik Conglomerate Member and the Hemlock Conglomerate have not been identified west of the Bruin Bay fault. The Tyonek Formation overlies the Hemlock Conglomerate, and the upper part of the Tyonek overlaps the Bruin Bay fault and rests unconformably on the West Foreland Formation as at Capps Glacier.

The Bruin Bay fault marks the western boundary of the potential petroleum province in lower Cook Inlet. West of this fault the rocks are plutonic, extrusive volcanic, volcaniclastic sediments, or metamorphosed sedimentary units. East of this fault are gently folded unmetamorphosed sedimentary rocks.

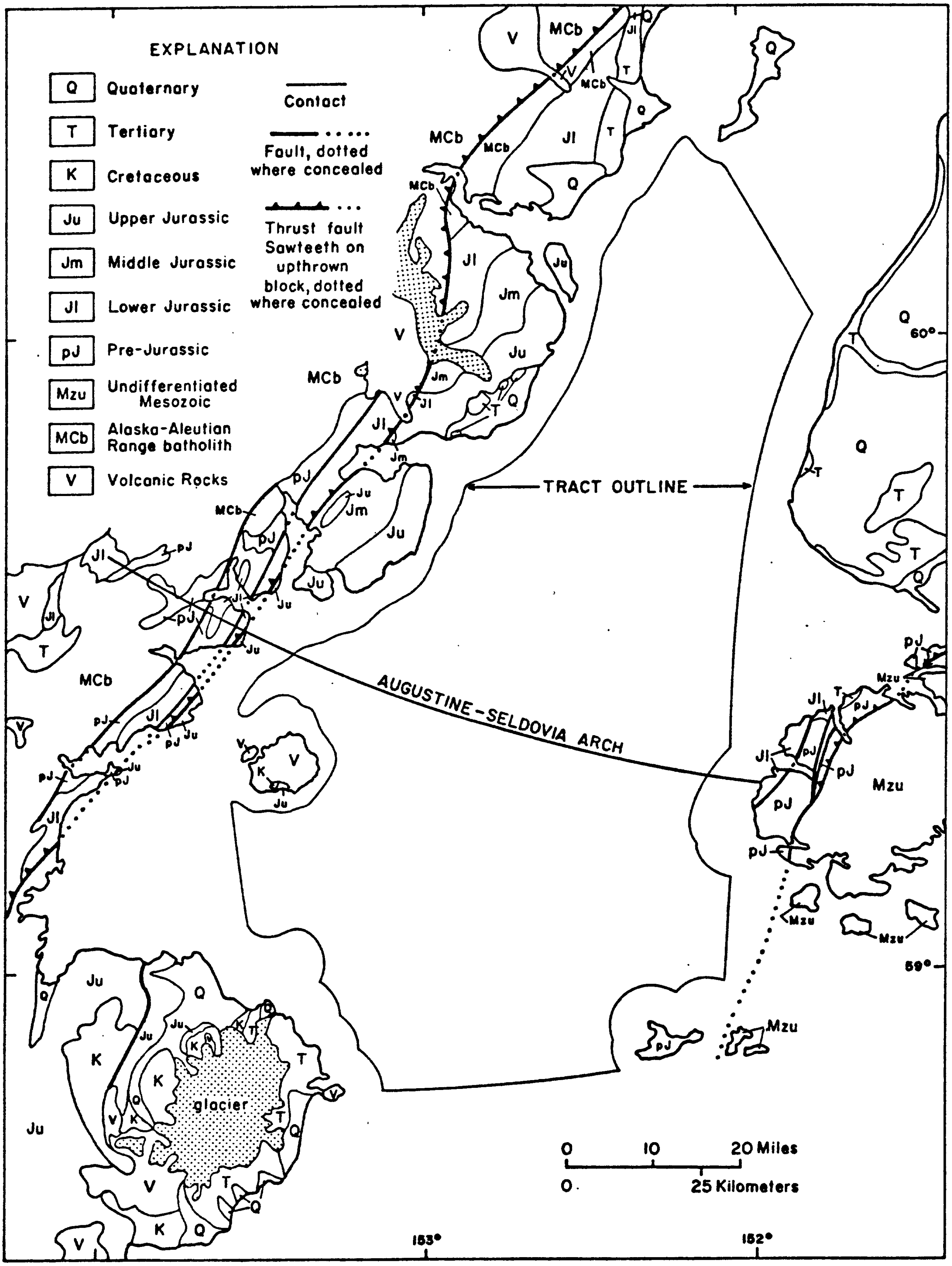


Figure 5. Generalized geologic map of lower Cook Inlet.

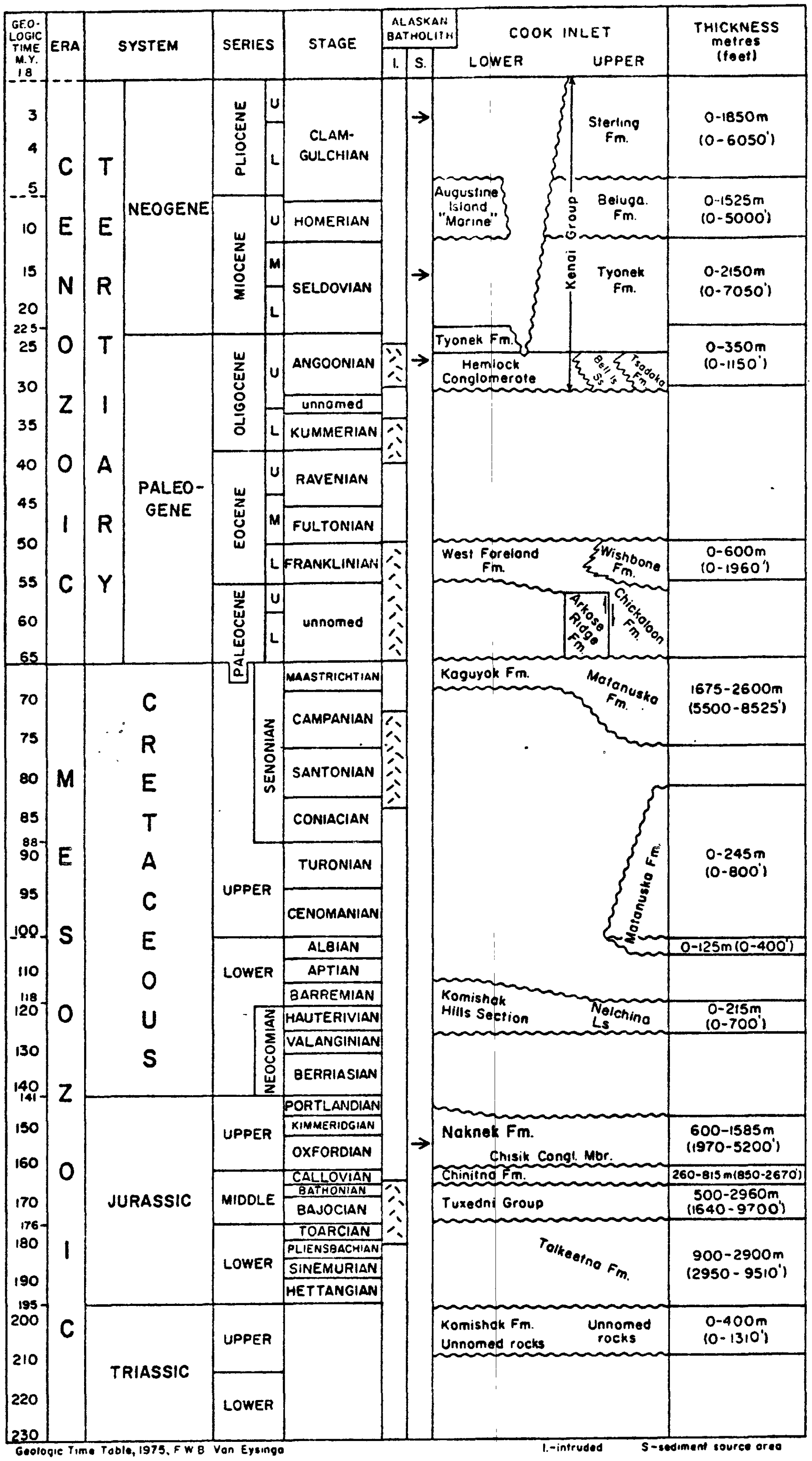


Figure 6. Stratigraphic section in Cook Inlet area.

Matanuska Terrane

Pre-Triassic Rocks: There are indications of pre-Triassic rocks in the vicinity of Cook Inlet (Churkin, 1973; Clark, 1972; Jones and others, 1972). West of the Border Ranges fault the sedimentary rock may be late Paleozoic in age as some data suggests, but the terrane east of the Border Ranges fault is probably Triassic and younger.

Upper Triassic: Rocks of Late(?) Triassic age are located on the west side of the Bruin Bay fault from Kamishak Bay (Detterman and Reed, in press) to the Iniskin-Tuxedni region (Detterman and Hartsock, 1966) In the Seldovia area rocks of similar age are exposed between Port Graham and Koyuktolik Bay (Martin and others, 1915). On the west side of Cook Inlet part of the Triassic rocks are assigned to the Kamishak Formation. Triassic rocks are as much as 400 metres (1,310 ft.) thick and consist of metamorphosed limestone, tuff, chert, sandstone, shale, and basaltic lava flows (Detterman and Hartsock, 1966). These rocks lie west of the Border Ranges fault and on or east of the Alaskan-Aleutian batholith. Pelecypods of Late Triassic age are present on both sides of Cook Inlet, but they are more abundant in the Seldovia area (Detterman and Hartsock, 1966; Martin and others, 1915). This suggests that Upper Triassic rocks are present under the Inlet and marine influences increase southeastward.

Radiolarian cherts and ellipsoidal basalts mapped along the south shore of Kachemak Bay east of the Border Ranges fault are ~~not~~ Triassic as suggested by Martin, Johnson, and Grant (1915).

Lower Jurassic: The Lower Jurassic rocks on the west side of lower

Cook Inlet are represented by volcanic agglomerates and breccias of the Talkeetna Formation (Detterman and Hartsock, 1966). These are extrusive andesitic volcaniclastic rocks that probably issued from a magma chamber that was later to become the Alaska-Aleutian batholith. In the Iniskin-Tuxedni region the formation ranges in thickness from 1,500 to 2,800 metres (4,900-9,200 ft.).

The Talkeetna Formation near Seldovia consists of volcanic tuff, agglomerate, breccia, and some interbedded marine sandstone, shale, and limestone (Martin and others, 1915; Forbes and Lanphere, 1973). The thickness of the formation is uncertain, but with an estimated 30° dip northwest, the thickness is calculated to be 300 metres (1,000 ft.) (Martin and others, 1915). The marine fauna suggests an Early Jurassic age for these sedimentary rocks (Martin and others, 1915).

The Talkeetna Formation probably underlies the lower Cook Inlet. This formation is considered the economic basement for the area because it probably lacks petroleum source and reservoir rock characteristics.

Middle and Upper Jurassic: Overlying the Lower Jurassic volcaniclastic rocks are the thick Middle and Upper Jurassic marine sedimentary rocks. These rocks are exposed only on the west side of the Inlet, east of the Bruin Bay fault. In upper Cook Inlet these rocks are penetrated in some of the oil fields, for example the Swanson River oil field in the Kenai Lowland. From Tuxedni Bay south to Kamishak Hills, Middle and Upper Jurassic rocks dip into and probably underlie the Inlet. Seismic evidence suggests these units are truncated and dipping west near the Kenai Peninsula and the Barren Islands (Fisher, M. A., oral commun., 1976). In this report the Middle and Upper Jurassic rocks are divided into the Tuxedni Group, Chinitna Formation, and Naknek Formation (fig. 6).

Unconformably overlying the Lower Jurassic is the Middle and Upper Jurassic Tuxedni Group. This unit probably represents debris from erosion of sediments overlying the Alaskan batholith. The rocks consist of alternating fossiliferous greywacke sandstone and siltstone deposited in a shallow marine environment. The Tuxedni Group is 1,515 to 2,960 metres (5,000 - 9,700 ft.) thick in the Iniskin-Tuxedni region and includes, in upward order, the Red Glacier Formation, Gaikema Sandstone, Fitz Creek Siltstone, Cynthia Falls Sandstone, Twist Creek Siltstone, and Bowser Formation (Detterman and Hartsock, 1966).

The Upper Jurassic Chinitna Formation unconformably overlies the Tuxedni Group and ranges in thickness from 260 to 815 metres (850-2,670 ft.). The Chinitna Formation is predominantly dark-grey siltstone that commonly includes large concretions. Exposures of this marine siltstone extend from Iniskin Bay northeast to Chisik Island in Tuxedni Bay. Though no geochemical data is available, the Chinitna is considered a petroleum source rock because of its color and grain size.

The Upper Jurassic Naknek Formation unconformably overlies the Chinitna Formation and crops out in the Kamishak Hills northeastward to Tuxedni Bay. In the Iniskin-Tuxedni region the Naknek Formation is as much as 1,585 metres (5,200 ft.) thick and is divided into the Chisik Conglomerate, lower sandstone, Snug Harbor Siltstone, and Pomeroy Arkose Members (Detterman and Hartsock, 1966). About 40 percent of the clasts in the Chisik Conglomerate are intrusive rock of the same radiometric age as the Lower to Middle Jurassic Alaska-Aleutian batholith (Detterman and Hartsock, 1966). The lenticular, conglomerate member is found east of the Bruin Bay fault only, suggesting the fault moved at this time. The conglomerate is the first indication of the Alaska-Aleutian batholith as a source for sediments and records deroofing of the plutons. The Naknek Formation represents a transgressive sequence that starts with a nonmarine or shallow-marine conglomerate (or the interfingering shallow-marine lower sandstone member) that grades up into the Snug Harbor Siltstone Member. The overlying Pomeroy Arkose Member is probably a deeper marine sandstone. The Naknek Formation exposed on the coast in Kamishak Bay is younger than the Pomeroy Arkose Member in the Iniskin-Tuxedni region (Imlay and Detterman, 1973). A stratigraphic section approximately 750 metres (2,460 ft.) thick, from the Bruin Bay fault on the coast to the Kamishak Hills, includes a conglomerate that is younger than the Chisik Conglomerate and is overlain by a thinly bedded, very fine grained fossiliferous, shallow-marine sandstone. Pelecypods collected from this section suggest an age younger than the Naknek strata at Chisik Island in the Iniskin-Tuxedni region.

<u>Lower Cretaceous</u>: The Lower Cretaceous rocks unconformably overlie Upper Jurassic beds in the Kamishak Hills at the northeastern end of the Alaska Peninsula (Jones and Detterman, 1966). Rocks of the same age have been described in the Nelchina area, northeast of Anchorage, as the Nelchina Limestone and in the Herendeen Bay area, on the Alaska

Peninsula, as the Herendeen Limestone (Jones and Detterman, 1966). The Lower Cretaceous rocks contain abundant Inoceramus fragments and belemnites. The age of the rocks ranges from the Berriasian to Barremian (Jones, 1973). There are no fossils of known Aptian age in this part of Alaska which suggests a slight emergence at this time (Jones, 1973).

Lower Cretaceous rocks about 215 metres (700 ft.) thick are exposed in the Kamishak Hills. This rock unit can be mapped from Kaguyak Bay northward through the Kamishak Hills, and it may be present in the subsurface in offshore lower Cook Inlet. The Lower Cretaceous rocks, described by Jones and Detterman (1966), are shown in figure 7.

Rocks of Albian age, considered part of the Matanuska Formation (fig. 6), are recognized in the Matanuska Valley (Jones and Grantz, 1967) and Wrangell Mountains (Jones, 1973). Minor unconformities are found in the sandstone and shale sequence, but this general depositional pattern continues in the Matanuska Valley into Late Cretaceous time (Jones and Grantz, 1967).

Upper Cretaceous: Upper Cretaceous rocks are assigned to the upper part of the Matanuska Formation (Jones and Grantz, 1967) and to the Kaguyak Formation (Keller and Reiser, 1959). The Matanuska Formation in the Upper Chitina Valley contains intraformational unconformities suggesting many orogenic pulses. The rocks range in age from Albian (mentioned above) to Maestrichtian and consist of sandstone, shale, and siliceous shale in the lower part with conglomerate, sandstone, siltstone, shale and limestone concretions in the upper part. Most

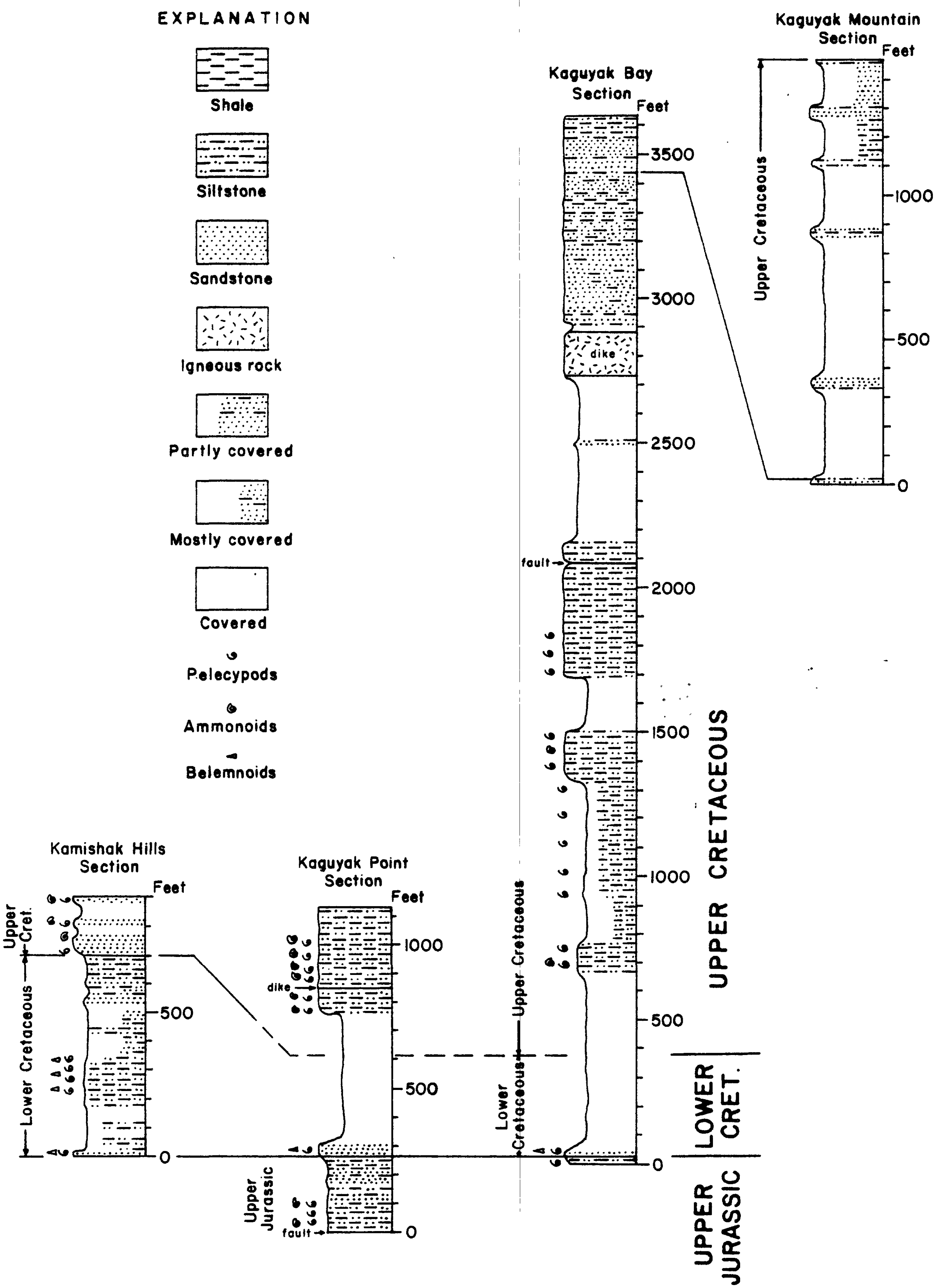


Figure 7. Lower and Upper Cretaceous measured sections.

of the sediment for the Matanuska Formation probably came from the north, but some rock units of the formation thicken and coarsen in the Chugach Mountains to the south, suggesting that this area was positive (Kirschner and Lyon, 1973).

The Kaguyak Formation is exposed in Kaguyak Bay, Kamishak Hills, and in an area 11 kilometres (7 mi.) north of Mount Douglas where it is unconformably overlain by Tertiary conglomerate (fig. 7). Maestrichtian ammonites are present near the base of this unit. In the Kamishak Hills the basal sandstone of the Kaguyak Formation unconformably overlies the Lower Cretaceous rocks. The Upper Cretaceous strata have been penetrated by drilling in upper Cook Inlet and in the Kenai Lowland (Kirschner and Lyon, 1973). The presence of Upper Cretaceous rocks at each end of Cook Inlet and in the subsurface around parts of lower Cook Inlet strongly suggest their presence offshore.

