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TERTIARY FORMATIONS IN THE KODIAK ISLAND AREA, ALASKA, AND THEIR PETROLEUM RESERVOIR AND SOURCE-ROCK POTENTIAL

By: William Lyle and Jeff Morehouse, Alaska Division of Geological and Geophysical Surveys, and Irven F. Palmer, Jr., J.G. Bolm, George W. Moore, and Tor H. Nilsen, U.S. Geological Survey.

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ABSTRACT

Tertiary sandstone suitable for petroleum reservoirs crops out in the Kodiak Island area. Detailed studies of stratigraphic sections and laboratory analyses of outcrop samples indicate a poor to fair reservoir potential for Miocene rocks and a poor to very poor reservoir potential for pre-Miocene rocks. The amount of thermal alteration of the organic matter indicates the maturity of the basin, and the type of kerogen indicates whether "wet" or "dry" hydrocarbons would be generated. A threshold level of 300 ppm C_{15}+ soluble hydrocarbon extracts was exceeded in many samples. General source-rock potential is considered good.

All the major structures in the area trend northeast. Formations have been folded, faulted, and cross-cut by intrusive bodies.

INTRODUCTION

Stratigraphic field work was jointly conducted during a 26-day period in May and June, 1976, in the Kodiak Island area (fig. 1) by the Alaska Division of Geological and Geophysical Surveys (DGGS) and the U.S. Geological Survey (USGS). Stratigraphic sections are measured in United States feet and inches to be compatible with geological logs in common use.

The major objective of the project was to acquire data on petroleum reservoir and source-rock characteristics of Tertiary stratigraphic sections reported to have some hydrocarbon potential. These data were needed for evaluation of nearby submerged lands, including the proposed Outer Continental Shelf (OCS) leasing areas.

DGGS is charged with determining the State's resource potential for both onshore and offshore state lands. The USGS is charged with the classification and evaluation of resources and with lease-block evaluation on all federal lands including the Outer Continental Shelf adjacent to offshore State lands. Because goals of the two agencies are similar, a cooperative approach to data acquisition was undertaken for the mutual benefit of both agencies.

Acknowledgments: We thank the late Don W. Peterson and his wife Laurel and Dudley D. Avery of Kodiak for their logistic support and hospitality.

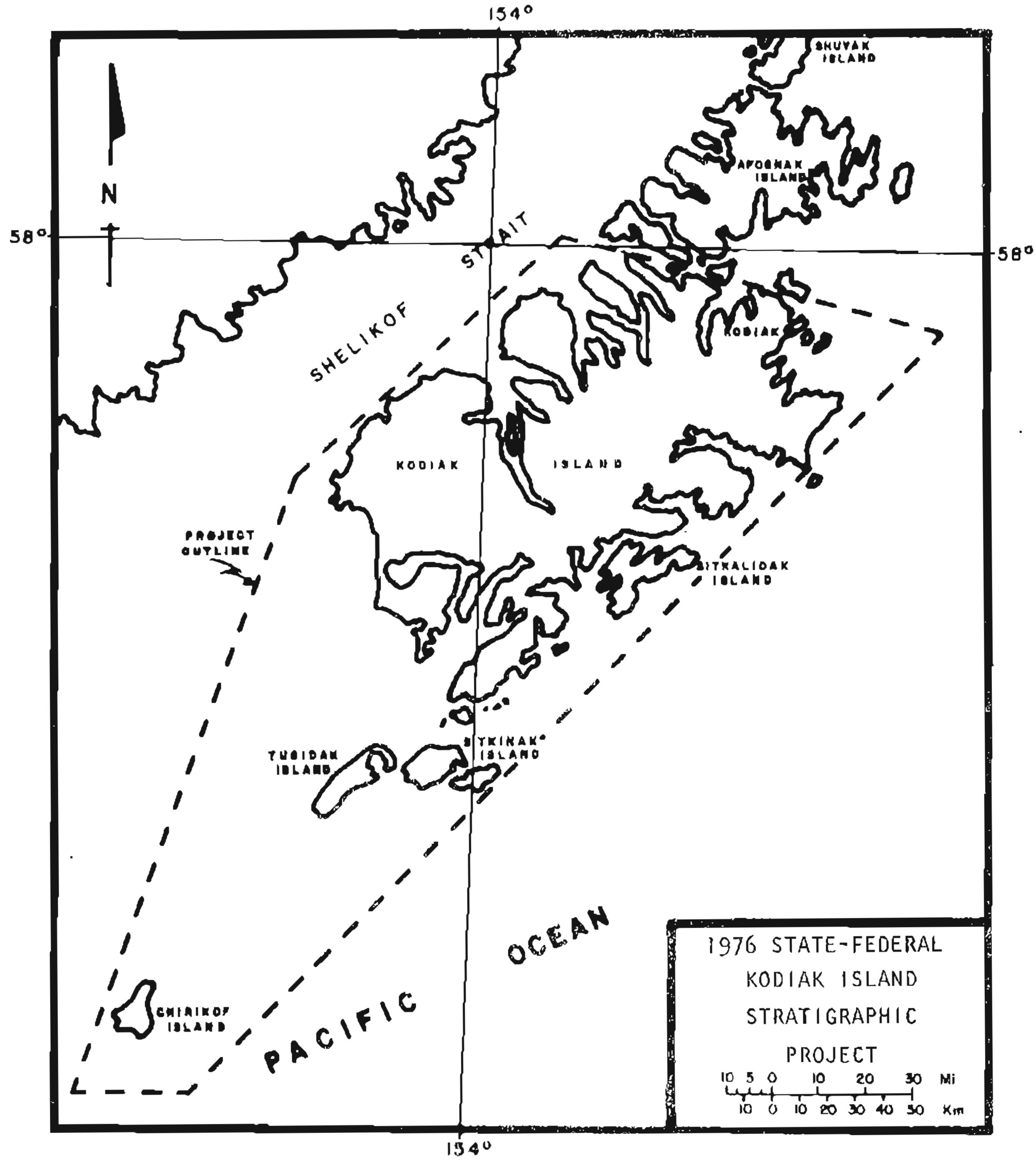

FIGURE 1. Index Map

We also thank Harold Christiansen of Old Harbor and David and Glenna Easter of the Whitney-Fidalgo cannery at Uyak Bay for their hospitality and for providing some needed supplies. The skills of Stuart Taft, helicopter pilot, and Darrell Monthieth, mechanic, contributed significantly toward making the project safe and successful.

Maurice Lynch, Richard Kornbrath, and George Petering of the USGS helped with measuring the Sitkinak Island stratigraphic section.

The U.S. Coast Guard Air Station, Kodiak, provided transportation for part of the work on Sitkinak Island. We thank Captain Bickford and the men of his command, especially CDR Edgecomb, LCDR Parker, LT Meiniger, AT2 Hanson, and AD2 Thresher. We also thank the Coast Guard personnel for their help.

FIELD METHODS

Stratigraphic sections and traverses were measured primarily with Brunton compass and tape. Occasionally, it was necessary to use the helicopter altimeter or photographs to determine thickness. Moore and Bolm estimated thicknesses in the field for their sections and later adjusted the thicknesses of units by comparing map distances between units. All stratigraphic thicknesses are true thicknesses; they were corrected for dip and slope either in the field or at the base camp prior to rough drafting.

Lithologic descriptions generally follow the accepted format listed below:

> Rock type, descriptive modifier, color (from GSA Rock Color chart), grain size (either Wentworth grade name or in actual metric units), sorting, mineralogical constituents, statements concerning degree of induration, porosity, and sedimentary structures.

Abbreviations are commonly used to save time and space; notations such as "as above" are used if little difference is noted. Unit descriptions usually include notations on bedding type, thickness, nature of contacts, and lateral variations.

SAMPLING

Samples from stratigraphic sections and spot sample localities were collected to provide material for laboratory analyses and for sample cuts for both agencies. Whenever possible, the freshest material available was sampled.

Most samples were identified by using the sample number, collector initials, and the last two digits of the year (1-IP-76). Some samples were identified with a letter code for the locations where they were collected and a sample number; for example, PC-11 designates the eleventh sample collected at Partition Cove.

On the quadrangle maps, the samples are numbered from west to east within each tier of townships starting with the northernmost tier; a cross-reference (table 1) can be used to correlate the sample number and its equivalent number on the maps.

In the 17,000 feet of section that was measured, 216 samples were collected. Thirty-six were processed for geochemistry, 76 for porosity and permeability, 36 for paleontological and palynological age determination, and 38 for hydrocarbon extract and basin maturity. Sixty sandstone samples were examined petrographically.

STRATIGRAPHY

The Kodiak Island area consists of a series of belts of folded rocks that strike northeast and become younger toward the southeast (Moore, 1967). Most present investigators assume that the deformation was caused by convergence between the North American plate and various plates in the Pacific basin at different times. Major northwest-dipping thrust faults divide the area into at least four major lithotectonic belts: (1) coherent stratified Upper Triassic sedimentary and volcanic rocks along the northwest coast of the island that are probably continuous with correlative rocks on the Alaska Peninsula and that have been intruded by Jurassic plutons; (2) a melange with an argillite, porcellanite, and tuff matrix that contains ultramafic bodies and exotic blocks as old as Permian and which has been partly metamorphosed to blueschist facies during Early Jurassic time; (3) a melange composed of an argillite matrix containing blocks which include Lower Cretaceous pillow lava and radiolarian chert; and (4) an Upper Cretaceous flysch sequence overlain by Tertiary marine and nonmarine rocks with generally continuous folding and faulting except for volcanism and plutonism in the Paleocene (Moore, 1969; Moore and Connelly, 1977; Carden and others, 1977).

The Upper Cretaceous and Tertiary rocks consist, in ascending sequence, of the Kodiak, Ghost Rocks, Sitkalidak, Sitkinak, Narrow Cape, and Tugidak Formations.

Kodiak Formation

The Kodiak Formation contains Upper Cretaceous marine fossils (Jones and Clark, 1973) and generally consists of interbedded slate and medium-grained sandstone beds that average about 12 inches in thickness. Beds of conglomerate are also locally present, mainly on the northwest side of the island. The formation is repeated by isoclinal folding and associated low-angle shear zones. The total exposed thickness is estimated at 16,500 feet. The Kodiak Formation has been intruded by a batholith, which has a late radiometric age of 58 million years.

Ghost Rocks Formation

The Ghost Rocks Formation is mainly black argillite and also contains graded beds and beds of fine-grained sandstone, pillow lava and tuffaceous sandstone. Parts of the formation may be a melange. The upper surface of pillows is commonly capped by a limestone layer about 4 inches thick that contains foraminifers. The best age-diagnostic sample from this formation is from near Gull Point on Kodiak Island at 57°23.0' N., 152°36.1' W. R. Z. Poore (written commun., 1976) analyzed the thin sections and identified a Paleocene assemblage containing specimens tentatively referred to as "Globigerina" pseudobulloides, Subbotina triangularis or S. triloculinoides, and Planorotalites sp.

The Ghost Rocks Formation has been estimated to be 16,500 feet thick (Moore, 1969). It is intruded by a few basalt dikes and by granitic stocks that are satellite to the batholith.

Sitkalidak Formation

The Sitkalidak Formation consists of repetitive interbedded graded sandstone turbidites and shale. It is distinguished from the overlying Sitkinak Formation by a general lack of conglomerate beds. Total thickness is about 9900 feet. Samples collected for foraminiferal analysis in this investigation indicate that it is Eocene to Oligocene (table 2).

Sitkinak Formation

The Sitkinak Formation is characterized by numerous beds of conglomerate. It is composed of a lower marine unit in which channelized conglomerate layers are interbedded with finer grained turbidites and a nonmarine unit that crops out only on Sitkinak Island and contains numerous thin beds of coal and middle to late Oligocene fossil plants (Wolfe, 1977, p. B5).

