UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

RESOURCE REPORT FOR PROPOSED OCS SALE NO. 60

LOWER COOK INLET-SHELIKOF STRAIT

By

L. B. Magoon, A. H. Bouma, M. A. Fisher,
M. A. Hampton, E. W. Scott, and C. L. Wilson

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Menlo Park, California
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SUMMARY

1. Geological data for the lower Cook Inlet greatly exceeds that for the Shelikof Strait. The U.S. Geological Survey did not receive advance notice that the Shelikof Strait was to be included in the sale area until the map of the proposed OCS (Outer Continental Shelf) Sale No. 60 was received.

2. Mesozoic marine sedimentary rocks underlie the proposed sale area and extend from upper Cook Inlet to the Shelikof Strait.

   a. Middle Jurassic siltstone (Tuxedni Group) is the source for the oil currently being produced from reservoir rocks of Tertiary age in upper Cook Inlet. The thermal maturity of the middle Jurassic rocks results from deep burial in Cook Inlet and from igneous intrusion in Shelikof Strait.

   b. Upper Jurassic sandstone (Naknek Formation) is the oldest unit penetrated by the COST (Continental Offshore Stratigraphic Test) No. 1 well. The sandstone has very poor to inadequate reservoir characteristics because the pores and pore throats are filled by laumontite (sodium and zeolite).

   c. Lower and Upper Cretaceous sandstones penetrated by the COST No. 1 well have fair to good reservoir potential, respectively.

3. Cenozoic nonmarine sedimentary rocks underlie the proposed sale area. The rocks are thickest (7,600 m) in upper Cook Inlet and thin toward Shelikof Strait.

   a. The West Foreland Formation, penetrated by the COST No. 1 well, is not a potential source for oil, but may be a source for gas. The sandstone

within this unit has good to excellent reservoir properties and account for 2 percent of the oil being produced in upper Cook Inlet.

b. The Kenai Group, composed of conglomerate, sandstone, siltstone, and coal, is not a source for oil but is a source for nonassociated gas of low-temperature biological origin. Sandstone and conglomerate in the Group provide excellent reservoirs for oil and gas. Eighty percent of oil currently produced in the upper Cook Inlet area is from the oldest formation in the Group, the Hemlock Conglomerate, and 18 percent is from the overlying Tyonek Formation. The youngest formations in the Group, the Beluga and Sterling Formations, provide a source and reservoir for low-temperature biogenic gas in Cook Inlet only.

4. Based on the data we have and interpretations we have made of the petroleum geology of the sale area, we predict that the two areas most likely to be leased for petroleum exploration in this sale are: (1) along the southeast side where potential reservoir rock of Tertiary age directly overlies potential source rocks of Middle Jurassic age, and (2) in the lower Cook Inlet where anticlines associated with the Augustine-Seldovia arch may provide structural traps. Other leases outside of the areas specified above may be nominated by industry if they have additional data and geologic interpretations which support such nominations. In our opinion the entire sale area has some potential for hydrocarbon accumulation.

5. The resource assessment for the proposed sale area is as follows:

   a. Lower Cook Inlet oil--0.25 to 1.2 billion barrels at 95 percent and 5 percent probability levels, respectively, with a statistical mean of 0.6 billion barrels of oil.

   b. Lower Cook Inlet gas--0.25 to 1.2 trillion cubic feet at the 95 percent and 5 percent probability levels, respectively, with a statistical mean of 0.6 trillion cubic feet of gas.

c. The resource potential of the Shelikof Strait ranges from 0.5 to 1.0 billion barrels of oil and from 0.05 to 1.0 trillion cubic feet of gas. A probabilistic resource assessment was not made for this area, so probability values are not available.

6. Environmental geologic studies indicate several potentially hazardous conditions.

a. The entire sale area occurs in an area of high seismic activity, but a thin cover of modern sediment in lower Cook Inlet is not disrupted by surface faulting. This unbroken sediment cover indicates that ground shaking and ground failure are not significant problems. In Shelikof Strait, in contrast, the few data that does exist indicate a thicker muddy sediment cover, and therefore, a potentially greater earthquake ground response problem. The potential disruption of the sea floor by surface faulting is relatively low in lower Cook Inlet where only a few small faults offset the sea floor. In contrast, large faults in the northern Shelikof Strait pose a serious threat locally from sea floor offset. Earthquake-produced vertical shifts of the shoreline and tsunami constitute a threat to shore-based installations adjacent to the sale area.

b. Volcanic activity, particularly nuées ardents and lahars, presents a potential hazard to shore-based or other installations in the vicinity of active volcanoes such as on Augustine Island.

c. A blanket of sand, which locally exceeds 2 m in thickness, covers the sea floor in the central part of lower Cook Inlet. This sand seems to move actively in the form of large bedforms (2 to 12 m high), particularly during peak spring tides, posing the potential hazard for scouring, undermining, or covering structures on the sea floor.

7. Despite the disparity of available geologic information within the proposed sale area, we recommend that the proposed area for nominations be unchanged.

8. We estimate that exploratory drilling will continue for 10 years after the sale, and production platforms will be installed during a period of 4 to 11 years following the sale. Individual fields have an anticipated life of 25 years and oil platforms will be removed within 40 years after the start of production.

9. Exploration supply bases will probably be at Kenai for activities in lower Cook Inlet and at Kodiak for those in Shelikof Strait.

10. Production facilities in lower Cook Inlet and the northern part of Shelikof Strait would resemble those used in the North Sea to water depths of 200 m. The water depth in the southwestern two-thirds of Shelikof Strait is between 200 and 300 m and would require advanced production technology. Onshore and offshore oil and gas production facilities may include a LNG (liquid natural gas) plant.

11. Approximately 80 percent of the manpower required for exploration would come from outside of Alaska, but 80 percent of the manpower required for production and construction is available within Alaska.

12. Heavy-duty drillships and semisubmersibles required for operation in the proposed sale area will be available after the sale, although supplies for all types are currently in short supply.

13. The narrow channel between Kodiak Island and Whale Island (Kupreanof Strait), the probable supply route between operations in Shelikof Strait and a base at Kodiak, has a shallow (< 20 m) rocky bottom, and poses an above-average navigation risk.

INTRODUCTION

Federal OCS (Outer Continental Shelf) Sale No. 60 is proposed for lower Cook Inlet and Shelikof Strait in southern Alaska. The Bureau of Land Management (BLM) requested that the U.S. Geological Survey prepare this Resource Report before BLM requests industry to make tract nominations. This report summarizes the framework geology, petroleum geology, resource assessment, sale outline, environmental geology, and time frame and infrastructure for development of the lower Cook Inlet and the Shelikof Strait. The outline of Sale No. 60 is shown on figure 1.

The proposed sale area lies southwest of upper Cook Inlet, an important petroleum province. Work in Cook Inlet basin (upper and lower Cook Inlet) by the petroleum industry and the U.S. Geological Survey has emphasized the framework geology. Pertinent industry publications include Kirschner and Lyon (1973) and Boss, Lennon, and Wilson (1976). U.S. Geological Survey publications include Detterman and Hartsock (1966), Magoon, Adkison, and Egbert (1976), and Fisher and Magoon (1978). Informative publications on the framework geology for the Shelikof Strait area include Keller and Reiser (1959), Moore (1967), Moore (1974), and Imlay and Detterman (1977).

Publications on the petroleum geology for lower Cook Inlet are Kelley (1963, 1968), Alaska Geological Society (1970), Magoon and others (1975, 1976), Blasko (1976a, 1976b), Claypool and Threlkeld and Magoon (in prep.), and Magoon and Claypool (in press a, in press b). In contrast, no publications on the petroleum geology for the Shelikof Strait exist.

Publications on the resource assessment for the lower Cook Inlet include Magoon and others (1975 and 1976) and Miller (1975). No publications on the resource assessment for the Shelikof Strait exist.

Publications on the environmental geology for lower Cook Inlet include Walker (1966), National Research Council (1972), Bouma and Hampton (1976), Bouma

