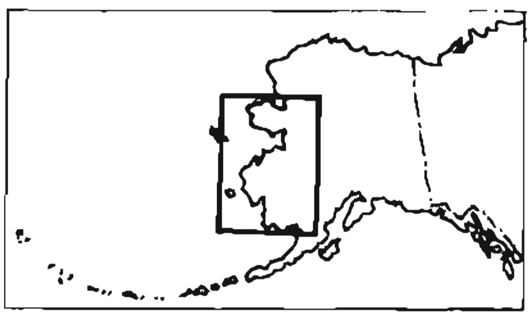
STATE OF ALASKA
DEPARTMENT OF NATURAL RESOURCES

HYDROCARBON RESERVOIR AND SOURCE-ROCK CHARACTERISTICS FROM SELECTED AREAS OF SOUTHWESTERN ALASKA

By
W.M. Lyle
Alaska Division of Geological and Geophysical Surveys
and
I.F. Palmer, Jr., J.G. Bolm, and T.O. Flett
U.S. Minerals Management Service

PROFESSIONAL REPORT 77



Published by
DIVISION OF GEOLOGICAL & GEOPHYSICAL SURVEYS

ROSS G. SCHAFF
STATE GEOLOGIST

1982

PROFESSIONAL REPORT 77

HYDROCARBON RESERVOIR AND SOURCE-ROCK CHARACTERISTICS FROM SELECTED AREAS OF SOUTHWESTERN ALASKA

By
W.M. Lyle, I.F. Palmer, Jr., J.G. Bolm, and T.O. Flett

For sale by Alaska Division of Geological and Geophysical Surveys, P.O. Box 80007, College, 99708; 323 E. 4th, Anchorage, 99501; P.O. Box 7438, Ketchikan, 99901; and 230 So. Franklin, Juneau, 99811. Price: $6.50.

CONTENTS

FIGURES

TABLES

PLATES

METRIC CONVERSION FACTORS

To convert feet to meters, multiply by 0.3048. To convert inches to centimeters, multiply by 2.54. To convert miles to kilometers, multiply by 1.61.

HYDROCARBON RESERVOIR AND SOURCE-ROCK CHARACTERISTICS FROM SELECTED AREAS OF SOUTHWESTERN ALASKA

By W. M. Lyle[1], I.F. Palmer, Jr.[2], J.G. Bolm[2], and T.O. Flett[2]

ABSTRACT

A joint state-federal project conducted during July 1978 in southwestern Alaska resulted in considerable new data on petroleum reservoir and source-rock potential. Six stratigraphic sections totaling 7,332 feet were measured, and 236 samples were collected from these stratigraphic sections and various spot localities. Some potential reservoir sandstones measured at coastal exposures at Nunivak Island and Nelson Island exceed 75 feet in thickness; similar sand bodies probably extend offshore, but their limits are unknown. Laboratory analyses of outcrop samples indicate poor reservoir quality owing to tight packing and alteration of mineral constituents. All samples had porosities less than 10 percent, and all but two samples had permeabilities less than 7 millidarcies.

On the basis of thermal-alteration indices, most samples are immature to mature (2- to 3+). Most samples also contain dominant herbaceous and woody primary kerogen constituents. Only 13 samples have an organic carbon content greater than 0.5 percent, and extractable hydrocarbons averaged 48 ppm with a range of 6 to 99 ppm. These data show a lean hydrocarbon source potential with a greater likelihood of gas than oil generation.

INTRODUCTION

Stratigraphic field studies were conducted in selected upland areas adjacent to Norton Sound and Kuskokwim Bay during July 1978 by the U.S. Minerals Management Service (then the Conservation division, U.S. Geological Survey) and the Alaska Division of Geological and Geophysical Surveys (fig. 1). This project was similar in scope to previous cooperative state-federal field projects completed annually since 1975. Both agencies are charged with evaluation of petroleum potential of submerged lands under their respective jurisdictions. Because geologists from the two agencies collaborate on these projects, geological data are collected and processed uniformly, research efforts are not duplicated, and both agencies realize significant savings. Interpretations based on data collected are extrapolated into adjacent submerged areas and are used in evaluation programs for petroleum lease sales.

Commercial facilities at Bethel, Nome, and Unalakleet served as bases of operations. A Bell 206B Jet Ranger II helicopter was the primary means of crew transport in the field, and fuel for the helicopter was cached at several remote locations by fixed-wing charter aircraft.

All stratigraphic sections but one were measured by using Brunton compasses and 100-foot tapes; a Jacob's staff was used on the exception. Samples were collected to determine porosity, permeability, age, depositional environment, hydrocarbon content, and basin maturity. Sample localities are shown on plate 1. All samples are identified with a sample number, the collector's initials, and the year (e.g., 1-GB-78). Samples are cross-referenced to quadrangle map, township, range, and stratigraphic unit (table 1). Results of geochemical analyses of samples appear in tables 2 and 3, porosity and permeability data are presented in table 4, paleontological data are presented in tables 5 and 6, and results of petrographic studies are summarized in table 7. For continuity, the tables, which are lengthy, are placed at the end of the text.

STRUCTURAL GEOLOGY

The following outline of the structural geology of the investigated area is based on published work by Sainsbury and others (Seward Peninsula, 1970), Patton (Yukon-Koyukuk basin, 1973), and Hoare (lower Kuskokwim-Bristol Bay region, 1961). Figure 2 shows the structural entities mentioned in this section.

The bedrock of the Seward Peninsula consists of metamorphic rocks of Precambrian age and Paleozoic rocks that are unmetamorphosed in the west but become metamorphosed and of progressively higher grade eastward. The structure of this region is dominated by imbricate thrust sheets that are generally horizontal or gently southward-dipping in the west and become folded with a progressive increase in complexity eastward. Most folding on the Seward Peninsula is related to thrusting.

Two ages of thrusting are evident on the peninsula. The earlier was directed eastward and was accompanied by intense folding; the later, directed northward, was not accompanied by major folding. Rocks as young as Mississippian have been cut by thrusts, and thrust sheets have been intruded by plutons of Late Cretaceous age. The absence of upper Paleozoic and lower Mesozoic rocks in the thrust sheets precludes determination of the age of thrusting closer than post-Mississippian to pre-Late Cretaceous. Sainsbury and his coauthors (1970) believe it is most likely of Early Cretaceous age.

The Yukon-Koyukuk basin is a large Cretaceous basin in which sedimentary rocks have been tightly folded and much faulted. In the western part of the basin, folds trend north-south near the Seward Peninsula and shift to a northeasterly trend south of that area; Patton (1973) interpreted these folds to have formed in a strong eastward compression associated with thrusting on the Seward Peninsula.