Interfingering facies of the Sitkinak Formation and structural complexities make estimation of its total thickness uncertain. The most nearly complete section is on Sitkinak Island and totals about 3175 feet.

The deltaic and marine deposits of the Sitkinak Formation contain red chert and granitic clasts which suggest that uplift and erosion were active along the Kenai-Kodiak-Shumagin axis during their deposition. Although conglomerates may vary in thickness and character laterally, the general contemporaneity of both marine and nonmarine conglomerates will be useful in offshore correlation.

Narrow Cape Formation

The Narrow Cape Formation crops out only at the axis of a syncline on Sitkinak Island and at the type locality on Kodiak Island, where it is 2300 feet thick. The lithology is similar at the two localities, mainly silty sandstone, but its age, based on fossil mollusks and benthonic foraminifers, differs--that on Sitkinak Island being late Oligocene (?) to Miocene (M. K. Fisher, USGS, unpub. date, 1977), and that at Narrow Cape being early and middle Miocene (Allison, 1976). At both localities, the formation is transgressive, at Sitkinak Island conformably over deltaic deposits of the Sitkinak Formation and at Narrow Cape over an angular unconformity on the Sitkalidak Formation. Because of the differing ages and geographic separation of the outcrops, future offshore subsurface information may provide a lithogenetic basis for subdividing the unit.

Tugidak Formation

The Tugidak Formation crops out at two places, at the type locality on Tugidak Island and at the north end of Chirikof Island. These two exposures occur at the margin of a much more extensive offshore distribution in the Tugidak basin to the north (von Huene and others, 1976); they probably are representative of a considerable thickness of the unit in the large Albatross basin offshore to the southeast.

The Tugidak Formation consists of siltstone and sandstone containing randomly distributed pebbles. It contains several beds that are rich in molluscan fossils that establish the age of the unit as Pliocene. The thickest section, located at Tugidak Island, is about 4950 feet (Moore, 1969).

Stratigraphic Sections

Geese Island:

This stratigraphic section (pl. I) is located in secs. 5, 6, and 8, T. 40 S., R. 29 W., Seward Meridian, where the sea cliffs along the coast on the northern half of the large, middle island in the Geese Islands afford excellent exposure of the Eocene to Oligocene Sitkalidak Formation.

The rock types are predominantly light-gray, fine- to medium-silty sandstone and gray to black shale and mudstone. These two rock types occur both as thin beds in interbedded marine turbidite sequences and as thicker beds that are not parts of such turbidite sequences. Many of the thicker sandstone units contain spherical concretions up to 3 feet in diameter.

All of the sandstone units have very low porosity (0.02 to 3.5 percent) and almost no permeability. Organic carbon content in the shale and mudstone is very low (0.33 to 0.64 percent).

McDonald Lagoon:

A traverse was made along the west shore of McDonald Lagoon, Sitkinak Island (pl. II), and segments of sections were sampled, measured, and described. The rocks consist of massive, moderately to well indurated sandstone and conglomerate with lesser amounts of claystone and siltstone. Shale rip-up clasts (app. E-1) are common and concretions and crossbeds are present but rare. Some channel deposits (app. E-2) were noted in parts of the measured section.

All of these segments are in the Sitkinak Formation. The average porosity is 3 percent, with a maximum of 4.1 percent. The average permeability is 2 millidarcies (mD) with a maximum of 1.88 mD.

Narrow Cape:

The Narrow Cape stratigraphic section (pl. III) is located from 152°21' to 152°24' W. and 57°26' N. The section is exposed along a south-facing sea cliff west of Narrow Cape (app. E-3) and was measured from the axis of a northeast-trending syncline west to where the Narrow Cape Formation overlies the Sitkalidak Formation across a distinct angular unconformity. Stratigraphic thickness totals over 1700 feet. The section is composed mainly of massive bedded silty sandstone that contains many prominent concretion beds. The sandstone is fossiliferous and locally contain coal fragments, carbonaceous debris, and burrows oriented normal to the bedding. Pebble conglomerate is also common at several places. Visual porosity is sparse. Laboratory analysis of 16 samples show an average porosity of 7.4 percent and permeability of 7.6 mD and a maximum porosity of 17 percent and permeability of 30 mD. Similar sands, if any are preserved on the OCS, could make fair reservoirs.

Ocean Bay:

This measured section (pl. IV) is located in secs. 32-33, T. 35 S., R. 24 W., Seward Meridian, where the Eocene to Oligocene Sitkalidak Formation is well exposed in cliffs on the east side of Ocean Bay. Much of the section is stratigraphically equivalent to the section that was measured at Partition Cove; the two sections are from one to two miles apart along the strike of the formation. We are unable to correlate any individual bed between the two sections.

The predominant lithologies are fine- to coarse-grained, light-gray sandstone and gray or black shale and mudstone. Thin beds of these two lithologies are commonly interbedded in marine turbidite sequences and occur also in thicker beds that are not part of such turbidite sequences. The samples that were collected in the Ocean Bay area are from poor exposures of the Sitkinak Formation west of this measured section.

Partition Cove:

This section (pl. V) is located in secs. 27 and 34, T. 35 S., R. 24 W., Seward Meridian, where the Eocene to Oligocene Sitkalidak Formation is well exposed in cliffs along the west side of Partition Cove (app. E-3).

The predominant rock types are light-gray, fine- to coarse-grained sandstone and gray and black shale and mudstone. Thin beds of these lithologies are interbedded in marine turbidite sequences and also occur in thicker beds that are not part of such sequences. Many of the thicker sandstone units were deposited as fill in channels that had been cut into other lithologic units.

All of the sandstone units have low porosity (0.2 to 2.9 percent) and essentially no permeability. The organic carbon content in shale and mudstone is very low (0.42 to 0.53 percent).

Sitkinak Island:

The Sitkinak Island stratigraphic section (pl. VI) is located in sec. 30, T. 42 S., R. 31 W., and in secs. 25 and 34-36, T. 42 S., R. 32 W., Seward Meridian. The section is located at the type section of the Sitkinak Formation and is composed of 2200 feet of conglomerate, coal, mudstone, and sandstone. These beds represent deposition in a deltaic to nonmarine environment during Eocene to Oligocene time. Strata totaling 980 feet of the Miocene Narrow Cape Formation overlie the nonmarine Sitkinak Formation. These beds consist of interbedded mudstone and fossiliferous sandstone.

Twoheaded Island:

This measured section (pl. VII) is located in secs. 7 and 12, T. 38 S., R. 27 and 28 W., Seward Meridian. The Eocene to Oligocene Sitkalidak Formation is well exposed on the steep south side of the island (app. E-7, E-8) and conglomerate of the Sitkinak Formation crops out near the top of the island. The rock type is dominantly well-indurated light-gray and gray-green, fine-grained sandstone with interbeds of siltstone and gray to black shale and mudstone.

Very limited microfossil control indicates that the sandstone is marine. A 49-foot-thick sandstone (11-WL-76) has thinly laminated beds one-half to one inch thick and appears to have been deposited in a marine environment. Many thin laterally continuous mudstones, siltstones, and shales are interbedded with the sandstone and appear to be of marine origin.

All of the sandstone units have very low porosity and permeability (1 to 2 percent porosity and essentially no permeability).

ENVIRONMENTS OF DEPOSITION

Kodiak Formation

The Kodiak Formation, of Late Cretaceous age, consists of thick and voluminous turbidites, most commonly interbedded sandstone and shale organized into Bouma (1962) sequences. With the turbidite facies association of

Mutti and Ricoi Lucchi (1972), the beds represent primarily basin-plain deposits. On the northwestern flank of Kodiak Island, however, turbidites characteristic of slope environments crop out, along with some channelized conglomerate beds containing abundant synsedimentary rip-up clasts. Locally, thin outer-fan sandstone lobes are developed; these may represent minor fans developed in small intraslope basins.

Paleocurrents uniformly indicate sediment transport toward the southwest. The Kodiak Formation is believed to have been deposited on the floor and side of a southwest-trending oceanic trench (T. H. Nilsen and G. W. Moore, USGS unpub. data, 1977).

Ghost Rocks Formation

The depositional environment of the Ghost Rocks Formation, of Paleocene and Eocene age, is difficult to interpret, partly due to extensive deformation and shearing. The environment most likely represents slope sedimentation, but clear-cut evidence in support of this interpretation is lacking. The formation consists generally of thick pelitic intervals with thinly bedded, fine-grained turbidites having a low sandstone-shale ratio. Some of these could also represent basin-plain turbidites, but the amount of deformation, much of which is synsedimentary, indicates extensive downslope slumping and translation. Paleocurrent and paleoslope data are equivocal; however, the grain mineralogy suggests a local derivation from southern Alaska.

Sitkalidak Formation

The Sitkalidak Formation, of Eocene and Oligocene age, consists of turbidites deposited as a deep-sea fan. On northeastern Sitkalidak Island below the Sitkinak Formation and on southeastern Sitkalidak Island west of Partition Cove, thinning-upward cycles characteristic of middle-fan channels crop out. On Geese Islands and at Narrow Cape, thickening-upward cycles characteristic of outer-fan lobes crop out.

Paleocurrents indicate variable directions of sediment transport, generally toward the northeast and southwest on opposite sides of Sitkalidak Island, suggesting the presence of a fan apex at Sitkalidak Island. Other fan apices were present at Sitkinak and Chirikof Islands, with sediments transported northeastward and southwestward from these apices. The facies distribution and paleocurrent patterns suggest deposition of several relatively small deep-sea fans on the floor of a probably inactive trench.

Sitkinak Formation

The Sitkinak Formation, of Eocene to Oligocene age, consists of conglomerate and associated sandstone and shale turbidites that represent inner-fan channel deposits. Paleocurrents at outcrops on the eastern part of the island indicate eastward sediment transport. The Sitkinak Formation on Sitkinak Island consists of conglomerate probably deposited in braided-stream or braided-deltaic distributary channel complexes that are interbedded with silty coal-bearing interchannel swamp, lake, lagoon, and interdistributary-bay deposits (app. E-5, E-6, E-7). The regular alternation of conglomerate and finer grained deposits suggests deposition in a fan-delta environment adjacent to nearby highlands and in nonmarine to marginal-marine conditions. On Sitkinak Island, paleocurrents indicate sediment transport toward the southeast, and facies relations indicate a northeast-trending shoreline.

Narrow Cape Formation

Shallow-water marine invertebrates are abundant in the Narrow Cape Formation, of Oligocene (?) and Miocene age. Locally, burrows (app. E-4) are oriented normal to the bedding, and articulated fossil clams stand in life position. Carbonaceous debris, reed imprints, and coal fragments are also locally abundant. Pebble-conglomerate planar beds as well as lenses and pods are important lithologic constituents, but the bulk of the formation consists of silty sandstone, probably deposited as a transgressive inner-shelf sequence in generally quiet water beyond the surf zone. At one locality, beds of pebble conglomerate and conglomeratic sandstone exhibit large crossbeds or foresets that are 7-50 feet wide (app. E-4). Many of the beds are graded finer upward (app. E-5). These deposits may represent delta-front deposits of a small deltaic complex that entered the largely upper neritic environment that was the depositional site for the sandstone that constitutes the bulk of the formation.

On the basis of the molluscan faunas, Allison (1976) suggests deposition in mild-temperate water for the assemblage on Sitkinak Island, and in sub-tropical to warm-temperate water for the younger assemblage at Narrow Cape.