Tertiary: The Tertiary rocks of the Cook Inlet basin (including Matanuska Valley) are divided into an early Paleogene sequence and a late Paleogene-Neogene sequence (fig. 8). The early Paleogene sequence includes the Arkose Ridge and Chickaloon Formations, of Paleocene age, and the Wishbone and West Foreland Formations and unnamed rocks near Copper Lake (west of Ursus Cove), all of late Paleocene to early Eocene age. The late Paleogene-Neogene sequence, of Oligocene to Pliocene age, includes, in upward order, the Hemlock Conglomerate and lateral equivalents (Bell Island Sandstone and Tsadaka Formation), and the Tyonek, Beluga, and Sterling Formations. In the Cook Inlet area Tertiary rocks are commonly termed the Kenai Group and divided into

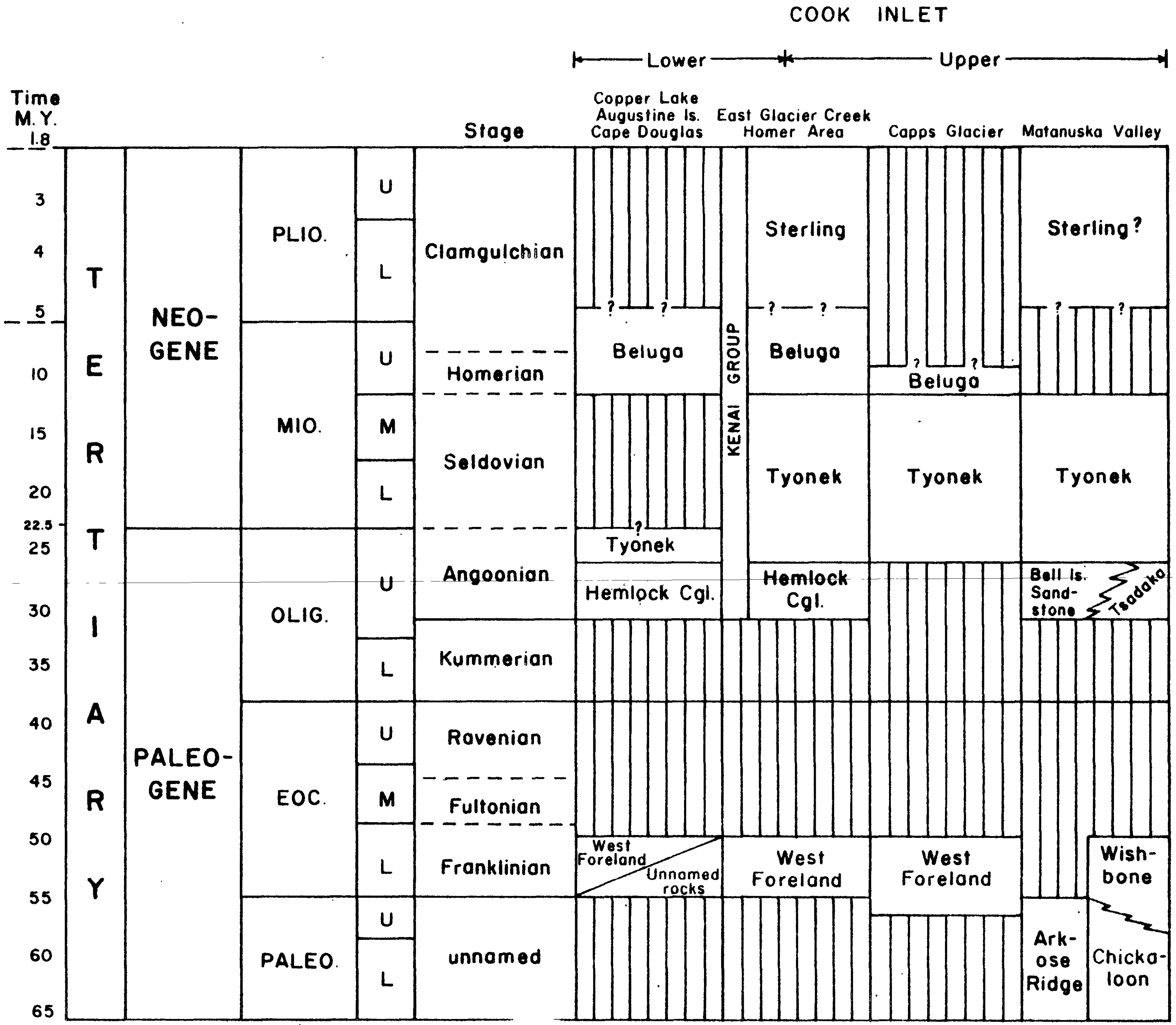


Figure 8. Tertiary correlation chart

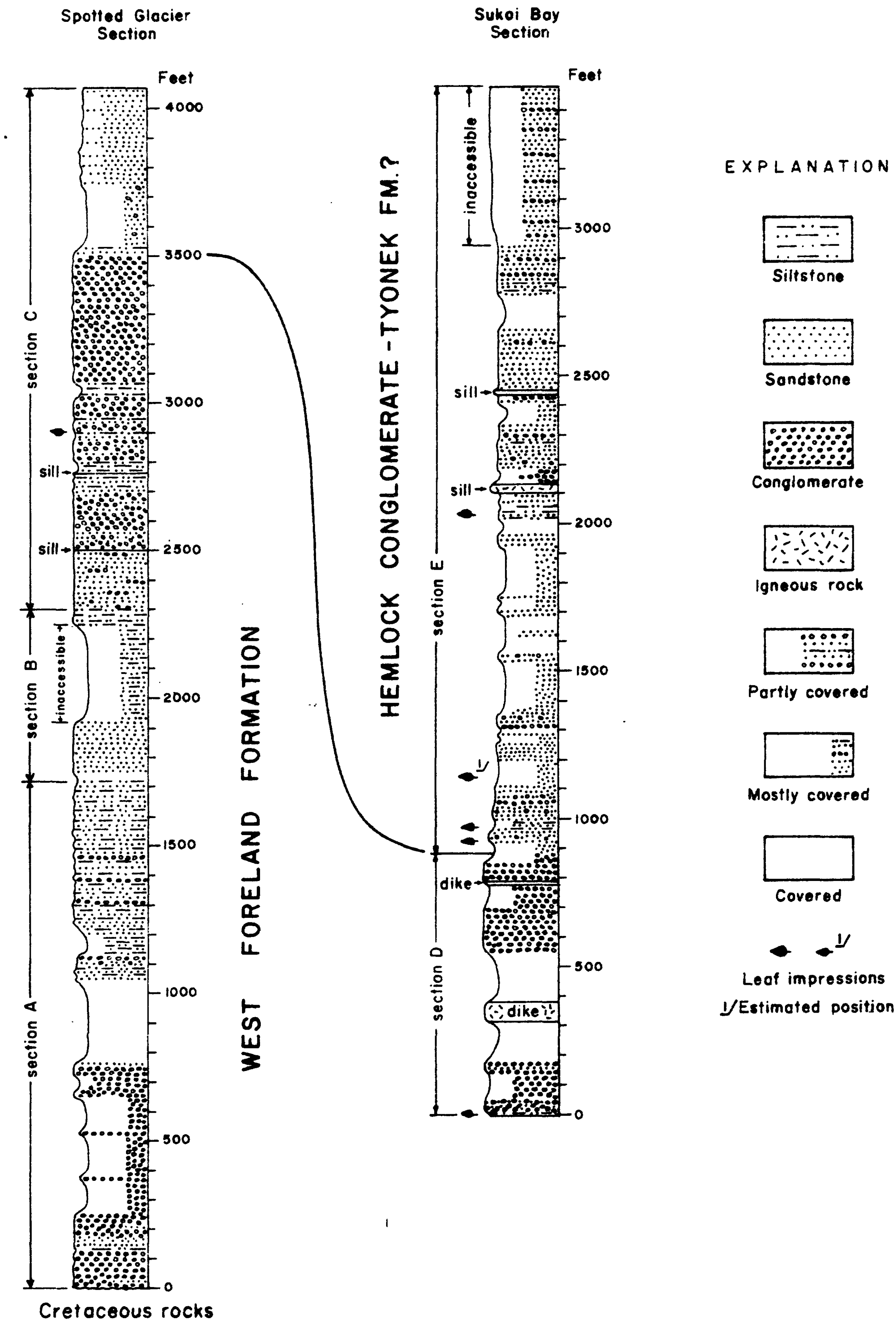


Figure 9. Cape Douglas Tertiary measured section.

the West Foreland Formation, Hemlock Conglomerate, and Tyonek, Beluga, and Sterling Formations (Calderwood and Fackler, 1972).

The classification of Calderwood and Fackler (1972) is used here except that the West Foreland Formation is excluded from the Kenai Group (fig. 8). The lithologic composition of the West Foreland is considerably different from the younger formations in that it generally includes much tuffaceous and volcaniclastic material. The younger Tertiary formations compose a related sequence of conglomerate, sandstone, siltstone, and coal. In addition a considerable hiatus between the West Foreland and the overlying Hemlock Conglomerate is suggested by recent work on fossil leaves by J. A. Wolfe (oral commun., 1975). He assigns an early Eocene age to the upper part of the West Foreland and a late Oligocene age to the Hemlock.

Blueschist Facies

A glaucophane-bearing metamorphic rock was first recognized by Martin, Johnson, and Grant (1915) near Seldovia, Alaska (figs. 1, 5). Forbes and Lanphere (1973) described this rock as a blueschist facies of Late Triassic to Early Jurassic age (190$\pm$10 m.y. ago). Lawsonite, jadeite, and aragonite have not been found in these rocks, but crossite, epidote, albite, chlorite, and quartz are present with trace quantities of carbonate, mica, and pumpellyite. The presence of epidote and calcite suggests a high-temperature subdivision of the blueschist facies as defined by Taylor and Coleman (1968). Associated with the blueschist facies is some greenschist which is probably a product of this high-temperature blueschist.

The surface geology indicates that the blueschist rocks are in fault contact with Triassic and Lower Jurassic rocks. The Triassic rocks on the west include pillow and amygdaloidal basalt, tuffaceous conglomerate and breccia, chert, and serpentinite. The Lower Jurassic rocks dip northwest and consist of agglomerate and tuff with intercalated shale and limestone.

The rock that makes up the blueschist facies is considered a dismembered ophiolite sequence that formed from oceanic crust (Forbes and Lanphere, 1973). The blueschist facies is a product of subduction rather than continental collision for the following reasons: 1) lack of continental crust on either side of the suture, 2) the blueschist facies appears to be faulted in with high-angle faults rather than low-angle thrust faults, and 3) the high-temperature nature of the facies suggests considerable depth, not a near-surface high-pressure phenomena.

Border Ranges Fault

The Border Ranges fault is considered the boundary between the subducted oceanic plate and the continental plate (MacKevett and Plafker, 1974) and is considered the eastern boundary of the forearc basin. As the glaucophane-bearing metamorphic rocks at Seldovia suggest, subduction between these plates occurred between Late Triassic and Early Jurassic time. The most recent movement along the Border Ranges fault occurred in late Mesozoic or early Tertiary time. Mesozoic rocks are faulted; middle Tertiary rocks apparently are not offset.

Chugach Terrane

McHugh Complex: The McHugh Complex includes metasedimentary and metavolcanic rocks in the Chugach Mountains near Anchorage (Clark, 1972, 1973) and on the Kenai Peninsula east of the Border Ranges fault. The metasedimentary rocks include siltstone, sandstone (greywacke, arkose) and conglomerate. The metavolcanic rocks include pillow basalt and massive greenstone with slightly metamorphosed radiolarian chert and argillite. The age of the McHugh Complex is Late Jurassic and (or) Cretaceous (Clark, 1972, 1973).

The metamorphic grade of the McHugh Complex varies from the zeolite to the prehnite-pumpellyite facies. Parts of this complex can be described as a melange (Clark, 1973). The McHugh Complex is more deformed than the Valdez (?) Group (Clark, 1972).

Valdez (?) Group: The Valdez (?) Group is a thick unit of sedimentary rock that extends 1,600 kilometres (1,000 mi.) from the Chugach Mountains to Sanak Island (Payne, 1955; Burk, 1965; and Moore, 1975). This group, a flysch sequence, is also known as the Kodiak Formation or the Shumagin Formation. The rocks consist of highly deformed and metamorphosed sandstone, siltstone, shale, and some conglomerate (Clark, 1972). The sandstone and siltstone are commonly rhythmically bedded (Clark, 1972). The depositional environment is considered deep water in excess of that for the coeval Matanuska Formation. The age of the Valdez (?) Group is considered Maestrichtian, as suggested by *Inoceramus kusiroensis* in a few fossil collections, but the lower part could be as old as Late Jurassic (Jones and Clark, 1973).

The metasedimentary rocks are phyllitic in some areas and metamorphic minerals suggest a lower greenschist facies. Minerals include chlorite, white mica, albite, and epidote (Clark, 1972). Prehnite is absent in the Valdez (?) Group except where it is in fault contact with the McHugh Complex (Clark, 1972).

Geophysics

Seismic data: In the summer of 1975 the U.S. Geological Survey contracted with Western Geophysical, Inc. to obtain 485 kilometres (300 mi.) of 36-fold marine seismic data in lower Cook Inlet.
The energy source was an array of six guns; each gun detonated a mixture of propane, oxygen, and air in an expandable rubber boot (Aquapulse [TM]). The detectors were 72 groups of hydrophones arranged along a 2700-metre (8,860 ft.) streamer. Six seconds of data sampled at a 2-millisecond rate were recorded using DDS-888 instruments. The navigation system was a combined Raydist-RPS system operated by Navigation Services, Inc. The positional accuracy of this system is about 15 metres (50 ft.). Petty-Ray Geophysical, Inc. prepared the data for interpretation.

A simplified schematic representation of the major reflecting horizons observed in the seismic data is shown in a northwest-southeast cross section compiled from the data north of Cape Douglas (fig. 10). Strata above the A-horizon onlap that horizon to the north and northwest. There is good seismic evidence that the A-horizon represents an erosional surface. It appears to truncate deeper reflectors, and angular discordance of reflectors is evident across the A-horizon. The B-horizon apparently truncates deeper reflectors, so it too may be an erosional surface.

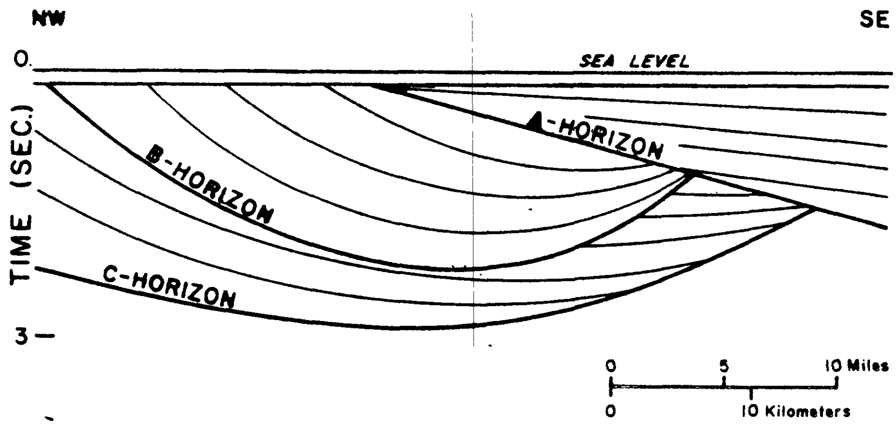


Figure 10. Simplified relations between major horizons in a northwest-southeast cross section. The A- and B-horizons may be returned by erosional surfaces; the C-horizon forms the acoustic basement.

The acoustic basement, labeled C-horizon in figure 10, allows no information to return from deeper reflectors, so the geologic nature of that surface and underlying rock units remains unknown. The strata just above the C-horizon appear to lap southeastward onto northeast-sloping topography formed by the C-horizon. Preliminary ties to onshore geology yield the following tentative correlations: the A-horizon might be near the base of the Tertiary; the B-horizon could be a basal Tertiary or a Cretaceous erosional surface; and the C-horizon might be from a Jurassic or older interface. Further study is necessary to date the offshore stratigraphy adequately.

Generalized contour maps of two-way seismic traveltime have been produced for the shallow A-horizon (fig. 11) and the deep C-horizon (fig. 12). These maps also show axes of anticlines interpreted from the data. The water-transit time (between .04 and .25 seconds) has not been removed from the traveltimes, so the contours are referenced to sea level.

Seismic data above the A-horizon indicate that the reflectors onlap northwestward to the outcrop of the A-horizon at the bottom of the Inlet waters. The outcrop line (fig. 11) follows the water bottom, therefore it is not an isochron. Near the outcrop line the reflectors above the A-horizon onlap an anticlinal structure. Further to the southeast, near line 757, the same reflectors are involved in anticlinal folding. Time transgression may thus be indicated for the deposition of the reflectors or the formation of the structures or both. There are insufficient data to distinguish the order of

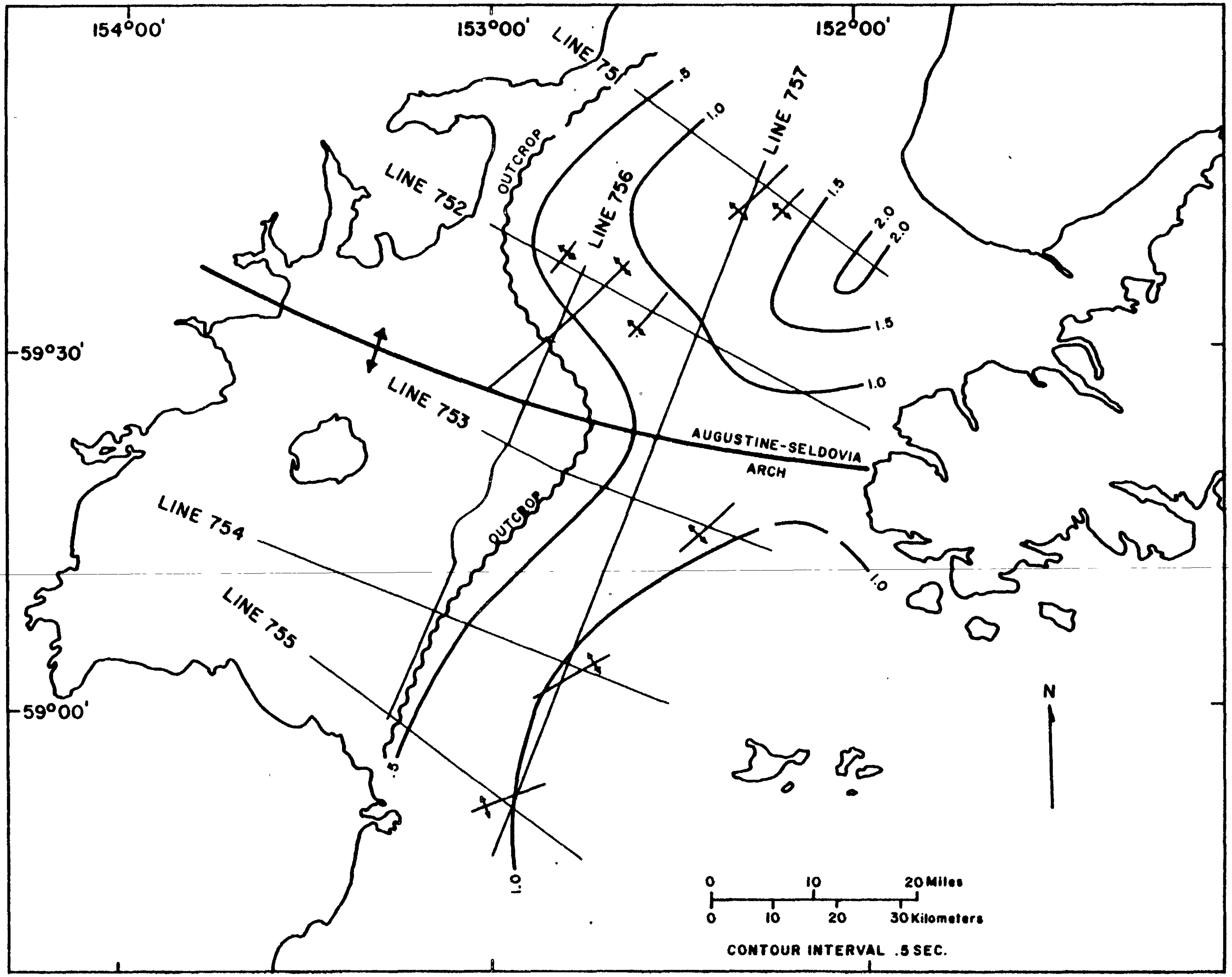


Figure 11. Generalized contours of two-way time to the A-horizon. The outcrop line on the map is not an isochron but shows the location of the truncation of the A-horizon at the sea floor.