Folds trend northeastward all along the southeastern margin of the Yukon-Koyukuk basin. This is parallel to the predominant structural grain in the adjacent lower

[1]Alaska Division of Geological and Geophysical Surveys.
[2]U.S. Minerals Management Service.

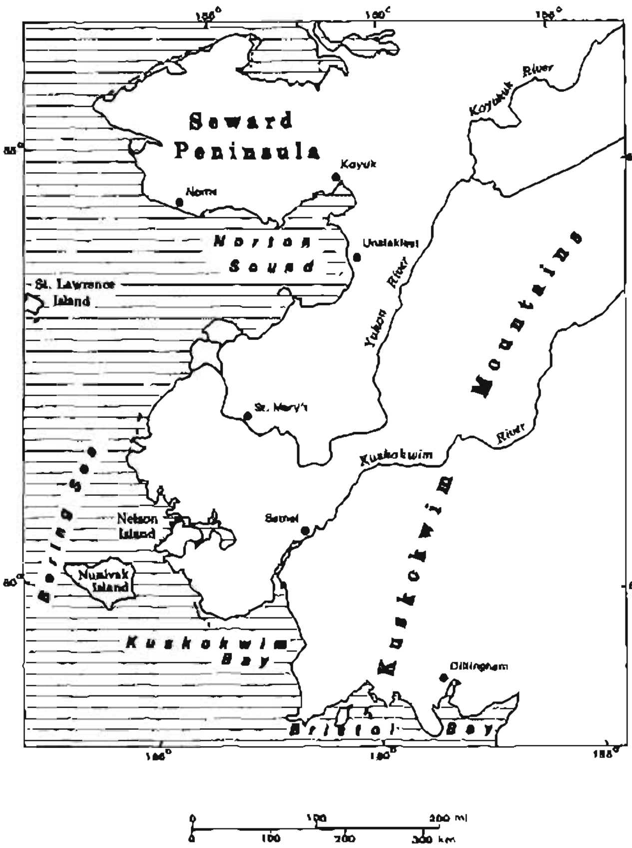


Figure 1. Location map.

Kuskokwim-Bristol Bay region.

Folds trend east-west along the northern margin of the Yukon-Koyukuk basin. The formation of this trend was associated with the rise of the ancestral Brooks Range, as was the orogenic activity that resulted in the formation of the east-west-trending Hogatza plutonic belt of Cretaceous age in the northernmost part of the study area. This belt is in an area of general uplift in which volcanic rocks of Early Cretaceous age crop out. These rocks separate northerly trending folded sedimentary rocks near Seward Peninsula from easterly and northeasterly trending folded sedimentary rocks along the northern and eastern margins of the basin.

The east-northeast-trending Kaltag fault cuts across the middle of the Yukon-Koyukuk basin. Right-lateral displacement across this fault has offset geologic trends in the basin by 40 to 62 miles, and recent movement along the fault is evidenced by drainage offsets of as much as 1.5 miles.

The lower Kuskokwim-Bristol Bay region contains a series of northeast-trending basins and uplifts. From northwest to southeast these are the Ruby arch, the Kuskokwim basin, the Goodnews arch and Alaska-Yukon arch, and the Alaska Range basin.

Tectonic development began in this area in Cretaceous time with local uplift and subsidence of highly deformed, fine-grained sedimentary and volcanic rocks of Precambrian to Early Cretaceous age. As basins formed, they were filled by sediments stripped from adjacent uplifts. Consequently, basin-fill rocks onlap limbs of arches unconformably but become more nearly conformable with underlying rocks as they approach synclinal axes. Isolated patches of Upper Cretaceous rock located near axes of arches indicate that onlapping Cretaceous strata once blanketed the uplifted structures. The numerous intraformational unconformities in the basin-fill rocks indicate that uplift and subsidence were intermittent through middle Late Cretaceous time.

Cretaceous rocks in the basins have been intensely folded on a scale that ranges from inches to miles. Sandstones and conglomerates are generally smoothly flexed, but folds in shales tend to be disharmonic. Fold axes trend northeasterly except in the saddle between the Goodnews arch and Alaska-Yukon arch, where folds trend northwesterly and may have formed as a result of strike-slip movement along the Farewell fault. Hoare (1961) believes the rocks in the basins were deformed by horizontal compression, which drove more competent, uplifted structural elements together in latest Cretaceous or earliest Tertiary time.

Major faults in the lower Kuskokwim-Bristol Bay region trend east-northeasterly. Many of these faults appear to have had Late Cretaceous or early Tertiary strike-slip movement, but more recent movement has been predominantly dip-slip, which indicates southeastward or northwestward compression. Offsets of alluvium across some east-northeast-trending faults in this region may be tears between areas of unequal crustal shortening.

FORMAL ROCK UNITS STUDIED

Although some stratigraphic sections were measured in and some spot samples collected from outcrops of rock that have not been assigned to any formal rock unit, most work was done in three rock units: the Gemuk, Kuskokwim, and Shaktolik Groups.

GEMUK GROUP

The Gemuk group, named by Cady and others (1955), comprises massive dark siltstone with interbedded graywacke, volcanic rocks, chert, and limestone. This group crops out extensively in and adjacent to the central and lower Kuskokwim River region. The following description is based principally on that presented in the original, defining work.

Siltstone, the principal lithology in the group, is a microbreccia of angular, equant grains of coarse silt in a matrix of finer silt and clay. This lithology grades to fine graywacke and pebble breccia.

Andesite flows and tuffs are the main volcanic rock types in the Gemuk Group. Outcrops of flows and coarser tuffs are similar in appearance to the siltstone, and vitric tuffs are easily mistaken for chert.

Chert is present in distinct, thin beds that commonly grade into other lithologies. Sericite, chlorite, carbonate, carbon, clay minerals, and iron oxide are common inclusions in the chert, and chert beds commonly display rectilinear systems of closely spaced carbonate or silica veins. Silty chert contains probable Radiolaria and fragments of other microfossils.