Tugidak Formation

Tugidak Island was not visited during the field project. The Tugidak Formation, of Pliocene age, consists of interbedded siltstone and sandstone characterized by randomly distributed pebbles and cobbles (Moore, 1969). These floating clasts may represent ice-rafted dropstones, in which case the depositional environment was probably shallow glacial-marine, and therefore similar to that of the Yakataga Formation exposed along the northern Gulf of Alaska.

RESERVOIR CHARACTERISTICS

Examination of many stratigraphic sections along the eastern coastline of Kodiak and adjacent islands indicates that sandstone with intergranular porosity and permeability will probably be the reservoir rock for any commercial accumulations of hydrocarbons in the Kodiak Tertiary province. Sandstone suitable for reservoirs is contained in rocks that crop out onshore, but its offshore extent is not known. Samples from the deep ocean indicate that sand has been carried across the continental shelf into deeper waters. Sufficient sources of sand may have been available to form reservoirs on the OCS areas, but many more offshore samples are needed to test this supposition (von Huene and others, 1976).

Reservoir Geometry and Size

The deep-water environment of the Sitkalidak Formation should give rise to three main geometries if the offshore Sitkalidak facies are similar to the Tertiary Californian turbidite facies that can be related to deep-sea sediments now forming off the present-day California coast (Hand and Emery, 1964). These geometries are: (1) shoestring turbidites that occupy channels; (2) turbidite fans; and (3) turbidite sheets. Sullwold (1961) cites an example of a shoestring turbidite that is 150 feet thick and 2000 feet wide. The Rosedale channel (Miocene) of the San Joaquin basin is about 100 miles wide and contains some 1200 feet of turbidites (Selley, 1970). The late Miocene Tarzana submarine fan is about 6 miles wide and 4000 feet thick. By contrast, the sheet facies of the lower Pliocene Repetto Formation of former usage are more than 2500 feet thick and cover some 800 square miles (Shelton, 1967).

Other delta complexes such as in the Sitkinak Formation exposed on Sitkinak Island or the sandstone facies of such a delta complex are likely within the OCS area. Prograding sands are manifested in elongated bar-finger units (Fisk, 1954; Fisher, 1972) and in broad lobate sandy delta-front deposits (Frazier, 1967).

Perhaps the depositional model most likely to be represented in the offshore stratigraphic section that appears to have the most potential (Narrow Cape Formation or its equivalents) is a linear clastic shoreline that preserves various shoreface sand bodies. These sand bodies include a variety of beach or barrier deposits paralleling paleoshorelines. Thicknesses can vary from tens of feet to over 3000 feet, and areal extent can exceed many square miles. Sea-level fluctuations probably deposited sands offshore similar to those exposed at Narrow Cape.

Reservoir-Structure Spatial Relationship

Little is known of the relationship between the described potential reservoir sand bodies and the the geologic structure of the area, mainly because steeply dipping beds limit lateral observations. The only two exposures of the Narrow Cape Formation occur in synclines, and no facies changes can be observed.

The Narrow Cape Formation and its equivalents were probably distributed over the adjacent OCS area prior to the tectonic activity that produced the local structural highs seen in the seismic data. Truncation of these structural highs may indicate anticlinal thinning of Narrow Cape Formation equivalents in most of the OCS area. Offshore linear clastic reservoirs probably trend northeast-southwest, roughly paralleling the present coastline.

Reservoir occurrence offshore will most likely depend on unknown transgressive or regressive cycles and sea-level stillstand positions rather than structural position of the sand bodies.

POROSITY, PERMEABILITY, AND THICKNESS

Sitkalidak Formation. -- This formation has probably the least potential of Tertiary rocks according to analyzed samples (table 3). A total of 6680 feet of sandstone and conglomerate were measured in four stratigraphic sections. Of 110 beds measured, the average bed thickness was 73 feet. Although porosity measurements range from 0.2 to 13.6 percent, the permeability was consistently measured at less than 0.01 mD.

Sitkinak Formation. -- Twelve hundred and fifty feet of sandstone and conglomerate were measured and sampled from this formation at Sitkinak Island and McDonald Lagoon. The beds ranged from 2 feet to 200 feet, with an average thickness of 47 feet. Eleven samples were analyzed and porosity ranged from 2.5 percent to greater than 10 percent, with 4.38 percent as an average. Permeability ranged from 0.1 to 1.88 mD, with an average of 0.52 mD.

Narrow Cape Formation. -- This, the most promising formation, was measured at its type section and contained 1470 feet of potential reservoir sandstone and conglomerate with an approximate average of 74 feet per bed. Bed thickness ranged from 27 feet to 200 feet. According to 16 analyses, porosity ranged from 1 to 17 percent and averaged 7.4 percent. Permeability was higher than in older formations; readings ranged from less than 0.01 to 30 mD, and averaged 7.59 mD.

HYDROCARBON SOURCE ROCKS

Thirty-eight samples (table 4) were taken for soluble-hydrocarbon analysis--25 from the Sitkalidak Formation, 11 from the Sitkinak Formation, and 1 each from the Tugidak and Narrow Cape Formations. The overall average for the 38 samples is 339.8 parts per million (ppm), above the generally accepted threshold level of 300 ppm. The low was 135 ppm and the high was 620 ppm.

The 25 samples analyzed from the Sitkalidak Formation had an average of 355.6 ppm, a minimum of 155 ppm and a maximum of 620 ppm. The 11 analyzed from the Sitkinak Formation had an average of 319.4 ppm, a minimum of 173 ppm, and a maximum of 601 ppm. The sample from the Narrow Cape Formation had 389 ppm; the Tugidak Formation sample had 606 ppm hydrocarbon.

BASIN MATURITY

A total of 38 samples were assessed for visual kerogen by Geochem Laboratories, Inc., of Houston, Texas (table 5). These samples were collected from widely separated Tertiary potential source rocks. The rocks of different ages show no essential difference in the type of organic matter present or the degree of maturation of the organic matter. The thermal alteration rank of all samples varies from 1+ to 2+ and is dominantly from 2- to 2+. This rank is thought by many, such as Staplin (1969), to indicate a mature to submature stage of organic alteration that would generate either "wet" or "dry" associated hydrocarbons, depending on the type of hydrocarbon precursor kerogen.

In the 38 samples the predominant kerogen type is herbaceous-spore/cuticle; less abundant types of kerogen are coaly, amorphous-sapropel and woody grains. Thus, the most likely type of associated hydrocarbon is dry gas. However, 33 of the 38 samples contain amorphous grains in either moderate or trace amounts, which is indicative of the capability to generate "wet" hydrocarbons.

PETROGRAPHY OF POTENTIAL RESERVOIR SANDSTONE

Sixty samples of sandstone from spot localities and from the stratigraphic sections measured in the Kodiak Island were examined petrographically. Eight samples were from the Ghost Rocks Formation, 31 from the Sitkalidak Formation, 11 from the Sitkinak Formation, and 10 from the Narrow Cape Formation. Modes for these samples were estimated and a tabular summary of petrographic data is in Table 6. The following discussion of these samples uses the sandstone classification of Williams and others (1954, p. 289-297; see also fig. 2 of this report).

The samples contain from 20 to 30 percent clay- and silt-size silicate matrix. Most of the samples contain more than 10 percent of such matrix and thus should be classified as wackes. Many of the samples from the Sitkalidak and younger formations contain sparry calcite in amounts that vary from a trace to nearly 50 percent of the sample, and the relative abundance of this calcite is inversely proportional to the abundance of silicate matrix. There is no apparent relationship between the amount of silicate matrix in a sample and a stratigraphic unit. There is, however, an apparent relationship between the nature of the silicate matrix and the formation.

Silicate matrix in sandstone of the Narrow Cape Formation consists largely of murky brown clay that varies in shade and in silt content (from 0 to 40 percent) from area to area; boundaries between areas of different shades coincide with those of different silt content. This and the occurrence of ghosts of sedimentary rock fragments in some large areas of matrix indicate that the matrix is primarily mashed sedimentary rock fragments. The mashed fragments that now form matrix must have been relatively soft at the time

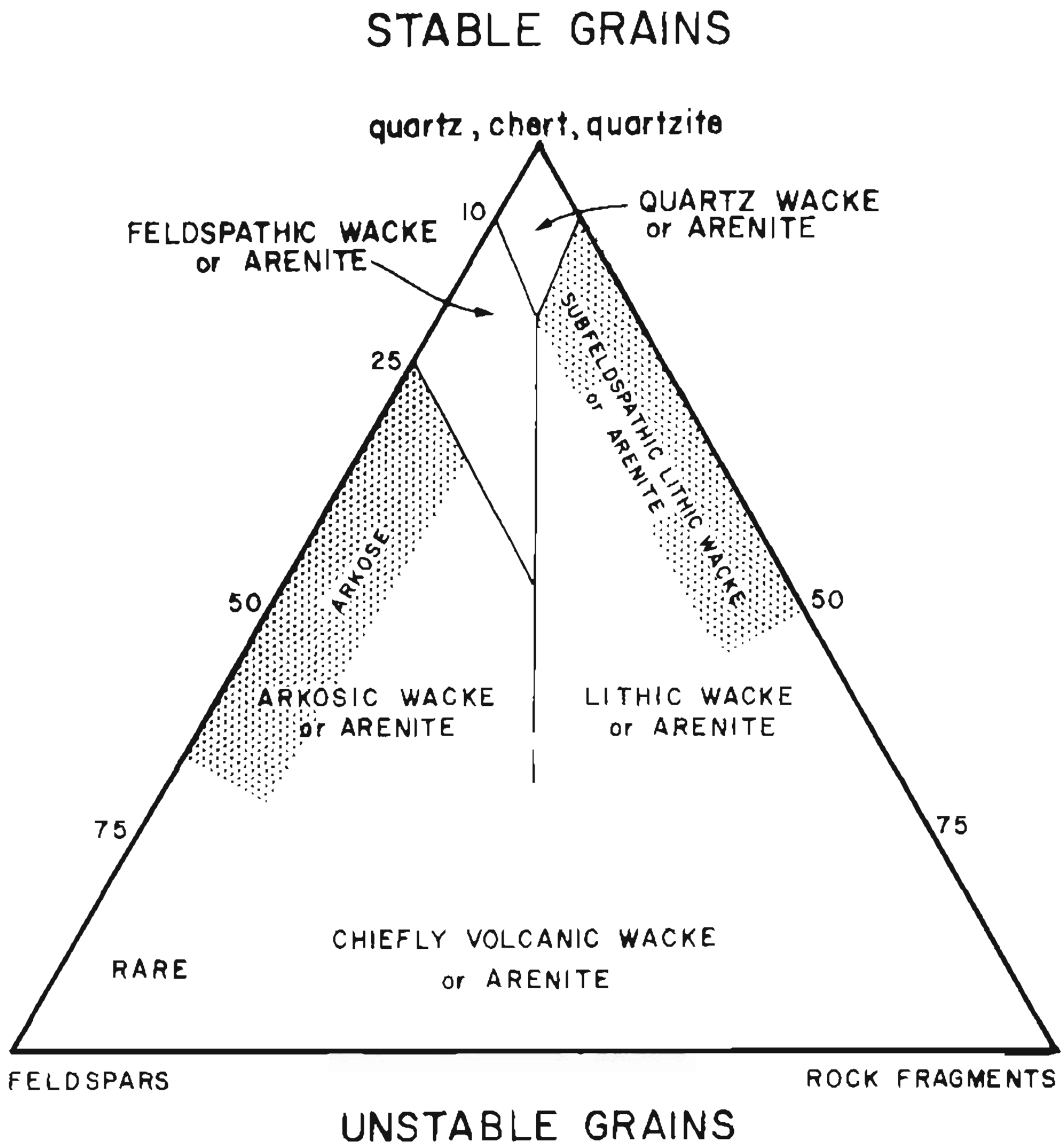

Figure 2. Classification of sandstones (after Williams and others, 1954, pp. 289-297). A sandstone is first classed as an arenite or a wacke depending on whether its framework grains constitute more or less than 90 percent of its total volume. It may then be further classified on the basis of the composition of its framework grains in accordance with the above diagram.

of deposition and were probably rip-ups from other, nearby depositional environments. Minor amounts of coarse, yellowish, transparent clay rims some framework grains in the samples and probably is authigenically recrystallized from matrix material.