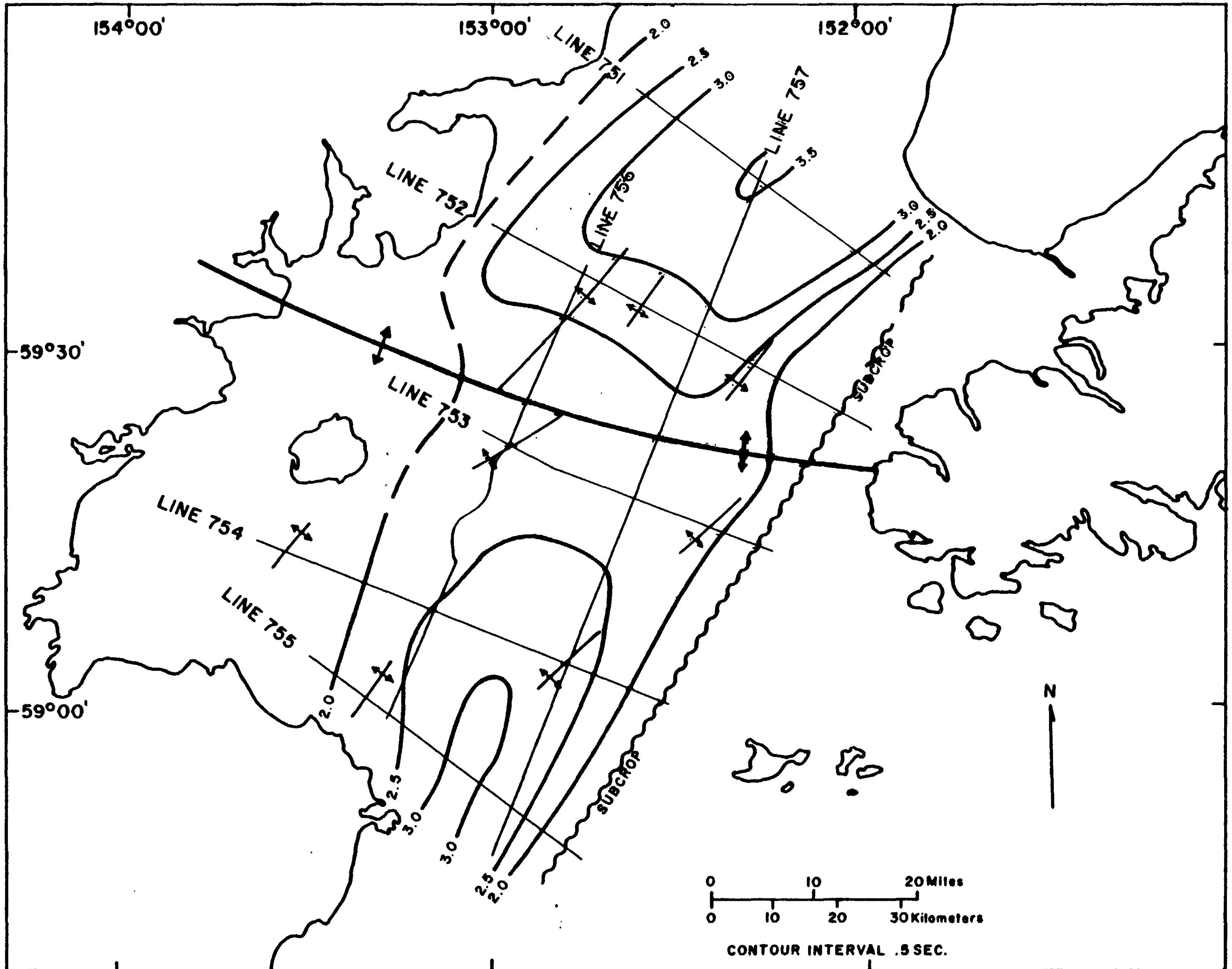


Figure 12. Generalized contours of two-way time to the C-horizon. The subcrop line on the map is not an isochron but shows the location of the truncation of the C-horizon by the A-horizon.

occurrence, but the folds seem to have formed during the burial of the A-horizon.

The anticlinal folds mentioned above appear to strike to the northeast wherever determination of the trend can be based on two seismic lines. The northeast-trending structural axes conform to the strikes of structural axes reported from upper Cook Inlet by Kirschner and Lyon (1973), from the Iniskin Peninsula by Detterman and Hartsock (1966), and from the Kamishak Hills. Consequently, where no control exists for the trend of structures interpreted from the seismic data, a northeast trend has been assumed. Some anticlines are breeched on one flank by high-angle reverse faults. Along line 752 these faults are mostly confined to the flank that faces the deeper part of the basin. Similar faulted anticlines in upper Cook Inlet are described by Kirschner and Lyon (1973). Thus upper Cook Inlet may be useful as a structural analog for lower Cook Inlet. The wavelengths of the folds appear to average about 8 to 12 kilometres (5-7 mi.). Line 752 shows that the wavelengths of the anticlines appear to increase as the sedimentary rocks in the basin thicken (relative sediment thickness is assumed to be roughly indicated by the time to the deep C-horizon). The thickness of the sedimentary rocks in the basin may have a controlling influence on the wavelengths of the folds. However, the true strikes of the anticlines are unknown, and the apparent increase in wavelength could be due to increasingly oblique angles between the seismic line and the anticlinal axes.

The major structural feature of lower Cook Inlet is an east-trending transbasin arch informally called the Augustine-Seldovia arch (fig. 11). The arch shows clearly in the contours of figure 11 just northeast of Augustine Island. It has a wavelength of about 30 kilometres (19 mi.), so it is much larger than the northeast-trending folds described above. The importance of this transbasin arch to the structural geology of lower Cook Inlet is shown by the plunging of the Cook Inlet trough to the north and to the south from this feature; the arch forms a hinge about which the entire trough is flexed. Reflectors above the A-horizon appear to thin toward the crest of the arch and to change character across it. Reflectors just below the A-horizon apparently do not thin or differ in character. Therefore, the arch may have influenced the type or amount of sediment deposited on its north and south sides after formation of the A-horizon, but perhaps it exerted no influence before the A-horizon formed.

The Augustine-Seldovia arch may extend to the northwest beyond Augustine Island along the strike depicted in figure 11. The geologic map by R. L. Detterman and B. L. Reed (unpub. data) shows Triassic rocks at Ursus Head that are bounded on the north and south by Jurassic rocks. The relatively large size and geographic extent of the arch suggest that it resulted from major crustal processes, but the genesis of the arch remains enigmatic because its axis nearly parallels the direction of compression from the Aleutian trench to the southeast.

The contour map of the C-horizon indicates the minimum thickness of sedimentary rocks in the Inlet. The C-horizon is truncated by the A-horizon as shown schematically in profile (fig. 10). The nearly straight line of truncation depicted in plan (fig. 12) is not an isochron but shows the geographic location of the subcrop. Within the resolution and line spacing of the seismic data, the subcrop line apparently is not horizontally deflected by the Augustine-Seldovia arch, nor is it seismically evident that reflectors deeper than the A-horizon thin onto the arch. However, the outcrop of the A-horizon is horizontally deflected, and reflectors above the A-horizon appear to thin onto the arch. Determining the geologic age of the A-horizon is an important objective of future research, because the Augustine-Seldovia arch may have formed at about the same time.

In places the C-horizon is involved in folds that are not evident in the A-horizon. Disharmony between the shallow and deep structural styles suggests at least one intervening period of uplift and erosion. One period may be represented by the B-horizon.

The Augustine-Seldovia arch may well be the focus of petroleum exploration in lower Cook Inlet. Thinning of the shallow reflectors could form stratigraphic traps on the flanks of the arch. In the strata below the A-horizon, where no effects of the arch on sedimentation are seismically evident, the traps may be structural and near the crest of the arch. Because the arch flexes the Cook Inlet trough, updip migration from both upper Cook Inlet and Shelikof Strait could bring petroleum to the vicinity of the arch. The Augustine-Seldovia arch offers closure in a north-south direction; some of the northeast-trending anticlines could provide needed additional closure in an east-west direction at their intersection with the arch. Such an intersection may occur about 20 kilometres (12 mi.) northeast of Augustine Island. An anticline near the intersection of lines 756 and 752 (fig. 11) may be large enough to extend southwest to an intersection with the arch. Structural traps may occur northeast of Augustine Island at the intersections of the arch with speculative extensions of the structures on the Iniskin Peninsula (Detterman and Hartsock, 1966). Several other northeast-trending anticlines in lower Cook Inlet have potential as sites for petroleum accumulations. At the southeast end of line 751, west of Homer, reflectors rise onto a structure at the mouth of Kachemak Bay, but the seismic line does not cross the structural axis. No seismic evidence was found that indicated the presence of hydrocarbon accumulations, but no process specifically tuned to locate amplitude anomalies ("bright spots") was applied to the data.

Gravity Data: The gravity data available for northern Cook Inlet shows a large negative simple Bouguer anomaly of about -150 mgal (Barnes, 1967). The anomaly is centered over the Inlet waters north of the Forelands (fig. 13). Thick accumulations of Tertiary strata with significant petroleum reserves are in this part of the Cook Inlet trough. The gravity data for lower Cook Inlet shows steadily increasing gravity values southward. An area of positive anomaly (up to 50 mgal) occurs near Cape Douglas, the Barren Islands, and the Kenai Peninsula. Mesozoic rocks are exposed in the areas of strongest positive anomaly. The gravity data suggests that the thick Tertiary section in northern Cook Inlet gradually thins toward the south and pinches out near the outcrop of Mesozoic rocks. Because of the reduced Tertiary thickness

Figure 13. Bouguer gravity map, Cook Inlet area, D. F. Barnes.

in the south, the Mesozoic rocks probably will become the primary target of oil exploration. The gravity data shows an area of positive anomaly trending approximately westward from near Seldovia. This is an expression of the Augustine-Seldovia arch, where dense Mesozoic rocks are brought closer to the surface.

Magnetic data: Total-intensity aeromagnetic coverage in the southern Cook Inlet consists of two northwest-trending profiles which begin near Seldovia and end near the Iniskin Peninsula (Grantz, Zietz, and Andreasen, 1963). The profiles are not adjusted to a common datum; so only qualitative comparison between profiles is possible. The relatively high magnetic anomaly near the center of the Inlet may be due to accumulations of volcaniclastic rock of the Lower Jurassic Talkeetna Formation. Toward the Kenai Peninsula, the magnetic anomaly decreases, perhaps signifying decreasing thickness of the volcaniclastic rocks eastward. Following the magnetic profiles to the northwest of the center of the Inlet, magnetic features are encountered which may be due to faulting. Grantz, Zietz, and Andreasen (1963) correlated a feature between magnetic profiles which follows the trend of the Bruin Bay fault; another magnetic indication of possible faulting is located just offshore from the Iniskin Peninsula.

Geologic History

Lower Cook Inlet is part of the eastern Aleutian arc-trench system that has a geologic history dating back to at least Triassic time. The rock record is not complete, but there seems to be sufficient evidence to make some general conclusions. First, the arc has remained stationary with respect to the forearc basin, thus the trench migrated away from the arc as accretion took place. Second, tectonic deformation in coeval sediments increases as the trench is approached. Third, the tectonic style involves compression and underthrusting represented as high-angle faults. This compression is expressed in the rock record in the forearc basin by low-amplitude folds, that continually grow and are partially truncated by those succeeding cycles that end in periods of erosion. Fourth, vertical uplift, resulting in emergence of submarine sediment, can occur in the arc area as well as in the outer-arc ridge area. Finally, this accretionary arc-trench system can be divided into six tectonic cycles lasting 35-45 m.y. each. Each cycle in the evolution of this arc-trench system is discussed below.

Triassic through Early Jurassic time (40 m.y.): During most of Triassic time, oceanic deposition of pelagic and hemipelagic sediments predominated. In Late Triassic time a subduction belt commenced in the vicinity of Seldovia (at least no farther southeast) and continued into Early Jurassic time until extrusive volcanic activity occurred and portions of the Alaska-Aleutian batholith were emplaced. Why a subduction zone occurred in oceanic crust is uncertain, but there may be a present-day analog in the Indian Ocean where shallow epicenters are located (Dewey and Bird, 1970). The Lower Jurassic Talkeetna Formation, consisting of extrusive volcanic material, probably overlapped the subduction zone near Seldovia and might have been faulted up later. Seaward of the subduction zone, oceanic sedimentation continued.

Middle through Late Jurassic time (35 m.y.): By the end of Early

Jurassic time, extrusive volcanism ceased, and uplift of the Alaska-Aleutian batholith ensued. The uplift provided a source area for shallow-water deposits of Middle and Late Jurassic age. These strata include the Tuxedni Group, Chinitna Formation, and Naknek Formation. The subduction belt or trench was accreting to the southeast from Seldovia, and the continental (?) shelf was narrow, allowing terrigenous sediments to reach deep water and form the McHugh Complex. The presence of pillow basalts in the McHugh suggests that it contains portions or scrapings of oceanic crust. This tectonic setting continued to the end of Jurassic time and possibly into Early Cretaceous time.

Early Cretaceous (Berriasian-Aptian; 35 m.y.): During Early Cretaceous time, shallow-water sediments were being deposited on the shelf or in the area of the Kamishak Hills. The youngest part of the McHugh Complex or the oldest part of the Valdez (?) Group was probably being deposited in the fore-slope and trench. A thin veneer of sediments could have been deposited over the outer-arc ridge while a much thicker sequence was being deposited in the fore-slope, trench, and abyssal plain. The forearc basin underwent several periods of uplift-erosion and downwarp-sedimentation during the Cretaceous.

Early through Late Cretaceous (Albian-Maestrichtian; 45 m.y.): The Early Cretaceous (Albian) shallow-water strata and the Late Cretaceous shallow-to deep-water sedimentary rocks are represented by the Matanuska and Kaguyak Formations. This tectonic-sedimentation cycle was complete in Late Cretaceous time. At the end of this time the depositional environment of the fore-arc basin changed from deep marine to nonmarine, and the older McHugh Complex was thrust over the Valdez (?) Group.

In the Chugach Mountains near Anchorage the McHugh Complex is thrust over the Valdez (?) Group (Clark, 1972). The McHugh and Valdez are not found west and north of the Border Ranges fault which can be traced southward to the Seldovia area (MacKevett and Plafker, 1974). Near Seldovia a blueschist assemblage of Late Triassic to Early Jurassic age is in fault contact with the Talkeetna Formation on the west and, on the east, with the McHugh Complex and Valdez (?) Group (Forbes and Lanphere, 1973).

Paleocene through early Oligocene (30. m.y.): This period of readjustment is represented in the Cook Inlet trough by nonmarine conglomerates, sandstones, siltstones, coals, and volcaniclastic rocks. The rocks range in age from Paleocene through early Eocene and are represented by Chickaloon, Arkose Ridge, Wishbone, and West Foreland Formations. During Paleocene time the area between the Alaskan batholith and the trench probably was in anomalously high compression which uplifted the complete forearc basin, thrust the McHugh Complex over the younger Valdez (?) Group, and initiated movement along a high-angle reverse fault in the area of Seldovia (Border Ranges fault). These rocks probably are thickest in the area between West Foreland and the mouth of the Susitna River.

In the forearc basin from middle Eocene through early Oligocene time, there was a period of erosion and non-deposition. This quiescence in the forearc basin set the stage for the final arc-trench tectonic sequence.

Late Oligocene through Holocene (30+ m.y.): From middle Oligocene time the record of events in the forearc basin is comparatively clear. The outer-arc ridge, or Kenai Peninsula, remained emergent to the present. At least once, the outer-arc ridge was a significant source area, but generally it lacked the drainage system to contribute large volumes of sediment to the basin. In late Oligocene time the forearc trough was a half or full graben bounded by highlands which contributed very little sediment. Most of the sediment probably came from a river system (possibly an ancestral Susitna River) with headwaters as far away as the Canadian Shield (Kirschner and Lyon, 1973). The bounding faults during the early part of this cycle probably were the Bruin Bay fault to the northwest and a concealed fault that extends from Turnagain Arm to the Homer Spit. The faults probably limited deposition of the oldest strata, the Hemlock Conglomerate, which is as much as 245 metres (800 ft.) thick. Later, a northern source area began to contribute large amounts of sand and silt (Hartman and others, 1972) that now make up the Tyonek Formation. This formation, as much as 2,135 metres (7,000 ft.) thick, overlaps the faults that confined the deposition of the Hemlock Conglomerate. By middle Miocene time the edges of the Tyonek Formation were uplifted and eroded. The outer-arc ridge became the source area for the next unit, the Beluga Formation (Hayes and others, 1975). The Beluga, as much as 1,525 metres (5,000 ft.) thick, is characterized as a braided stream deposit. During deposition of the Tyonek and Beluga Formations, peat deposits periodically accumulated to considerable thicknesses; these deposits later became beds of lignite and coal. After deposition of the Beluga, the north flank was again uplifted to become the source area for sediments of the Sterling Formation of late Miocene and Pliocene age. The Sterling Formation plus Quaternary deposits can be as much as 2,750 metres (9,000 ft.) thick (Hartman and others, 1972).

Presently deposition in the Cook Inlet is characterized as estuarine; sediments come mainly from Susitna River (Hayes and others, 1975; Ovenshine, A. T., oral commun., 1975). The sediment source area is the Mount McKinley area. Proportionally small amounts of sediment are coming from the Matanuska River Valley. Tectonically this entire area is being uplifted southeast of the Kenai Peninsula area (Plafker, 1969).

PETROLEUM GEOLOGY

Related Hydrocarbon Production

The oil and gas fields in upper Cook Inlet lie between Kalgin Island and the Susitna River (fig. 2). Most of the fields are offshore along the northwest side of the Inlet (table 1). Onshore production includes the Swanson River oil field and the Beluga and Kenai gas fields. The oil, and some associated gas, comes from the lower part of the late Tertiary cycle, whereas the non-associated gas comes from the upper part of this cycle.

The producing oil fields in upper Cook Inlet are: McArthur River, Middle Ground Shoal, Swanson River, Granite Point, Trading Bay, and Beaver Creek. Cumulative production at the end of 1975 is about 677 million barrels of oil. Stratigraphically, 80 percent of the

TABLE 1

OIL AND GAS FIELDS, UPPER COOK INLET

		Cumulative production (12-31-75)		Remaining Recoverable Reserves
Oil fields	Status	Oil (bbl)	Casinghead gas (Mcf)	Oil (bbl)
Beaver Creek	Producing	1,114,905	387,080	---
Granite Point	Producing	60,495,670	56,879,971	49,504,000
McArthur River	Producing	294,217,241	92,888,099	208,784,000
Middle Ground Shoal	Producing	96,332,793	45,821,890	89,166,000
Redoubt Shoal	Shut-in	1,596	456	---
Swanson River	Producing	163,099,388	528,772,426	60,101,000
Trading Bay	Producing	62,577,313	41,421,614	---
Gas fields	Status	Dry gas (Mcf)	Natural gas liquids (bbl)	Dry gas (Mcf)
Albert Kaloa	Shit-in	118,774	---	---
Beaver Creek	Shut-in	291,516	---	400,000,000
Beluga River	Producing	34,647,415	---	687,000,000
Birch Hill	Shut-in	65,331	---	20,000,000
Falls Creek	Shut-in	18,983	---	80,000,000
Ivan River	Shut-in	---	---	5,000,000
Kenai	Producing	639,619,605	9,888	2,250,000,000
Lewis River	Shut-in	---	---	785,000,000
McArthur River	Producing	36,919,664	---	785,000,000
Moquawkie	Shut-in	985,059	---	---
Nicolai Creek	Producing	921,385	---	50,000,000
North Cook Inlet	Producing	268,001,981	---	1,410,000,000
North Fork	Shut-in	104,595	---	20,000,000
North Middle Ground Shoal	Shut-in	---	---	125,000,000
Sterling	Producing	1,848,006	---	200,000,000
Swanson River	Shut-in	11,839,353	---	300,000,000
West Foreland	Shut-in	---	---	120,000,000
West Fork	Shut-in	---	---	100,000,000

production comes from the Hemlock Conglomerate, the lowermost unit in the late Tertiary cycle. Much of the remaining 20 percent comes from the overlying Tyonek Formation. Less than 2 percent of the production is from the West Foreland Formation of the oldest Tertiary cycle.

Non-associated gas production comes from the following gas fields: Kenai, North Cook Inlet, Beluga River, and a few other small fields. Most of the production is from the Beluga and Sterling Formations in the upper part of the late Tertiary cycle. Older formations produce minor amounts of non-associated gas. Presumably, the bulk of this gas is formed by bacterial degradation of the organic matter in the coal deposits found in these formations.

Probability of Hydrocarbon Accumulations

Hydrocarbon Model: The necessary ingredients required to create a commercial oil and/or gas field include: 1) source rock, 2) reservoir rock, 3) cap rock, and 4) trap. These items not only have to be present, but they must also be in a proper time and space relationship to allow hydrocarbons to be generated from the source rock, then migrate through a conduit to some obstruction or trap, and accumulate in a reservoir in sufficient quantities to be commercial. The reservoir must have adequate porosity and permeability. These parameters are discussed separately as they relate to the lower Cook Inlet OCS area.

Source rocks: The potential, but mostly undocumented, source rocks that might contain enough organic material to be source beds for oil and associated gas are the Triassic, Upper Jurassic, and Upper Cretaceous rocks. The Tertiary section may include source rocks for non-associated gas. Of the potential source rocks, the Triassic beds are the least likely. These rocks are highly altered northwest of the Bruin Bay fault. The Triassic rocks underlie the volcanics and volcaniclastics of the Talkeetna Formation, through which it would be difficult for any generated hydrocarbons to migrate upward into the younger and shallower reservoir units. The Beal 1 well on the Iniskin Peninsula penetrated source rocks of middle Jurassic age (fig. 14). A possible Upper Jurassic source rock is the Chinitna Formation, a dark-grey marine siltstone. The Kaguyak Formation is a potential Upper Cretaceous source rock. Tertiary coals, some of which are present on Cape Douglas, are potential source rocks for non-associated gas.

Thermal History: The generation of hydrocarbons from a source rock requires heat over a sufficient period of time (Hood and others, 1975). Sediments generally undergo an increase in temperature with burial. In lower Cook Inlet cumulative thickness of over 7,600 metres (25,000 ft.) for Mesozoic and Tertiary units seems sufficient to suggest maturity for much of the potential source rocks. In this area the temperature increase may be greater than normal for at least two reasons. First, the geothermal gradient probably increases from the upper Cook Inlet Tertiary province to the predominantly Mesozoic province in lower Cook Inlet. Second, the proximity of intrusive and extrusive volcanics may locally affect the country rock as in the Cape Douglas area.