Limestone is present in scattered, lone, thin, lenticular

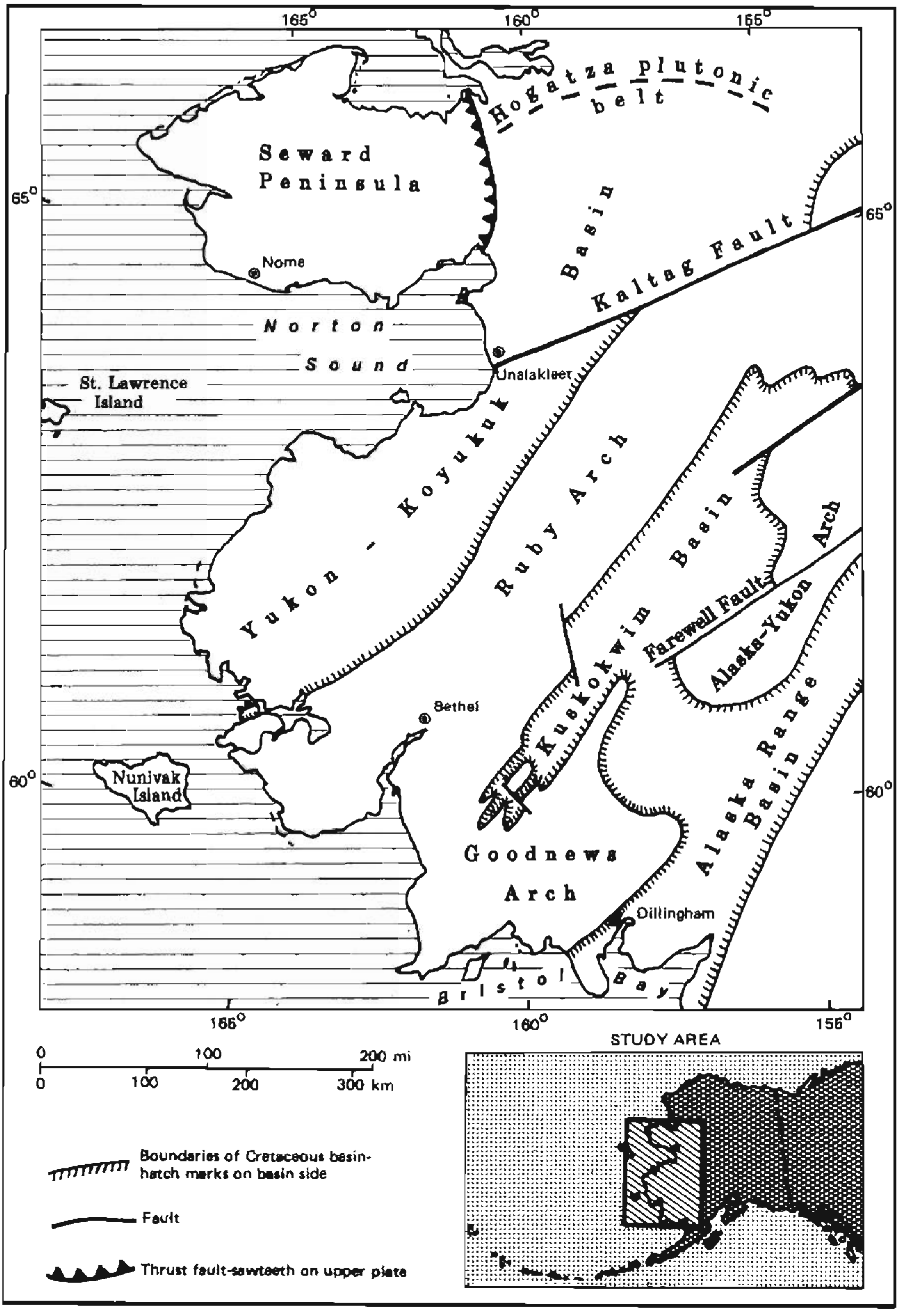


Figure 2. Tectonic map of southwestern Alaska.

beds of fossil hash in a micritic matrix. Rectilinear systems of closely spaced carbonate veins are common in limestone beds, and insoluble residues consist mainly of quartz and chert with lesser amounts of ferruginous material and clay.

The details of regional stratigraphy within the Gemuk Group are unknown, and the base of the group is not exposed. The thickness of exposed Gemuk Group rocks varies greatly, but the maximum exposed thickness is probably between 15,000 and 25,000 feet.

Cady and others (1955) reported Early Cretaceous and Late Triassic pelecypods from the Gemuk Group in the central Kuskokwim region and believed that unfossiliferous rocks, which seemed to be the stratigraphically lowest part of the group in that region, were probably of Permian or Carboniferous age. Hoare and Coonrad (1961) reported several collections of fossils of Permian, Triassic, and probable Carboniferous as well as Cretaceous age from the Gemuk Group in the Goodnews Quadrangle; thus, the age of the group may be taken to extend from Carboniferous to Cretaceous.

KUSKOKWIM GROUP

The Kuskokwim Group consists predominantly of interbedded sandstone and siltstone which are the principal rocks of the Kuskokwim Mountains and are widely exposed elsewhere in southwestern Alaska. The group was named by Cady and others (1955), and the following discussion is based primarily on the original, defining work.

Both sandstone and siltstone are of graywacke composition, characterized by angular grains and poor sorting. The sandstone, which is medium gray to black, consists of metamorphic rock fragments, chert, quartz, volcanic rock fragments, feldspar, sedimentary rock fragments, and mica in an abundant intergranular matrix. It is so well indurated that it fractures across grains. The composition of larger clasts varies with location relative to source terrane in the stratigraphically lower part of the group, but such correlation between clast composition and local source terrane is not evident in the upper part of the group. Larger, elongate clasts tend to be oriented parallel to bedding. Beds of conglomerate and breccia are present locally in the sandstone.

Siltstone is black and compositionally similar to sandstone except that rock fragments are much less abundant because of the finer grain size. Tiny muscovite flakes in the siltstone are generally oriented parallel to bedding and produce a parting in that plane. Thin zones of well-preserved marine fossils and some minor, thin coal seams are present locally in the siltstone.

The Kuskokwim Group overlies the Gemuk Group and older rocks unconformably. Structural complexities preclude accurate thickness determination for the Kuskokwim Group, but a thickness of 40,000 to 65,000 feet has been estimated. Massive sandstone and siltstone beds hundreds of feet thick predominate in the bottom 5,000 to 10,000 feet of the group, but in the upper part of the group, beds are seldom more than 2 feet thick.

Cady and others (1955) reported marine fossil assemblages of early and middle Late Cretaceous age from the Kuskokwim Group, and Hoare and Coonrad (1959) found fossils of Albian (late Early Cretaceous) age in the basal part of the group. Thus the Kuskokwim Group is of Albian to at least middle Late Cretaceous age.

SHAKTOLIK GROUP

The Shaktolik Group consists primarily of interbedded medium-gray to black sandstone and siltstone that crop out extensively in the area between Yukon River and Norton Sound. The group was named by Smith and Eakin (1911) for excellent exposures in cliffs along Shaktoolik River. Patton abandoned the name without suggesting any other in 1973, but we retain it for ease in referring to the appropriate rocks. The following discussion is based on work by Patton (1973), whose description is the most comprehensive yet published.