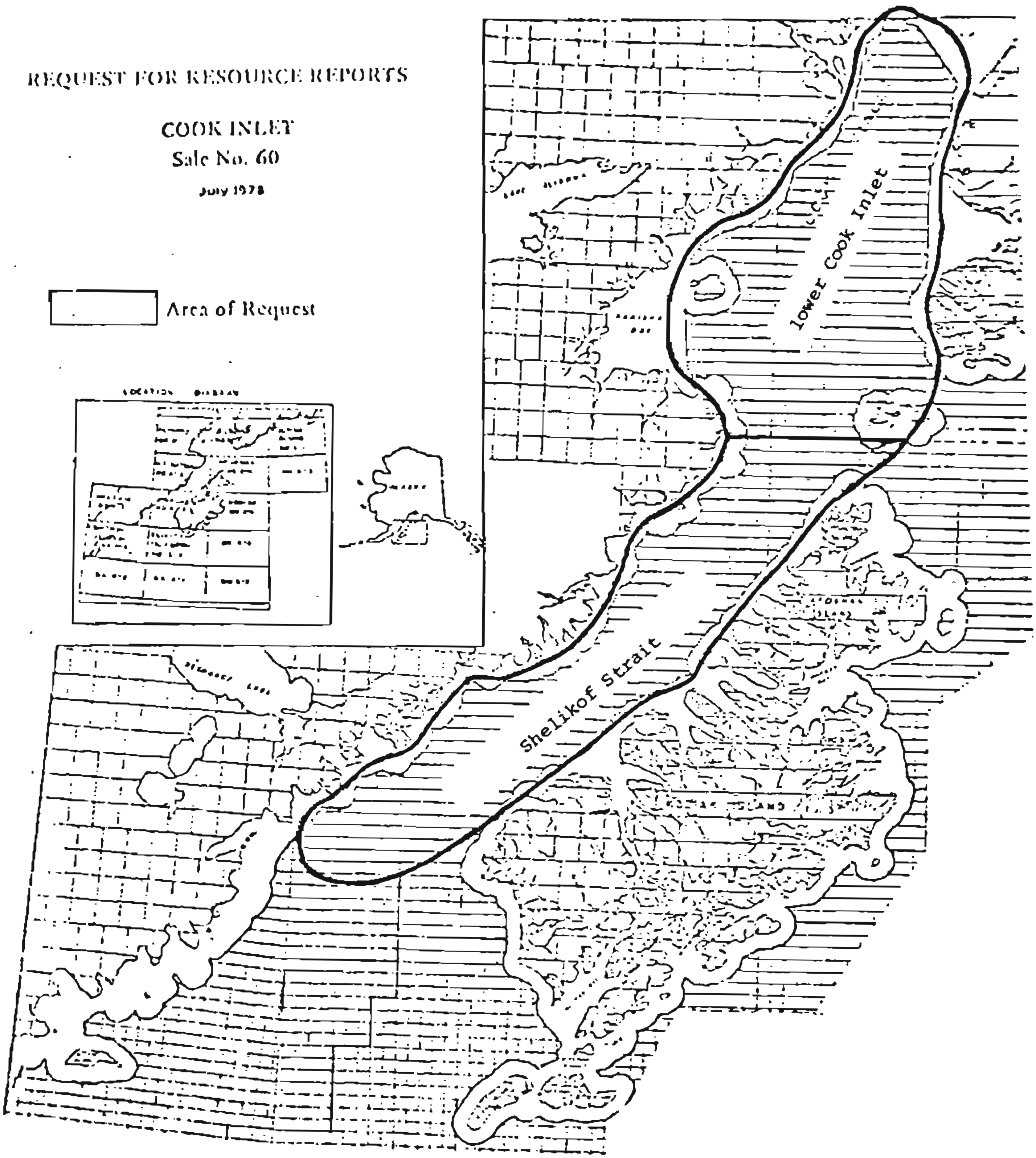


Figure 1.--Outline of the proposed Federal OCS Sale No. 60 in lower Cook Inlet and Shelikof Strait.

Hampton, and Orlando (1977), Burbank (1977), Bouma and others (1978a, 1978b), and Muench, Mofield, and Charnell (1978). No publications on the environmental geology for Shelikof Strait exist.

Publications on the time frame and infrastructure for development of lower Cook Inlet include Magoon and others (1975, 1976). No publications on the time frame and infrastructure exist for the Shelikof Strait. A publication on weather and water conditions by National Oceanic Survey (1977) covers both areas.

The relative abundance of publications for the two areas indicates the disparate amount of information publicly available for lower Cook Inlet compared to Shelikof Strait. The geology of lower Cook Inlet has been investigated actively by the U.S. Geological Survey for the past four years, and additional information is provided by the COST No. 1 well. Shelikof Strait, in contrast, has received little attention because the area was only recently included in the sale area. Additional data are needed on the framework geology and petroleum geology in the Shelikof Strait to provide a better resource assessment, and more geoenvironmental information is required for an adequate geohazard map. The location of the COST No. 1 well and the geographic names used throughout the text are shown on figure 2.

People responsible for the content of specific sections are (1) Magoon and Fisher, framework geology; (2) Magoon, petroleum geology; (3) Scott, resource assessment; (4) Bouma and Hampton, environmental hazards; and (5) Wilson, time frame and infrastructure.

GENERAL GEOLOGY

Lower Cook Inlet

About 480 km of deep-reflection seismic data are available publicly in lower Cook Inlet. This seismic data proved adequate to delineate all the large anticlinal structures that were leased in Sale No. CI (Cook Inlet) and sufficient to

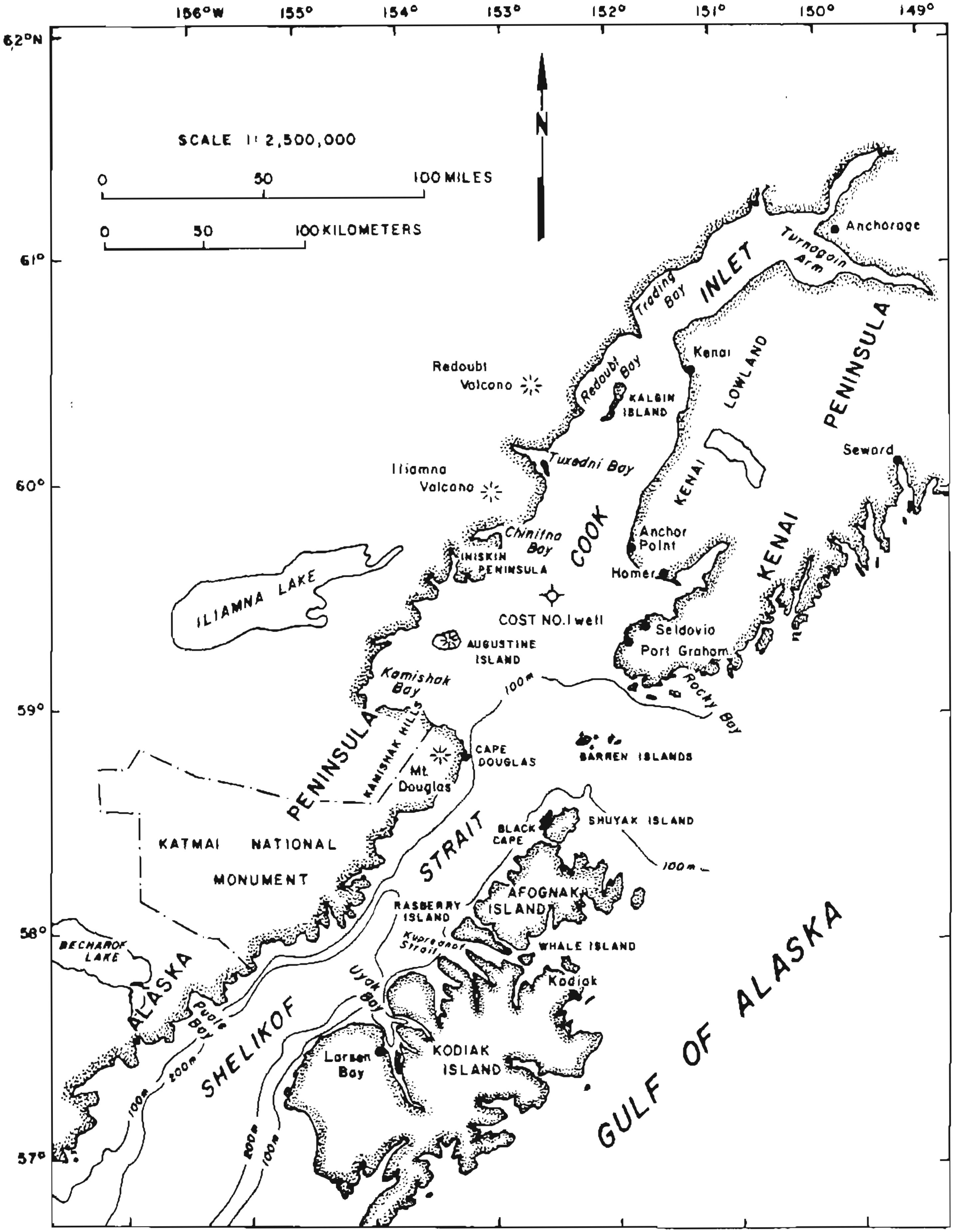


Figure 2.--Geographic names of places and geomorphic features in Cook Inlet, Shelikof Strait, and adjacent areas. The COST No. 1 well is located in lower Cook Inlet.

establish the regional geology of the offshore area. Rocks of lower Cook Inlet are part of a belt of Mesozoic and Cenozoic sedimentary rocks that extend northeastward into upper Cook Inlet and southwestward down the Alaska Peninsula and the Shelikof Strait. Along this belt, marine Mesozoic rocks may be more than 10,786 m thick; continental Cenozoic rocks are as much as 7,600 m thick. Four major northeast-trending geologic features that flank Cook Inlet are the Alaska-Aleutian Range batholith and the Bruin Bay fault on the northwest side, and the Border Ranges fault and the undifferentiated Mesozoic terrane on the southeast side. The geology of the Cook Inlet-Shelikof Strait area is shown on figure 3. The stratigraphic units and symbols used on figures 3, 5, and 6 are shown on figure 4. Three cross sections (A-A', B-B', and C-C') are located on figure 3 and shown on figure 5. Stratigraphic names and thicknesses are shown on figure 6.

The Alaska-Aleutian Range batholith, exposed on the northwest basin flank, is mostly quartz diorite. Although younger plutons exist, most of the batholith was emplaced between 176 and 154 m.y. ago or during Middle and Upper Jurassic time.

The Bruin Bay fault, a high-angle reverse fault, can be traced along the northwest side of the lower Cook Inlet basin for 215 km. In Kamishak Bay the fault plane dips 60° northwest. Just north of Chinitna Bay, stratigraphic throw across the fault is as much as 3,000 m; granitic rocks and rocks of Early Jurassic age or older on the northwest are faulted against rocks of Middle Jurassic age or younger on the southeast.