Reservoir Rocks: Exposed reservoir beds are restricted to the Upper Jurassic, Lower and Upper Cretaceous, and Tertiary coarse clastic rocks

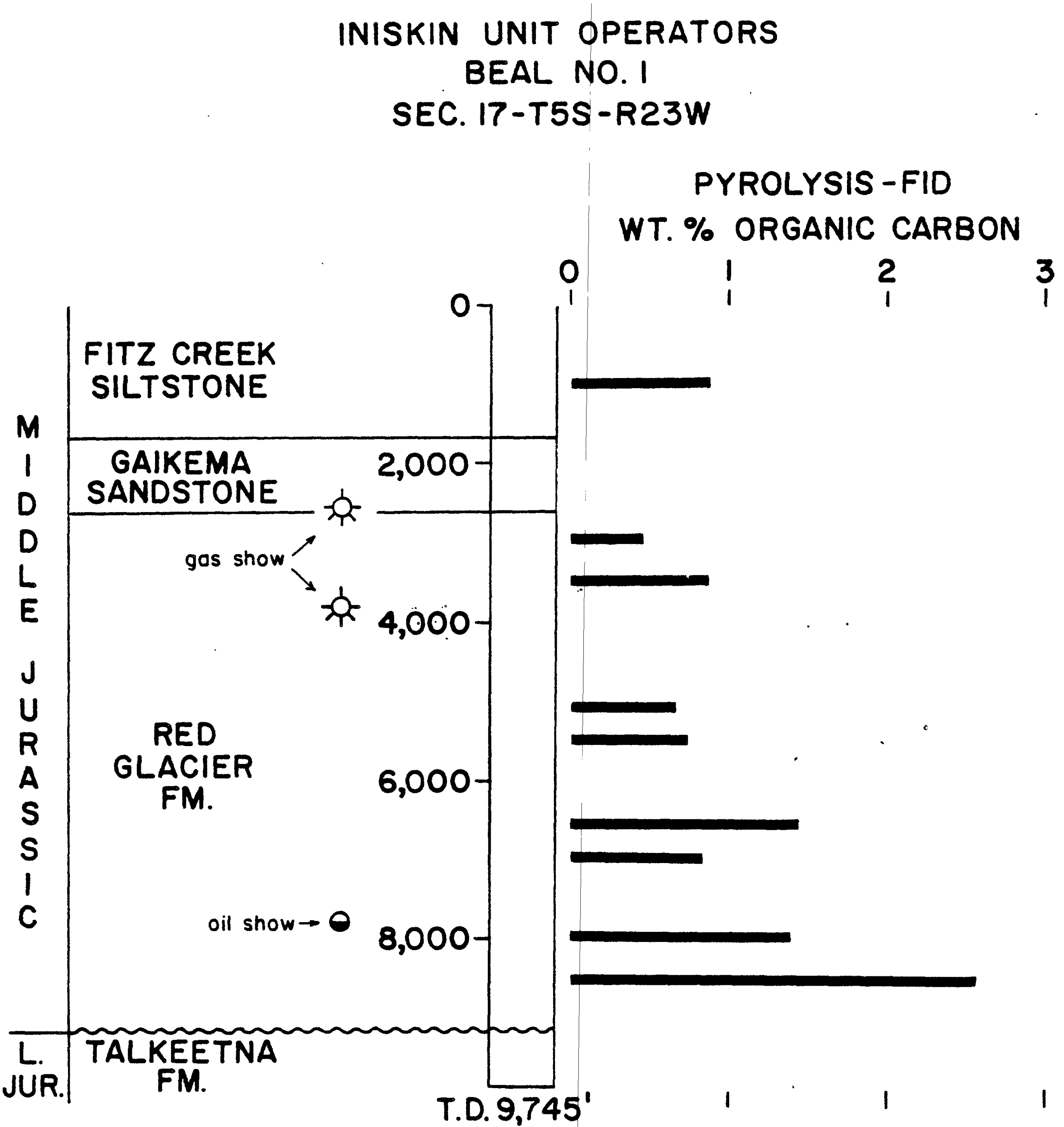


Figure 14. Organic carbon content, Beal No. 1 well.

(table 2). At the mouth of Douglas River and on Augustine Island, sandstones of the Upper Jurassic Naknek Formation are friable and porous enough to be an adequate reservoir or migration conduit.

The basal sandstone of the Lower Cretaceous crops out in Kaguyak Bay and in the Kamishak Hills, and it appears to have sufficient porosity to constitute a reservoir rock. This unit probably is present in the subsurface under OCS waters.

The Upper Cretaceous Kaguyak Formation is of questionable reservoir quality in outcrop. The upper 610 metres (2,000 ft.) of this formation consists of deep-water turbidite sandstones and siltstones. A high clay content is suspected, but similar turbidite sandstones are productive in the Ventura basin in Southern California.

Cap Rocks: Cap rocks are important for both migration paths and traps. Lithologically, a cap rock is any strata impervious to the flow of hydrocarbons, but generally it is restricted to siltstone and shale. In this area a cap rock is difficult to recognize because there are too few wells in the Mesozoic rocks to indicate subsurface physical characteristics, and surface exposures generally are altered significantly by weathering. Most of the strata in this area can be considered cap rocks except for the potential reservoir rocks mentioned above.

Traps: A trap exists where reservoir and cap rocks occur together in such a way as to obstruct the flow of the hydrocarbons. Generally, three categories of traps are considered; 1) structural, 2) stratigraphic and 3) combination. The limited seismic data from lower Cook Inlet

TABLE 2
Porosity and Permeability Data
Core Analysis

Location	Sample	Formation	Depth	Porosity %	Permeability Millidarcies
Standard Oil Co. of Cal.	Core	Tyonek	6,103 - 6,104.4	17.5	5.68
Deep Creek Well #1	Core	Tyonek	10,244 -10,259	2.4	< 0.01
Sec. 15, T2S, R13W	Core	Tyonek	10,264 -10,266.3	16.3	8.77
Kenai Peninsula	Core	Tyonek	10,286 -10,287.3	4.4	0.01
	Core	Tyonek	11,990.4-11,991.6	8.8	0.47
	Core	Tyonek	12,118.5-12,120.3	9.1	1.14
	Core	Hemlock Cong.	12,182 -12,183.6	3.4	4.74
	Core	Hemlock Cong.	12,235 -12,236.5	12.1	3.69
	Core	West Foreland	13,657.4-13,658.9	4.4	0.09
Hickerson Lake; SW 1/4-11-3S-21W	1974-4 Otc.	West Foreland		9.8	18
Augustine Island; SW 1/4-1-10S-25W	1974-5 Otc.	Naknek		4.7	0.02
Kaguyak Point; 58°34'50"N, 153°54'00'	0029EA-28	Naknek		7.8	0.57
Kaguyak Bay; 58°37'15"N, 153°54'45"	0068AL-32	Lower Cretaceous		3.4	< 0.01
Kaguyak Bay; 58°36'50"N, 153°50'20"	0092ML-28	Kaguyak		3.1	< 0.01
Kaguyak Bay; 58°36'30"N, 153°48'45"	0127ML-45	Kaguyak		5.3	< 0.01
Spotted Glacier North; 58°58'05"N, 153°32'20"	0153EL-100	Cretaceous		4.9	< 0.01
Spotted Glacier South; 58°57'50"N, 153°24'05"	019LM-47	Tertiary		6.9	< 0.01
Spotted Glacier South; 58°57'40"N, 153°24'40"	0213ML-71	Tertiary		7.3	0.10
Sukoi Bay Cove; 58°52'05"N, 153°21'05"	0223AE-45	Tertiary		7.4	0.02
~~Sukoi Bay Bench; 58°53'40"N, 153°21'30"~~	~~0240AE-62~~	~~Tertiary~~		~~3.3~~	~~0.01~~
Sukoi Bay Mountain; 58°54'10"N, 153°21'20"	0306EM-105	Tertiary		12.4	0.10
Sukoi Bay Mountain; 58°54'10"N, 153°21'20"	0308EM-107	Tertiary		6.5	0.53
Akumwarvik; Sec. 17, T13S, R28W	0328AL-145	Naknek		9.3	0.13
Kamishak Hills #3; Sec. 14, T15S, R29W	0331AL-155	Naknek		10.1	0.21
Kamishak Hills #3; Sec. 14, T15S, R29W	0332AL-156	Lower Cretaceous		8.2	0.09
Kamishak Hills #3; Sec. 14, T15S, R29W	0333AL-157	Lower Cretaceous		3.2	< 0.01
Kamishak Hills #4; Sec. 2, T16S, R29W	0346ALF-170	Lower Cretaceous		10.1	0.03
Kamishak Hills #4; Sec. 2, T16S, R29W	0350ALF-174	Lower Cretaceous		18.0	0.16
Kamishak Hills #4; Sec. 2, T16S, R29W	0351ALE-175	Lower Cretaceous		0.9	0.80
Kamishak Hills #4; Sec. 2, T16S, R29W	0355ALE-179	Lower Cretaceous		21.8	2.06
Kamishak Hills #5; Sec. 2, T16S, R29W	0362EAL-118	Lower Cretaceous		3.0	< 0.01
Kamishak Hills #5; Sec. 2, T16S, R29W	0370EL-126	Lower Cretaceous		8.9	0.06
Kamishak Hills #5; Sec. 2, T16S, R29W	0372EL-128	Kaguyak		10.2	0.21
Kamishak Hills #5; Sec. 2, T16S, R29W	0374EL-130	Kaguyak		8.6	0.15
Mouth Douglas River; Sec. 3, T13S, R27W	0429MA-1	Naknek		1.5	< 0.01
Mouth Douglas River; Sec. 4, T13S, R27W	0502M-150	Naknek		5.6	0.03
Seldovia	75JK-147	Triassic		0.2	< 0.01

Analyses by Chemical and Geological Laboratories of Alaska, Inc.

suggests faulted anticlinal traps are present. These traps probably are similar to those in upper Cook Inlet. Stratigraphic traps in Lower Cretaceous rocks may occur locally because these beds probably are regionally truncated by the Upper Cretaceous rocks. Also possible are combination traps that are neither purely stratigraphic nor structural.

Timing: Timing is of great importance to the accumulation of commercial quantities of hydrocarbons. If a trap forms after hydrocarbons have migrated through an area, there is no chance for an accumulation. A significant amount of work remains to be done on this parameter, but if the timing in lower Cook Inlet is similar to that in upper Cook Inlet, then there is reason to believe that at least some structures developed prior to hydrocarbon migration.

Hydrocarbon indications: Indications of oil and gas in the lower Cook Inlet are sparse but significant. The North Fork gas field, located about 16 kilometres (10 mi.) north of Homer (fig. 2), is the best indication of subsurface oil and gas in the Tertiary rocks. This field consists of one shut-in gas well, but some oil was recovered from sandstone that probably is equivalent to the Hemlock Conglomerate. On the Iniskin Peninsula a few wells have been drilled in the Jurassic rocks, and indications of oil and gas in the Middle and Upper Jurassic beds were reported.

Surface indications of oil and gas are restricted to the Jurassic rocks on the Iniskin Peninsula (Detterman and Hartsock, 1966) and in the Kamishak Bay area (Miller and others, 1959). The rocks of Jurassic age at the mouth of the Douglas River in the Kamishak Bay area smell of oil.

Summary: Available data suggests there is a good possibility that commercial quantities of hydrocarbons are present in lower Cook Inlet. Oil and gas are produced in upper Cook Inlet from rock units that are also present in lower Cook Inlet. Surface and subsurface indications of hydrocarbons are sparse and widely scattered in the Mesozoic and Tertiary rocks. Source, reservoir, and cap rocks probably are present. The stratigraphic column is sufficently thick to provide the temperature necessary to generate hydrocarbons, and structures were possibly formed early enough to trap migrating oil and gas. Additional work must be done to define these parameters more precisely, but presently the lower Cook Inlet OCS should be regarded with optimism.

OIL AND GAS RESOURCE POTENTIAL

Area Evaluated

The proposed federal lease sale area of about 9,100 square kilometres (3,500 sq. mi.) (fig. 2) lies within the Cook Inlet province which was evaluated recently in a U.S. Geological Survey study of the Nation's resources (Miller and others, 1975). All of the proposed lease sale area is in less than 200 metres (660 ft.) of water.

The sale area is treated as a part of this larger area and discussion of its resource potential is incorporated within this context.

Data Used

The geology, as related to the petroleum potential of the lower Cook Inlet, is discussed elsewhere in this report. For resource appraisal purposes, geologic data based on these and other publicly available data were summarized on comprehensive data format sheets which contained an inventory of information sources and characterized the basic geology and pertinent exploration, production, and resource data (Appendix). The data formats were reviewed by the Resource Appraisal Group and other U.S. Geological Survey personnel, with emphasis on accuracy of planimetered areal measurements, thickness and volume of sediments, and selection of realistic geologic analogs and yield values.

Data format information for onshore and offshore Cook Inlet province was further summarized on single-page data summary sheets to facilitate data handling when appraisals were being made (form 3, Appendix).

Appraisal Procedures

Several resource appraisal procedures were followed in the Cook Inlet province utilizing information contained in the data summary sheets. Although the onshore and offshore parts of the province were appraised separately, the offshore potential was evaluated in reference to that onshore.

A series of geological and volumetric-yield analog procedures was applied to provide a suite of oil-and gas-yield values. Geologic analogs can be considered as only approximate, and those for which volumetric-yield data were available were limited to the United States and Canada. Those analogs selected for offshore Cook Inlet were the Ventura basin, California, considered somewhat similar in tectonic setting, and the McAlester basin, Oklahoma, a compressional basin filled with a thick sequence of clastic rocks. Onshore Cook Inlet was also used as an analog during the appraisal procedure. Only rocks above the depth of 10,000 metres (32,800 ft.) were considered to have hydrocarbon potential in this analog analysis.

In addition to the volumetric-analog method, a series of Hendricks' hydrocarbon potential categories (Hendricks, 1965) was calculated for each commodity on the basis of province area. Finally, all published and documented resource appraisal estimates were compiled on a summary form (form 4A, Appendix) along with all of the values calculated by the methods discussed above.

A comprehensive review of all the above information was made by a Resource Appraisal Group geologist, who made an initial appraisal of undiscovered recoverable resources by a subjective probability technique as follows: first, a minimum resource estimate corresponding to a 95 percent probability (19 in 20 chances) that there is at least that amount present; second, a maximum resource estimate with a 5 percent probability (1 in 20 chance) that there is at least that amount present; last, a modal estimate of the resource which the estimator associates with the highest probability of occurrence. These initial estimates were recorded on appraisal summary sheets (form 4, Appendix) for use in the final evaluation.

A Resource Appraisal Group committee considered a comprehensive geologic review of the province from a resource standpoint and members made individual resource estimates at the cited probabilities. Following a thorough discussion of the basis of variations between these individual appraisals, a final Resource Appraisal Group estimate was derived by consensus. This estimate was reviewed with geologists of the Branch of Oil and Gas Resources who were familar with the subject area and who compiled the basic geologic information.

The final figures determined by the Resource Appraisal Group for the low (95 percent), high (5 percent), and mode were considered "raw" estimates which were statistically analyzed as discussed below.

Resource Data Analysis and Display

Subjective probability judgments were made for the Cook Inlet province as percentile assessments limited to quantities associated with the 5 and 95 percent probability range, which were selected to account for 90 percent of the range of the probable undiscovered recoverable oil and gas resources, and to assessment of a modal ("most likely") value.

A lognormal distribution was fitted by computer program (Kaufman, 1962) to the high, low, and modal value of the Resource Appraisal Group's assessments to compute the probability distribution for greater Cook Inlet offshore. Lognormal curves for oil and gas (figs. 15 and 16) were generated for the full range of probability values.

For greater Cook Inlet offshore, the oil curves show that at the 95 percent probability (19 in 20 chance) there is estimated to be at least 0.5 billion barrels, while at the 5 percent probability (1 in 20 chance) there is estimated to be at least 2.4 billion barrels. Higher or lower estimates than those within the 5 and 95 percent probability range can be read from these curves. For instance, the 1 percent (1 in 100 chance) probability value for oil in figure 15 is about 4 billion barrels.

Oil and Gas Resource Estimate

The proposed Federal OCS lease sale area comprises about 9,100 square kilometres (3,500 sq. mi.) and contains approximately 64,400 cubic kilometres of prospective sedimentary rock above 10,000 metres (32,800 ft.) depth. The proposed OCS lease sale area has about 50 percent of the sedimentary rock volume of the total Cook Inlet Province offshore (upper and lower Cook Inlet, State and Federal waters) and is estimated to contain approximately 60 percent of the undiscovered recoverable resource potential of the Cook Inlet offshore. A following table summarizes these estimates (table 3).

Additional hydrocarbons, occurring as natural gas liquids (NGL), might be anticipated in lower Cook Inlet if large quantities of natural gas are present. Data do not permit direct estimation of these liquids, but the NGL/gas production ratio in upper Cook Inlet is approximately 0.4 barrels of NGL for each million cubic feet of gas produced.

In general, the productive portion of upper Cook Inlet provides the clearest indication of the hydrocarbon potential of the undeveloped portions of the basin. Here, in onshore and offshore areas at the end of 1975, more than 539 million barrels of oil and 1.3 trillion cubic feet of gas had been produced, and measured reserves are estimated at 474 million barrels of oil and 6.0 trillion cubic feet of gas.

Development to date has taken place generally in the more accessible and least hostile parts of Cook Inlet. Economic constraints

TABLE 3

Undiscovered Recoverable Resources
Proposed OCS Lease Sale Area, Lower Cook Inlet

	Approximate Probability 95%	5%	Statistical Mean
Oil (billions of barrels)	0.3	1.4	0.7
Gas (trillion cubic feet)	0.6	2.7	1.4

imposed in lower Cook Inlet, particularly as encountered in deeper water areas, may render accumulations similar to some of those found onshore in upper Cook Inlet uneconomic. However, there appears to be sufficient sedimentary rock thicknesses and distribution to allow for a productive area in lower Cook Inlet similar to that of upper Cook Inlet if proper structural settings exist.

The appraisals originally made for the offshore Cook Inlet province in the recent U.S. Geological Survey study considered the principal prospective rocks in the province to be of Jurassic and Tertiary ages. Cretaceous rocks, because of their imperfectly understood distribution, common absence over producing structures of upper Cook Inlet, and lack of productive history where penetrated, were not considered at that time as principal objectives. However, as much as 1,600 metres (5,250 ft.) of prospective Cretaceous rocks are probably present under portions of lower Cook Inlet. The Cretaceous rocks are thought to comprise considerably less volume than the Jurassic and Tertiary rocks but may have significant unassessed potential.

Rocks of Tertiary age are the productive measures for oil and gas in upper Cook Inlet to date. These rocks are believed to extend in a generally similar facies into lower Cook Inlet, although locally they may be absent as a result of erosion or nondeposition. Oil, with associated gas, is produced principally from the Hemlock Conglomerate and Tyonek Formation of the lowermost part of the late Tertiary cycle; most non-associated gas is produced from the upper part of this cycle. Minor amounts of oil and gas are produced from older Tertiary units.

External productive analogs are difficult to find for Cook Inlet. Those used in the original analysis represent basins which, although possessing certain similarities, also deviate in significant ways from this basin. Like Cook Inlet, both the Ventura and McAlester (Arkoma) basins are filled with very thick sequences of clastic rocks and are productive principally from sandstone reservoirs in which structure is an important trapping mechanism. Rocks of the Ventura basin are of Tertiary age, as is the case in the Cook Inlet, but those of the McAlester basin are principally Paleozoic in age. Structurally, both analogs are deep basins showing substantial compressional elements, as Cook Inlet, but they differ in specific tectonic setting from the Inlet which appears to have originated as a forearc depression. Source rocks for oil in Cook Inlet and source rocks of the analog basins are probably the associated siltstones and shales. In Cook Inlet the Jurassic siltstones may be particularly significant. Non-associated gas in upper Cook Inlet appears to be derived from humic material within the Tertiary sequence.

Analogy might also be made to some of the intermontane Tertiary basins of the Rocky Mountains. These basins, which contain thick Tertiary nonmarine sequences and Cretaceous mixed marine and nonmarine sequences, provide hydrocarbon yields per unit sediment volume which are less than either the Ventura basin for oil or the McAlester basin for gas.

Analog-yield values, based on discovered volumes of oil and gas from the McAlester and Ventura basins, were applied in the original analysis of the Cook Inlet province to the estimated volume of Tertiary and Jurassic rocks (form 4, Appendix). In further analysis, if latest yields from these analog basins are applied only to estimated Tertiary and Jurassic rock volumes within the proposed sale area of Cook Inlet, the following calculated volumes of oil and gas may be derived for this area (table 4).

It should be noted, that were these resources present in the Cook Inlet proposed federal lease sale area, those parts deriving from smaller fields of the analogs would not be recoverable in the rigorous economic constraints imposed by operations in Cook Inlet.

Hendricks' areal yield Categories 2 and 3 were considered appropriate and applied to the greater (total) Cook Inlet offshore, Category 3 representing in general, an "average" basinal yield, while Category 2 encompasses many of the most productive basins of the world (form 4, Appendix).