The basal part of the Shaktolik Group comprises a thick marine turbidite sequence of interbedded volcanic graywacke and mudstone with some conglomerate near basin margins and interbedded tuff adjacent to the Hogatza plutonic belt east of Seward Peninsula. Sandstone in this part of the group consists primarily of volcanic rock fragments and plagioclase in abundant argillaceous matrix.

Atop the basal portion of the group is a sequence of shallow-marine rocks that grade into coal-bearing nonmarine rocks. In the western part of the outcrop area the shallow-marine section comprises calcareous graywacke and mudstone with abundant carbonate detritus from the Seward Peninsula and the Brooks Range. Westward, these rocks coarsen and grade into nonmarine facies that lap onto older volcanic and metamorphic terranes of Seward Peninsula and Yukon Delta. In the eastern part of the outcrop area, shallow-marine sandstone and shale grade upward into nonmarine sandstone, siltstone, shale, and coal. The transition from marine to nonmarine rocks in this part of the area is locally marked by probable strandline deposits in which sorting is better and quartz and other resistant clast types are more abundant than in the group generally. The uppermost part of the Shaktolik Group is present only in the northern and northeasternmost parts of the basin and comprises quartz conglomerate.

Patton (1973) estimated a total thickness for the Shaktolik Group of more than 33,000 feet. A few isolated ammonites indicative of Albian (late Early Cretaceous) age have been recovered from the basal (turbidite) part of the group, and some Cenomanian (early Late Cretaceous) fossils are known from the shallow-marine part of the group. Plant fossils of probable Cretaceous age have been collected from the quartz conglomerate that makes up the uppermost part of the group. Patton and Miller (1968) reported a potassium-argon radiometric age of 83.4 ± 2.2 m.y. from biotite from an ash-fall tuff interbedded with that conglomerate. Evidently the Shaktolik Group ranges in age from late Early Cretaceous to Late Cretaceous.

STRATIGRAPHIC SECTIONS

YUKON RIVER (LOCALITY 18)

This stratigraphic section (pl. 2) is located in sec. 11, T. 18 N., R. 69 W., where interbedded siltstone, mudstone, and minor sandstone, which were mapped as Gemuk Group by Hoare and Coonrad (1959b), crop out in the right bank of Yukon River.

Of six samples submitted for micropaleontological analysis, five were barren. The sixth contained a few Radiolaria, which suggests depostion in a marine environ-

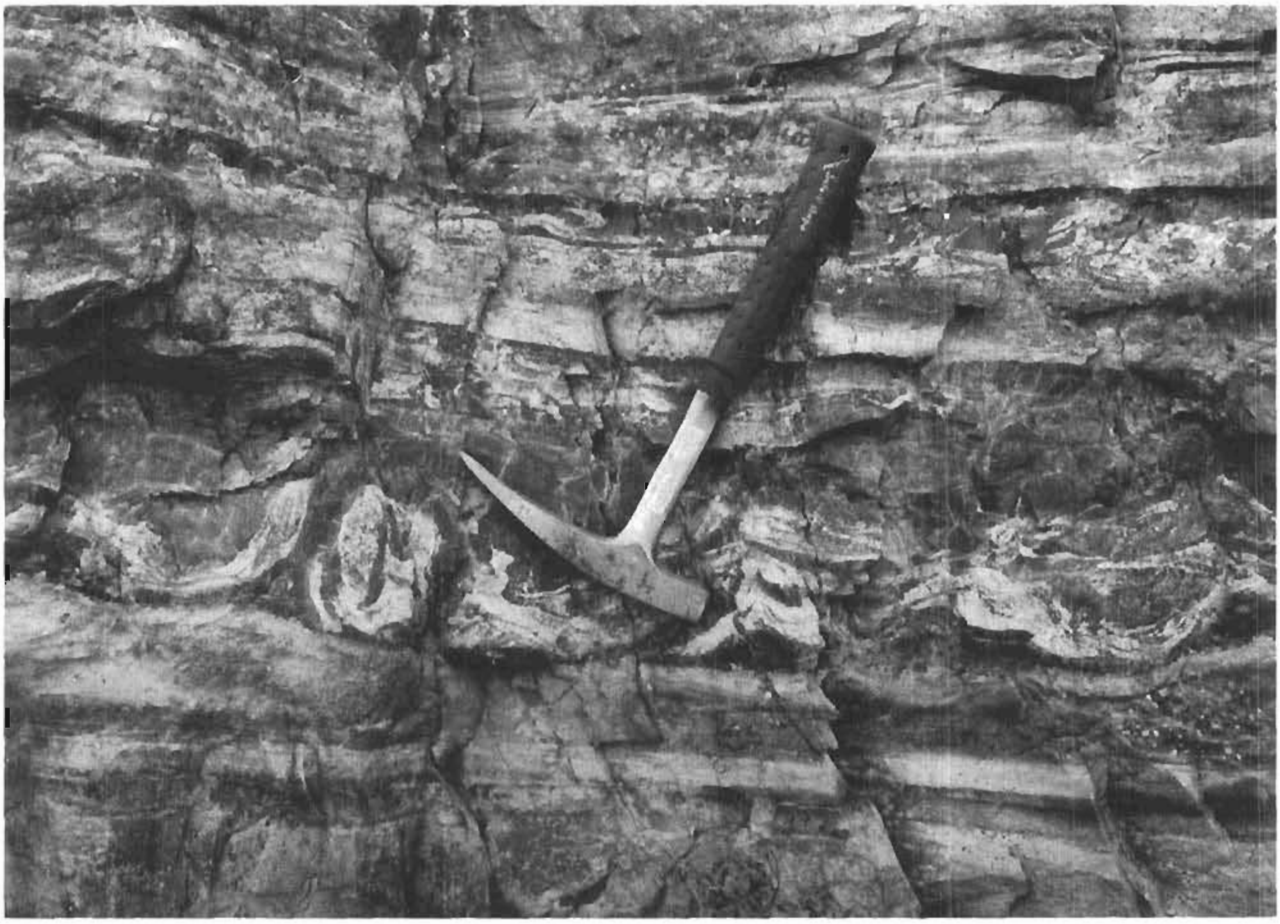


Figure 3. Soft-sediment deformation features in interbedded sandstone and siltstone of Toklik stratigraphic section.

ment. The presence of graded and finely laminated beds suggests deep-water turbidite deposition. Locally, soft-sediment deformation subsequent to deposition is indicated by crenulation of laminae.