A surface fault near Seldovia, part of the Border Ranges fault, is interpreted to extend northeast beneath the Kenai lowland, and southwest through the Barren Islands to the northwest side of Kodiak Island. In the Kenai lowland, the fault is overlapped by Tertiary sedimentary rocks, but in the Seldovia area, the fault separates potentially petroliferous Mesozoic shelf deposits (Jurassic

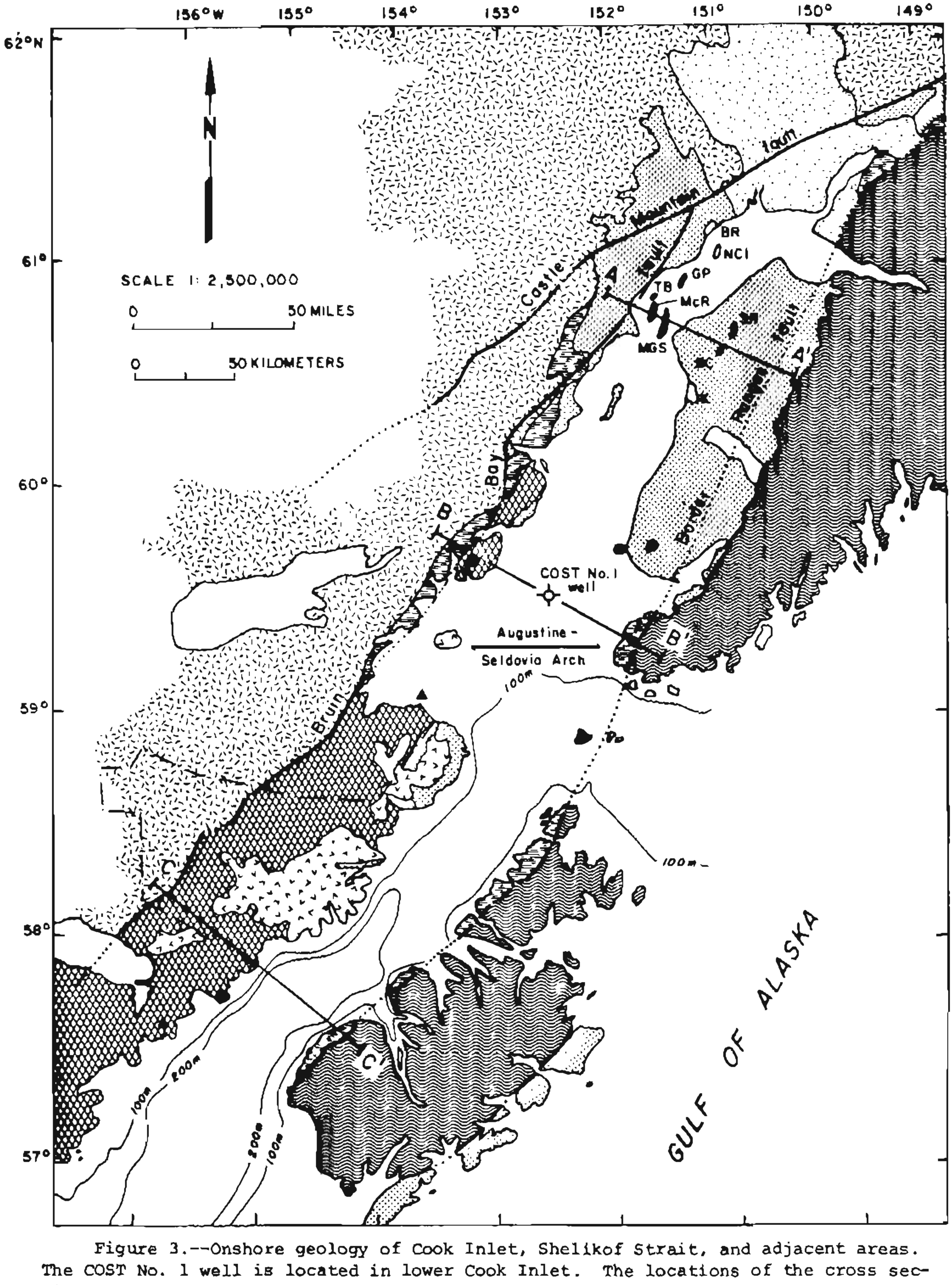


Figure 3.--Onshore geology of Cook Inlet, Shelikof Strait, and adjacent areas. The COST No. 1 well is located in lower Cook Inlet. The locations of the cross sections A-A', B-B', and C-C', presented in figure 5, are shown. Indication of oil in wells and at the surface are shown around lower Cook Inlet and on the Alaska Peninsula.

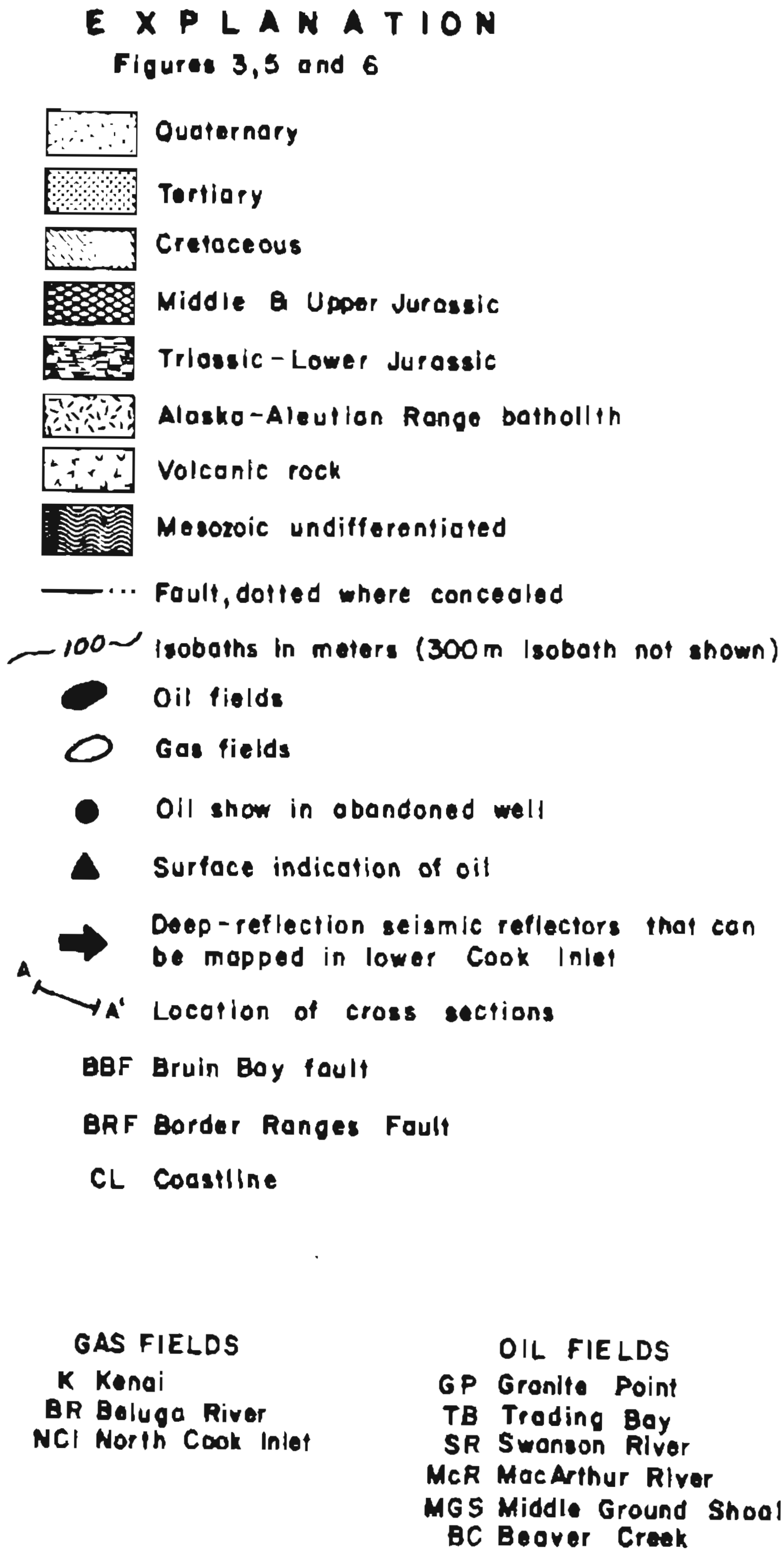


Figure 4.--Explanation of symbols and abreviations used on figures 3, 5, and 6.

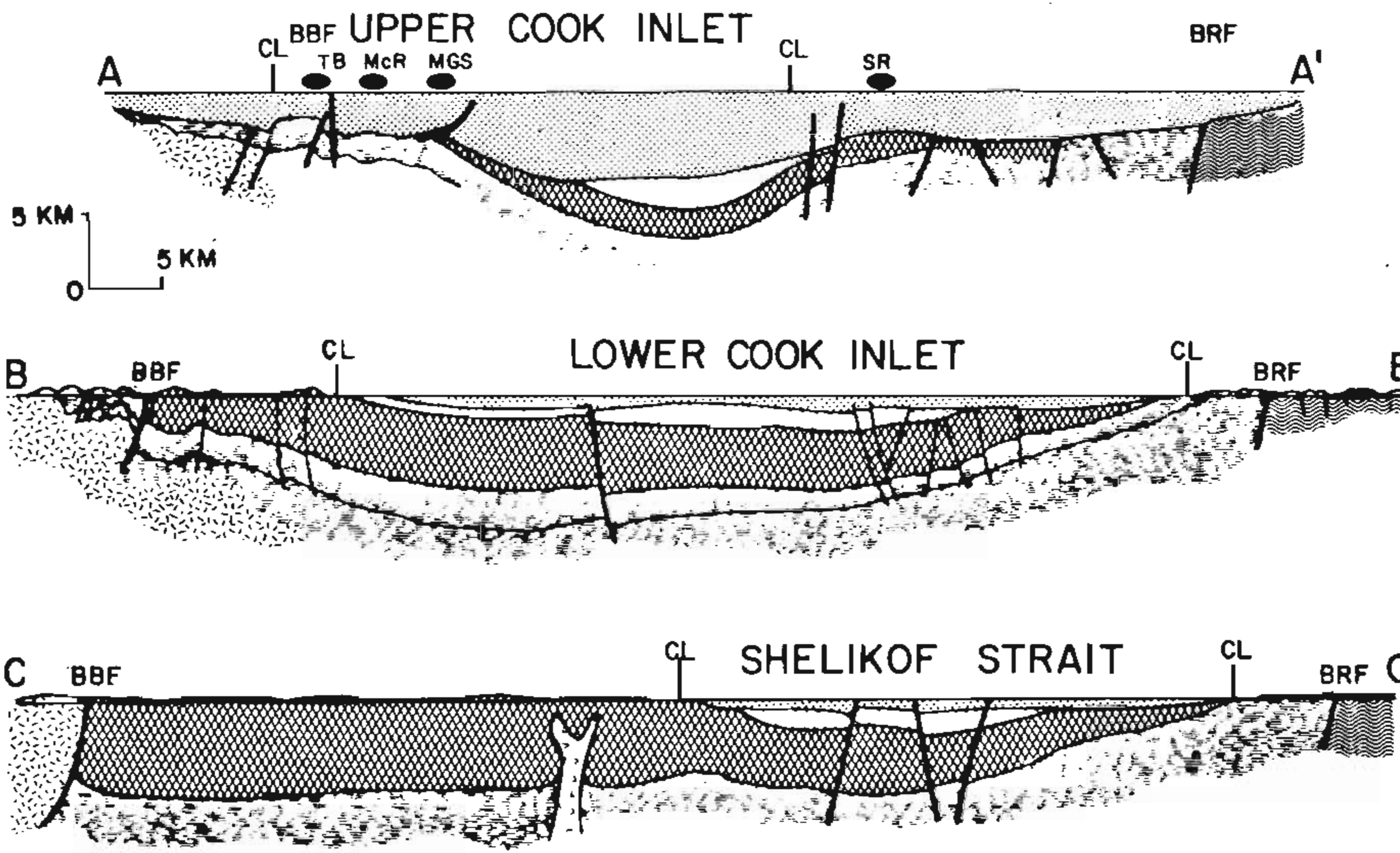


Figure 5.--Subsurface geology on cross sections A-A' through upper Cook Inlet, B-B' through lower Cook Inlet, and C-C' through the Alaska Peninsula and the Shelikof Strait. Cross section C-C' is conceptual except for onshore surface geology. The locations of these cross sections are shown on figure 3.