When considering the proposed sale area within the context of the total offshore Cook Inlet, data indicate the prospective sedimentary rock volumes within the proposed sale area constitute approximately 55 to 60 percent of the total sedimentary rock volumes outside of the currently productive area and an only slightly lesser percent of the total sedimentary rock volume of the province.

Summary

Based on distribution of prospective rocks and structural settings within lower Cook Inlet, it is considered that of the total undiscovered recoverable oil and gas potential of greater Cook Inlet offshore (figs.

TABLE 4

Analog Calculated Recoverable Oil and Gas

	Oil (billions barrels)	Gas (trillions cubic feet)
McAlester Basin analog	0.7	2.3
Ventura Basin analog	2.1	4.1

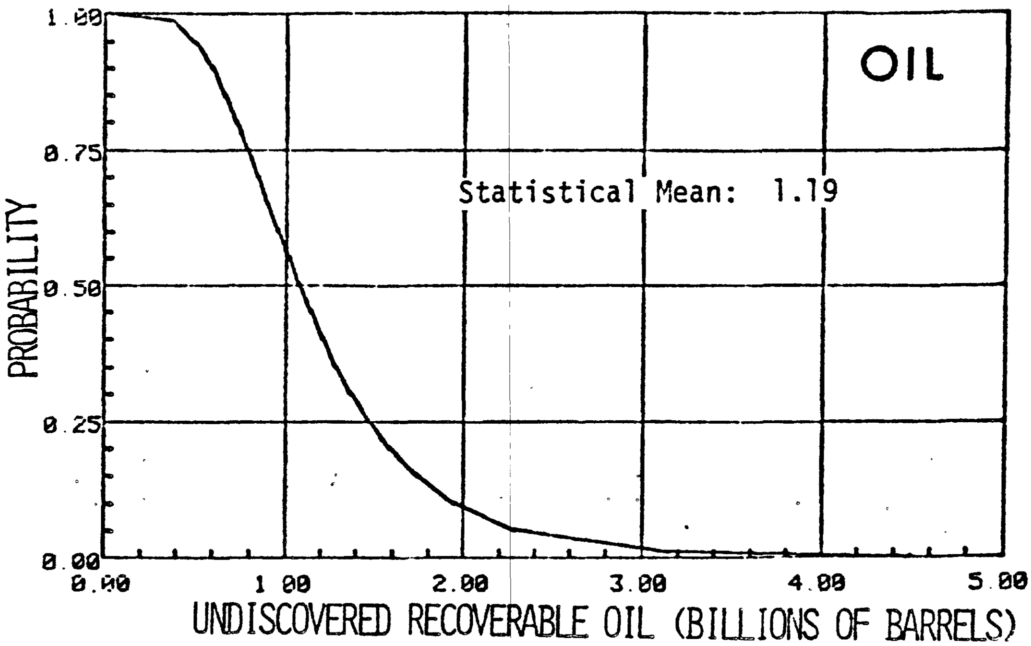


Figure 15. Lognormal probability curves showing estimates of undiscovered recoverable oil for the total offshore lower Cook Inlet (0-200 m).

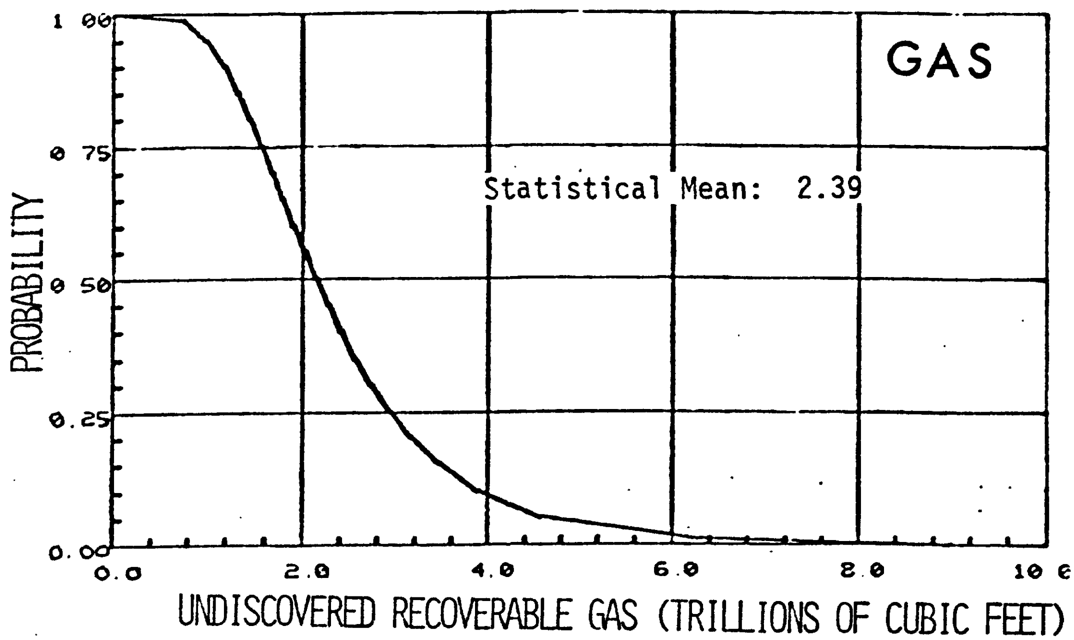


Figure 16. Lognormal probability curves showing estimates of undiscovered recoverable gas for the total offshore lower Cook Inlet (0-200 m).

15 and 16), approximately 60 percent lies within the proposed sale area. On this basis, resources are estimated to range from 0.3 to 1.4 billion barrels of oil (fig. 15), and from 0.6 to 2.7 trillion cubic feet of gas (fig. 16) at the approximate 95 percent and 5 percent probability levels respectively.

For the greater Cook Inlet offshore, of which this sale area is a part, the oil curves show that at the 95 percent probability (19 in 20 chance) there is estimated to be at least 0.5 billion barrels, while at the 5 percent probability (1 in 20 chance) there is estimated to be at least 2.4 billion barrels. Higher or lower estimates than those within the 5 and 95 percent probability range can be read from these curves. For instance, the 1 percent (1 in 100 chance) probability value for oil in figure 15 is about 4 billion barrels.

GEOLOGIC HAZARDS

General Statement

Lower Cook Inlet is in an area with a number of geologic hazards that pose potential problems to future installations within the Inlet and along the adjacent coastline. However, oil and gas exploration, development, and production activities have been conducted safely for a number of years in the nearby upper Cook Inlet, which shares the same general coastal and marine environments. Technology developed for oil and gas activities in upper Cook Inlet should be applicable to potential geologic hazards of comparable severity in the proposed lease sale area.

The information presented below is summarized from published literature and from unpublished reports. It should be regarded as preliminary because little environmental geologic information is available, especially for areas within Cook Inlet. The U.S. Geological Survey will begin detailed marine geologic work in lower Cook Inlet in the spring and summer of 1976 to provide answers to many of the potential problems mentioned below.

Hazards Associated with Seismic Activity

The Gulf of Alaska-Aleutian range is part of an extensive belt of tectonic activity that encircles the entire Pacific Ocean basin. It is one of the most seismically active regions on earth, accounting for about 7 percent of the annual world-wide release of earthquake energy. The earthquakes are believed to result from sporadic slippage of the Pacific Ocean crust as it is thrust northward under the Aleutian Island arc and Alaska mainland.

Most of the earthquakes originate between the Aleutian trench and the mainland, at depths less than about 50 kilometres (31 mi.), and foci generally deepen from the trench toward the mainland. Since 1899, nine Alaska quakes have exceeded Richter magnitude 8, and more than 60 have exceeded magnitude 7. Thirteen earthquakes of magnitude 6 or greater have occurred in the general Cook Inlet area in this time (table 5).

The last major seismic damage in the Cook Inlet area was caused by the Prince William Sound earthquake of March 27, 1964, which was one of the largest earthquakes ever recorded, at Richter magnitude 8.3 - 8.7. A smaller quake in December 1969, located on the west

TABLE 5

Earthquakes in the vicinity of the lower Cook Inlet, 1912 through 1973. Includes earthquakes greater than magnitude 6, whose epicenters lie between 59.00° and 60.50° north latitude and 151.00° and 153.00° west longitude. (Data courtesy of John Lahr and Robert Page, U.S. Geological Survey).

Date Day	 Month	 Year	Origin Time Hr/Min Gmt.	Latitude (Degrees N.)	Longitude (Degrees W.)	Depth Kilometers	Magnitude
07	06	12	0955	59.00	153.00	0	6.40
10	06	12	1606	59.00	153.00	0	7.00
24	12	31	0340	60.00	152.00	100	6.25
18	06	34	0913	60.50	151.00	80	6.75
11	10	40	0753	59.50	152.00	0	6.00
05	12	42	1428	59.50	152.00	100	6.50
03	10	54	1118	60.50	151.00	100	6.70
24	01	58	2317	60.00	152.00	60	6.38
19	04	59	1503	59.00	152.50	0	6.25
26	12	59	1519	59.74	151.38	0	6.25
24	06	63	0426	59.50	151.70	52	6.80
17	12	68	1202	60.17	152.84	86	6.50
16	01	70	0850	60.31	152.72	91	6.00

side of the Inlet, had minor effects on nearby drilling equipment (Evans and others, 1972). As population and urbanization of the Inlet increase, the level of earthquake risk also increases. This is well illustrated by the 1971 San Fernando Valley earthquake in southern California, which although only of magnitude 6.5, caused comparable property damage to the 1964 Alaska quake because it occurred in a heavily populated area.

Earthquake reoccurrence intervals within a given area along the Gulf of Alaska - Aleutian system have been estimated by various geoscientists. An average reoccurrence interval of about 800 years has been estimated from geologic evidence and the uplift sequence of Middleton Island (Plafker, 1972). On the basis of historic seismic patterns recorded over the past 75 years, Sykes (1971) estimated a minimum interval of 33 years. The occurrence of a major earthquake within the lifetime of an oil-producing province in this area is reasonable to expect.

Earthquake monitoring is being conducted in the Cook Inlet area by the U.S. Geological Survey, the National Oceanic and Atmospheric Administration, and the University of Alaska. The USGS project is designed to study the tectonic processes in southcentral Alaska to evaluate seismic hazards, and also to specifically monitor and study Augustine Island.

The Cook Inlet area is included in seismic risk zone 3, defined as areas susceptible to earthquakes of magnitude 6.0 - 8.8 and where major structural damage could occur. Damage can be caused either directly by ground shaking, fault displacement, and surface warping or indirectly by seismic sea waves (tsunamis), ground failure, and consolidation of sediments.

Ground Shaking: Damage from ground shaking is likely to be greatest in areas underlain by thick accumulations of saturated unconsolidated sediments, 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. Moreover, ground shaking can weaken sediments and thereby trigger other hazardous events such as landsliding and ground fissuring.

Within the Cook Inlet area, Anchorage and Homer experienced significant damage directly due to ground shaking during the 1964 earthquake, but shaking generally was subordinate to other seismic effects in terms of property damage. The potential of shaking as a danger to structures such as drilling platforms within the Inlet is uncertain and cannot be evaluated until the thickness and properties of the sediments are determined. Visser (1969) states that for design of oil platforms presently in use in upper Cook Inlet, earthquake forces were considered to be small in comparison to forces generated by ice.

Surface Faulting: The distribution of active surface faults within lower Cook Inlet is poorly known. Recent activity evidently has occurred on the Castle Mountain fault, a short distance northwest of the Inlet (fig. 17), as shown by lineations and offset of Pleistocene glacial deposits (Evans and others, 1972). After the 1964 earthquake, Foster and Karlstrom (1967) mapped an extensive zone of ground fissures

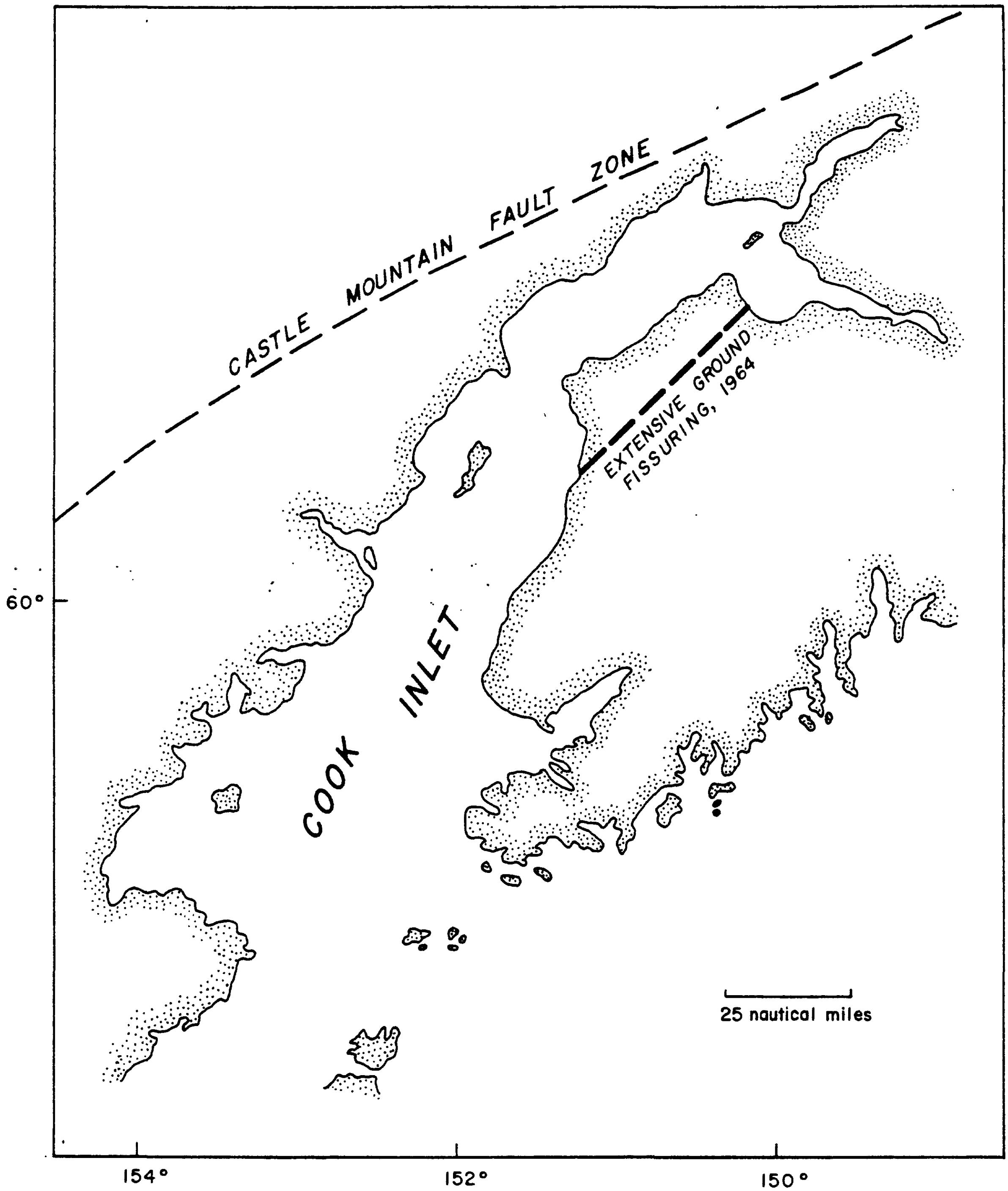


Figure 17. Location of Castle Mountain fault and zone of extensive 1964 ground fissuring.

adjacent to the southeast margin of the Inlet, extending from Kasilof to Chickaloon Bay (fig. 17), and suggested that the zone might be underlain by an active fault. If this speculation is correct, the fault could extend into lower Cook Inlet.

Closely spaced high-resolution seismic reflection lines are needed to determine the distribution of active faults in lower Cook Inlet, because installations located on active faults are almost certain to sustain some deformation or damage during major movement.

Surface Warping: Abrupt tectonic deformation accompanies most large earthquakes. For example, the 1964 earthquake caused a landward tilting of the continental margin, involving an offshore zone of uplift extending at least to the outer edge of the continental shelf and a shoreward zone of subsidence extending onto the mainland. Maximum uplift was about 15 metres (50 ft.) (Malloy and Merrill, 1972), and maximum subsidence was about 2.5 metres (8 ft.) (Plafker, 1969), indicating the probable magnitude of vertical displacement that could accompany a major quake.

Most of Cook Inlet experienced tectonic subsidence of less than 1.3 metres (4 ft.) in the 1964 quake, but an area extending from Kamishak Bay to near the mouth of Drift River is believed to have been slightly uplifted, less than 0.7 metres (2 ft.) (Plafker, 1969).

Tectonic deformation can produce problems both for shipping and for grounded installations. Along the coastline, tectonic uplift can elevate docks and facilities above water, as occurred at Cordova where the 1964 earthquake resulted in 2 metres (6.5 ft.) of uplift (Eckel, 1969). Navigation channels in uplifted areas may become unsafe and require recharting and perhaps dredging. Tectonic subsidence offshore might deepen channels, making them better for shipping, but subsidence of coastlines can lower facilities, thus flooding them or making them more susceptible to destruction by seismic sea waves. Offshore installations might be raised or lowered to undesirable or nonworkable positions by tectonic movements.

Tsunamis: Seismic sea waves (tsunamis) are 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). 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. For example, deformation in 1964 hinged around an axis trending northeast from Kodiak Island to northern Prince William Sound. The most intense radiation of the tsunami's energy was perpendicular to this axis (Pararas-Carayannis, 1967), resulting in extensive damage to the subsided seaward-facing coastal areas of Kodiak Island and the Kenai Peninsula (Plafker, 1969). Maximum runup from this tsunami was about 60 feet above mean lower low water, at Narrow Cape, Kodiak Island (Berg and others, 1972). The Kodiak Islands shielded much of the southeast-facing coast of the Alaskan Peninsula from serious inundation from the tsunami (Spaeth and Berkman, 1972).

Tsunamis do not occur with every submarine earthquake, and their prediction is not yet certain. They are seldom detectable in the open ocean and build up to significant destructive heights only close to and along the shoreline.

The degree of damage by tsunamis is partly controlled by the level of the tide. The 1964 earthquake occurred near the time of low tide, and consequently runup from the first tsunami wave did not extend above normal high tide at some places. Tsunamis persist for several hours after the main shock, however, so that destruction might be delayed until the next high tide. For example, the town of Cordova was hit by a 7 metre (23 ft.) wave at high tide, approximately 7 hours after the main 1964 earthquake.

The narrow elongate geometry of the Cook Inlet reduces the chances that a tsunami generated outside the Inlet will propagate significant destructive energy into it. The tsunami generated by the 1964 earthquake produced damage in the lower Cook Inlet area at Rocky Bay and Seldovia. It hit most of the west coast of the lower Cook Inlet, but caused no damage. If a regional tsunami should be generated within the Inlet, it probably would have little effect in open waters but could produce significant damage along the Inlet coastline.

Local tsunamis are likely to occur along steep indented coastlines such as exist along some parts of lower Cook Inlet, when unstable rock masses are shaken loose from steep slopes or when submarine landslides occur on unconsolidated alluvial deltas. They are a particularly dangerous seismic hazard because they strike without warning, during or shortly after an earthquake. Most damage by locally generated waves usually is confined to the embayments within which they originate.

Local tsunamis can be exceptionally large; a surge wave ran 530 metres (1,740 ft.) (vertically) up the slopes of Lituya Bay in the

Eastern Gulf of Alaska during the 1958 southeastern Alaska earthquake. Local tsunamis accounted for more loss of life than any other factor in the 1964 earthquake.

Ground Failure: Various types of ground failure, both on land and under water, are a major cause of destruction associated with large earthquakes, especially in areas underlain by thick unconsolidated sediments. The many deltas that occur along the Alaskan coastline are appealing sites for construction because they commonly are the only extensive flat ground along the coast, but many of these deltas are especially prone to earthquake-induced liquefaction and sliding because of their loose water-saturated sandy nature. An example is the disastrous sliding and resulting waves at Valdez in 1964 which caused extensive damage and loss of life (Coulter and Migliaccio, 1969). Local slides also occurred at Homer, Seward, and Whittier in 1964.

Underwater dispersal of slide sediments also poses a problem. The sediment can travel a few miles from the origin of the slide, perhaps as a turbidity current, and cause burial or physical damage to structures on the sea floor. Burial and breaking of submarine cables has been reported for slides at Valdez (Coulter and Migliaccio, 1969) and for many large-scale deep-water submarine slope failures (Heezen and Ewing, 1952; Menard, 1964).

Translatory block gliding occurred at Anchorage in 1964 and caused most of the damage there. Failure generally took place in the Bootlegger Cove Clay, a Pleistocene deposit up to 75 metres (250 ft.)

thick that underlies much of Anchorage (Hansen, 1965; Miller and Dobrovolny, 1959). The clay unit was weakened and failed under seismic stresses, causing the overlying material to slide downslope as large translatory blocks. Some landsliding in Anchorage is also believed to have resulted from liquefaction of sand layers within the Bootlegger Cove Clay.

Ground fissures and associated sand extrusions occurred extensively in the Cook Inlet area in 1964 (Foster and Karlstrom, 1967). As noted previously, a large zone of fissures, 95 kilometres (60 mi.) long and 10 kilometres (6 mi.) wide, developed between Kasilof and Chickaloon Bay. Fissures developed mainly in unconsolidated sediments and were as much as 10 metres (33 ft.) across and 8 metres (26 ft.) deep. They split several trees that straddled them. Only a few avalanches and slumps were noted along the coast of Cook Inlet, which is perplexing considering the abundance of steep slopes and soft sediments.