Organic carbon ranged from 0.05 to 0.10 percent in six samples tested. Thermal-alteration indices on visual kerogen, which was dominated by herbaceous, woody, and amorphous types, ranged from 1+ to 2 for six samples analyzed. Porosity ranged from 4.7 to 7.6 percent and permeability from 0.30 to 0.40 millidarcy for three samples from this section.

TOKLIK (LOCALITY 19)

This stratigraphic section (pl. 3) is located in sec. 30, T. 18 N., R. 68 W., and sec. 25, T. 18 N., R. 69 W., where interbedded siltstone, mudstone, and minor sandstone, mapped as Gemuk Group by Hoare and Coonrad (1959b), crop out in the right bank of Yukon River (fig. 3). All lithologies are well indurated, and beds range from a few inches to several feet thick. Sandstone is very fine to fine grained, and many sandstone beds grade upward into siltstone. We interpret the rocks in this exposure to have been deposited by deep-marine turbidity currents.

Five samples were submitted for micropaleontological analysis. Three of these were barren. Sparse Radiolaria and spicules in the other two samples suggest deposition in an open marine environment but are indeterminate of age. One sample submitted for palynological analysis was barren, but palynological analysis of a second sample suggested deposition in a marginal marine environment during Tertiary time. We believe these determinations are spurious and probably resulted from contamination of the sample.

Organic carbon ranged from 0.07 to 0.59 percent in seven samples tested. Thermal-alteration indices on visual kerogen, which was predominantly herbaceous and woody, ranged from 2- to 2+ for these samples. Porosity ranged from 0.2 to 7.5 percent and permeability from 0.01 to 2.07 millidarcies in five samples from this section. Another sample was fractured and had a permeability of 6.31 millidarcies and a porosity of 5.5 percent.

NELSON ISLAND 1 (LOCALITY 20)

This stratigraphic section (pl. 4) is located along the west coast of Nelson Island in sec. 28, T. 7 N., R. 89 W., and comprises mudstone and minor sandstone outcrops that were mapped as part of a graywacke-siltstone sequence of Cretaceous age by Coonrad (1957).

Well-preserved fossil leaves are common in the rocks of the section. Of six samples collected for palynological study, the ages of three were indeterminate and three others indicate deposition during Albian time. Deposition in marginal marine and probable nonmarine environments is also indicated by the palynological samples. Seven micropaleontological samples were barren.

Seven geochemical samples contained from 0.07 to 0.38 percent organic carbon and had thermal-alteration indices of 2 to 3- on visual kerogen, which consisted of woody, herbaceous, and coaly material. Two sandstone samples tested 2.8 and 7.2 percent porosity and 0.02 and 0.21 millidarcy permeability.

NELSON ISLAND 2 (LOCALITY 21)

This stratigraphic section (pl. 5) is located along the west coast of Nelson Island in sec. 31, T. 7 N., R. 89 W., where sandstone and mudstone similar to those of the preceding stratigraphic section crop out (fig. 4). These rocks were mapped as part of the graywacke-siltstone sequence by Coonrad (1957).

Three samples collected for micropaleontological study were barren, but palynological study of three other samples indicated deposition in a marginal marine environment during Albian time. Geochemical analyses of three samples revealed 0.08 to 0.19 percent organic carbon with thermal-alteration indices of 2 to 2+ on visual kerogen, which was predominantly herbaceous, woody, and coaly. Five sandstone samples tested from 4.7 to 7.4 percent porosity and 0.04 to 0.50 millidarcy permeability.

NUNIVAK ISLAND (LOCALITY 22)

This stratigraphic section (pl. 6) is located along the north side of Iookswarat Bay on the north coast of Nunivak Island in sec. 13, T. 3 N., R 100 W., where silty mudstone, which contains concretionary zones and localized concentrations of carbonaceous debris and leaf and reed imprints, is interbedded with minor lenticular beds of sandstone with conglomeratic bases (fig. 5).

Palynological study of seven samples was indeterminate of age but suggested deposition in a nonmarine environment. Also, no age determination was possible for eight micropaleontological samples, but one of them contained fossils that suggest deposition in a marine environment.

Eight samples analyzed geochemically contained from 0.12 to 0.28 percent organic carbon. Thermal-alteration indices on visual kerogen, which consisted of woody, coaly, and herbaceous material, ranged from 2+ to 4- for these samples. Four sandstone samples tested 2.2 to 5.6 percent porosity and 0.05 to 0.13 millidarcy permeability.

GREAT RIDGE (LOCALITY 25)

This stratigraphic section (pl. 7) is located along the crest of a spur perpendicular to the trend of Great Ridge in secs. 31 and 32, T. 1 S., R. 67 W. and secs. 34, 35, and 36, T. 1 S., R. 68 W., where interbedded sandstone, mudstone, and minor conglomerate, mapped as part of the Kuskokwim Group by Hoare and Coonrad (1959), crop out. Conglomerate beds are lenticular, and many sandstone beds are festoon cross-bedded. Well-preserved pelecypods are present in many mudstone beds and are abundant in two horizons.

Micropaleontological study of 17 samples was indeterminate of age, but two of these samples contained fossils

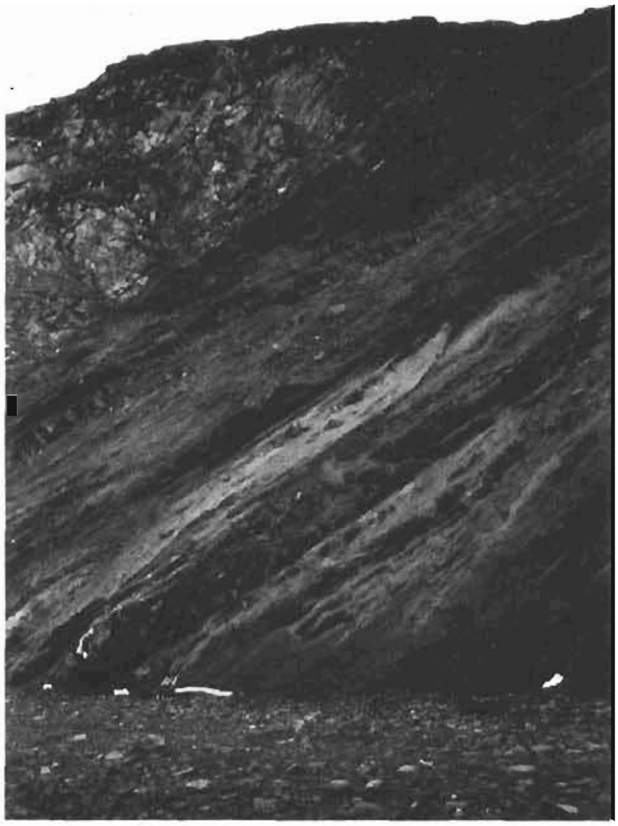


Figure 4. Nelson Island 2 stratigraphic section.

that suggest deposition in a marine environment. Palynological analysis of 14 samples suggested deposition in a nonmarine environment but was indeterminate of age.