In sandstone of the Sitkalidak and Sitkinak Formations the silicate matrix contains some of the mashed rip-up material such as predominates in the Narrow Cape Formation. Much of the matrix in samples from these older formations is composed of authigenic clay (like that in the Narrow Cape) and silica, as chert where it is mixed with the authigenic clay and as quartz elsewhere. Where authigenic clay and silica occur together, the clay forms a rim on framework grains and the silica is located farther from the framework grains. Locally, partial rims of authigenic clay separates syntaxial overgrowths of quartz from their clasts. Obviously authigenic clay formed before the matrix silica.

In sandstone samples from the Ghost Rocks Formation, the silicate matrix consists completely of authigenic clay and silica. Except as a fracture filling, there is little calcite. The calcite is sparry and has commonly replaced, at least partially, many of the framework grains with which it is in contact in the rocks of the younger formations. In some calcite-rich samples the framework grains are completely supported by calcite, which may have partially replaced some framework grains.

The inverse-abundance relationship between silicate matrix and calcite, coupled with the apparent detrital origin of much of the silicate matrix, suggests that the calcite may have been introduced into these rocks allochemically by solutions. Calcite has not replaced any phyllosilicates in these rocks. In some samples, calcite has replaced framework grains with authigenic clay rims, but has not replaced nearby rimless clasts of the same mineralogy. Therefore, calcite formed after authigenic clay, probably after burial to considerable depth. Other samples have calcite with no authigenic clay or other silicate matrix, however.

For all the samples, the size range of the framework grains is from coarse silt to very coarse sand, although the range in any single sample is much smaller and seldom exceeds four Wentworth grades. Framework grains are quartz, chert, feldspar, and rock fragments (fig. 3). Feldspar constitutes from 8 to 28 percent of the framework grains in the samples, and there is no apparent relationship between feldspar abundance in a sample and the stratigraphic unit. The ratio of silica (quartz and chert) to rock fragments is different for samples from different formations. The ratio varies from 1:6 to 1:1 in the Ghost Rocks Formation, and from 4:5 to 3:1 in the Sitkalidak and Sitkinak Formations. The ratio is at least 3:1 in the Narrow Cape Formation. The relationships are shown graphically in Figure 3; these rocks may be classified as feldspathic, lithic, and subfeldspathic lithic arenites or, more commonly, wackes.

The quartz grains are generally angular to subrounded and subequant. Monocrystalline grains predominate in most samples and tend to have undulatory extinction; mosaic structure developed in some grains. Schistose polycrystal-

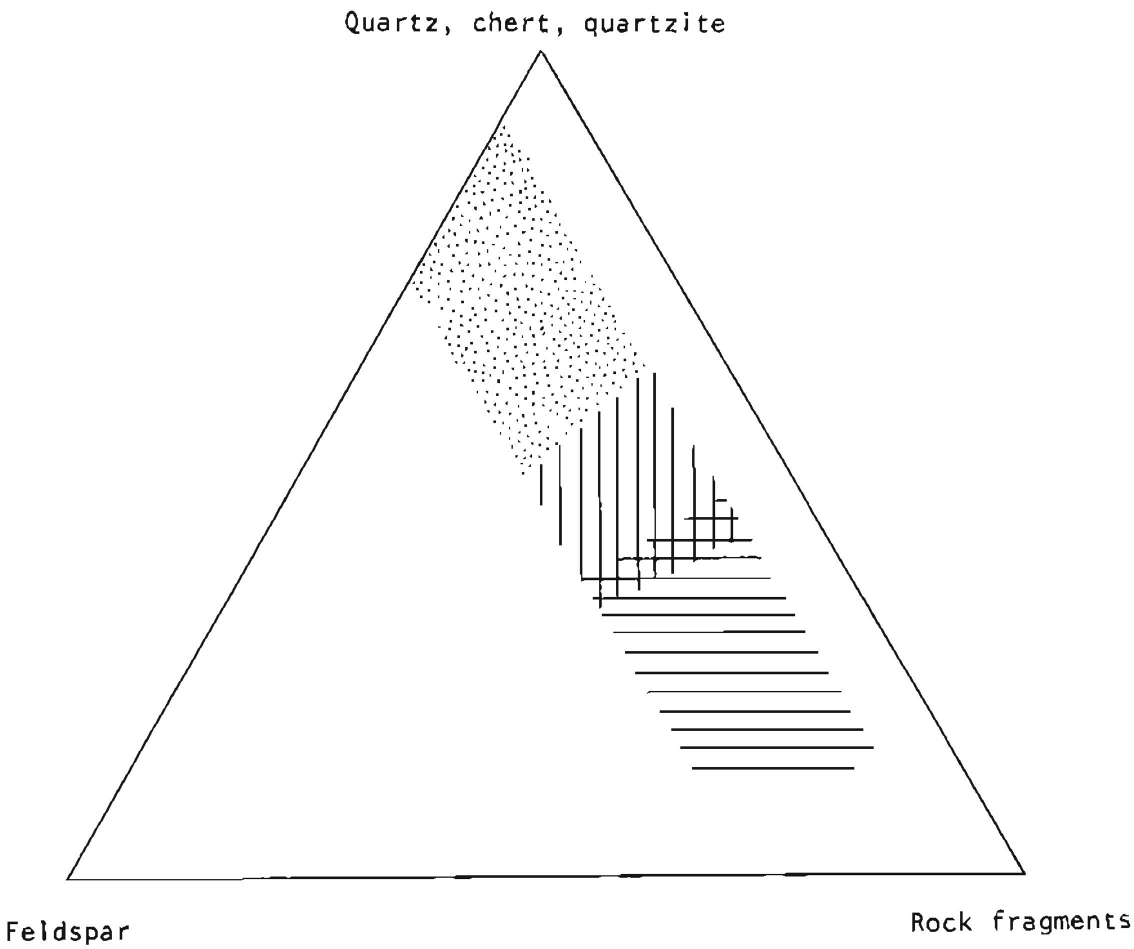

Figure 3. Distribution of principal types of framework grain. Horizontal rule indicates Ghost Rocks Formation; vertical rule is Sitkalidak and Sitkinak Formations; stippled area indicates Narrow Cape Formation.

line grains are common in all the samples, and in some they are actually more abundant than monocrystalline grains. Corroded boundaries are common, and some clasts are embayed by calcite. Local boundary adjustment has occurred along some contacts with other framework grains. Chert grains are generally better rounded than quartz grains in the same sample.

Both plagioclase and potassium feldspar are present in all the samples. Both are angular to rounded and tend to be subequant. Ratios of plagioclase to potassium feldspar range from 1:1 to 3:1, with no apparent relationship to a stratigraphic unit. Plagioclase is sodic to intermediate in composition, most commonly oligoclase with minor albite and andesine. Albite twins are common, and many clasts have pericline twins and are zoned. Potassium feldspar is commonly untwinned, but some clasts are grid-twinned. Graphic and myrmekitic intergrowths with quartz and perthite and antiperthite grains exist in the feldspar fraction of these rocks, and the boundaries of feldspar grains are generally corroded and commonly show evidence of adjustment along contacts with other framework grains.

Volcanic, sedimentary, and metamorphic rocks occur as rock fragments. Except for the schistose polycrystalline quartz grains already discussed, metamorphic types are rare and occur mainly as a few grains of phyllite in the Sitkalidak and younger formations.

Rock fragments range from subangular to rounded, and volcanic rock fragments may be somewhat less rounded than sedimentary fragments in the same sample. Rock fragments are generally subequant, but elongate shapes are common among larger sedimentary fragments. Volcanic rock fragments are three to five times as abundant as sedimentary fragments in samples from the Ghost Rocks Formation, but in the younger formations the two types are of subequal abundance or sedimentary types are slightly more prevalent. Volcanic rock fragments are generally holohyaline or hyalopilitic, or felted, or pilotaxitic. Sedimentary rocks occurring as fragments include shale, claystone, silty claystone, and minor siltstone.

Chlorite and biotite are significant framework grains in all the samples. Both are commonly associated with magnetite and have commonly been crinkled in compaction. Magnetite, epidote, zircon, sphene, muscovite, garnet, apatite, and tourmaline occur in small amounts. Glauconite was present in Narrow Cape Formation samples, and diopside and green hornblende were identified in Ghost Rock Formation samples.

Iron oxide occurs in fractures in samples from all the formations studied. Zeolite filled the fractures in the Sitkalidak and Sitkinak, and calcite and quartz filled the fractures in the Ghost Rocks. In one Ghost Rocks sample, a calcite-filled fracture has been so sheared that sigmoidal gashes formed in the calcite and were subsequently filled with quartz. This suggests that quartz fracture fillings in the Ghost Rocks samples are younger than calcite fracture fillings.

In the Ghost Rocks samples, areas of clastic texture are separated by shear zones in which cataclastic texture, including fluxion structure, is developed. In some clasts authigenic clay-filled extension fractures are at right angles to fluxion planes, an indication that the fluxion planes are perpendicular to the axis of maximum compressive stress associated with cataclasis.

Samples from the Sitkalidak and younger formations also display clastic texture and are either framework- or martix-supported depending on the amount of matrix. Although very few clasts, including even very fragile elongate ones, have been broken in compaction, these rocks are tightly compacted and display no visible porosity.

STRUCTURAL GEOLOGY

The Kodiak Formation and younger formations in the Kodiak Island area have been folded and faulted. All major structures trend northeast.

Northwest-facing limbs of large asymmetric folds dip moderately in the Kodiak Formation, and southeast-facing limbs dip steeply or are overturned. Asymmetry of the folds is variable in younger formations. Slaty cleavage has developed parallel to the axial planes of these folds in pelitic rocks of the Kodiak Formation, and a less perfect axial-plane cleavage has developed locally in the Ghost Rocks Formation. No such cleavage is evident in the Sitkalidak Formation or in younger formations. Southeast-facing limbs have been sheared along thick zones subparallel to axial planes in the Kodiak Formation, and fracturing was pervasive in the Ghost Rocks Formation. Younger formations have not been significantly sheared. Later drag folds formed on the limbs of large folds in the Kodiak, Ghost Rocks, Sitkalidak, and Sitkinak Formations. The drag folds are similar in all four formations, and the folded beds are generally variable in axial-plane thickness; thus the drag folds were probably formed by the flexural-flow mechanism as defined by Donath and Parker (1964).

Some minor kink bands occur locally in the Kodiak Formation, generally near large intrusive bodies; a phyllitic sheen is common on cleavage surfaces where kinks have developed.

The Kodiak and Ghost Rocks Formations are cut by intrusive bodies which include basalt and aplite dikes, sills, tonalite stocks, and a batholith. The batholith and commonly the stocks are elongated northeasterly and are generally discordant. Along contacts the country rocks have been metamorphosed to hornfels. The massive structure, crosscutting relationships and absence of folding of intrusive rocks indicate that their emplacement postdates folding.

The Kodiak Formation and younger formations in the area are cut by steeply dipping northeast-trending faults across which significant vertical displacement occurred. Generally, the southeast block has been down-dropped, and formations of greatly different ages are commonly juxtaposed across these faults.