Too little is known of the geotechnical properties of bottom sediments to predict potentially unstable areas and the probability of ground movement on the floor of lower Cook Inlet.

Consolidation: Ground subsidence resulting from consolidation and/or lateral spreading of sediments, without actual sliding, is another expectable seismic hazard. This increases the likelihood of extensive flooding along coastal areas and could possibly cause submergence of affected marine installations. Consolidation subsidence of up to 1.5 metres (5 ft.) occurred on Homer spit in 1964, contributing to the closing of port facilities there, and also occurred near the head of Turnagain Arm.

Hazards Associated with Volcanic Activity

Five active volcanoes are located in the Cook Inlet area, along the east margin of the Alaska Peninsula (fig. 2). They are Mounts Augustine, Iliamna, Douglas, Redoubt, and Spurr. All but Mt. Douglas have erupted in historic time (table 6), and all five can be considered likely to erupt in the future.

The Alaskan volcanoes are part of the much larger circum-Pacific seismic and volcanic belt. Eruption of circum-Pacific volcanoes is believed to occur as a result of partial melting of oceanic crust and upper mantle as it is thrust into the deeper mantle. Alaskan volcanoes are andesitic and produce relatively violent eruptions compared to the basaltic volcanoes of oceanic basins.

Some of the potential hazards associated with Alaskan volcanoes include ash falls, lava flows, gas clouds, mudflows, landslides, flash floods, lightning discharges, corrosive rains, earthquakes, and tsunamis. All of the phenomena have occurred in Alaska in historic times. Most of these are local in their effects, but some can cause damage on a regional scale. For example, ash falls can deposit significant thicknesses of ejecta up to 160 kilometres (100 mi.) from the eruptive center, depending on the direction and magnitude of wind, as shown by deposits of 0.3 metres (1 ft.) on Kodiak Island from the 1912 Katmai event. Ash fallout from Mt. Spurr in 1953 damaged aircraft and required extensive cleanup in Anchorage.

Volcanically induced tsunamis also can cause damage away from an eruptive center. The 1883 eruption of Augustine produced a mudflow

TABLE 6

Volcanoes of the Cook Inlet Area.
(From Evans and others, 1972)

Name	Last eruption	Present state
Augustine	1976	Active and potentially eruptive
Iliamna	None in recent years	Active but quiescent
Mt. Douglas	None in historic time	Quiescent
Redoubt	1966	Active and potentially eruptive
Mt. Spurr	1953	Active but quiescent

that moved into the sea and generated a large seawave within Cook Inlet. The wave struck English Bay, near Port Graham, with a maximum amplitude of 7 metres (23 ft.) and caused some damage there.

Augustine is considered the most active volcano in the Cook Inlet area. It erupted significant quantities of ash in February 1976, and it could erupt again at any time. Because of its marine setting, Augustine could possibly produce a Krakatoan-type eruption, which involves large explosions probably caused by inrush of sea water into the lower part of the volcano as melt moves into it. Installations or persons near Augustine obviously would be in danger from such an eruption. History suggests this type of eruption is statistically remote. Augustine presently is under continuous seismic surveillance by the University of Alaska and the U.S. Geological Survey. An early-warning system from these institutions to industry personnel working in the surrounding area could reduce the danger from volcanic activity.

Sedimentation

The distribution of suspended and bottom sediments in Cook Inlet is controlled primarily by tidal currents, but also by seasonally varying fresh-water discharge into the Inlet. Little is known of the nature of sub-bottom unconsolidated sediments in the lower Inlet, but they probably reflect Pleistocene glacial processes for the most part (see Karlstrom, 1964).

The main sources of suspended sediments are the Knik, Matanuska, and Susitna Rivers that enter the upper Inlet. Highly turbulent tidal currents maintain much of the silt and clay-size particles in suspension and transport them into the lower Inlet where some are deposited and the remainder are carried into Shelikof Strait. Coriolis effect and tidal inflow of saline ocean water cause an uneven distribution of suspended material in the lower Cook Inlet. Loads are lowest and the water is clearer on the east side where incoming tidal waters concentrate (Wright and others, 1973; Anderson and others, 1973).

Bottom sediments are supplied by rivers entering the Inlet and by limited coastal erosion. Gravelly material is carried into the Inlet during river flooding, but some coarse bottom sediments probably are relict glacial debris.

The bottom sediments are divided into three sharply bounded facies (Sharma and Burrell, 1970). East of the Susitna River in the head of the Inlet, sediments are sand; in the middle Inlet, north of about Iliamna Point, sediments are sandy gravel and gravel; and in the lower Inlet, sediments are mainly gravelly sand with some minor silt and clay (fig. 18). Some transverse variation exists in the upper and middle Inlet, with coarser sediments in midchannel and finer sediments near the shore. Also, the percentage of fine sediment is relatively high in protected bays and coves.

The coarsest bottom sediment, the middle Inlet facies, corresponds to the zone of highest tidal velocities and turbulence in the constricted Forelands region. Finer grained material, prevented from being deposited in this area, is distributed up and down the Inlet until it is deposited by slackening currents.

Pollutants can be transported as adsorbed coatings on individual

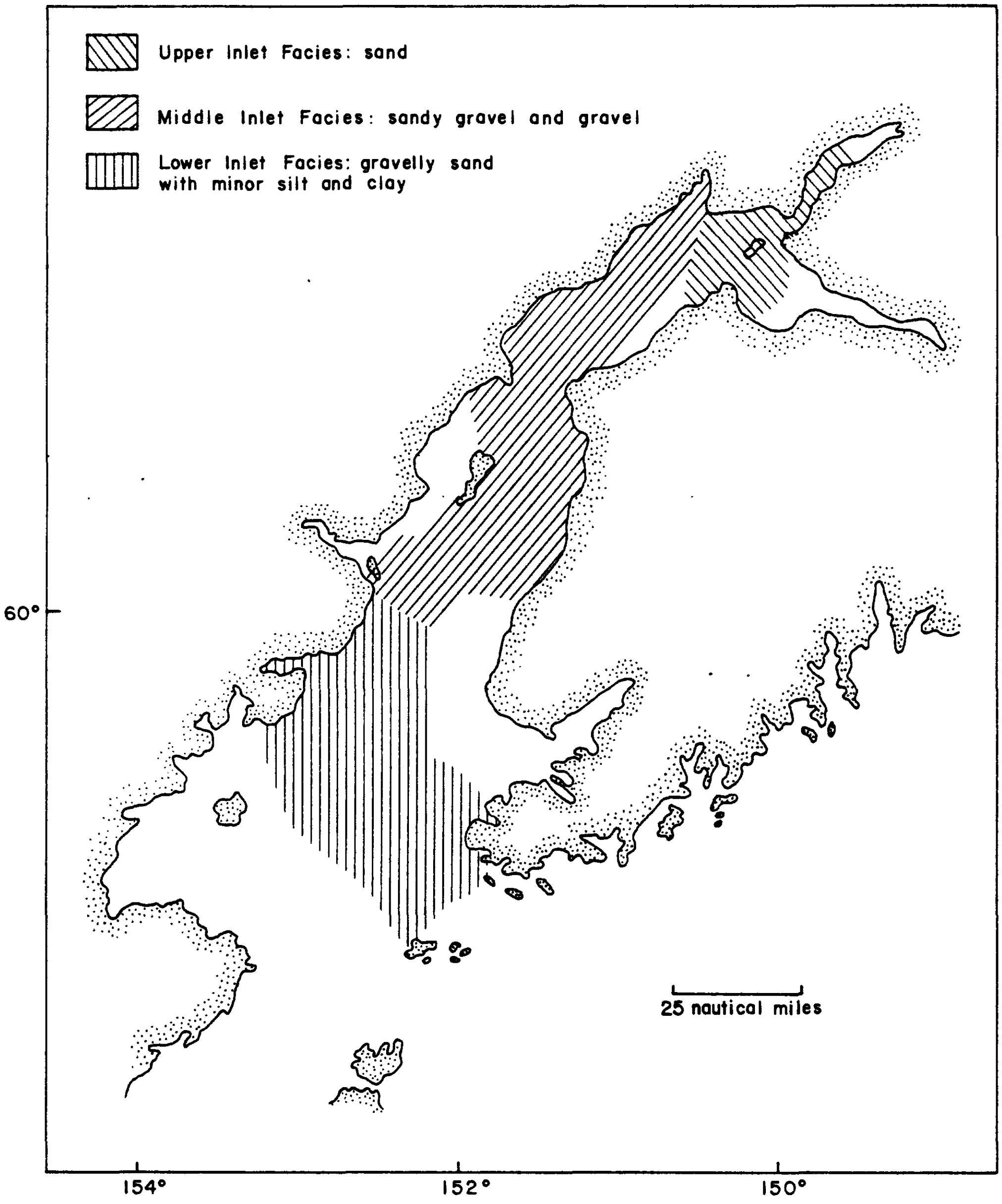


Figure 18. Distribution of bottom sediments in Cook Inlet, Alaska.

sediment grains and reside for long periods of time in sedimentary deposits upon which bottom-living organisms feed. The suspended-sediment data indicate that pollutants adsorbed to particles within the water column would collect in greatest concentrations in the west side of the Inlet, and some adsorbed material would find its way into Shelikof Strait. The probability of bottom deposition of adsorbed pollutants would be least in the area of the Forelands (middle Inlet facies) and increase for some distance away in both directions.

Visser (1969) mentioned that suspended sediments can abrade fixed structures in areas of high suspended-sediment concentration. However, present installations within Cook Inlet show no evidence of significant structural damage from abrasion (U.S. Army, 1974).

Erosion and redistribution of bottom sediments is a potential hazard in the Cook Inlet, but not enough data are available to pinpoint specifically troublesome areas. Erosion of bottom sediments around grounded structures is possible in areas of high tidal-current velocities and/or low-threshold sediments such as fine sand and also in areas of migrating sand waves if they are present in the Inlet.

In some coastal areas tsunamis and seiches (a free or standing-wave oscillation of the surface of water) could be expected to redistribute significant amounts of sediment. Reimnitz and Marshall (1965) reported temporary shoaling of 10 metres (33 ft.) in some channels in Orca Inlet, Prince William Sound, after the 1964 earthquake. The channel fill evidently was eroded from nearby tidal flats by seiche surges. Tidal currents were later able to redeepen the channels.

Two potential problems associated with sub-bottom glacial sediments are: 1) interference of boulders with dredging and 2) instability of slopes that are underlain at depth by weak proglacial lake deposits. Extensive seismic profiling and sub-bottom sampling are necessary before areas of concern can be identified.

TECHNOLOGY

Requirements

Technology and operational activities for offshore oil and gas exploration and development in the lower Cook Inlet OCS area will be influenced by the physical and environmental conditions of the area. Some of the more important physical and environmental conditions which will affect design, location of facilities, and operating procedures are briefly described below.

1. Climate, weather, and sea conditions will be major factors in the design, emplacement, and operation of offshore exploration, production, and transportation equipment and facilities.

   Cook Inlet is in the transitional zone of Alaska and is characterized by pronounced temperature variations throughout the day and year, and frequent cloudiness and medium humidity, precipitation, and wind levels (Evans and others, 1972). Table 7 summarizes meteorological data from two stations in the lower part of the Inlet. Climatic conditions and weather extremes will necessitate design for adequate working conditions (heated, insulated, enclosed

Table 7

METEOROLOGICAL DATA - COOK INLET

	JANUARY					JULY					YEAR							
Station	Temp[1] Min. Avg.	Temp Mean Av.	Temp Max. Avg.	Total[2] Precip.	Snow[2]	Temp Min. Avg.	Temp Mean Avg.	Temp Max. Avg.	Total Precip.	Snow	Temp Min. Avg.	Temp Mean Avg.	Temp. Max. Avg.	Total Precip.	Snow	Elev. Feet	Prev. Wind Direct.	Mean Hourly Wind Speed
Homer 1943-1971	14.0	20.7	27.3	1.73	10.4	44.6	52.4	60.2	1.69	0.0	29.2	36.4	43.6	23.08	55.4	67	NE	6.5 mph
Seldovia*	18.1	23.2	28.2	2.3	10.2	48.6	55.8	57.7	1.40	0.0	33.7	41.0	48.2	26.3	50.8	0-30	N	11.5 - 17.5 mph

*Unofficial local records
1/ °F
2/ Inches

Source: Evans et al., 1972

areas) and will require careful scheduling of such critical activities as emplacement of platforms and pipelines to avoid the extreme conditions of the winter season.

Mean hourly wind speed is moderate, but under extreme conditions, winds of 75 to 100 knots can occur over open water, and storms with 50- to 75-knot winds are experienced nearly every winter (Evans and others, 1972). Waves and sea conditions must be considered, but available information indicates only moderate maximum wave heights compared with other offshore areas undergoing oil and gas development.

Cook Inlet is noted for its extreme diurnal tidal ranges up to 9.1 metres (30 ft.) at Anchorage and the resulting high currents reaching a mean maximum velocity of 3.8 knots in the Forelands region (Evans and others, 1972). Tidal ranges and accompanying currents are less extreme in the lower Cook Inlet with a diurnal range of 5.4 metres (17.7 ft.) at Seldovia and 4.2 metres (13.8 ft.) at the mouth of the Inlet. Table 8 shows the tidal statistics for Seldovia. The turbulence caused by high tides and currents increases difficulty of offshore operations and requires added time and equipment for certain activities, such as anchoring and maintaining position of drilling vessels, laying of pipelines, and diving operations.

2. Ice forms in upper Cook Inlet in the winter months and may cause damage to vessels and structures, and interference with marine traffic and other marine operational

TABLE 8

Tidal Statistics for Seldovia

	Feet	Metres
Highest Tide	23.0	7.0
Mean High High Water	17.8	5.4
Mean High Water	17.0	5.2
Mean Tide Level	9.3	2.8
Mean Low Water	1.6	.5
Mean Low Low Water	0.0	0.0
Lowest Tide	- 5.5	-1.7
Mean Range	15.4	4.7
Diurnal Range	17.8	5.4
Extreme Range	28.5	8.7

Source: Evans and others, 1972.

activities. Ice thicknesses of nearly 1 metre (3.3 ft.) can be expected during a "normal" year (Hutcheon, 1972).

Design analysis of oil platforms for upper Cook Inlet shows that ice loading is by far the largest force that would be exerted on such a platform and that the forces of wind, waves, and even earthquakes are relatively small compared with the ice forces (Visser, 1972).

Generally, ice conditions in lower Cook Inlet are considerably less severe than in the upper parts. This is attributable in part to high salinities, inflow of warm ocean waters, and less land-runoff influence in lower Cook Inlet. Lower Cook Inlet is generally free from ice with only protected embayments becoming ice bound. However, under extreme conditions (the winter of 1970-71), ice has been found as far south as Cape Douglas on the west side and Anchor Point on the east side. At this time, sea ice attached to the shore (fast ice) extended up to 5 kilometres (3 mi.) off the northern shore of Kachemak Bay (Hutcheon, 1972).

Design requirements for ice loading by floe ice are recognized as the major design factor for upper Cook Inlet facilities. The less severe ice conditions in lower Cook Inlet may reduce or eliminate the necessity for ice-load design depending upon the location of the proposed facility within the lower Cook Inlet area.

Ice loading due to surface or superstructure icing (freezing spray) may occur under certain wind and weather conditions during the coldest winter months and must be taken into account throughout the Alaska offshore areas.

3. Potential seismic loading and earthquake effects must be considered in combination with other design criteria for all offshore and onshore structures and facilities because the lower Cook Inlet area is located in an active seismic zone and may be subject to severe earthquake activity. Earthquake design criteria and site location must consider potential damage and hazards from direct and indirect causes including ground shaking (vibration), fault displacement, surface warping (uplift or subsidence), sea waves (tsunamis), and ground failure (onshore and submarine landslides).

Tsunamis associated with large submarine earthquakes have occurred in various areas of the Pacific Ocean and must be considered in connection with operations and facilities on the Gulf of Alaska margin. Local tsunamis or sea waves, as a result of earthquake caused land slides, are particularly hazardous to onshore facilities in low-lying areas and to near-shore facilities and must be considered in their location and design.

4. As with other areas of Alaska, lower Cook Inlet is isolated and remote from major population centers, industrial areas, and oil-supply centers, with no significant industrial complex closer than Seattle, Washington. The lower Cook

Inlet area is more or less undeveloped and would require development of local onshore supply bases, transportation facilities, and living areas for workers and families, in addition to onshore terminals, storage facilities, and other industrial complexes. The deep-water port at Kodiak and the Homer docking facilities, which are primarily involved in support of the fishing industry, would likely be utilized for oil exploration and development in the proposed lease sale area.

The oil and gas supply and service facilities at Kenai and Anchorage would likely be utilized for lower Cook Inlet development in addition to local sites that may be developed. It is also possible that existing marine terminals, refineries, and other facilities in upper Cook Inlet might be used for handling oil from parts of lower Cook Inlet within reasonable proximity to those facilities.

5. Potential offshore drilling and producing operations in lower Cook Inlet could be as near as 5.6 kilometres (3.5 mi.) and as far as 74 kilometres (46 mi.) from the shores of the Cook Inlet in water depths of less than 16.4 metres (54 ft.) to more than 150 metres (500 ft.). It is estimated that over three-fourths of the lower Cook Inlet area is less than 100 metres (330 ft.) deep. Figure 19 is a map of the bathymetry of the Cook Inlet.

6. Active volcanoes are located along the west margin of

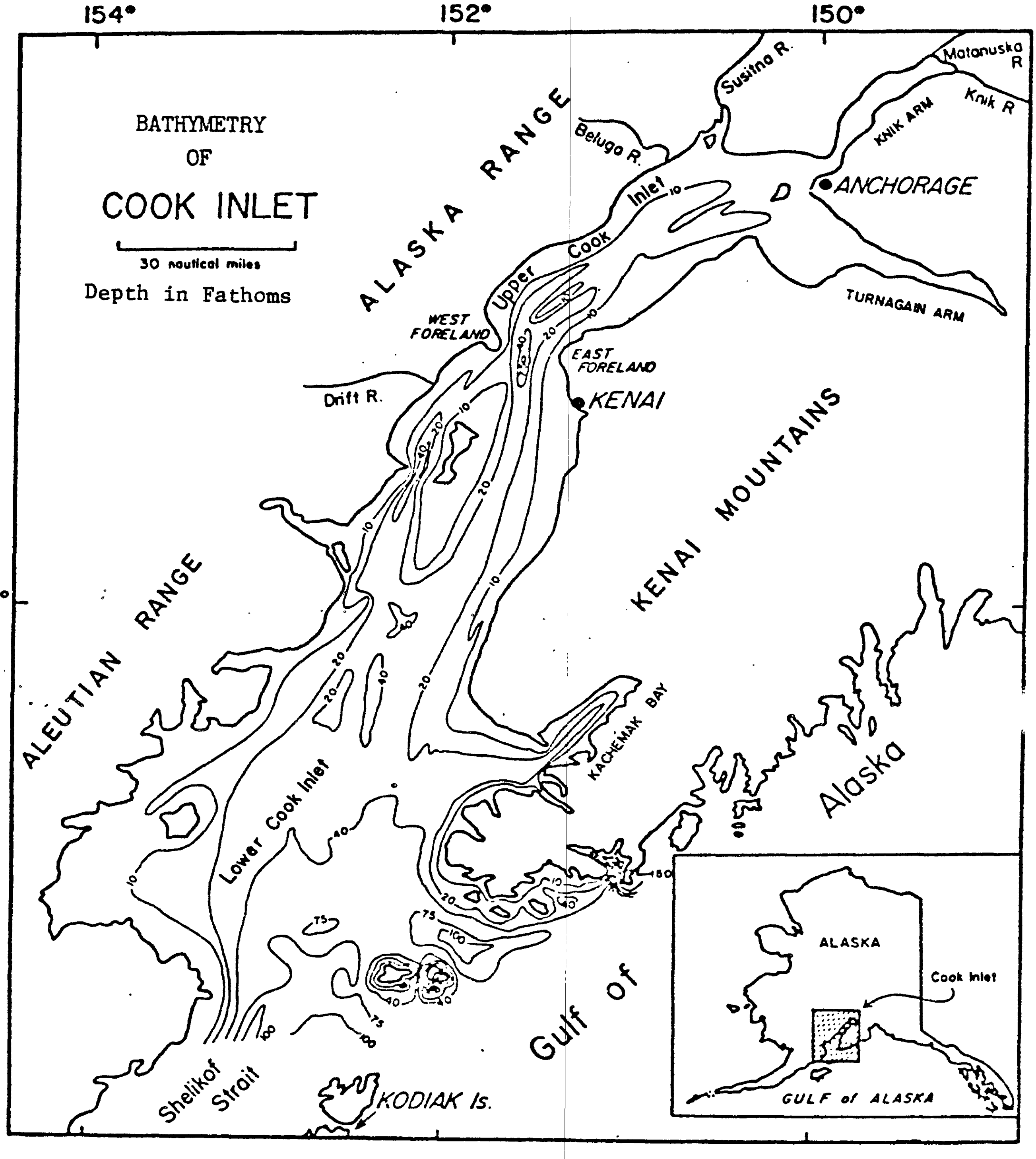


Figure 19

Source: Sharma and Burrell, 1970.

the lower Cook Inlet, and one, Augustine Island, rises out of the lower Cook Inlet. Detterman (1973) describes Augustine volcano as a symetrical composite volcano about 1,227 metres (4,025 ft.) high formed by lava, rubble and breccia, volcanic mud, cinders, and pumice lapilli with a summit crater and plug dome. The volcano has been active intermittently in historic times with recorded major eruptions in 1812, 1883, 1902, 1935, 1963, 1964, and 1976. Detterman (1968) described the initial major eruption in 1963 as a nuee ardente; a section of the crater rim collapsed and was incorporated with the hot ash and other volcanic debris flowing down the side of the volcano. There were also flows composed mainly of mud and pumaceous sand believed to be mobilized by melt water from snowfields.