Organic carbon ranged from 0.25 to 1.05 percent in 17 samples tested. Thermal-alteration indices on visual kerogen, which consisted of herbaceous, woody, and coaly material, ranged from 2- to 3- for these samples. Twenty-nine sandstone samples tested from 0.5 to 3.6 percent porosity and 0.02 to 0.24 millidarcy permeability.

SPOT-SAMPLE DESCRIPTIONS

Spot samples were collected to provide a wider distribution of data than could have been obtained by sampling only from measured stratigraphic sections. In areas of poor exposure, samples were collected from rubblecrops, slumps, or frost boils. Locations, descriptions, and laboratory data for spot samples follow.

LOCALITY 1

Sample 39-GB-78 was collected in sec. 22, T. 9 N., R. 6 W. on the north side of Mangoak River (fig. 6). The sample is from one of several lenticular very fine sandy silt layers that are interbedded with 2- to 10-foot-thick silty, very fine to very coarse pebbly sand beds and 1- to 6-foot-thick sandy gravel beds. Pebbles, cobbles, and boulders in these unconsolidated sediments are almost exclusively rounded to well-rounded leucocratic granitic rocks. About 50 feet of moderately west-southwestward-dipping section is exposed. The hill in which the exposure is located is capped at its culmination west of the exposure with subhorizontal flow basalt; thick talus covers the lower part of the hill in that area, and whether the sediments are overlain by or adjacent to the basalt was not determined. Patton and Miller (1968) considered these sediments to be of Tertiary age; our sample contained rare *Laevigatosporites* sp., which indicates Cenozoic age, and the dark color of this plant material, produced by thermal alteration, suggests a Tertiary rather than Quaternary age.

LOCALITY 2

Samples 43- to 45-GB-78 were collected in sec. 25, T. 9 S., R. 11 W., where steeply dipping interbedded sandstone and siltstone crop out in the beach on the east side of Norton Bay. Sandstone is fine grained, grayish-orange 10YR 7/4, and calcareous, and occurs in lenticular ½- to 4-inch-thick beds. Siltstone contains some very fine sand, is moderate yellowish-brown 10YR 5/2, and occurs in ½-inch-thick beds. Sample 45-GB-78, a sandstone, tested 2.7 percent porosity and 0.07 millidarcy permeability. Testing of sample 44-GB-78, a siltstone, revealed an organic carbon content of 0.41 percent and a thermal-alteration index on visual kerogen of 2- to 2; herbaceous and woody material was abundant, and coaly material was rare among the visual kerogen. Palynological study of sample 43-GB-78 suggests a probable Neogene age for the rocks in this exposure, but the sparse assemblage on which that determination is based is very likely composed of contaminants from the modern environment. These rocks probably belong to the Shaktolik Group, which they resemble lithologically and structurally and which has been mapped nearby by Cass (1959).

LOCALITY 3

Samples 54- to 57-GB-78 were collected in sec. 12, T. 15 S., R. 12 W. at the north end of a sea cliff in which steeply dipping interbedded sandstone and siltstone are exposed along the east end of Norton Sound between Beeson Slough and Blueberry Creek. In this area sandstone is the prevalent lithology. Sandstone beds are 6 inches to 10 feet thick and range in grain size from fine to coarse sand; individual beds are well sorted but may be graded near their bases, where streaks of poorly sorted sandstone are not uncommon. Some shale and siltstone rip-up clasts are present in the sandstones. The sandstone is slightly calcareous and contains some calcareous concretions. Among these sandstone beds are a few laminated siltstone beds and some sequences of minor graded beds 1 to 3 inches thick. Two sandstone samples collected from this locality had porosities of 1.1 and 0.2 percent and permeabilities of 0.05 and 0.06 millidarcy. One sample, from a single 4-inch-thick black silty shale in which abundant coaly debris is visible, contained 4.3 percent organic carbon and had a thermal-alteration index on visual kerogen of 3+. Woody and coaly material was abundant and herbaceous material common among the visual kerogen. The micropaleontological study of one sample was indeterminate of age, but the presence of rare *Eponides*(?) sp. suggests a possible marine environment of deposition. One sample was barren of palynomorphs. These rocks have been mapped as part of the Shaktolik Group of Cretaceous age by Cass (1959).

LOCALITY 4

Sample 53-GB-78, a sandstone, was collected from the Shaktolik Group in a sea cliff in sec. 12, T. 17 S., R. 12 W., 1.6 miles south of Egavik. This sandstone tested 1.2 percent porosity and 0.05 millidarcy permeability.

LOCALITY 5

Samples 9- and 10-GB-78 were collected from a cutbank along Unalakleet River in sec. 1, T. 19 S., R. 11 W., where muddy fine sandstone, which Cass (1959b) mapped as part of the Shaktolik Group, crops out. This sandstone is dusky-yellow-green 5GY 5/2 and contains abundant well-rounded black shale rip-up clasts. Abundant silty shale occurs as float in this area. The shale is olive-gray 5Y 4/1 and contains abundant carbonaceous plant debris locally. A sandstone sample tested 3.6 percent porosity and 0.30 millidarcy permeability. A shale sample, barren of paleontological material, contained 0.18 percent organic carbon with a thermal-alteration index of 3- to 3 on visual kerogen, which consisted of abundant woody and coaly material and common herbaceous material.