During the late Cenozoic, Kodiak Island was uplifted and small basins were formed on the continental shelf area. Albatross basin, 30 miles wide and 370 miles long, lies southeast of Kodiak Island, and Tugidak and Portlock basins, each about 30 miles in diameter, flank the island to the southwest and northeast, respectively. They contain more than 20,000 feet of gently folded strata (von Huene and others, 1976). Farther southeast, however, near the oceanic trench and on the trench slope, sub-bottom profiles and Deep Sea Drilling Project holes in young strata have revealed very extensive deformation that has been inferred to be related to present-day convergence between Alaska and the Pacific tectonic plate.

CONCLUSIONS

In the 1976 State-Federal Kodiak Island field project, seven stratigraphic sections totaling 17,000 feet were measured and 216 samples were collected and analyzed. Significant new data were obtained on reservoir and source-rock potential, depositional environments, paleontological age dating, structural geology, petrographic characteristics, and geochemical control. Porosity and permeability analyses indicate a range of poor to fair reservoir potential for Miocene reservoir sandstone and poor to very poor potenti for pre-Miocene sandstone. Source-rock potential is considered good.

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TABLES 1 through 7

FIGURES 4 through 19

TABLE 1. CROSS REFERENCE FOR SAMPLE AND MAP NUMBERS

KODIAK QUADRANGLE (PLATE A)

Random Sampling

Map No.	Sample No.	Analysis done
1	10-JM-76	Geochemical
2	11-JM-76	do.
3	2-JM-76	do.
4	9-JM-76	do.
5	8-JM-76	do.
6	12-JM-76	Geochemical
7	13-JM-76	do.
8	4-JM-76	do.
9	3-JM-76	do.
10	56-WL-76	do.
11	57-WL-76	Geochemical
12	14-JM-76	do.
13	15-JM-76	do.
14	1-JM-76	do.
15	7-JM-76	do.
16	5-JM-76	Geochemical
17	6-JM-76	do.
18	58-WL-76	do.
19	59-IP-76	do.
20	60-IP-76	do.
21	58-IP-76	Geochemical
22	61-IP-76	do.
23	1-JB-76	do.
24	57-IP-76	do.
25	47-IP-76	do.
26	26-IP-76	Porosity and permeability

Narrow Cape stratigraphic section (plate III)

Map No.	Sample No.	Analysis done
27	27-IP-76	Hydrocarbon
28	28-IP-76	Kerogen
29	29-IP-76	Porosity and permeability
30	30-IP-76	Porosity and permeability
31	31-IP-76	Porosity and permeability
32	32-IP-76	Porisity and permeability
33	33-IP-76	Lithology
34	34-IP-76	Porosity and permeability
35	35-IP-76	Porosity and permeability
36	36-IP-76	Porosity and permeability
37	37-IP-76	do.
38	38-IP-76	do.
39	52-IP-76	do.
40	53-IP-76	do.
41	54-IP-76	Paleontology
42	55-IP-76	Porosity and permeability
43	56-IP-76	Macrofossil
44	40-IP-76	Macrofossil
45	41-IP-76	Kerogen, vitrinite reflectance
46	42-IP-76	Porosity and permeability
47	43-IP-76	Paleontology
48	44-IP-76	Porosity and permeability
49	45-IP-76	Oriented sandstone
50	46-IP-76	Paleontology

Random Sampling

51	No Sample	
52	63-IP-76	Geochemical
53	62-IP-76	do.
54	2-JB-76	do.
55	71-IP-76	do.
56	64-IP-76	Geochemical
57	65-IP-76	do.
58	68-IP-76	do.
59	69-IP-76	do.
60	70-IP-76	do.
61	66-IP-76	Geochemical
62	67-IP-76	do.

McDonald Lagoon stratigraphic section segments (plate II)

Map No.	Sample No.	Analysis done
63	1-IP-76	Porosity and permeability
64	2-IP-76	do.
65	3-IP-76	do.
66	4-IP-76	Porosity and permeability
67	5-IP-76	Paleontology
68	6-IP-76	Hydrocarbon
69	7-IP-76	Kerogen
70	8-IP-76	Paleontology
71	9-IP-76	Hydrocarbon
72	10-IP-76	Porosity and permeability
73	11-IP-76	Lithology
74	12-IP-76	Paleontology
75	13-IP-76	Porosity and permeability
76	14-IP-76	Porosity and permeability
77	15-IP-76	Porosity and permeability
78	16-IP-76	Paleontology
79	17-IP-76	Hydrocarbon
80	18-IP-76	Kerogen
81	19-IP-76	Paleontology
82	20-IP-76	Hydrocarbon
83	21-IP-76	Paleontology
84	22-IP-76	Hydrocarbon
85	23-IP-76	Paleontology
86	24-IP-76	Paleontology
87	25-IP-76	Porosity and permeability

Random Sampling, Cape Barnabas area

88	CB-1	Porosity and permeability
89	CB-1	Paleontology
90	CB-2	Porosity and Permeability
91	CB-3	Porosity and permeability
92	CB-3	Hydrocarbon and kerogen
93	CB-4	Porosity and permeability

Ocean Bay stratigraphic section (plate IV)

94	OB-1	Porosity and permeability
95	OB-2	Hydrocarbon and kerogen

Map No.	Sample No.	Analysis done
96	OB-3	Hydrocarbon and permeability
97	OB-4	Porosity and permeability
98	OB-4	Hydrocarbon and kerogen
99	OB-5	Porosity and permeability
100	OB-5	Hydrocarbon and kerogen
101	OB-6	Porosity and permeability
102	OB-7	Hydrocarbon and kerogen
103	OB-7	Paleontology
Random Sampling		
104	51-IP-76	Porosity and permeability
105	48-IP-76	Paleontology
106	49-IP-76	Hydrocarbon
107	50-IP-76	Kerogen
Partition Cove stratigraphic section (plate V)		
108	PC-1	Porosity and permeability
109	PC-2	Porosity and permeability
110	PC-2	Paleontology
111	PC-3	Porosity and permeability
112	PC-4	?
113	PC-5	Porosity and permeability
114	PC-6	Porosity and permeability
115	PC-6	Hydrocarbon and kerogen
116	PC-7	Porosity and permeability
117	PC-8	Porosity and permeability
118	PC-9	Hydrocarbon and kerogen
119	PC-10	Porosity and permeability
120	PC-11	Porosity and permeability
121	PC-11	Hydrocarbon and kerogen
122	PC-11	Paleontology
123	PC-12	Porosity and permeability
124	PC-13	Porosity and permeability
125	PC-14	Hydrocarbon and kerogen
126	PC-14	Porosity and permeability
127	PC-16	Porosity and permeability
128	PC-16	Hydrocarbon and kerogen
129	PC-17	Porosity and permeability

TRINITY ISLAND QUADRANGLE (PLATE B)

Sitkinak Island stratigraphic section (plate VI)

Map No.	Sample No.	Analysis done
130	33-WL-76	Paleontology
131	32-WL-76	Macrofossil
132	31-WL-76	Kerogen
133	30A-WL-76	Coal
134	30-WL-76	Kerogen
135	29-WL-76	Paleontology
136	28-WL-76	Porosity and permeability
137	27-WL-76	Porosity and permeability
138	26-WL-76	Kerogen, vitrinite reflectance
139	25-WL-76	Petrography
140	24-WL-76	Porosity and permeability
141	23-WL-76	Porosity and permeability
142	22-WL-76	Hydrocarbon
143	21-WL-76	Paleontology
144	20-WL-76	Macrofossil
145	19A-WL-76	Coal
146	19-WL-76	Kerogen, vitrinite reflectance
147	18-WL-76	Paleontology
148	17A-WL-76	Coal
149	17-WL-76	Kerogen, vitrinite reflectance

Random Sampling

Map No.	Sample No.	Analysis done
150	34-WL-76	Paleontology
151	35-WL-76	Kerogen
152	36-WL-76	Hydrocarbon
153	37-WL-76	Porosity and permeability
154	38-WL-76	Oriented sandstone
155	39-WL-76	Porosity and permeability
156	40-WL-76	Paleontology
157	41-WL-76	Paleontology
158	42-WL-76	Hydrocarbon
159	43-WL-76	Porosity and permeability
160	44-WL-76	Porosity and permeability
161	45-WL-76	Kerogen, vitrinite reflectance
162	46-WL-76	Paleontology

Map No.	Sample No.	Analysis done
163	47-WL-76	Hydrocarbon
164	48-WL-76	Porosity and permeability
165	49-WL-76	Hydrocarbon
166	50-WL-76	Paleontology

KAGUYAK QUADRANGLE (PLATE C)

Twoheaded Island stratigraphic section (plate VII)

172	1-WL-76	Porosity and permeability
173	2-WL-76	Hydrocarbon
174	3-WL-76	Paleontology
175	4-WL-76	Kerogen
176	5-WL-76	Porosity and permeability
177	6-WL-76	Paleontology
178	39-IP-76	Porosity and permeability
179	7-WL-76	Hydrocarbon
180	8-WL-76	Paleontology
181	9-WL-76	Kerogen
182	10-WL-76	Porosity and permeability
183	11-WL-76	Porosity and permeability
184	12-WL-76	Hydrocarbon
185	13-WL-76	Paleontology
186	14-WL-76	Paleontology
187	15-WL-76	Porosity and permeability
188	16-WL-76	Porosity and permeability

Random Sampling

189	TH-2	Porosity and permeability
191	TH-1	Hydrocarbon and kerogen

Geese Island stratigraphic section (plate I)

192	G-1	Porosity and permeability
193	G-1	Hydrocarbon and kerogen
194	G-1	Paleontology
195	G-2	Hydrocarbon and kerogen
196	G-3	Porosity and permeability
197	G-3	Hydrocarbon and kerogen
198	G-4	Hydrocarbon and kerogen

Map No.	Sample No.	Analysis done
199	G-4L	Paleontology
200	G-5	Porosity and permeability
201	G-5	Porosity and permeability
202	G-6	Hydrocarbon and kerogen
203	G-7	Hydrocarbon and kerogen
204	G-8	Porosity and permeability
205	G-9	Porosity and permeability
206	G-10	Porosity and permeability
207	G-11	Hydrocarbon and kerogen
208	G-12	Porosity and permeability
209	G-13	Porosity and permeability
210	G-14	Hydrocarbon and kerogen
211	G-15	Porosity and permeability
212	G-16	Porosity and permeability
213	G-17	Hydrocarbon and kerogen
214	G-17	Paleontology
215	G-18	Porosity and permeability
216	G-19	Porosity and permeability
217	G-20	Hydrocarbon and kerogen

TABLE 2. PALEONTOLOGY AND PALYNOLOGY DETERMINATIONS

Radiolarian assemblages similar to assemblages found in the subsurface of the Alaska Peninsula occur in several outcrop samples. These radiolaria are included in the following sample-by-sample Foraminifera report.

Determinations performed by Anderson, Warren, and Associates, consulting micropaleontologists, San Diego, CA, August, 1976.

Sample No.	Age	Environment	Fossil assemblages (A=abundant, C=common, F=frequent, and R=rare)
5-IP-76	Possible Paleocene to Eocene	Neritic to upper bathyal	Ammosphaeroidinia ? sp. (R), Globobulimina ? sp. (R), Haplophragmoides spp. (R).
8-IP-76	Eocene to Oligocene	Neritic	Ammosphaeroidinia sp. (F), Bathysiphon sp. (R), Haplophragmoides, cf. becki (R), H. spp. (R), H. deformes (R), Trochammina ? sp. (R). pyrite (F).
12-IP-76	Indet.	Indet.	Barren.
16-IP-76	Eocene to Oligocene	Neritic	Ammosphaeroidina sp. (F), Bathysiphon cf. alexanderi (R), Haplophragmoides deformes (R), H. spp. (R), Trochammina ? sp. (R), Verneuilina ? sp. (R), diatoms (F).
19-IP-76	Indet.	Neritic?	Haplophragmoides cf. crassus (R), H. deformes (R), H. sp. (R), pyrite (F).
21-IP-76	Eocene to Oligocene	Outer neritic	Ammosphaeroidina ? sp. (R), Globobulimina auriculata (R), Haplophragmoides cf. crassus (R), H. cf. deformes (R), H. sp. (?), pyrite (R).