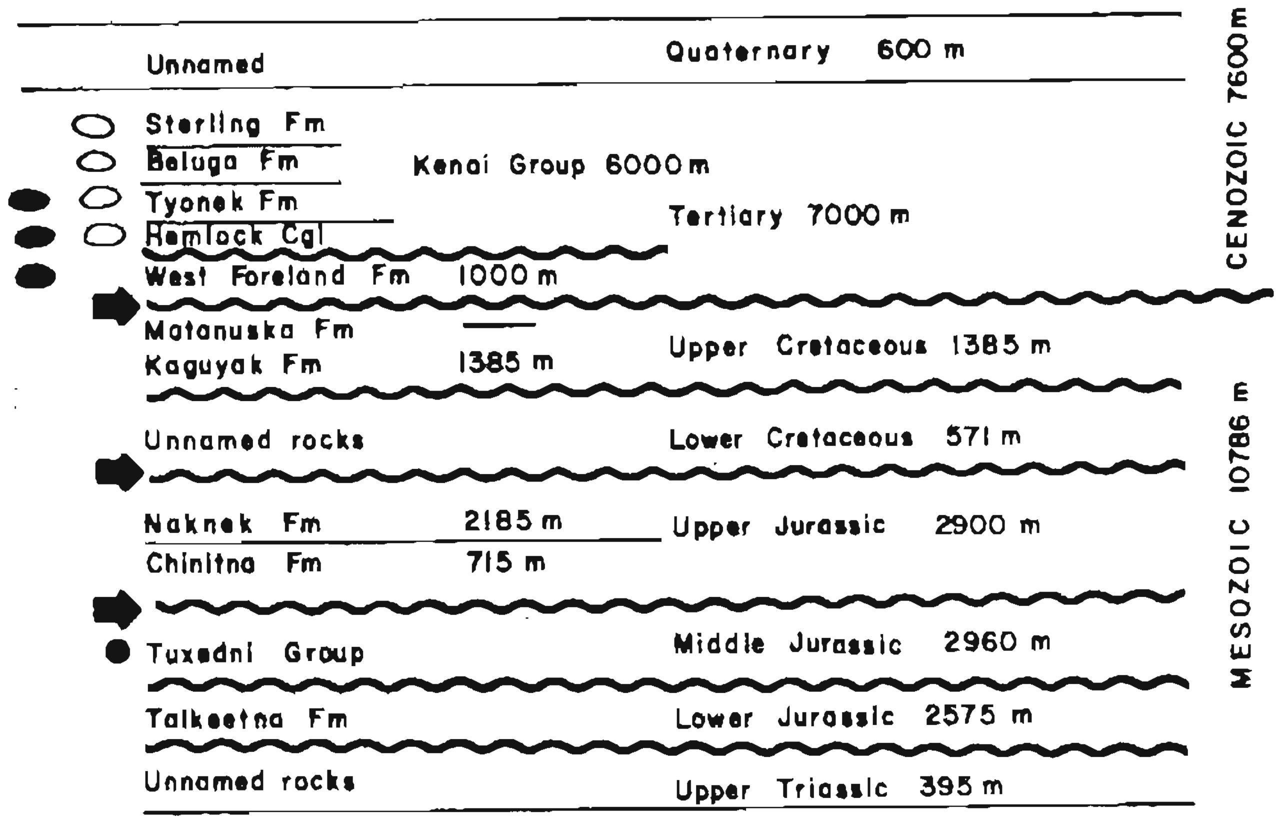


Figure 6.--Stratigraphic names and thicknesses of the rock units located between the Alaska-Aleutian Range batholith and the undifferentiated Mesozoic rocks in the Cook Inlet-Shelikof Strait area are outlined. Indications of oil and gas in the rock units are on the left. Three seismic reflectors, mapped in lower Cook Inlet, are indicated by arrows (used to make cross section B-B'). Refer to figure 4 for explanation of symbols.

through Cretaceous rocks) on the west from Mesozoic melange and flysch deposits (Mesozoic undifferentiated) on the east that have neither source nor reservoir potential for oil or gas. Sedimentary rocks, at least as old as Triassic, are present in the sale area between the Alaska-Aleutian Range batholith and the Mesozoic melange and flysch deposits.

Upper Triassic rocks.--On the northwest side of lower Cook Inlet, rocks of Late Triassic age are exposed in scattered outcrops on both sides of the Bruin Bay fault from Kamishak Bay to Tuxedni Bay. At the head of Tuxedni Bay, Upper

Triassic rocks are as much as 395 m thick and consist of metamorphosed limestone, tuff, chert, sandstone, shale, and basaltic lava flows. On the southwest side of lower Cook Inlet, Upper Triassic rocks exposed west of the Border Ranges fault consist of fossiliferous marine limestone and fine-grained tuff. Upper Triassic rocks also are exposed on the westernmost island of the Barren Islands. These rocks do not have petroleum resource potential.

Lower Jurassic rocks.--Rocks of Early Jurassic age are exposed on both sides of the Inlet. On the northwest side, the outcrop belt is as much as 15 km wide and is cut in several places by the Bruin Bay fault. South of Tuxedni Bay, Lower Jurassic rocks dip generally southeast and consist of poorly bedded volcanic agglomerates, breccias, and lava flows of the Talkeetna Formation. In the Iniskin-Tuxedni area the formation is as much as 2,575 m thick. Near Seldovia, Lower Jurassic strata consist of volcanic tuff, agglomerate, and breccia and interbedded marine sandstone, shale, and limestone, and the estimated thickness of these rocks is 300 m. On the basis of lithology and age, the rocks near Seldovia have been assigned to the Talkeetna Formation. Two wells in Redoubt Bay and two on the Iniskin Peninsula penetrate this unit. The presence of this formation on both sides of lower Cook Inlet and in some offshore areas suggests that the formation is continuous beneath the Inlet. These rocks, along with the Upper Triassic rocks, do not have petroleum potential and are considered economic basement.

Middle and Upper Jurassic rocks.--Unconformably 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 lower Cook Inlet east of the Bruin Bay fault, but the rocks have been penetrated by two wells on Kalgin Island, by three wells on the Iniskin Peninsula, by the lower Cook Inlet COST (Continental Offshore Stratigraphic Test) No. 1 well, and by one well on the Kenai lowland. Thus, these rocks are continuous under the Inlet. The Middle

Jurassic rocks are the source rocks for the oil being produced in upper Cook Inlet. The Upper Jurassic sandstones have very poor to inadequate reservoir properties.

Middle and Upper Jurassic rocks are divided, in upward order, into the Tuxedni Group, the Chinitna Formation, and the Naknek Formation. The Tuxedni Group, of Middle Jurassic age, consists of alternate beds of fossiliferous graywacke, sandstone, and siltstone. In the Iniskin-Tuxedni region, the Tuxedni is as much as 2,960 m thick. The Chinitna Formation, of Late Jurassic age, unconformably overlies the Tuxedni Group. The Chinitna is mostly dark-gray marine siltstone with large concretions and is as much as 715 m thick in the Iniskin-Tuxedni area. The Naknek Formation, of Late Jurassic age, unconformably overlies the Chinitna Formation and has greater areal exposure than the underlying rocks; the Naknek crops out from the Kamishak Hills to Tuxedni Bay. In the Iniskin-Tuxedni region the Naknek is as much as 1,435 m thick and is composed of fossiliferous marine conglomerate, sandstone, and siltstone. The part of the Naknek exposed along the coast in Kamishak Bay is approximately 750 m thick and is younger than the part of the Naknek exposed in the Iniskin-Tuxedni region. The combined thickness of the Naknek in these two areas exceeds 2,185 m. The lower Cook Inlet COST No. 1 well penetrated 1,664 m of the Naknek Formation. Unconformable contacts within and between the Middle and Upper Jurassic strata may be good seismic reflectors.

Lower Cretaceous rocks.--In the lower Cook Inlet area, 215 m of Lower Cretaceous rock unconformably overlies Upper Jurassic strata in the Kamishak Hills. The beds consist of siltstone and sandstone that are rich in *Inoceramus* fragments. Lower Cretaceous rocks are interpreted to be present near the Swanson River oil field northeast of Kenai. Lower Cretaceous strata are penetrated by the lower Cook Inlet COST No. 1 well (571 m thick) and by a well at Anchor Point.

The unit is present in a large area of offshore lower Cook Inlet. The Lower Cretaceous shale is not potential oil or gas source rock, but the sandstone has fair reservoir properties. This unit is bounded by unconformities that may be good seismic reflectors.

Upper Cretaceous rocks.--Upper Cretaceous rocks in the Cook Inlet basin south of Seldovia are assigned to the Kaguyak Formation; north of Seldovia, to the Matanuska Formation. The Kaguyak Formation crops out in the Kamishak Hills-Cape Douglas area, where 1,385 m of rock unconformably overlies Lower Cretaceous strata. In upward succession, this formation consists of shallow-marine sandstone, bioturbated gray siltstone, and turbidite sandstone and siltstone. On the Kenai lowland many wells penetrate the Matanuska Formation. In the subsurface, Upper Cretaceous strata exists from the upper Cook Inlet to Kachemak Bay and were encountered in the lower Cook Inlet COST No. 1 well. The distribution of Upper Cretaceous rocks in the Cook Inlet basin suggests these rocks are present in the subsurface of offshore lower Cook Inlet. Upper Cretaceous shale and siltstone is not potential source rock, but the sandstone has good reservoir properties.