LOCALITY 6

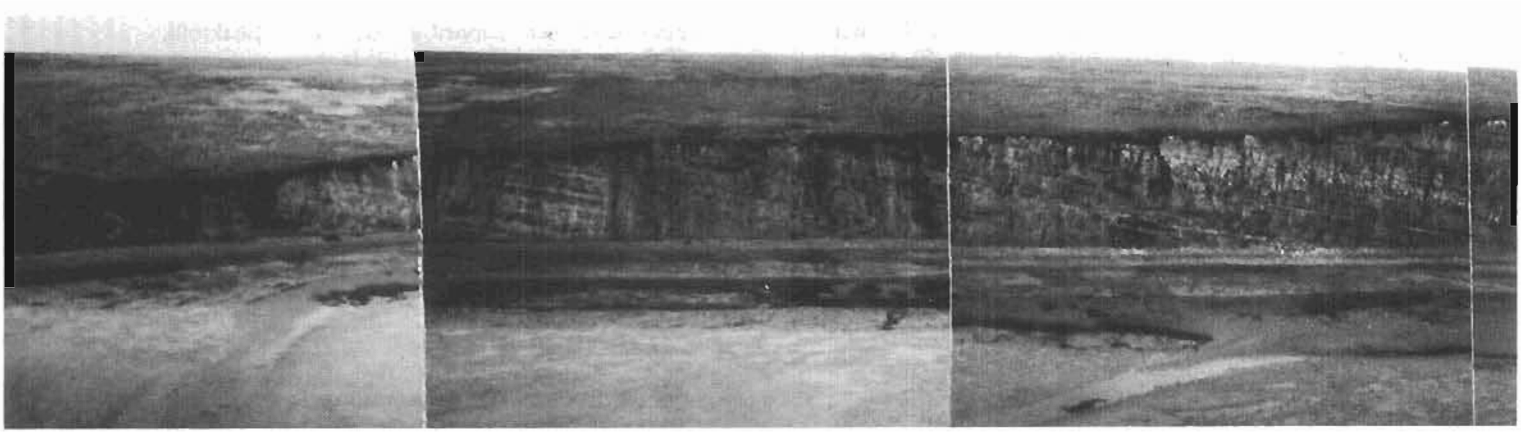
Samples 13- and 14-GB-78 were collected from a cutbank along Unalakleet River in sec. 4, T. 19 S., R. 10 W., where interbedded sandstone and shale, which were included in the Shaktolik Group of Cretaceous age by Cass (1959b), crop out. Sandstone, which is the predominant lithology, is medium-gray N5, silty, fine grained, calcareous, and contains shale rip-up clasts locally. The shale is dark-gray N3 and silty. A sandstone sample tested 2.0 percent porosity and 0.08 millidarcy permeability. A shale sample contained 0.21 percent organic carbon with a thermal-alteration index of 3- to 3 on visual kerogen, which consisted of abundant herbaceous material and common woody and coaly material; this sample was barren of paleontological material.

LOCALITY 7

Samples 11- and 12-GB-78 were collected from a cutbank along Unalakleet River in sec. 36, T. 18 S., R. 10 W., where interbedded sandstone and shale, mapped as belonging to the Shaktolik Group by Cass (1959b), crop out. The sandstone is light-olive-gray 5Y 5/2 and fine to medium grained with some pebble-size shale rip-up clasts locally. The shale is dark-gray N3 and silty. A sandstone sample tested 2.1 percent porosity and 0.09 millidarcy permeability. A shale sample, which was barren of paleontological material, contained 0.61 percent organic carbon and had a thermal-alteration index of 2 to 2+ on visual kerogen, which included abundant herbaceous, woody, and coaly material.

LOCALITY 8

Samples 7- and 8-GB-78 were collected from a cutbank along Unalakleet River in sec. 8, T. 18 S., R. 8 W., where interbedded silty shale, siltstone, and silty fine sandstone



crop out. These rocks were included in the Shaktolik Group by Cass (1959b). The sandstone is medium-light-gray N6, slightly calcareous, weakly laminated, contains shale partings locally, and is in 3- to 6-foot beds. Contacts between sandstone and shale are gradational, effected by an increase in number and thickness of shale partings. The shale is dark-gray N3 and noncalcareous. The siltstone, which comprises about 75 percent of the outcrop, is dark-gray N3, muddy, and laminated. A sandstone sample tested 2.2 percent porosity and 0.14 millidarcy permeability. A shale sample, barren of paleontological material, contained 0.18 percent organic carbon and had a thermal-alteration index of 3- to 3 on visual kerogen, which included abundant woody and coaly material and common herbaceous material.

Figure 6. Outcrop of unconsolidated sand and gravel at locality 1 along Mangoak River.

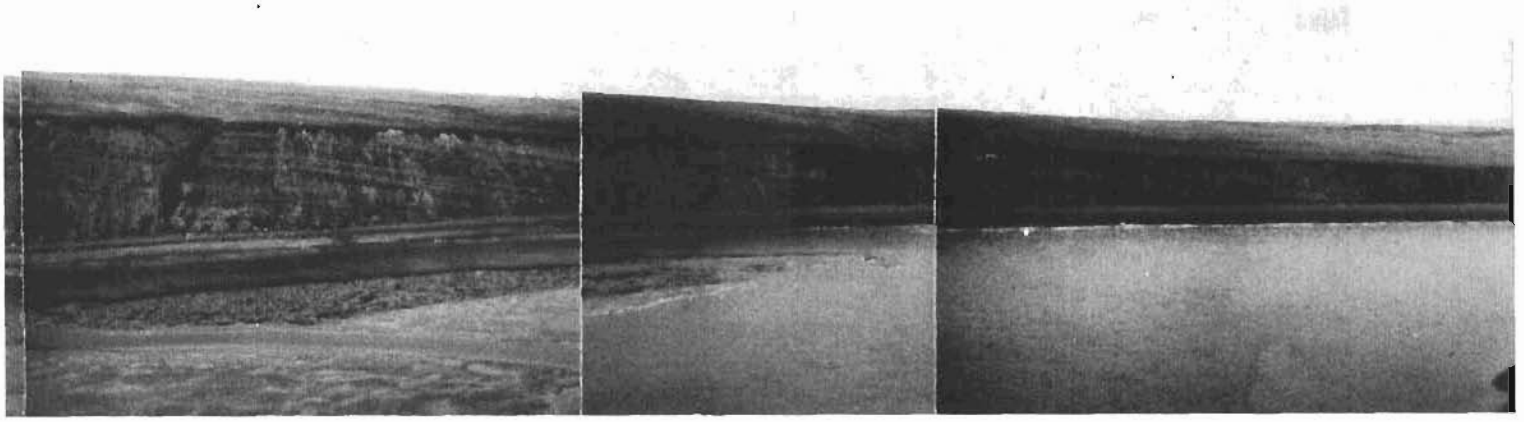


Figure 5. Panoramic view of Nunivak Island stratigraphic section.