Sample No.	Age	Environment	Fossil assemblages (A=abundant, C=common, F=frequent, and R=rare)
23-IP-76	Indet.	Neritic?	Haplophragmoides cf. deformes (R), H. sp. (R), pyrite (R).
24-IP-76	Eocene to Oligocene	Neritic?	Ammosphaeroidinia ? sp. (F), Bathysiphon cf. alexanderi (R), Haplophragmoides cf. crassus (R), H. cf. deformes (R), H. sp. (R), pyrite (R).
26-IP-76	Indet.	Marine	Bathysiphon cf. alexanderi (R), pyrite (R), pyrite sticks (R).
46-IP-76	Indet.	Neritic to	Cyclammina cf. pacifica (F), Haplophragmoides ? sp. (R), shell fragments (F), coal (R).
48-IP-76	Indet.	Marine	Bathysiphon sanctaecrucis (R), Haplophragmoides sp. (R).
54-IP-76	Indet.	Indet.	Barren. Shell fragments (C).
74-IP-76	Probable Cretaceous	Probable middle neritic to bathyal	Arenaceous spp. (F), Bathysiphon sp. (R), Cribroelphidium ? sp. (R), Haplophragmoides ? sp. (R), Lenticulina spp. (R), silicosigmoilina californica (R), Verneuilinoides ? sp. (R), Inoceramus prisms (F).
75-IP-76	Probable Cretaceous	Middle neritic to bathyal	Arenaceous spp. (R), Cibicides ? sp. (R), Cribroelphidium ? sp. (R) Lenticulina spp. (R), Silicosigmolina california (large) (F), Verneuilinoides ? sp. (R), Inoceramus prisms (A).
78-IP-76	Jurassic to Cretaceous	Marine	Haplophragmoides sp. (R), Inoceramus prisms (F)

Sample No.	Age	Environment	Fossil assemblages (A=abundant, C=common, F=frequent, and R=rare)
80-IP-76	Jurassic to Cretaceous	Marine	Barren. *Inoceramus* prisms (C).
82-IP-76	Jurassic to Cretaceous	Marine	Barren. *Inoceramus* prisms (F).
83-IP-76	Jurassic to Cretaceous	Marine	Barren. Shell fragments (C), *Inoceramus* prisms (A).
86-IP-76	Indet.	Indet.	Barren.
88-IP-76	Indet.	Possible Marine	*Trochammina* cf. *sablei* (R).
94-IP-76	Indet.	Indet.	Barren. Shell fragments (F).
96-IP-76	Indet.	Indet.	Barren.
3-WL-76	Indet.	Indet.	Barren. Pyrite (R).
6-WL-76	Indet.	Indet.	Barren. Coal (VA).
8-WL-76	Indet.	Indet.	[illegible] *sp.* ? (R).
13-WL-76	Indet.	Possible marine	*Bathysiphon sanctaecrucis* (R), fish scales (F).
14-WL-76	Possible Eocene to Oligocene	Marine	*Ammosphaeroidinia* ? *sp.* (R), *Bathysiphon alexanderi* (R), *B. sanctaecrucis* (R).

Sample No.	Age	Environment	Fossil assemblages (A=abundant, C=common, F=frequent, and R=rare)
18-WL-76	Indet.	Marine	Arenaceous sp. (R), Bathysiphon sanctaecrucis (F), Saccammina sp. (R), radiolaria (R), coal (C).
21-WL-76	Indet.	Marine	Arenaceous sp. (R), Bathysiphon sanctaecrucis (R), radiolaria (R), coal (F).
29-WL-76	Possible Miocene	Possible outer neritic to bathyal	Bathysiphon sp. (F), Cassidulina cf. crassipunctata (R), Cibicides cf. pacifica (R), Globobulimina sp. (R), Nonion cf. pompilioides (R), shell fragments (C), pyrite (F), coal (F).
33-WL-76	Possible Miocene	Probable middle neritic to upper bathyal	Cyclammina sp. (R), Glanulina sp. (R), Haplophragmoides cf. deformed (C), H. cf. excavata (F), Saccammina sp. (R), Trochammina sp. (R), diatoms (pyritized) (R), radiolaria (R), shell fragments (F), glauconite (R), pyrite (F).
34-WL-76	Indet.	Indet.	Barren. Shell fragments (F), sponge spicules (R).
41-WL-76	Indet.	Indet.	Barren.
46-WL-76	Indet.	Possible marine	Bathysiphon cf. alexanderi (R), pyrite (C).
50-WL-76	Indet.	Marine	Bathysiphon sanctaecrucis (R), Trochammina sp. (R), radiolaria (pyritized) ? (F), pyrite (C).
52-WL-76	Indet.	Indet.	Barren.

Sample No.	Age	Environment	Fossil assemblages (A=abundant, C=common, F=frequent, and R=rare)
55-WL-76	Indet.	Indet.	Barren.
CB-1	Eocene to Oligocene	Neritic	Ammosphaeroidina ? sp. (C), Arenaceous spp. (F), Bathysiphon sp. (F) Haplophragmoides sp. (R), Reophax sp. (R), Trochammina sp. (R), pyrite (F).
G-1	Possible Eocene to Oligocene	Marine	Ammosphaeroidina ? sp. (R), Arenaceous sp. (R), pyrite (F).
G-17	Eocene to Oligocene(?)	Marine?	Ammosphaeroidina ? sp. (R), pyrite (F), pyrite sticks (C).
G-41	Indet.	Indet.	Barren.
OB-7	Eocene to Oligocene	Neritic	Ammosphaeroidina ? sp. (C), Arenaceous sp. (R), Bathysiphon sp. (F), Haplophragmoides cf. deformes (R), Trochammina sp. (F), diatoms (pyritized) (F), pyrite (F).
PC-2	Indet.	Indet.	Barren. Pyrite (F), vein calcite ? (A).
PC-11	Possible Eocene to Oligocene	Neritic	Ammosphaeroidinia ? sp. (R) Bathysiphon sp. (C), Trochammina sp. (R), diatoms (pyritized) (R), pyrite (F).

TABLE 3. POROSITY AND PERMEABILITY ANALYSES

Map No.	Sample No.	Effective Porosity %	Permeability (mD)
29	29-IP-76	13.0	12
30	30-IP-76	6.4	1.02
31	31-IP-76	10.1	10
32	32-IP-76	16.0	30
34	34-IP-76	2.1	0.22
35	35-IP-76	4.6	0.33
36	36-IP-76	12.5	30
37	37-IP-76	12.0	26
38	38-IP-76	10.2	4.48
39	52-IP-76	4.8	0.02
40	53-IP-76	17.0	5.53
41	54-IP-76	2.0	0.01
42	55-IP-76	0.6	0.01
46	42-IP-76	1.0	0.01
48	44-IP-76	2.3	0.02
49	45-IP-76	3.8	1.80
63	1-IP-76	4.1	0.02
64	2-IP-76	3.1	0.02
65	3-IP-76	4.0	0.48(HF)[a]
66	4-IP-76	2.7	0.11
72	10-IP-76	2.6	0.02
75	13-IP-76	2.8	0.06
76	14-IP-76	2.7	1.88
77	15-IP-76	2.7	0.07
87	25-IP-76	2.5	0.01
88	CB-1	0.2	0.01
90	CB-2	5.1	10(HF)
91	CB-3	1.9	0.01
93	CB-4	0.9	0.01
94	OB-1	5.3	0.20

[a] HF = horizontal fracture

Map No.	Sample No.	Effective Porosity %	Permeability (mD)
97	OB-4	3.5	0.11
99	OB-5	0.6	0.01
101	OB-6	0.7	0.01
104	51-IP-76	1.6	0.01
105	48-IP-76	3.2	0.04
108	PC-1	0.6	0.01
109	PC-2	0.4	0.01
111	PC-3	0.2	0.01
113	PC-5	0.2	0.02
114	PC-6	1.7	0.02
116	PC-7	2.0	0.01
117	PC-8	1.1	0.01
119	PC-10	0.6	0.01
120	PC-11	0.5	0.01
123	PC-12	2.9	0.01
124	PC-13	0.2	0.01
126	PC-15	1.7	0.01
127	PC-16	1.3	0.01
129	PC-17	1.5	0.01
136	28 WL 76	15.5	12(HF)
137	27 WL 76	9.0	0.08
140	24 WL 76	10.3	1.30
141	23 WL 76	10.7	1.12
153	37 WL 76	4.6	0.01
159	43 WL 76	7.4	0.01
160	44 WL 76	5.3	0.01
172	1 WL 76	1.1	0.01
176	5 WL 76	2.3	0.01
178	39-IP-76	1.9	0.01
182	10 WL 76	2.0	0.01
183	11 WL 76	1.7	0.01
188	16 WL 76	13.6	0.01
189	TH-2	1.2	0.01
190	TH-1	1.9	1.16(HF)
192	G-1	1.6	0.01
196	G-3	0.5	0.01
200	G-5	2.3	0.01
201	G-6	3.5	7.99(HF)
204	G-8	0.3	0.01
205	G-9	0.2	0.01

Map No.	Sample No.	Effective Porosity %	Permeability (mD)
206	G-10	0.8	0.01
208	G-12	1.0	0.01
209	G-13	0.9	0.01
212	G-16	1.1	0.01
215	G-18	0.2	0.01
216	G-19	0.5	0.01

TABLE 4. CONCENTRATION OF EXTRACTED MATERIALS IN ROCK
Analysis by Geochem Laboratories, Inc., Houston, Texas

		Hydrocarbons		Nonhydrocarbons
Map No.	Sample No.	Total extract (ppm)	Organic carbon (%)	Precipitated asphaltene (ppm)
27	27-IP-76	165	0.36	123
68	6-IP-76	601	0.88	324
71	9-IP-76	374	0.35	206
79	17-IP-76	227	0.95	141
82	20-IP-76	335	0.56 (0.56)	214
84	22-IP-76	457	0.53	251
92	CB-3	288	0.47	170
95	OB-2	556	0.70	267
96	OB-3	135	0.21	104
100	OB-5	401	0.49	190
102	OB-7	533	0.67 (0.64)	243
106	49-IP-76	434	0.36	338
112	PC-4	221	0.52	123
115	PC-6	299	0.46	186
118	PC-9	323	0.50	214
121	PC-11	249	0.50	153
125	PC-14	197	0.42 (0.42)	129
128	PC-16	295	0.53	179
134	30-WL-76	389	0.38	326
142	22-WL-76	229	0.50 (0.53)	167
152	36-WL-76	606	0.58	242
158	42-WL-76	242	0.42	139
163	47-WL-76	180	0.35	127
165	49-WL-76	173	0.35 (0.38)	112
169	53-WL-76	3.76	0.60	259
173	2-WL-76	394	0.46	317
179	7-WL-76	339	0.44	263
184	12-WL-76	302	0.46	213
191	TH-1	564	0.64	342
193	G-1	293	0.44	181

Map No.	Sample No.	Hydrocarbons: Total extract (ppm)	Hydrocarbons: Organic carbon (%)	Nonhydrocarbons: Precipitated asphaltene (ppm)
195	G-2	343	0.53	222
197	G-3	620	0.64	394
198	G-4	273	0.28	188
202	G-6	344	0.46 (0.44)	230
203	G-7	301	0.42	184
207	G-11	252	0.39	188
213	G-17	226	0.55	151
217	G-20	361	0.35 (0.35)	232