Potential hazards from volcanic activity from Augustine volcano appear to be mainly local to the volcano or in drainages where lava flows, mud flows, or flooding might occur.

Ash, lava, mud flows, gas clouds carrying toxic gas and ash, heat radiation, corrosive rains, and sea waves caused by displacement of water or associated seismic activity might be expected in the event of an eruption. The ash falls and corrosive rains might occur over a wide area, but the effects from the flows of material down the volcano, possibly into the waters of the Cook Inlet, and toxic concentrations of gases should not present serious hazards except in the close vicinity of the island, probably less than 8 kilometres (5 mi.).

Certainly there should be no facilities or structures located on the island or in the shallow waters nearby, unless the facilities or structures are expendable or are protected against the hazards just described.

The remote microearthquake monitoring system established on Augustine Island by the University of Alaska offers a possible warning system which could be developed in the event of leasing and potential operations in the vicinity of Augustine Island (Mauk and Kienle, 1973).

7. Lower Cook Inlet is a prolific habitat for fish, shellfish, sea mammals, and sea birds. Various species of fish and shellfish are important to the economy of the lower Cook Inlet area. Special operating procedures and special equipment may be necessary to assure protection of the marine habitat and compatible multiple use of the area.

Availability

Technology for offshore oil and gas exploration and production has evolved from shallow-water near-shore operations in moderate climates, into deeper water and more hostile environments. Figure 20 shows the present water-depth capability for mobile drilling and underwater well-completion systems, underwater production and manifold systems, and fixed platforms with an industry-capability projection of drilling and production systems into deeper water in the short term.

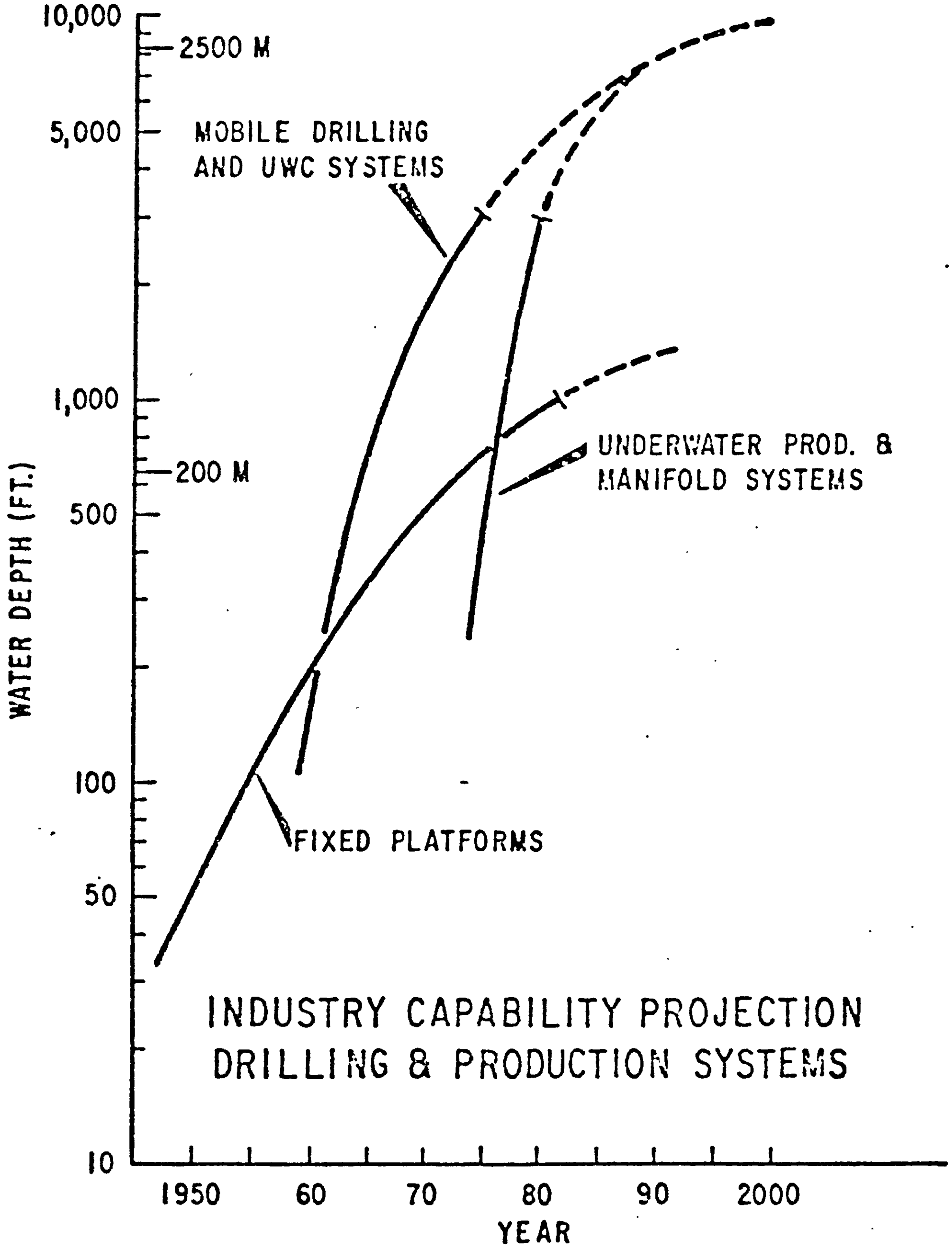


Figure 20

Source: Geer, 1973

Industry has demonstrated the ability to extend its operational capabilities at a rapid rate (National Petroleum Council, 1975). Recent projections by the National Petroleum Council on industry capability for exploration drilling and production for Alaska offshore areas are shown on table 9.

The technology for oil and gas development and operational capability in Cook Inlet has been demonstrated by the development and production of offshore fields in upper Cook Inlet.

After discovery of the first offshore oil and gas in the upper Cook Inlet in 1963, rapid exploration followed and resulted in the discovery of four major offshore oil fields and one offshore gas field. Development of these fields began with installation of the first fixed platform in 1964 and first production in 1965. These fields are being developed and produced by 14 self-contained fixed platforms which have been in place for 7-10 years. More than 150 miles of offshore pipelines have been installed in upper Cook Inlet. Oil production is transported to the Nikiski marine terminal on the east side of the Inlet or to the Drift River marine terminal on the west side of the Inlet for movement by tankers to West Coast refineries. Gas from the North Cook Inlet field is transported to a liquefication plant at Nikiski and is transported to Japan in LNG tankers. Figure 21 is a map of the Cook Inlet showing the oil and gas fields, pipelines, and related facilities in the upper Cook Inlet.

The Cook Inlet is considered a major oil- and gas-producing province. Oil and gas production for June 1975 and the cumulative

Table 9

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

	Maximum Water Depth Capabilities		Earliest Date	
Area Province	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.

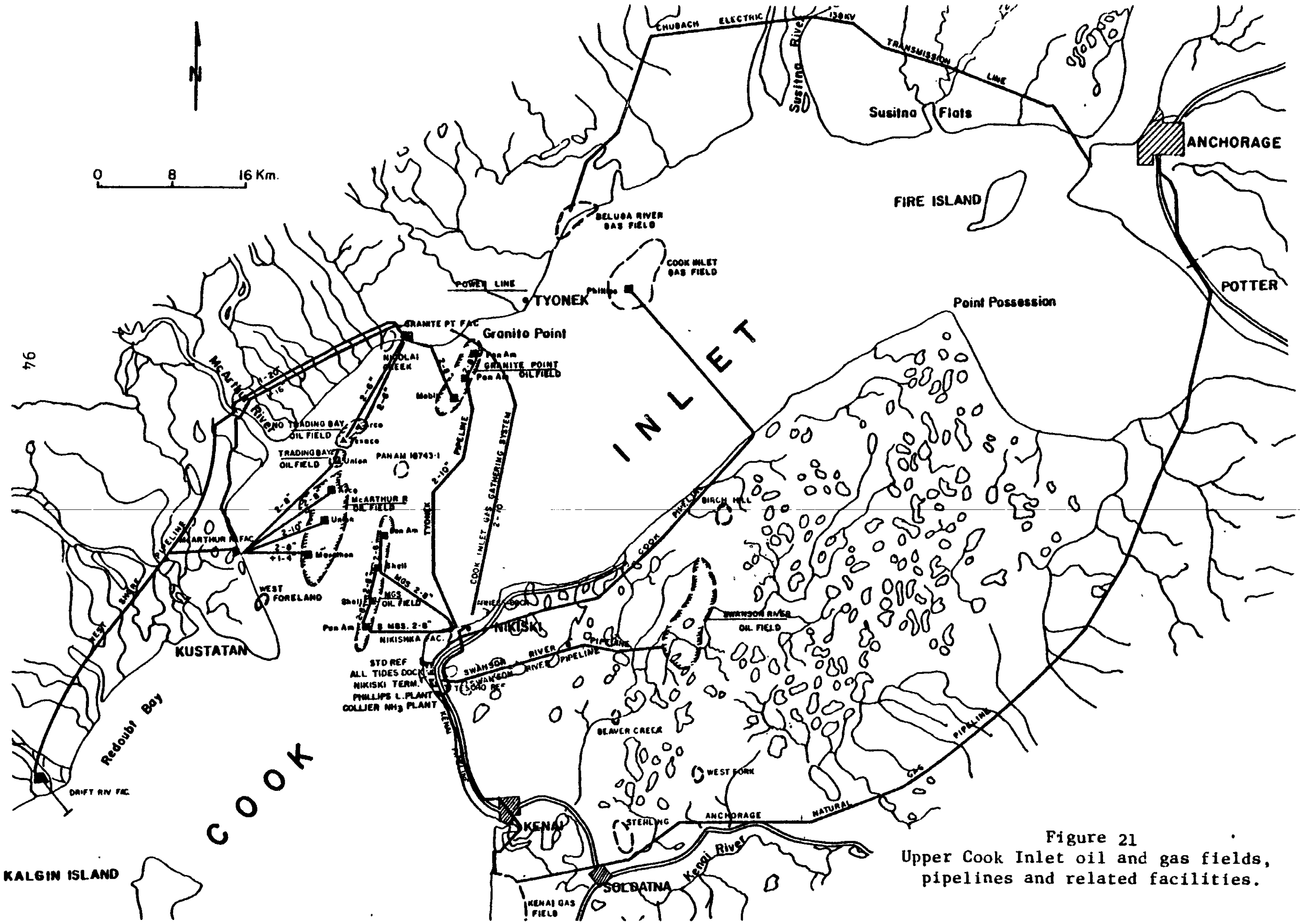


Figure 21
Upper Cook Inlet oil and gas fields, pipelines and related facilities.

production for offshore oil and gas fields follows (State of Alaska, 1975; table 10).

Special design features for the upper Cook Inlet platforms include one-, three-, and four-legged tower-type platforms with minimum surface area at the water level to provide minimum exposed area to the moving ice (Visser, 1969). Wells are drilled through the legs, and the legs are attached to the sea floor by as much as 65 metres (213 ft.) of grouted piling designed to withstand required stresses and unstable bottom conditions. Figure 22 shows design loads on a tower-type structure in Cook Inlet.

The technology for development of the deep-water part of lower Cook Inlet is also available and may be adapted from the North Sea and other offshore areas where oil and gas operations have moved into deeper water utilizing newly developed technology.

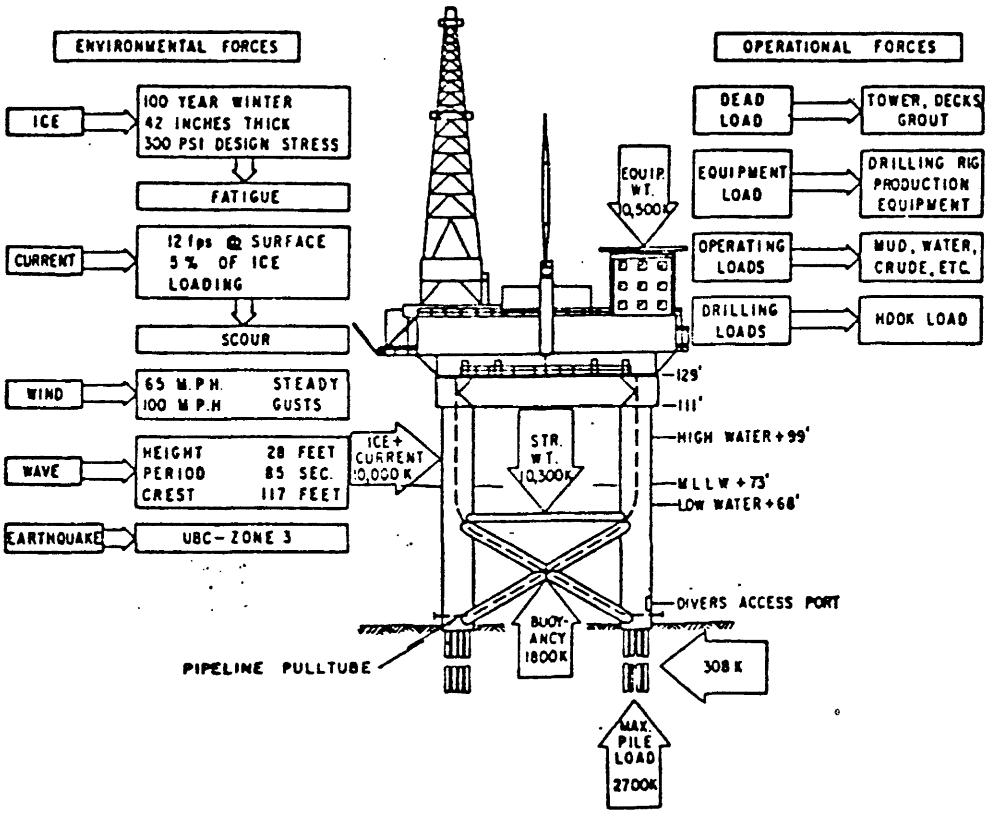
In the North Sea area, drilling has been successfully conducted in water depths exceeding 200 metres (660 ft.), and drilling and production platforms have been placed in 125 metres (410 ft.) of water. A concrete platform was recently placed in 140 metres (460 ft.) of water at the Brent Field north of 61° latitude in the North Sea. Large-diameter pipelines, 81 centimetres (32 in.), have been installed successfully in water depths of 146 metres (480 ft.), and new equipment under construction will extend that capability to deeper water (Rainey, 1974). There are several offshore storage and tanker-loading facilities in use or planned for North Sea fields. The offshore terminals are designed for permanent use in some fields and for temporary or

TABLE 10

Monthly and Cumulative Oil and Gas
Production for and through June 1975

Field	June 1975 Oil (bbls)	June 1975 Gas (Mcf)*	Cumulative (through 6/75) Oil (bbls)	Cumulative (through 6/75) Gas (Mcf)
Granite Point	377,004		58,344,635	
McArthur River	3,303,532		273,327,506	
Middle Ground Shoal	715,137		91,814,814	
Trading Bay	523,207		59,743,472	
N. Cook Inlet		2,697,998		220,592,058
Total	4,918,880	2,697,998	483,230,427	220,592,058

*Solution gas from oil fields not shown.



Design loads on a tower structure in Cook Inlet.

Figure 22

Source: Visser (1972)

supplemental use in others until pipelines and shore facilities can be completed. Some typical North Sea offshore terminals are described below:

1. Ekofisk field - A million-barrel concrete storage tank combined with an SBM (Single Buoy Mooring, Inc.) tanker facility.

2. Brent field - Concrete production platforms with up to a million-barrel storage capacity per platform used in combination with a submersible storage and tanker-loading facility (Shell group SPAR systems).

3. Argyle field - A semi-submersible production platform with subsea wells used in conjunction with a submersible SBM tanker-loading facility.

Between 1960 and 1975, 252 subsea wells were completed worldwide in water depths of 15-114 metres (50-375 ft.) in various offshore areas (Ocean Industry, 1975). Several subsea production systems are in the prototype or test stage for use in water depths of 91-456 metres (300-1,500 ft.) and are being developed for use in deep water in conjunction with fixed platforms or in areas where platforms are not feasible. Several advanced subsea production systems are in actual use or in the process of installation in the Gulf of Mexico and the North Sea areas.

The type of development in the lower Cook Inlet will depend upon the water depth, distance from shore, the type of oil or gas deposit to be developed, and the physical and environmental factors at the discovery location. Shallow-water development would likely follow conventional use of fixed-steel platforms with pipelines to shore, similar to the upper Cook Inlet fields. Deep-water development may involve: 1) conventional fixed-steel platforms as in shallow water, 2) a combination of fixed-steel or concrete platforms, and 3) structures with subsea wells and production systems with pipelines to shore.

Recent developments in marine geophysical technology provide methods for detecting surface and subsurface geologic hazards so that they may be avoided in the selection of locations for wells, fixed platforms, pipelines, or other offshore facilities. These geophysical data, in conjunction with core sample tests, are used in analyzing soil characteristics and foundation design for bottom-supported structures. High-resolution acoustic surveys, along with pertinent geological and engineering studies, will be required prior to permitting wells or the placement of a platform or structure.

Since lower Cook Inlet is an active seismic area, onshore and offshore structures and facilities must be designed to withstand potential earthquake hazards to assure personnel safety, protect the environment, and avoid loss of property.

Procedures for analyzing seismic forces and for designing offshore structures to withstand earthquakes are available. Offshore structures have been designed and installed in various active seismic areas including the upper Cook Inlet, offshore southern California, southeast Asia, the Persian Gulf, and the Tasman Sea. The expected seismic activity in lower Cook Inlet is comparable to that in the upper Cook Inlet area. New techniques for evaluating earthquake probability and seismic risk, new techniques for analyzing structural behavior, and new procedure for investigating and analyzing soil characteristics and bearing capacity have improved design capability and reliability for offshore structures in earthquake-prone areas.

Design technology for structures to withstand earthquakes combines an analysis of seismically induced ground motion with an analysis of structure and foundation behavior. This involves statistical studies and evaluation of seismicity and probabilistic ground motion at the site, taking into consideration local geology and foundation materials (Page, 1975; Idriss and others, 1975). Structural design and analysis procedures involve analysis of probabilistic structural behavior and response, including foundation behavior and foundation-structure interaction, from seismic-induced forces to show design capability to withstand the expected ground shaking duration and intensity within acceptable criteria for operation and safety (Hasselman and others, 1975; Kallaby and Millman, 1975; API, 1975).

Minimum acceptable design criteria for offshore structures will require:

1. No structural damage from ground motion in the event of the maximum probable earthquake that might occur during the life of the structure.
2. Installation of motion-sensing device for monitoring platform motion and automatic shut-down of wells and facilities in the event ground shaking would impair safe operation.

DRILLING UNIT AVAILABILITY

The relatively shallow water depths and the moderate sea conditions of the lower Cook Inlet will allow exploratory drilling by jack-up rigs as well as drillships and seim-submersible vessels. Operators will be required to show that drilling vessels are equipped and designed to satisfactorily conduct drilling operations under the environmental conditions of the area prior to issuance of a drilling permit.

At present (June 1976), there is only one mobile offshore drill vessel in Alaskan waters, the GEORGE FERRIS, a jack-up rig owned by Sun Marine Drilling Company. This drill vessel is badly damaged and is located in Kachemak Bay near Homer, Alaska. There are only a few mobile drilling vessels located or under construction on the Pacific Coast of the United States which are suited for operations in the Cook Inlet area.

Mobile offshore drill vessels for the Alaska offshore areas must be obtained from other parts of the world. This will require considerable transit time and expense because most offshore mobile drilling units are being constructed or working on the Gulf Coast of the United States or in foreign areas, mainly in the European and Far East areas. Cost of mobilization and moving a drilling unit from the North Sea to the Cook Inlet area is estimated to be 1.5 - 5 million dollars, depending upon the type of rig.

The trend in new drillships and semi-submersible vessels has been toward capability of drilling in deeper water and in more harsh environmental climates. Most drillships and semi-submersibles constructed in recent years, and nearly all of these under construction or planned, are of the class and type designed for extended operations in rigorous environmental regions such as the North Sea, offshore Eastern Canada, and the Gulf of Alaska. The semi-submersible rigs are designed for stability under adverse sea and weather conditions, whereas the drill-ships are designed for maximum mobility and self-sufficiency. Both semi-submersible and drillships are capable of drilling in water depths to 300 metres (1,000 ft.) using anchor systems and can be used in deeper water if they are equipped with dynamic-positioning equipment. Floating drill vessels are susceptible to delay and down time during extreme weather conditions, and drilling productivity will likely be reduced during the stormy fall and winter season even though the newer rigs are designed for year-round operations under these conditions.

A recent count of mobile offshore rigs showed 298 units in operation, of which 83 are floating drillships or barges, 139 are jack-up (bottom supported), and 76 are semi-submersible. An additional 139 units are under construction or planned, including 33 drillships, 55 jack-up, and 51 semi-submersibles (Offshore Rig Data Services, 1975). Table 11 indicates mobile offshore rigs under construction with a breakdown of completion dates through 1977 by rig type.