Tertiary rocks.--Tertiary rocks of lower Cook Inlet are all nonmarine or continental and consist of the West Foreland Formation and the overlying Kenai Group. The conglomeratic West Foreland Formation includes much tuffaceous and volcaniclastic material. In outcrop, this unit unconformably overlies progressively younger rocks from north to south along the northwest side of lower Cook Inlet. West of Redoubt Bay, the unit overlies Lower Jurassic rocks; north of Chinitna Bay, Upper Jurassic rocks; near Cape Douglas, Upper Cretaceous rocks. Near Cape Douglas the unit attains a maximum thickness of 1,000 m. The West Foreland Formation is penetrated by wells on the Kenai lowland and offshore by the lower Cook Inlet COST No. 1 well (419 m thick). The West Foreland Formation does not have oil-source potential but may have gas-source potential. The conglomeratic sandstone has good to excellent reservoir properties.

The Kenai Group is composed of conglomerate, sandstone, siltstone, and coal. Exposures are present west of Redoubt Bay, near Cape Douglas, and overlap the Border Ranges fault in the Kenai lowland and near Seldovia. Tertiary rocks of unknown age occur on the Barren Islands. Well data indicate the total Tertiary (7,000 m) and Quaternary sequence is more than 7,600 m thick north of Kenai, whereas outcrop data obtained near Cape Douglas show that Tertiary rocks are about 1,850 m thick. The Kenai Group rocks are not an oil source but are a low-thermal gas source. The sandstone and conglomerate are excellent reservoirs for oil and gas. The widespread unconformity between Mesozoic and Tertiary rocks is probably a good seismic reflector.

Lower Cook Inlet COST No. 1 well.--The stratigraphic units penetrated in the Atlantic Richfield Company lower Cook Inlet COST No. 1 well located in Block 489 are the West Foreland Formation, Upper and Lower Cretaceous rocks, and the Naknek Formation. Sandstones of potential reservoir quality were encountered in the West Foreland Formation, Upper and possibly Lower Cretaceous rocks. The Naknek Formation is diagenetically altered by zeolitization. Rocks were not encountered that contained sufficient organic material or that have a favorable thermal history to generate commercial amounts of oil or gas.

The Upper Jurassic Naknek Formation was penetrated from 2,112 m (6,930 ft) to total depth (TD) of 3,776 m (12,387 ft). Depths to all formation tops and stratigraphic thicknesses are measured from the Kelly bushing. The top of the Naknek is placed just below the rocks containing abundant *Inoceramus* fragments found in a sidewall core at 2,109 m (6,920 ft) and just above the rocks that contain the first indication of zeolites (laumontite) at 2,146 m (7,040 ft). Resistivity, velocity, and density curves are indented at the top of the Naknek

Formation. Paleontological data in this interval is sparse, but the data suggest Late Jurassic age. Most of these rocks indicate a marginal to shallow marine environment, possibly ranging as deep as middle neritic. Sidewall cores consist of mainly siltstone, shale, and sandstone. Modal analyses of 38 thin sections indicate an average composition of $Q_{24}F_{55}L_{21}$ (lithofeldspathic sandstone). Only 12 of 172 recorded sidewall cores have favorable reservoir properties. The average porosity and permeability of sandstones from sidewall cores is 17.9 percent and 39 millidarcies, respectively. Data from conventional cores indicate reservoir properties ranging from very poor to inadequate. The upper part (450-600 m) of the Naknek Formation in this well probably correlates with rocks exposed along the southwest coast of the Kamishak Bay, and the lower part (1,200-1,600 m) probably correlates with the Naknek Formation exposed in the Iniskin-Tuxedni region.

Lower Cretaceous rocks were penetrated from 1,541 m (5,055 ft) to 2,112 m (6,930 ft) and are 571 m (1,875 ft) thick. The top of this unit is placed at a large abrupt excursion of the resistivity log and at a slight excursion on the interval velocity and density logs. An increase in interval velocity occurs near the base of the Lower Cretaceous at the top of the calcite-rich sandstone rocks which contain no zeolite (laumontite), but the rocks are diagenetically altered. A diverse population of marine microplankton and calcareous nannofossils in addition to foraminiferal data from rocks between 1,594 m (5,230 ft) and 2,109 m (6,920 ft) indicate a Lower Cretaceous age. The foraminiferal data suggest middle bathyal to inner neritic marine environments. Sidewall cores consist of sandstone, siltstone, shale, and *Inoceramus* fragments. Modal analyses of 37 thin sections indicate an average composition of $Q_{36}F_{44}L_{20}$ (lithofeldspathic sandstone). The average porosity and permeability of sandstones from sidewall cores is 21.5 percent and 80 millidarcies, respectively. Conventional cores recovered from depths of 1,642 m (5,390 ft) to 1,649 m (5,412 ft) contain sandstone that average 13.9 percent porosity and 0.3 millidarcies permeability. The core data are significantly lower than averages from sidewall core data, probably because of formation fracturing induced by the sidewall core gun. The unit in the COST No. 1 well is the same age as the Lower Cretaceous rocks in the Kamishak Hills where the rocks are 215 m (705 ft) thick.

Upper Cretaceous rocks were penetrated from 832 m (2,730 ft) to 1,541 m (5,055 ft) and 709 m (2,325 ft) thick. The top of this unit is placed on the abrupt excursion of the resistivity, velocity, and density curves at 832 m (2,730 ft). Through two intervals, 1,541 m (5,055 ft) to 1,036 m (3,400 ft) and 1,036 m (3,400 ft) to 832 m (2,730 ft), the age of this unit is Upper Cretaceous based on palynormorphs and foraminifera. Palynormorphs and foraminifera indicate that the water depth in which the rocks within these two intervals were deposited shallows upward from upper bathyal marine through mid-neritic marine to continental environments, or two regressive sequences within the Upper Cretaceous rocks. Sidewall cores include sandstone, siltstone, and some coal. Modal analyses of 21 thin sections have an average composition of $Q_{23}F_{61}L_{16}$ (feldspathic sandstone). The average porosity and permeability of sandstones from sidewall cores is 22.8 percent and 43 millidarcies, respectively. The Upper Cretaceous rocks in this well correlate with the Matanuska Formation and the Kaguyak Formation.

Based on palynology, the first indication (minimum depth) of lower Tertiary rocks is at 413 m (1,356 ft) and the last (deepest) indication is at 832 m (2,730 ft), which gives a minimum thickness of 419 m (1,374 ft). Foraminifera, calcareous nannofossils, and radiolaria are nondiagnostic. Sidewall core samples are sandstone, siltstone, coal and some conglomerate. Modal analyses of eight thin sections have composition of $Q_{23}F_{30}L_{47}$ (feldspatholith sandstone). The average porosity and permeability from sidewall cores is 22.7 percent and 108 millidarcies, respectively. The lower Tertiary unit is correlative with the West Foreland Formation, which crops out on the west side of the Cook Inlet basin.

Shelikof Strait

In Shelikof Strait about 450 km of deep-reflection seismic, gravity, and magnetic data are available in a coarse grid; this grid is inadequate to determine the location and trend of offshore structures. No wells have been drilled in the offshore area; reconnaissance geologic maps and onshore well information, however, are available. Seismic data are poor because of complex geology, but are good enough to show that less than 2,000 m of Cenozoic strata are present. Seismic reflections of possible Jurassic strata are returned from interfacies about 4,000 m beneath the surface. On the southeast side of the Strait, seismic data show Mesozoic strata dipping northwest and are truncated southeastward across the Strait by an unconformity at the base of Cenozoic strata, as on the southeast flank of lower Cook Inlet. Onshore geology and offshore seismic data indicate geologic features in the lower Cook Inlet can be extended into the Shelikof Strait area; these features include the belt of Mesozoic and Cenozoic sedimentary rocks, the Alaska-Aleutian Range batholith, the Bruin Bay and Border Ranges faults, and the Mesozoic melange and flysch deposits (Kodiak Formation). The thickness of specific stratigraphic units onshore are only generally known.

PETROLEUM GEOLOGY

Commercial oil production is presently restricted to Tertiary rocks in upper Cook Inlet. Eighty percent of the oil being produced is from the Hemlock Conglomerate; 18 percent is from the Tyonek Formation, both of the Kenai Group; and the remaining 2 percent is from the West Foreland Formation. Oil was recovered in tests of the Hemlock Conglomerate in two wells near Homer. Oil shows from the Middle Jurassic rocks were detected in wells drilled on the Iniskin Peninsula, and a "dead" oil smell was reported and confirmed in Upper Jurassic rocks near Cape Douglas. A series of seeps are located between Becharof Lake and Puale Bay on the Alaska Peninsula.

Possible source rocks.--The most likely sources of Cook Inlet oil are from nonmarine Tertiary, marine Cretaceous, and marine Middle Jurassic sequences. The nonmarine Tertiary sequence is rich in organic matter (mainly because of the presence of coal), but the samples analyzed to date are judged to be thermally immature. Jurassic samples analyzed to date are adequate in terms of organic richness and have reached thermal maturity.

The richness, type, and thermal maturity of organic matter in Cook Inlet sedimentary rocks was evaluated by thermal-evolution analysis employing a flame ionization detector (TEA-FID). In this analysis, a small sample of rock is heated under controlled conditions and hydrocarbons are measured as they are thermally evolved from the rock. Response of the detector is calibrated by analysis of known amounts of synthetic standard (4.24 percent n-$C_{20}H_{42}$ on Al_2O_3). Separately measured are (1) hydrocarbons present in the rock (peak I), (2) hydrocarbons produced by thermal decomposition of kerogen (peak II), and (3) the absolute temperature required to cause a maximum in pyrolysis products of the organic matter in the rock (peak II).

Type of organic matter and thermal maturity have been considered for rocks from five wells from the Iniskin Peninsula to the Kenai lowland. Wells on the Iniskin Peninsula and on the Kenai lowland contain Middle Jurassic rocks. In terms of TEA-FID measurement, Middle Jurassic rocks are the only potential oil source rocks. Thermal maturity of these rocks can be estimated using the temperature of maximum pyrolysis yield from TEA-FID analysis. Kenai lowland rocks are immature, whereas, Iniskin Peninsula rocks are mature.