TABLE 5. VISUAL KEROGEN ASSESSMENT

Analyses by Geochem Laboratories, Inc., Houston, Texas

		Visual Kerogen	
Map No.	Sample No.	Organic Matter Type[a]	Alteration Rank[b]
27	27-IP-76	H; C; Am	2 to 2+
68	6-IP-76	H; Am; C (W)	$\underline{2}$- to 2
71	9-IP-76	H; Am; C (W)	$\overline{2}$- to 2
79	17-IP-76	H; C; Am	$\overline{2}$- to 2
82	20-IP-76	H; C; Am	2 to 2+
84	22-IP-76	H; C; Am	2- to $\underline{2}$
92	CB-3	H; Am; C	$\underline{2}$ to $\overline{2}$+
95	OB-2	H; Am; C	$\overline{2}$- to 2
96	OB-3	H-C; Am; -	2 to $\overline{2}$+
100	OB-5	H; C; Am	$\underline{2}$ to $\overline{2}$+
102	OB-7	H; -; Am-C	2- to 2
106	49-IP-76	H-C; Am; -	2 to 2+
112	PC-4	H; C; Am	2
115	PC-6	H; C; Am-W	2- to $\underline{2}$
118	PC-9	H; -; C	2- to $\overline{2}$
121	PC-11	H; C; Am-W	2- to $\underline{2}$
125	PC-14	H; Am; W-C	$\underline{2}$ to $\overline{2}$+
128	PC-16	H; Am-C; -	$\overline{2}$- to $\underline{2}$
134	30-WL-76	H; C; -	2- to $\overline{2}$
142	22-WL-76	H; C; -	2- to $\underline{\overline{2}}$
152	36-WL-76	H; C; W (Am)	1+ to 2-
158	42-WL-76	H; C; -	2- to $\underline{2}$
163	47-WL-76	H; C; W	2- to $\overline{2}$
165	49-WL-76	H; C; W	2 to $\overline{2}$+
169	53-WL-76	H; C; Am	1+ to $\underline{2}$-
173	2-WL-76	H; C; Am	2 to 2+
179	7-WL-76	H; C; Am-W	2 to 2+
184	12-WL-76	H; C; W (Am)	2 to 2+
191	TH-1	H; -; Am-C	2- to $\overline{2}$
193	G-1	H; C; Am	2 to $\overline{2}$+
195	G-2	H; C; Am	2 to 2+
197	G-3	Am-H; -; C	$\underline{2}$ to 2+

Map No.	Sample No.	Visual Kerogen: Organic Matter Type[a]	Visual Kerogen: Alteration Rank[b]
198	G-4	Am-H; C; -	2 to 2+
202	G-6	H; C; Am (W)	2 to 2+
203	G-7	H; C; Am	2- to 2
207	G-11	H; C; Am	2- to 2
213	G-17	H; C; Am	2
217	G-20	H; Am; C	2

a. Kerogen key (in order listed): Predominant - 60 to 100%; Secondary - 20 to 40%; Trace - 1 to 20%.
Al = Algal, Am = Amorphous-Sapropel, H = Herbaceous-Spore/Cuticle, W = Woody, C = Coaly, U = Unidentified Material.

b. Scale from 1 = unaltered to 4 = severely altered; underlined number indicates dominate rank of alteration.

TABLE 6. PETROGRAPHIC DESCRIPTIONS OF SELECTED SAMPLES FROM STRATIGRAPHIC COLUMNS AND TRAVERSES

Samples determined to be petrographically similar were grouped together, and one sample from each group was described in detail. Part A shows the distribution of samples among the groups recognized, and Part B presents petrographic data from the samples studied in detail.

During this project, no samples were collected for petrographic study from the Ghost Rocks Formation. The samples which were studied from that formation were supplied by George Moore and Gary Winkler (USGS) from previous work on Kodiak Island.

PART A. Samples in each petrographically similar group.

Formation and sample group	Sample No.
Narrow Cape Formation	
A	29-IP-76, 30-IP-76, 32-IP-76, 36-IP-76, 52-IP-76, 53-IP-76
B	34-IP-76, 37-IP-75, 45-IP-76
C	54-IP-76
Sitkinak Formation	
D	24-WL-76
E	27-WL-76
F	1-IP-76, 2-IP-76, 3-IP-76, 4-IP-76
G	10-IP-76, 13-IP-76
H	14-IP-76, 15-IP-76, 25-IP-76
Sitkalidak Formation	
I	PC-2*, PC-6*, PC-8, PC-11*
J	1-WL-76, 16-WL-76, PC-3, PC-5, PC-7, PC-10, PC-12, PC-13, PC-15, PC-16, PC-17

Formation and sample group	Sample No.
Sitkalidak Formation (continued)	
K	10-WL-76, 11-WL-76, PC-1, 39-IP-76
L	G-1, G-3, G-5, G-6, G-8, G-9, G-10, G-12, G-13, G-16
Ghost Rocks Formation	
M	AMe-76-58, 72AWk-73A, 72AWk-76A
N	71AWk-71A, 72AWk-72A, 72AWk-78A, 63AMe-10, AMe-76-57

*These samples contain about 50% sparry calcite, and the volume of silicate matrix and framework grains reported for the group as a whole has been reduced proportionately.

PART B. Petrographic data for representative samples studied in detail.

Sample group	Selected Sample no.	Silicate Matrix (%)	Calcite (%)	Framework Grains (normalized to 100%) Silica	Feldspar	Rock Fragments	Range of Wentworth grade size-framework grains
Narrow Cape Formation							
A	30-IP-76	7	--	67	16	17	Silt to medium sand
B	45-IP-76	31	--	76	24	--	Silt to fine sand
C	54-IP-76	--	26	67	15	18	Very fine to medium sand
Sitkinak Formation							
D	24-WL-76	32	--	58	10	32	Very fine to medium sand
E	27-WL-76	15	--	45	15	40	Very fine to coarse sand
F	1-IP-76	9	4	48	23	30	Very fine to medium sand
G	13-IP-76	7	3	35	24	41	Fine to very coarse sand
H	25-IP-76	14	17	40	20	40	Very fine to coarse sand
Sitkalidak Formation							
I	PC-8	19	--	49	15	36	Silt to fine silt

Sample group	Selected Sample no.	Silicate Matrix (%)	Calcite (%)	Framework Grains (normalized to 100%)			Range of Wentworth grade size-framework grains
				Silica	Feldspar	Rock Fragments	
Sitkalidak Formation (continued)							
J	1-WL-76	18	3	54	24	22	Fine to coarse sand
K	10-WL-76	3	9	41	8	51	Very fine to coarse sand
L	G-1	16	--	40	23	37	Silt to medium sand
Ghost Rocks Formation							
M	AMe-76-58	2	--	11	28	61	Fine to coarse sand
N	72AWk-71A	10	--	36	21	43	Very fine to medium sand

TABLE 7. GEOCHEMICAL ANALYSES

Stream-sediment samples were analyzed for gold, silver, copper, lead, zinc, molybdenum, tin, uranium, and thorium. The results are in parts per million.

Sample No.	Gold	Silver	Copper	Lead	Zinc	Molybdenum	Tin	Uranium	Thorium
56-WL-76	0.10	0.0	37	20	98	2	0	1.1	3.75
57-WL-76	0.13	0.0	57	28	110	1	0	0.8	4.00
58-WL-76	0.15	0.0	46	15	110	0	0	1.0	4.00
1-JB-76	0.07	0.14	30.7	15	90.7	0	0	---	7.50
2-JB-76	0.05	0.19	16.3	16	71.0	0	0	---	6.25
1-JM-76	0.06	0.0	13	13	44	0	0	0.9	5.00
2-JM-76	0.06	0.0	21	16	74	0	0	0.7	7.50
3-JM-76	0.09	0.0	19	12	58	0	0	0.9	4.50
4-JM-76	0.11	0.0	44	19	102	0	0	0.8	4.75
5-JM-76	0.09	0.0	21	15	45	0	0	0.7	4.25
6-JM-76	0.12	0.0	45	20	98	0	0	0.9	4.75
7-JM-76	0.09	0.0	21	13	102	0	0	2.7	2.50
8-JM-76	0.05	0.0	16	10	57	0	0	0.8	3.75
9-JM-76	0.05	0.0	12	9	72	0	0	1.6	1.75
10-JM-76	0.04	0.0	17	13	56	0	0	5.7	2.75
11-JM-76	0.14	0.0	23	18	79	1	0	1.9	3.50
12-JM-76	0.15	0.0	33	25	95	1	0	1.6	4.75
13-JM-76	0.04	0.0	18	14	52	0	0	1.5	2.75
14-JM-76	0.07	0.0	25	19	72	0	0	1.0	4.75
15-JM-76	0.06	0.0	40	22	119	0	0	1.0	2.00
47-IP-76	0.06	0.0	33	21	91	0	0	1.5	5.00
57-IP-76	0.08	0.0	36	20	93	0	0	1.2	7.00
58-IP-76	0.04	0.0	47	18	101	0	0	1.0	4.75
59-IP-76	0.05	0.0	19	9	48	0	0	1.2	3.50
60-IP-76	0.10	0.0	15	12	37	0	0	0.5	3.25
61-IP-76	0.02	0.0	17	12	52	0	0	1.2	5.50
62-IP-76	0.08	0.0	38	20	101	2	0	1.1	6.25
63-IP-76	0.03	0.0	15	10	36	0	0	1.2	10.0
64-IP-76	0.09	0.0	37	17	79	0	0	0.9	7.75
65-IP-76	0.14	0.0	56	27	136	0	0	1.1	7.25

Sample No.	Gold	Silver	Copper	Lead	Zinc	Molybdenum	Tin	Uranium	Thorium
66-IP-76	0.11	0.0	39	26	119	2	0	1.2	5.00
67-IP-76	0.02	0.0	40	30	120	0	0	2.0	5.75
68-IP-76	0.08	0.0	30	24	92	0	0	1.6	5.25
69-IP-76	0.09	0.0	34	34	102	0	0	1.9	8.00
70-IP-76	0.08	0.0	33	23	99	1	0	1.2	5.25
71-IP-76	0.07	0.0	35	23	101	0	0	1.0	4.00

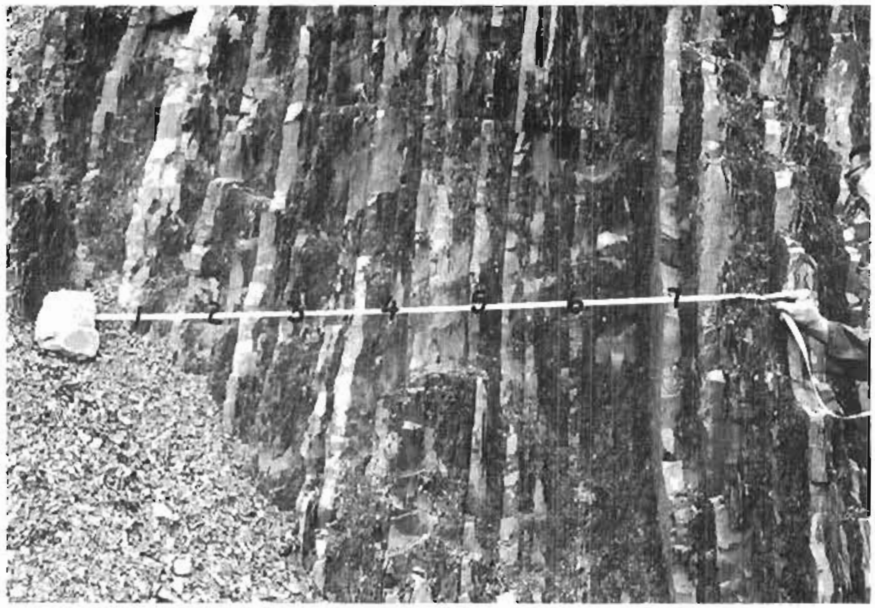
APPENDIX

Nearly vertical dipping massive beds of conglomerate exposed along east coast of Chirikof Island. These conglomerates appear to be submarine fan channel deposits which have cut down through adjacent turbidite squences composed of sandstone and shale graded bedded couplets.