Although mobile drilling vessels for lower Cook Inlet drilling must be transported from distant areas, it appears that there will be a good supply of the appropriate vessels available on a worldwide basis. Although it is difficult to predict future availability, there has been a recent weakening in the demand for such equipment, indicating

Table 11

Mobile Rigs Under Construction as of August 1975

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

Source: Offshore Rig Data Services, 1975.

a possible change from the shortage of offshore drilling vessels over the past few years.

MANPOWER

As in the case with drilling units, most of the skilled manpower for exploratory drilling will initially have to come from other areas. In general, the reservoir of manpower needed for the drilling, development and production, including the installation of platforms, pipelines, and onshore facilities is relatively small due to 1) the low population density in Alaska and 2) the continued need of qualified people on existing production facilities in upper Cook Inlet.

Some of the skilled manpower may be available in Alaska, depending on the stage of construction of the Trans-Alaska or other pipelines and of the Prudhoe Bay oil field. Also, it is expected that replacements will be recruited from the local labor market and trained in the skills required. As the energy shortage continues, many predict that skilled manpower for the oil and gas and related industries will be in short supply.

A large potential supply of manpower, available for training, exists in the Pacific Northwest and California. Its real availability will depend in large part on the relative state of the national economy and in finding a sufficient number of individuals willing to work far from home under harsh climatic conditions for long periods of time.

TIME FRAME FOR DEVELOPMENT

Estimates of a time frame for development and production from a new area are conjectural at best. Speculative factors which can affect development timing include the ready availability of needed equipment and material, water depth, discovery success, reservoir and hydrocarbon character, economic climate, and other conditions which can cause unforeseen delays (labor disputes, environmental hearings, and others).

A review of upper Cook Inlet development indicates the time from lease sale to first production varied from 4-7 years with peak production attained 1-2 years later. This would indicate a total time of 5-9 years from lease sale to peak or maximum production. It should be recognized that this time frame applies to relatively shallow-water areas, less than 30 metres (100 ft.), where drilling and development is less difficult and less expensive than in deeper water areas which require additional time for design and construction of special deep-water equipment and facilities.

Based upon upper Cook Inlet experience, it is estimated that it will be 1-2 years after a lease sale to substantial exploratory drilling, 4-8 years until initial production, and 6-10 years until peak or maximum production.

The expensive operating conditions and the expected high cost of equipment for Alaska operations will likely restrict development to the shallow-water areas with lower costs. Development in deeper water will be restricted to those fields which have very large recoverable reserves and sufficient potential productivity for economic development.

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APPENDIX

FORM #3

ALL IS < 200 M Water

Region 1 Offshore
RAG No.

PROVINCE SUMMARY SHEET

PROVINCE Cook Inlet Province - Tertiary (Magoon)

1975 FEA REPORT

*Stage of Exploration: Early ✓ Intermediate Some ✓ Late

*Area (Mi^2)-----Total Sed. Province: (6728) % Productive .005 (<1%)

Areas by Depth Units: 5000' 2654 5000-10,000' 957

10,000'-15,000' 1301 15,000-20,000' 1029

20,000'-30,000' 787 30,000'

*Thickness of sediments (Ft.): Avg. 10,058' (1.905) Max. 25,000'

*Volume of sediments ($Mi.^3$)

Total Province: (12,817 mi.³ = T) 26,239 mi³ TOTAL

% Drilled 25% } J + T

% Explored 40%

Stratigraphic Age Range: From Permo-Trias Through Holocene

*Producing and/or Prospective Horizons (oil) (oil) (oil)

	a.	b.	c.	d.	
Age:	Oligo-Mio	Mio-Plio	Pliocene		
Gross Thickness:	500	6000	6000		Total: 12,500'
	Hemlock	Tyonek	Beluga-Sterling		

*Dominant Lithology (Total Province)

Type	Ss/Silt.	Coal	Carb. Ss
% of Volume	70%	10%	20%

Ratio, Marine/non-marine 3:5

Types of Traps

Stratigraphic None

Structural Closed Anticline w/ some fault (Kilauea)

*Structural Aspects

Type Basin Intermontane within Unstable Coastal Margin

Geometry Symmetr. Gentle Slopes

Indications of Hydrocarbons ✓

Producing Trends 2 gas 2 oil trends

Seeps, Tar Sands, etc. Oil seeps, many. O & G shows in section

Probable Source Beds (Age and Lithology) M-Late Jurassic Siltstone w/ss.

Major Seals (Age and Lithology) Eocene-Pliocene Siltstone

Field Size Distribution: (onshore + offshore)

	Avg.	R.Min.	R.Max.
Oil (mill.bbls):	540 million	372 mill.	647 mill.
Gas (bcf):	210 Billion	20 Bill.	2,400 Bill.

Nature of Hydrocarbons:	Avg.	R.Min.	R. Max.
API Gravity	35.7°	29.7°	44°
Sulfur Content	0.08 Wt.%	0.02 Wt.%	0.15 Wt.%
*Recovery Factor	36%	30%	40%

*Production, Reserves, & Resources:	Crude Oil	NGL	Nat. Gas
Cum. Production (bill.bbls.;tcf)	0.394 Bo	0.003 Bbls	0.3931
Measured Reserves "	0.2120 "	—	1.561
Indicated Reserves "	0.0288 "	—	—
Inferred Reserves (.618 x .2120) =	0.1310 "	—	(.46 x 1.561) = 0.722

*Wells Drilled to Date: Date: 1/1/74

Exploratory Wells 165

Development Wells 296

*Resource Estimates (Undiscovered--In Billion BBLS and Trillion Cu.Ft.)

Program'd: 66% = 5.300 IP. } 9.734 x 10⁹ IP (Recoverable) (In Place)

Outside Sources Mi.-15: 7.9 x 10⁹ Cu. 14.6 x 10⁹ gas (Alaska 50) 211 x 10⁹ oil No gas fig.

U.S.G.S. Evaluator 1.05 x 10⁹ BO - no gas evaluation

Analogs Ventura Basin, Uinta Basin

RAG Estimate

*Province Qualitative Rating: Oil Gas

Posted by: Powers Date 3/12/75 Approved ✓ Date 3/13

* Data most pertinent to resource appraisals. 2/4/75

FORM # 4-A T.

(#1) ALL < 200 M

1975 RESOURCE APPRAISAL REPORT PROVINCE ESTIMATE

Region ONE, OFFSHORE (66%) RAG No.
Province COOK INLET - TERTIARY
Province Area {6728 = TERTIARY, 5913 = JURASSIC} (mi^2) Province Volume: 26,239 {12,817 = Tert, 13,422 = J} (mi^3)

* J ESTIMATES ARE INCLUDED IN THIS SHEET

PRODUCTION AND RESERVES	OIL (Bill. BBLS)	NGL (Bill. BBLS)	GAS (TCF)
Cumulative Production:	0.3940	0.003	0.3931
Identified Reserves:		—	
Measured Reserves	0.2120	—	1.561
Indicated Reserves	0.0288	—	—
Inferred Reserves	0.731 (used .618 factor)	—	0.722 (used .463 fac)
Total (Cumulative & Identified):	0.766	0.003	2.676

UNDISCOVERED RESOURCES Resource Appraisal Methods	OIL (Billion Barrels) In-Place	OIL Total Rec. Resource	OIL Undiscovered Rec. Resource	NGL (Billion Barrels) In-Place	NGL Total Rec. Resource	NGL Undiscovered Rec. Resource	GAS (Trillion Cubic Feet) In-Place	GAS Total Rec. Resource	GAS Undiscovered Rec. Resource
METHOD I--VOLUMETRIC-ANALOG									
Analog 1: McALESTER; Analog 2: VENTURA									
Yield Factors: Oil: 80,000 B/mi^3; 176,000 B/mi^3 — 1.		2.099	1.333					7.215	4.539
Gas: 275,000 mil cf/mi^3; 170,200 mil cf/mi^3									
Rec. Factors: — 2.		4.618	3.852					4.482	1.806
METHOD IV: HENDRICKS' CATEGORIES									
Dis.-Rec. Factors: 20/40/40 — Category #: 2	9.390	1.578	1.112	0.751	0.300	0.297	28.170	11.268	8.592
Category #: 3	2.347	0.469	-0-	0.187	0.075	0.072	4.695	1.878	-0-
METHOD: ( )									
Yield Factors: Oil: Gas:									
Prod.Area/Unexpl.Area:									
DOCUMENTED RESOURCE APPRAISAL ESTIMATES:		USE .36 Rec.						Using .80 Recov.	
AAPG, Memoir 15, 1971 Prorated 66% of 7900	5.292	1.905	1.139				9.773	7.818	5.142
Klein, Alska #50 (1974) Prorated (36% Rec.)			2.301						No Data
National Petroleum Council Estimates, 1973 Updated	4.257	1.533	0.767						
ANOGRE Estimates									
OTHER MAGOON —			1.05						No Data

Posted by POWERS Date 3/15/75 Approved ✓ Date 3/17/75

DOCUMENTATION FOR RESOURCE APPRAISAL METHODS USED ON FORM 4-A

METHOD I Volumetric - Analog	METHOD II Explored Area - Recovery Procedures	METHOD III Productive Area - Recovery Procedure	METHOD IV Hendricks' Categories
Analog I	Areas Explored:	Areas Productive (proved areas):	Category # 2
Basin or Province Name: McAlester	1. 2. 3.	1. 2. 3.	Discovery-Recovery Factors: 20/60/90
Yield factors used: OIL 50/100 GAS 275 prod	Areas Unexplored:	Areas Unexplored:	Modifications:
Recovery factors used: 20/60/40	1. 2. 3.	1. 2. 3.	Category # 3
Analog II	Yield per mi² of explored areas:	Yield per mi² of productive areas:	Discovery-Recovery Factors: 20/40/60
Basin or Province Name: Vr	1. 2. 3.	1. 2. 3.	Modifications:
Yield factors used: OIL 17/100 GAS 170/500 NGL Recovery factors used: 20/40/60			

AAPG, Memoir 15, 1971: Tables: ______ Pages: ______
NPC Estimates, 1973: Tables: ______ Pages: ______
ANGCRE Estimates: ______
Other Published Sources: Date: ______ Pages: ______
Other Procedures: ______

1975 FEA REPORT

DEFINITIONS FOR RESOURCE APPRAISAL METHODS USED ON FORM 4-B

REASONABLE MINIMUM -- That quantity which the estimator associates with a 95% probability that there is at least this amount.

MOST LIKELY -- That quantity which the estimator associates with the highest probability (of occurrence) that there will be this amount.

REASONABLE MAXIMUM -- That quantity which the estimator associates with a 5% probability that there is at least this amount.

EXPECTATION --Also called "EXPECTED VALUE" or "BEST ESTIMATE" -- A mathematical term. It is the only value we are entitled to add if we combine estimates of similar quantities in other provinces.

$$E = \frac{R.\ Min. + M.\ L. + R.\ Max.}{3} = \frac{50 + 300 + 850}{3} = 400$$

MARGINAL PROBABILITY -- That probability which the estimator would assign to his basic assumptions that oil and gas accumulations are actually present in the province to be evaluated.

FORM # 4-B

1975 FEA REPORT

RESOURCE APPRAISAL --PROVINCE ESTIMATE

Region ____ RAG No. ____
Province Cook Inlet {6724=T, 5913=J}
Province Area ____ (mi^2)
Province Volume: 26,239 {12,817=T, 13,422=J} (mi^3)

PRODUCTION AND RESERVES	OIL (Bill. BBLS)	NGL (Bill. BBLS)	GAS (TCF)
Total (Cumulative & Identified)	0.766	0.003	2.676

REGIONAL REPRESENTATIVE Resource Appraisal	OIL (Billion Barrels) In-Place	OIL Total Rec. Resource	OIL Undiscovered Rec. Resource	NGL (Billion Barrels) In-Place	NGL Total Rec. Resource	NGL Undiscovered Rec. Resource	GAS (Trillion Cubic Feet) In-Place	GAS Total Rec. Resource	GAS Undiscovered Rec. Resource
a. Reasonable Min. (95% "at least")			0.500						2.5
b. Reasonable Max. (5% "at least")			3.5						6.5
c. Most Likely			2.0						4.0
d. Expectation: $\frac{(a + b + c)}{3}$			2.0						4.3
Method:									
Rec.--Yield Factors:									
Classify: Hypothetical __ Speculative X									

Posted by Powers Date 3/18/75

RESOURCE APPRAISAL GROUP Recommended Appraisal:	OIL In-Place	OIL Total Rec. Resource	OIL Undiscovered Rec. Resource	NGL In-Place	NGL Total Rec. Resource	NGL Undiscovered Rec. Resource	GAS In-Place	GAS Total Rec. Resource	GAS Undiscovered Rec. Resource
a. Reasonable Min. (95% "at least")	6.3	1.266	0.5				9.19	3.676	1.0
b. Reasonable Max. (5% "at least")	15.33	3.066	2.3				18.19	7.276	4.6
c. Most Likely	8.83	1.766	1.0				11.69	4.676	2.0
d. Expectation: $\frac{(a + b + c)}{3}$	10.33	2.066	1.3				12.94	5.176	2.5
Method:									
Rec.--Yield Factors: 20/40									
Marginal Probability:									

Posted by Powers Date 3/18/75 Approved ✓ Date ____
YC 7/9/75

FORM #3

1976 FEA REPORT

Region 1 OFFSHORE.

RAG No.

PROVINCE SUMMARY SHEET

PROVINCE COOK INLET PROVINCE - JURASSIC

*Stage of Exploration: Early ✓ Intermediate ____ Late ____

*Area (Mi^2)-----Total Sed. Province: 5913 % Productive - 0 -

Areas by Depth Units: 5000' ____ 5000-10,000' ____

10,000'-15,000' NO 15,000-20,000' DATA

20,000'-30,000' ____ 30,000' ____

*Thickness of sediments (Ft.): Avg. 12,000' Max. 20,000+

*Volume of sediments ($Mi.^3$)

Total Province: 13,422

% Drilled - 0 -

% Explored - 0 -

Stratigraphic Age Range: From M. JURASSIC Through LOWER CRETACEOUS

*Producing and/or Prospective Horizons

Age: a. U. Juras b. ____ c. ____ d. ____

Gross Thickness: 12,000+ Total: 12,000'

*Dominant Lithology (Total Province)

Type Ss/SILT Conglom.

% of Volume 90% 10%

Ratio, Marine/non-marine 1:0

Types of Traps

Stratigraphic N. DATA

Structural "

*Structural Aspects

Type Basin UNSTABLE COASTAL (OROGENIC)

Geometry Synclinal

Indications of Hydrocarbons

Producing Trends - 0 -

Seeps, Tar Sands, etc. IN CRET. & JURAS ROX OUTCROPPING ONSHORE - SEEPS -

Probable Source Beds (Age and Lithology) SILT-Ss M-U JURASSIC

Major Seals (Age and Lithology) UNKNOWN

Field Size Distribution: Avg. R.Min. R.Max.

Oil (mill.bbls): None

Gas (bcf):

Nature of Hydrocarbons: Avg. R.Min. R. Max.

API Gravity

Sulfur Content None

*Recovery Factor

*Production, Reserves, & Resources: Crude Oil NGL Nat. Gas

Cum. Production (bill.bbls.;tcf)

Measured Reserves "

Indicated Reserves " None

Inferred Reserves "

*Wells Drilled to Date: None Date: 1/1/74

Exploratory Wells

Development Wells

*Resource Estimates (Undiscovered--In Billion BBLS or Trillion Cu.Ft.)

Recoverable In Place

Outside Sources NONE

U.S.G.S. Evaluator NONE

Analogs BIG SNOWY TROUGH, C. MONTANA

RAG Estimate

*Province Qualitative Rating: Oil FAIR Gas FAIR

Posted by: Powers Date 3/12/75 Approved ✓ Date 3/12

* Data most pertinent to resource appraisals. 2/4/75

FORM # 4-A J. *(#2) ALL < 200M

Region ONE, OFFSHORE RAG No. ____
Province COOK INLET - JURASSIC
Province Area 5,913 (mi^2) Province Volume: 13,422 (mi^3)

RESOURCE APPRAISAL --PROVINCE ESTIMATE 1975 FEA REPORT

PRODUCTION AND RESERVES	OIL (Bill. BBLS)	NGL (Bill. BBLS)	GAS (TCF)
Cumulative Production:			
Identified Reserves:			
Measured Reserves			
Indicated Reserves	←	NONE	→
Inferred Reserves			
Total (Cumulative & Identified):			

UNDISCOVERED RESOURCES Resource Appraisal Methods	OIL (Billion Barrels) In-Place	OIL Total Rec. Resource	OIL Undiscovered Rec. Resource	NGL (Billion Barrels) In-Place	NGL Total Rec. Resource	NGL Undiscovered Rec. Resource	GAS (Trillion Cubic Feet) In-Place	GAS Total Rec. Resource	GAS Undiscovered Rec. Resource
METHOD I--VOLUMETRIC-ANALOG Analog 1: Analog 2:									
Yield Factors: Oil: 1.									
Gas:									
Rec. Factors: 2.									
METHOD IV: HENDRICKS' CATEGORIES Dis.-Rec. Factors: Category #: 3									
Category #: 4									
METHOD: ( ) Yield Factors: Oil: Gas: Prod.Area/Unexpl.Area:									
DOCUMENTED RESOURCE APPRAISAL ESTIMATES: AAPG, Memoir 15, 1971									
National Petroleum Council Estimates,1973									
ANOGRE Estimates									
OTHER									

Posted by ____ Date ____ Approved ____ Date ____

DOCUMENTATION FOR RESOURCE APPRAISAL METHODS USED ON FORM 4-A

METHOD I Volumetric - Analog	METHOD II Explored Area - Recovery Procedures	METHOD III Productive Area - Recovery Procedure	METHOD IV Hendricks' Categories
Analog I	Areas Explored: 1. ____ 2. ____ 3. ____	Areas Productive (proved areas): 1. ____ 2. ____ 3. ____	Category # ____
Basin or Province Name: ____			Discovery-Recovery Factors: ____
Yield factors used: OIL ____ GAS ____ NGL ____	Areas Unexplored: 1. ____ 2. ____ 3. ____	Areas Unexplored: 1. ____ 2. ____ 3. ____	Modifications: ____
Recovery factors used: ____			Category # ____
Analog II	Yield per mi^2 of explored areas: 1. ____ 2. ____ 3. ____	Yield per mi^2 of productive areas: 1. ____ 2. ____ 3. ____	Discovery-Recovery Factors: ____
Basin or Province Name: ____			Modifications: ____
Yield factors used: OIL ____ GAS ____ NGL ____ Recovery factors used: ____			

AAPG, Memoir 15, 1971: Tables: ____ Pages: ____
NPC Estimates, 1973: Tables: ____ Pages: ____
ANOGRE Estimates: ____
Other Published Sources: Date: ____ Pages: ____
Other Procedures: ____

1975 FEA REPORT

DEFINITIONS FOR RESOURCE APPRAISAL METHODS USED ON FORM 4-B

REASONABLE MINIMUM -- That quantity which the estimator associates with a 95% probability that there is at least this amount.

MOST LIKELY -- That quantity which the estimator associates with the highest probability (of occurrence) that there will be this amount.

REASONABLE MAXIMUM -- That quantity which the estimator associates with a 5% probability that there is at least this amount.

EXPECTATION --Also called "EXPECTED VALUE" or "BEST ESTIMATE" -- A mathematical term. It is the only value we are entitled to add if we combine estimates of similar quantities in other provinces.

$$E = \frac{\text{R. Min.} + \text{M. L.} + \text{R. Max.}}{3} = \frac{50 + 300 + 850}{3} = 400$$

MARGINAL PROBABILITY -- That probability which the estimator would assign to his basic assumptions that oil and gas accumulations are actually present in the province to be evaluated.

FORM # 4-B

1975 FEA REPORT

1975 FEA REPORT

RESOURCE APPRAISAL --PROVINCE ESTIMATE

Region ______ RAG No. ______
Province ______
Province Area ______ (mi^2)
Province Volume: ______ (mi^3)

PRODUCTION AND RESERVES	OIL (Bill. BBLS)			NGL (Bill. BBLS)			GAS (TCF)		
Total (Cumulative & Identified)									

REGIONAL REPRESENTATIVE Resource Appraisal	OIL (Billion Barrels)			NGL (Billion Barrels)			GAS (Trillion Cubic Feet)		
	In-Place	Total Rec. Resource	Undiscovered Rec. Resource	In-Place	Total Rec. Resource	Undiscovered Rec. Resource	In-Place	Total Rec. Resource	Undiscovered Rec. Resource
a. Reasonable Min. (95% "at least")									
b. Reasonable Max. (5% "at least")									
c. Most Likely									
d. Expectation: $\frac{(a+b+c)}{3}$									
Method:									
Rec.--Yield Factors:									
Classify: Hypothetical ___ Speculative ___									

Posted by ______ Date ______

RESOURCE APPRAISAL GROUP Recommended Appraisal:									
a. Reasonable Min. (95% "at least")									
b. Reasonable Max. (5% "at least")									
c. Most Likely									
d. Expectation: $\frac{(a+b+c)}{3}$									
Method:									
Rec.--Yield Factors:									
Marginal Probability: ______									

Posted by ______ Date ______ Approved ______ Date ______