Saturated hydrocarbons extracted by solvents and analyzed by gas chromatography from Cretaceous and Tertiary rocks do not resemble Cook Inlet petroleum.

Solvent extracts from Middle Jurassic rocks on the Iniskin Peninsula, however, are similar to Cook Inlet petroleum.

The kind and amount of organic matter and the apparent degree of thermal maturity of the rocks penetrated in the COST (Continental Offshore Stratigraphic Test) No. 1 well are judged to be unfavorable for generation of significant amounts of hydrocarbons. The organic carbon content from sidewall cores generally is less than 0.4 wt percent. Gas content (methane through butane) of drill cuttings is low and decreases in concentration with increasing depth of burial. Optical reflectance of vitrinite increases with depth, and reaches a maximum of 0.65 percent at total depth. Thermal alteration index (TAI) approaches three on a scale of five. Vitrinite reflectance and TAI indicate thermal alteration sufficient for hydrocarbon generation to have occurred but no organic-rich rocks are present to generate oil or gas.

Oil fields.--Producing oil fields in upper Cook Inlet are located on the east and west flank of the basin. East flank fields include Swanson River and Beaver Creek; west flank fields include Middle Ground Shoal, McArthur River, Trading Bay (3 pools) and Granite Point. All these fields are structural traps: anticlines or faulted anticlines with separate oil pools or productive horizons having separate oil-water contacts. Oil reservoirs are nonmarine sandstone and conglomerate. Initial gas-oil ratios (GOR) range from 65 to 1,110.

For oil to migrate from the Middle Jurassic source rock into the lower Tertiary reservoir rock requires that migration occur prior to deformation of the Beluga and Tyonek Formations and Hemlock Conglomerate. Rocks of this age thin to the west thereby creating an eastward dip to the Hemlock Conglomerate and Tyonek Formation reservoir rocks. High porosity and permeability in the West Foreland Formation in McArthur River field area provides an avenue for oil migration from the Middle Jurassic source rock through the West Foreland

Formation and into the overlying Hemlock Conglomerate and Tyonek Formation. A large stratigraphic oil field occurred on the west flank at the end of Beluga Formation time. Later deformation caused the stratigraphically trapped oil to remigrate into the present-day structural traps.

Gas fields.--Producing gas fields in upper Cook Inlet are Beluga, North Cook Inlet, and Kenai gas fields. These gas resources occur as nonassociated gas fields and are in contrast to gas associated with the oil fields. Nonassociated gas occurrences are confined to the shallower Sterling, Beluga, and Tyonek Formations of the Kenai Group, whereas gas associated with oil occurrences are limited to the deeper (older) Tyonek Formation and Hemlock Conglomerate of the Kenai Group, and the West Foreland Formation. Nonassociated gas is dry (only methane), whereas associated gas is wet (methane through butane). The carbon isotope ratio of methane for nonassociated gas range from -56 to -62 permil while associated gas occurrences range from -43 to -49 permil. Carbon isotope values for nonassociated gas indicate a low-temperature biological origin, whereas carbon isotope values for associated gas indicate a thermal origin. The nonassociated gas originates from nonmarine sedimentary rocks of the Sterling, Beluga, and shallower (younger) Tyonek Formations while the associated gas comes from the Middle Jurassic.

Lower Cook Inlet

The two areas most likely to be leased in the lower Cook Inlet and Shelikof Straits are outlined on figure 7. This relative assessment is based on the local framework geology of source beds, thermal maturity, reservoir rocks, and trapping mechanisms. Areas of high bids in Sale No. CI (Cook Inlet) gave some indication of industry's major interests in that sale area. Our evaluation of target areas for this sale corresponds to industry's expression of interest in Sale No. CI and indicates that the southeast side of both lower Cook Inlet and

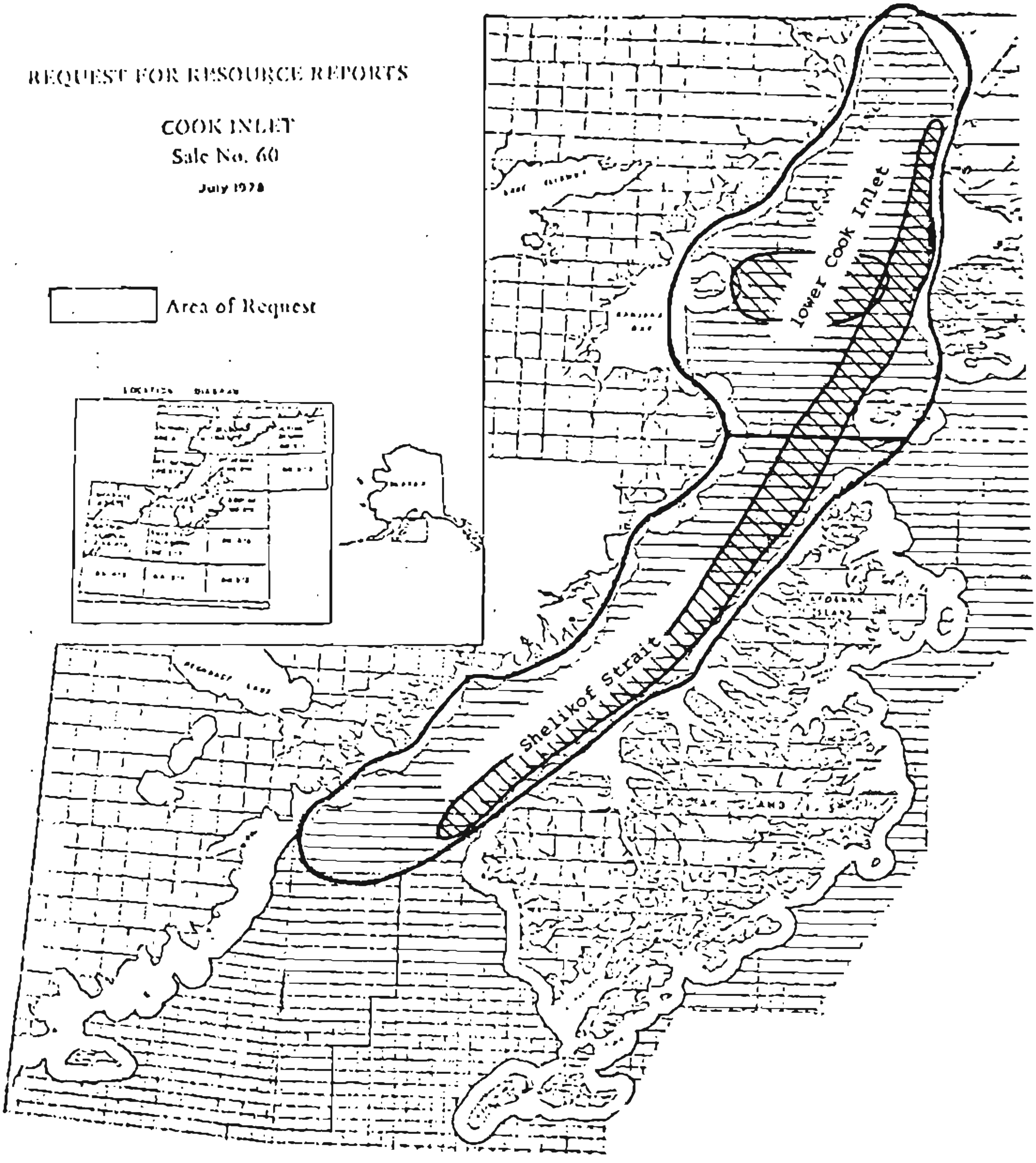


Figure 7.--Areas most likely to be nominated for sale (cross-hatched) in the lower Cook Inlet and Shelikof Straits sale area.

Shelikof Straits is one of two most likely areas for target nomination in the exploration of oil and associated gas in reservoir rocks of Tertiary age. In addition, leasing activity for similar reasons is most likely to continue in this sale on or around the Augustine-Seldovia arch. Lease nominations in the "most likely" areas, as shown on figure 7, and adjacent to the Kenai lowland, may be directed toward exploration for gas in the uppermost Tertiary rocks. Other tracts, however, outside the cross-hatched areas of figure 7 may be nominated because industry has specific information and their own geologic interpretations regarding oil and gas potential. Data and interpretations now available to Government do not allow a closer approximation of those areas likely to be nominated within the entire sale area. We infer that the entire area has some potential for hydrocarbon accumulations and therefore cannot be eliminated from consideration in this sale.

Shelikof Strait

The petroleum geology of the Shelikof Strait is poorly understood, but some observations are possible. Upper Triassic (Permian?) through Middle Jurassic oil-source(?) rocks (reported petroleum indications) are present onshore at the surface anticline adjacent to Puale Bay. Onshore geology and offshore seismic data indicate the Middle(?) Jurassic rocks are in the subsurface throughout the area between the Bruin Bay fault to somewhere offshore in the Shelikof Strait. Middle(?) Jurassic rocks do not crop out on Kodiak Island. These rocks are at considerable depth under the Alaska Peninsula but become shallower under Shelikof Strait. Seismic data indicate the Mesozoic rocks are truncated by Cenozoic rocks under Shelikof Strait.

In the Katmai National Monument, Tertiary volcanic rocks intrude the Middle(?) Jurassic rocks to provide a local heat source to generate oil and gas. The rocks at Cape Douglas were heated by this igneous intrusion and are thermally mature for oil and gas. The oil indications on the surface near Becharof Lake and Puale Bay may have been generated by this heat source. Burial depth however, of Middle(?) Jurassic rocks under the Alaska Peninsula may be sufficient to generate oil and gas.

The area of higher petroleum potential can be outlined, but the outline is based on very little geologic information. The area of higher resource potential is the southeast side of Shelikof Strait where the Cenozoic reservoir rocks unconformably overlies the Mesozoic source rocks. Tracts that fall outside the outline of higher petroleum potential are to be considered areas of lower petroleum potential.

RESOURCE ASSESSMENT

Lower Cook Inlet

The resource assessment of the "requested area" for Sale No. 60 is made in two parts, (a) lower Cook Inlet and (b) Shelikof Strait.