Sitkinak Formation sandstone exhibiting shale rip-up clasts exposed along McDonald Lagoon on Sitkalidak Island.

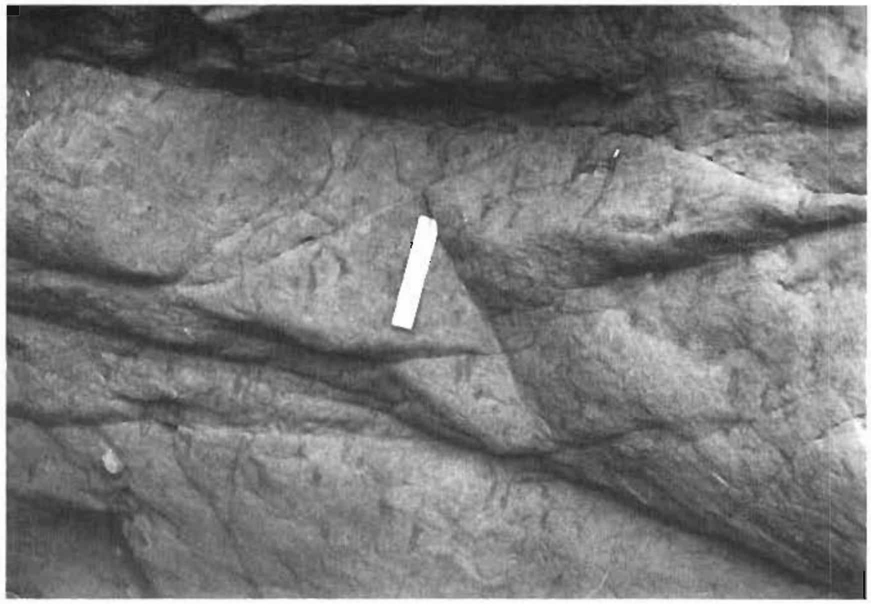
Sitkinak Formation channel cut and fill exhibiting graded bedding exposed at McDonald Lagoon on Sitkalidak Island.

Sitkinak Formation sandstone which contains many coal fragments exposed at McDonald Lagoon on Sitkalidak Island.

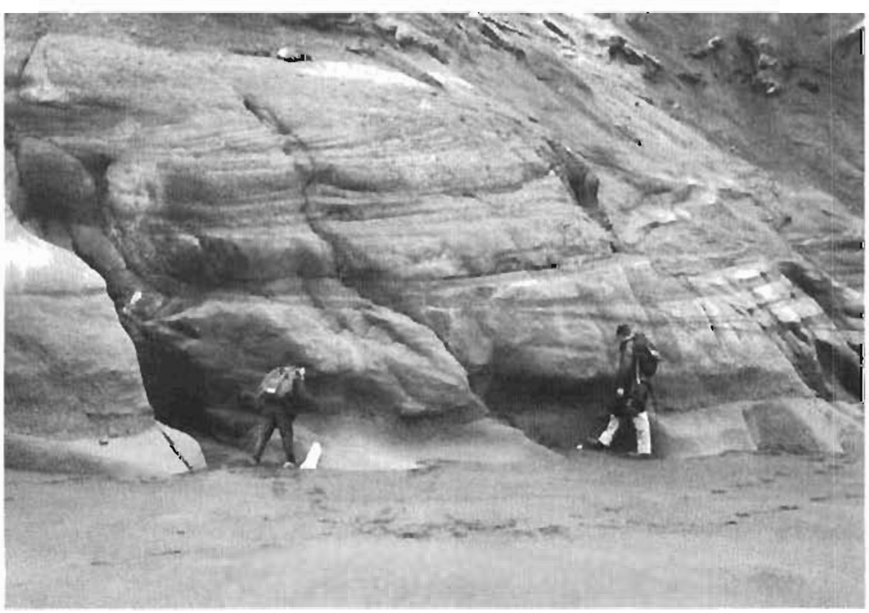


Alternating sandy siltstone and shale flysch deposits of the Sitkalidak Formation exposed near Partition Cove on Sitkalidak Island. Tape is marked in feet. Graded bedding is not evident. All contacts appear sharp. Thick sandstones should not be expected to occur seaward from these deep-water deposits within the Sitkalidak Formation.

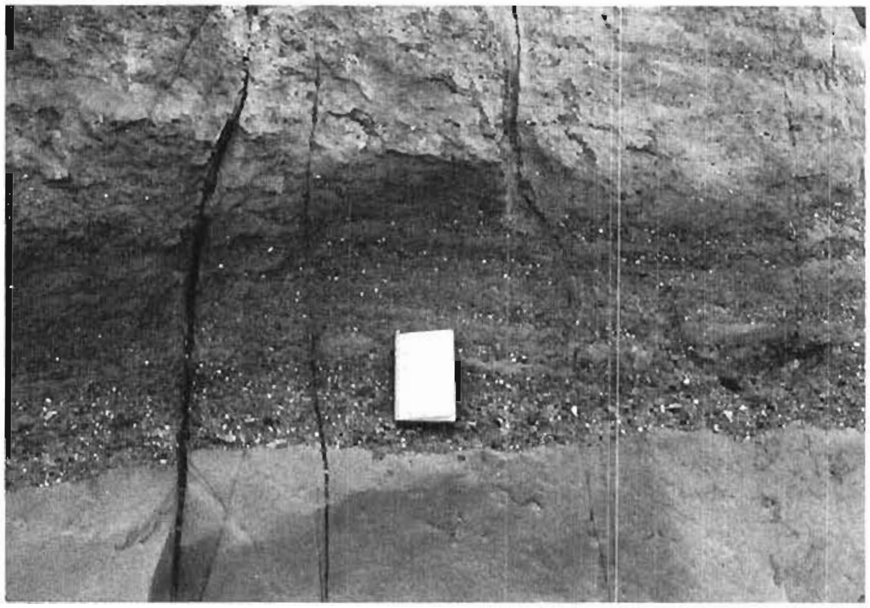
Basal contact (dashed line) between Narrow Cape Formation, Miocene and Sitkalidak Formation, Eocene, exposed at Narrow Cape.



Abundant burrows such as these oriented normal to bedding occur at several places within the Narrow Cape stratigraphic section.



Small deltaic complex exposed in the Narrow Cape stratigraphic section. Pebble conglomerates and sandstones similar to these should be excellent reservoirs if preserved in the OCS area.

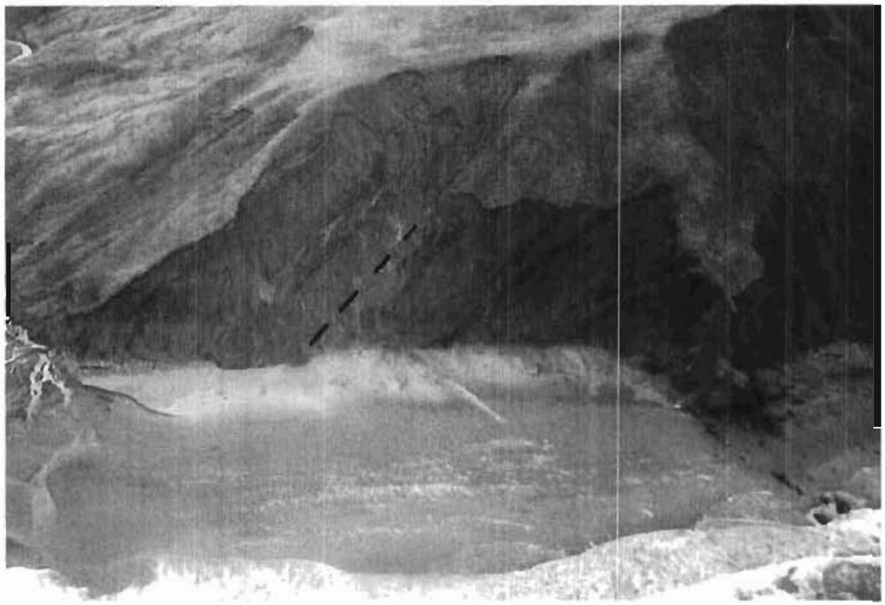


Upper Miocene Narrow Cape Formation channel cut and fill exhibiting graded bedding in the small deltaic complex exposed at Narrow Cape.

Basal part of Sitkinak stratigraphic section. The Sitkinak Formation consists of massive beds of pebble-cobble conglomerate with thinner interbeds of mudstone and coal.

One of several contacts between conglomerate and coal-mudstone units exposed on Sitkinak Island in Sitkinak Formation.

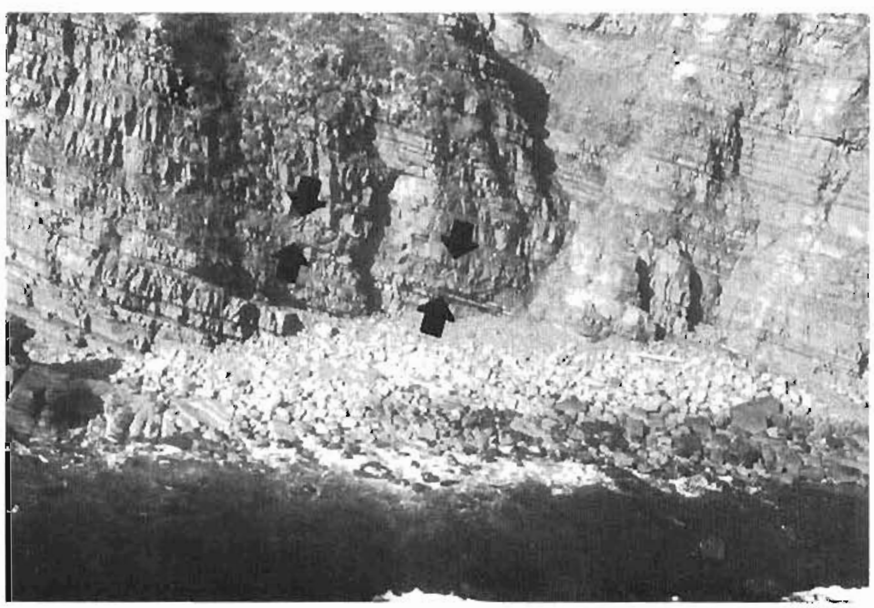
Middle part of Sitkinak stratigraphic section exposed near Tip triangulation station on Sitkinak Island. The sandstone facies of these massive conglomerates may occur in the OCS area to the east and southeast.



Contact between the continental Oligocene Sitkinak Formation on the right and the marine Miocene Narrow Cape Formation on the left exposed at Sitkinak Island. Contact is apparently conformable.

Basal part of Twoheaded Island stratigraphic section. The Sitkalidak Formation exposed here on the southwest coast of the island consists of rather massive sandstones at the base as indicated in photo and these sandstones thin upwards (see middle and upper parts of section photos).

Middle part of Twoheaded Island stratigraphic section. The fining upward packets of alternating sandstones, siltstones and shales were probably deposited in a middle fan environment.



Upper middle part of Twoheaded Island stratigraphic section. Note soft sediment deformation in one bed; arrows.