The resource assessments for the lower Cook Inlet are:

	95% Probability	5% Probability	Stat. Mean
Oil (billions of bbls)	0.25	1.2	0.6
Gas (Tcf)	0.25	1.1	0.6

A resource assessment was made for the lower Cook Inlet prior to Sale No. CI (Cook Inlet). The present figures show a slight reduction over the previous estimates. These reductions are based upon the results of the COST (Continental Offshore Stratigraphic Test) No. 1 well that indicated unfavorable conditions for organic content and thermal history. The thin Cenozoic section drilled in the well as compared to the Cenozoic section in the upper Cook Inlet is also a detracting factor.

Shelikof Strait

The resource assessments for the Shelikof Strait are:

	Minimum	Maximum
Oil (billions of barrels)	0.05	1.0
Gas (Tcf)	0.05	1.0

These figures are best estimates based entirely on background knowledge of the bounding land areas (Kodiak-Afognak Islands and the Alaska Peninsula) plus a cursory examination of a few seismic sections in Shelikof Strait.

A formal assessment has not been made of this area by the Resource Appraisal Group, hence, probability ranges are not given. If probability ranges had been derived, then the marginal probability that is usually applied to frontier areas would have been applied here and the resource figure at the 95% probability would be "0".

Additional geological-geophysical data will be required before a more formal assessment can be made for Shelikof Strait. A minimum requirement is a total sediment thickness map of the area. The map will have to be derived from seismic data and onshore geologic control.

ENVIRONMENTAL GEOLOGY

Lower Cook Inlet

The U.S. Geological Survey conducted three cruises in 1976, 1977, and 1978 in lower Cook Inlet. From this data and other published information, a number of geologic hazards have been identified that pose potential problems to future installations within lower Cook Inlet and along the adjacent coastline. However, oil and gas exploration has been conducted for several years in the adjacent upper Cook Inlet, which shares similar coastal and marine environments.

Hazards associated with seismic activity.--In the past 65 years, 13 earthquakes of magnitude 6 or greater have occurred within the lower Cook Inlet area.

Earthquakes of this size typically produce major structural damage, either directly by ground shaking, ground failure, surfae faulting, and surface warping, or indirectly by sediment consolidation, and tsunamis (seismic sea waves).

Ground shaking during the 1964 earthquake created severe damage in and around Anchorage and Homer. Thin surficial sediments consist of semiconsolidated pebbly mud, unconsolidated thin sand, or unconsolidated mud overlying bedrock as revealed by shallow-depth seismic profiling, accompanied by sampling, bottom television, and camera observations. Ground-shaking effects should be minor if the unconsolidated sediment blanket is less than 2 m thick.

Ground failure, both on land and under water, are a major cause of destruction associated with large earthquakes, especially in areas containing thick sections of unconsolidated sediment. Deltas are especially prone to earthquake-induced liquefaction and sliding. Underwater movement of slide sediment can cause physical damage to structures and exposed pipelines. Within the open-water area of lower Cook Inlet little effect from ground failure can be expected. Along coastlines potential problems are rock falls from precipitous areas, translatory block sliding, and ground fissuring with associated sand extrusions; little activity, surprisingly, of these types took place along the Inlet coastline during the 1964 earthquake.

Surface faulting rarely occurs in lower Cook Inlet. A few small faults have been observed north of the Augustine-Seldovia arch, but these could not be found on adjacent tracklines three miles away. South of the arch a few surface faults exist in the lease area. Normal faults with accompanying horsts and grabens are numerous near Augustine Island between Kenai Peninsula and Shuyak Island, and in northern Shelikof Strait; these three areas of surface faulting are shown on figure 8. Besides possible problems with pipelines near landfalls, faulting is not considered to pose a significant problem.

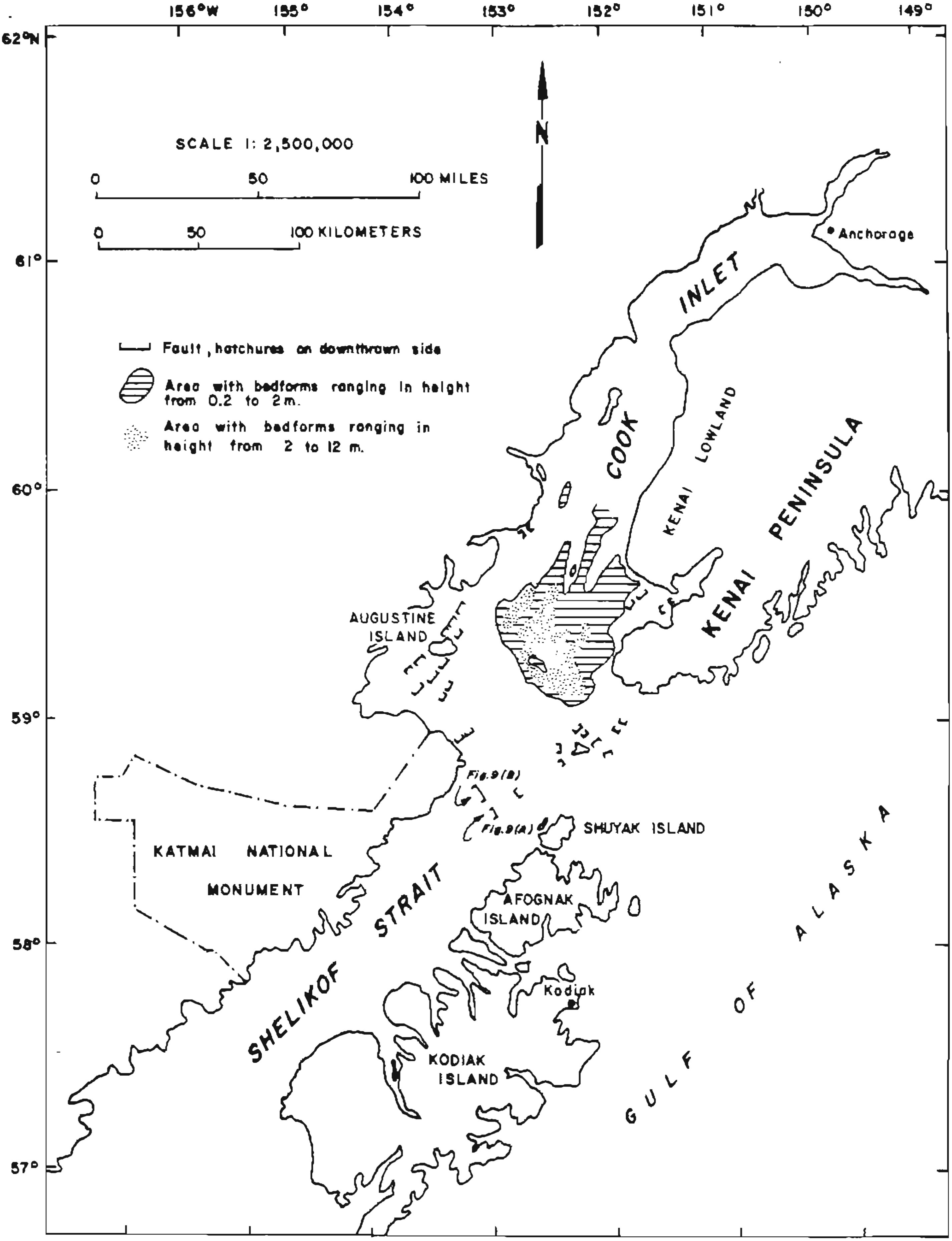


Figure 8.--Geoenvironmental aspects of lower Cook Inlet. Surface faulting that can be active are shown in the three areas (1) Augustine Island, (2) between Kenai Peninsula and Shuyak Island, and (3) in northern Shelikof Strait. Area with bedforms from 0.2 to 12 m are indicated.

Surface warping associated with earthquakes can put docks and facilities out of reach of water, as occurred at Cordova (Gulf of Alaska area) during the 1964 earthquake. Downwarping can cause flooding of originally dry land or structures. A change in the level of the coastline can be destructive, and presently no system of forewarning is known.

Sediment consolidation and the resulting subsidence is another expectable seismic-related hazard causing flooding along coastlines and consequent damage to onshore installations. Consolidation of sediment was a significant cause of subsidence along a spit near Homer and near the head of Turnagain Arm during the 1964 earthquake.

Tsunamis are generated when large volumes of water are suddenly displaced, either by tectonic displacement of the sea floor or by large rockfalls or landslides. The narrow, elongate geometry of Cook Inlet and the narrow entrances reduce the chance that a tsunami generated outside the inlet will propagate significant destructive energy into it. During the 1964 earthquake a tsunamis produced damage at Rocky Bay and Seldovia. Most of the west coast of the Inlet was hit, however, without causing damage. A locally created tsunami will affect neighboring coastlines but likely will not effect the open water. Such local tsunamis can be exceptionally large, a surge ran 530 m up the wooded slopes of Lituya Bay in the 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.

Hazards associated with volcanic activity.--Four active volcanoes are located in the lower Cook Inlet area: Redoubt and Iliamna Volcanoes, Augustine Island, and Mt. Douglas. All but Mt. Douglas have erupted in historic time. These volcanoes are andesitic and can have relatively violent eruptions. Augustine Island is the most active and erupted recently in 1964 and 1976. Its ejectiva are not considered serious more than 500 m away from the volcano throat, although fine ash can travel for hundreds of kilometers and be physically and chemically destructive. Augustine is also known to eject nuées ardentes, but little is known about the distance they can travel over water. If an adequate warning system is operating, most volcanic eruptions will be detected beforehand so offshore structures can be evacuated and machinery be shutdown. It is not advisable to construct onshore installations at the base of a volcano because nuées ardents and lahars could cause significant damage and loss of lives.

Hazards associated with sand waves.--A sand blanket covers the pebbly mud in lower Cook Inlet as shown on figure 9. This sand blanket varies in thickness from 0.2 m to at least 12 m and displays a number of different bedforms such as sand waves, sand ridges, dunes, sand ribbons, and sand patches. Data on this sand blanket come from high-resolution seismic-reflection surveys, side scan sonar, and bottom television-camera observations and a limited number of vertical current measurements. Bottom transport of sand is not continuous, but seems to occur during peak spring tides. The influence of currents during storms in unknown, but comparison of seismic records before and after storms suggests sand transport under storm action.

Movement of sand and bedforms can cause severe problems by undermining or covering fixed structures, anchors, semisubmersibles (when pontoons are close to sea bottom, 10 m), and pipelines. Presently, insufficient data exists for predicting the magnitude of this problem in lower Cook Inlet.

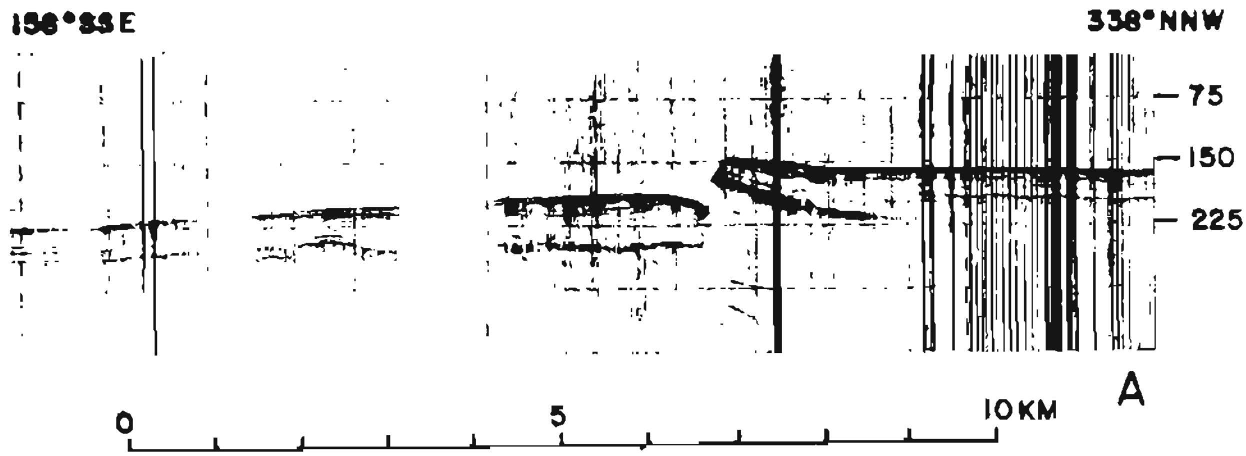
Shelikof Strait

Minor high-resolution seismic coverage and three sediment samples are available in the northeast part of Shelikof Strait from the three cruises in 1976, 1976, and 1978 in lower Cook Inlet. During a U.S. Geological Survey resource-oriented multichannel seismic cruise in 1977, an additional 350 km of shallow-reflection seismic data was acquired in Shelikof Strait. This net coverage provides the only public information available on the environmental geology of Shelikof Strait. With such a small amount of data, the environmental geology can only be broadly characterized.

The seismic-reflection records show moderately folded bedrock that crops out at the seafloor along the margins of the Strait, adjacent to the Kodiak-Afognak Islands and the Alaska Peninsula. Throughout most of Shelikof Strait, the bedrock is eroded and the folded upper surface is covered with well stratified, horizontal sediment that is typically 50 m thick but in localized bedrock depressions over 200 m thick. Three samples of this surficial layer consist of sandy to pebbly mud.

Major fault offset or surface faulting of the seafloor of about 60 m was recorded at two places shown on figure 9A and 9B in the Strait on a line between Black Cape (Shuyak Island) and Cape Douglas. The susceptibility of Shelikof Strait to large earthquakes is similar to lower Cook Inlet, and similar hazards exist. The relatively thick cover of muddy sediment suggests more dangerous ground response in the Strait. The large faults observed in northern Shelikof Strait almost certainly have experienced recent activity, based on the prominent appearance of the fault scarps on shallow-reflection seismic records as shown on figure 9. The placement of future installations near these faults should be avoided, and further work is needed to map their extent. No surface faulting is indicated in the remainder of Shelikof Strait as there is insufficient data to map these features.

Volcanism is another possible hazard in Shelikof Strait, as several active volcanoes in and around Katmai National Monument exist nearby on the Alaska Peninsula. Ash fallout and associated phenomena could occasionally disturb operations anyhwere in the Strait. The 1912 Katmai eruption produced significant



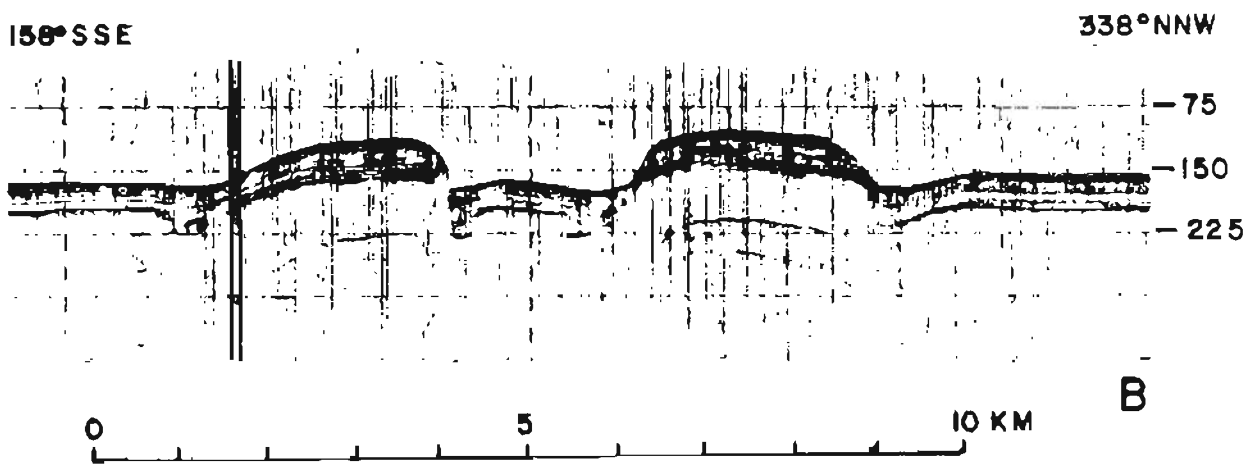


Figure 9.--Examples of surface faults that have been active in Quaternary time (last 10,000 years) are located in northern Shelikof Strait. The locations of these surface faults are shown on figure 8. The two shallow-penetration seismic reflection profiles show the prominent vertical offsets of these faults. Figure 9A shows one vertical offset, while figure 9B shows three vertical offsets. Water depth in meters is shown on the right side of each profile. The ship's bearing and the scale for the profiles are shown at the top and bottom of each profile.

amounts of volcanic ash as evidenced by deposits offshore and of 0.3 m thickness on Kodiak Island.

RECOMMENDED LEASE AREA OUTLINE

The lease area outline has not been changed. The lower Cook Inlet sale No. CI (Cook Inlet) stimulated a great deal of interest within industry. Some blocks received fairly high bids. Drilling that is in progress now and before Sale No. 60 will have an impact on the bidding in 1981, therefore, it is pre-mature to eliminate any blocks.

The Shelikof Strait is poorly understood as a petroleum basin. To downgrade the area before sufficient data on the petroleum geology can be acquired and interpreted would be a mistake. This lack of knowledge should not be used to eliminate it from the sale outline, rather this area must be included so a more accurate evaluation of the petroleum resources can be carried out by government and industry.

TIME FRAME AND INFRASTRUCTURE
LOWER COOK INLET AND SHELIKOF STRAIT

Estimated development timetable.--Based on experience gained from lease sales in the upper Cook Inlet, the Gulf of Alaska, and the lower Cook Inlet, we estimate that exploratory drilling would begin one year after leases are issued, and would be completed no later than the tenth year. This drilling would include expendable or delineation exploratory wells. Assuming exploratory successes, production platform installations would begin during the fourth year after leases are issued and would be completed in the eleventh year. Peak oil production, unless limited by facilities, would occur in the eighth year after the lease sale. Individual fields would have a twenty-five year life, and oil platforms will have been removed by the fortieth year after production begins.

Estimated facilities.--Exploration supply bases would be at Kenai on the Kenai lowland for activities in the lower Cook Inlet, and at Kodiak on Kodiak

Island for activities in Shelikof Strait. Less likely options include Homer, Port Graham, Seward, and Larsen Bay, with the latter being central to Shelikof Strait activities. Exploration equipment being serviced from the supply bases would include heavy-duty semisubmersibles and drillships.

If equivalent reserves are discovered, production facilities would compare to North Sea facilities for water depths to about 200 m (600 ft); concrete, however, would not be used for platform structures. The 200-m isobath in Shelikof Strait extends as far north as Raspberry Island. Water depths from 200 to 300 m cover the southwest two-thirds of the Shelikof Strait and is designated the deep-water zone. The deep-water zone would require a discovery of significant petroleum reserves to be commerical and advanced production technology to be produced. Water depths, weather conditions, and remote locations all make exploration and production difficult in the deep-water zone.

The first oil or gas production method for the deep-water zone would be subsea well completions with gathering lines to a bottom-anchored floating-production platform. A storage tank and a tanker hookup would be associated with a floating-production platform. A gas field requires the addition of a floating liquid natural gas (LNG) plant coupled to the floating-production platform. A second oil or gas production method would be subsea well completions with the oil or gas pipelined to an onshore facility on the western shore of Kodiak Island to a location such as the town of Larsen Bay in the protection of Uyak Bay. In addition to the usual onshore oil and gas production facilities for treating, separating, injecting, compressing, storing, and shipping, the only other processing facility around the proposed sale area would be a possible onshore LNG plant.

Manpower.--Approximately 80 percent of the exploration manpower would probably come from outside Alaska. For production and construction manpower, approximately 80 percent would come from personnel already in Alaska.

Drilling rig availability.--In the foreseeable future, rigs that will be available are the heavy-duty drillships and semisubmersibles required for operations in the proposed sale area. This rig availability will offer a significant advantage to prospective lessees and operators. Supplies of all types are currently in short supply (for example, drill pipe deliveries may be delayed as much as 18 months), but this condition will not likely extend into the 1980's.

Water routes.--The narrow channel between Kodiak Island and Small Whale Island at Kupreanof Strait has a rocky-bottom and is less than 20 m (60 ft) deep. This would be the probable route for supply vessels moving between the supply base at Kodiak and the proposed sale area in Shelikof Strait. This channel, however, represents an above-average navigation risk.

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