LOCALITY 9

Samples 32- to 35-GB-78 were collected from the beach south of Unalakleet between Cascade and Glacier Creeks in sec. 28, T. 20 S., R. 11 W., where float blocks of lithologies unlike the Shaktolik Group, which dominates local exposures, occur together with coalified wood fragments in solifluction lobes. Coalified wood fragments are commonly associated with light-olive-gray 5Y 6/1 fine sandstone, which contains scattered coarse sand and granule grains (fig. 7); this sandstone also occurs in small fragments without associated coal. Thin-bedded fine sandstone of greenish-gray 5G 6/1 color occurs in large blocks and was not observed in association with coal. Sandstones are very weakly indurated. Medium-yellowish-brown 10YR 5/2 sandy mudstone with abundant carbonaceous plant debris comprises a third lithology present in the float. A sample of the sandstone associated with the coal tested 6.9 percent porosity and 48 millidarcies permeability; a sample of the thin-bedded sandstone tested 6.1 percent porosity and 1.49 millidarcies permeability. Palynological study of a mudstone sample indicated Neogene age and deposition in a nonmarine environment. Analysis of a coal sample at the Department of Energy's Pittsburgh Coal Laboratory indicated high volatile C bituminous grade with a heating value of 11,350 Btu/lb on a moist, ash-free basis.

LOCALITY 10

Samples 29- and 30-GB-78 were collected from a sea cliff at the south side of the mouth of Glacier Creek in sec. 33, T. 20 S., R. 11 W., where steeply dipping interbedded sandstone and shale crop out. These outcrops were included in the Shaktolik Group by Cass (1959b). Sandstone occurs in 2- to 15-inch beds and is medium-gray N5, silty, fine grained, and laminated. Locally abundant shale partings define a cross-lamination in the sandstone. Shale is silty, occurs in ½-inch- to 3-foot beds, is dark-gray N3, and has hackly fracture. Sandstone and shale are of subequal abundance in this area. A sandstone sample tested 1.2 percent porosity and 0.08 millidarcy permeability. A shale sample contained 0.38 percent organic carbon with a thermal-alteration index of 3- to 3 on visual kerogen, which consisted of abundant woody and coaly material and common herbaceous material; the sample was barren of paleontological material.

LOCALITY 11

Samples 24- to 28-GB-78 were collected from a sea cliff at the south side of the mouth of Spruce Creek in sec. 13, T. 21 S., R. 12 W., where steeply dipping interbedded shale, siltstone, and sandstone, which Cass (1959b) included in the Shaktolik Group, crop out. Shale is dark-gray N3; siltstone contains some very fine sand, is medium-dark-gray N4, and has noncalcareous concretions along bedding surfaces. Shale and siltstone are laminated and contain minor plant debris and coal fragments and stringers. Sandstone is a minor lithology in this outcrop; it is cross laminated, very fine to medium grained, and medium-light-gray N6 with shale rip-ups and partings. Individual shale and siltstone beds range from ½ to 6 inches in thickness, and sandstone beds may be as thick as 3 feet. A sandstone sample tested 8.1 percent porosity and 0.12 millidarcy permeability. A shale sample was not datable by paleontological techniques but contained rare echinoid fragments suggestive of a marine depositional environment. Another shale sample contained 0.37 percent organic carbon with a thermal-alteration index of 3- to 3 on visual kerogen, which consisted of abundant herbaceous, woody, and coaly material. Analysis of a coal sample at the Department of Energy's Pittsburgh Coal Laboratory indicated semianthracite grade with 86 percent fixed carbon on a dry, ash-free basis.

LOCALITY 12

Samples 22- and 23-GB-78 were collected from a hill at Point Romanof in sec. 34, T. 26 S., R. 22 W., where interbedded sandstone and siltstone crop out. These exposures have been mapped as Cretaceous calcareous sandstone by Hoare and Condon (1971), and we consider them part of the Shaktolik Group. Siltstone in this outcrop is olive-gray 5Y 4/1, laminated, muddy, and calcareous; sandstone is fine grained, medium-greenish-gray 5GY 5/1, silty, slightly calcareous, and contains shale partings locally. One sandstone sample tested 2.9 percent porosity and 0.08 millidarcy permeability. A siltstone sample contained 0.10 percent organic carbon with a thermal-alteration index of 2 to 2+ for visual kerogen, which included abundant woody and coaly material and common herbaceous material. One sample was barren of paleontological material.

Figure 7. Coal and sandstone of Tertiary age in solifluction lobe at locality 9 on the beach south of Unalakleet.

LOCALITY 13

Samples 2- and 3-GB-78 were collected from a cutbank along Nunakogok River in sec. 32, T. 27 S., R. 19 W., where interbedded medium-dark-gray N4 fine sandstone and grayish-black siliceous shale crop out. These exposures have been mapped as Cretaceous noncalcareous sandstone by Hoare and Condon (1971), and we include them in the Shaktolik Group. Sandstone beds range up to 3 feet thick, and shale beds range up to 25 feet thick. A sandstone sample tested 2.5 percent porosity and 0.15 millidarcy permeability. A shale sample was barren of paleontological material but contained 0.45 percent organic carbon with a thermal-alteration index of 3 to 3+ on visual kerogen, which included abundant woody and coaly material and rare herbaceous material.

LOCALITY 14

Samples 17- to 20-IP-78 and 28- and 29-TF-78 were collected in the Kuzilvak Mountains in sec. 30, T. 22 N., R. 83 W. Sample 24-TF-78 was collected from a frost boil; the other samples were collected from rubblecrop. Medium-dark-gray N4, faintly laminated, very well indurated calcareous fine sandstone and dark-gray N3 silty shale, which were mapped as noncalcareous sandstone of Cretaceous age by Hoare and Condon (1971), were present. Three sandstone samples tested from 0.2 to 0.04 percent porosity and from 0.05 to 0.06 millidarcy permeability; a fourth sandstone sample, which is quite similar to the other sandstone samples lithologically, tested 4.9 percent porosity and 0.01 millidarcy permeability. Two shale samples contained 0.10 and 0.29 percent organic carbon and had thermal-alteration indices of 4- to 4 for visual kerogen, which was predominantly herbaceous. No paleontological samples were collected at this locality.

LOCALITY 15

Samples 50- to 52-GB-78 were collected from the right bank of Yukon River 0.2 mile west of Old Andreafsky in sec. 21, T. 23 N., R. 77 W., where steeply dipping interbedded sandstone and shale, which were mapped as laumontitized sandstone of Cretaceous age by Hoare and Condon (1966), crop out. We consider these exposures part of the Shaktolik Group. Sandstone is graded from pebbly fine to coarse grained to silty shale, is locally calcareous, contains some shale rip-ups, and commonly has load features at the base of beds; coarser sandstone beds are olive-brown 5Y 5/1. Shale is silty, grayish black N2, and contains some carbonaceous plant debris. A few calcareous concretions occur in both the sandstone and the shale, and some primary slump features, including disharmonic folds and sand rolls, were observed in this outcrop. A coarse sandstone sample tested 0.4 percent porosity and 0.05 millidarcy permeability, and a fine sandstone sample tested 5.1 percent porosity and 2.04 millidarcies permeability. A shale sample, which was not datable by paleontological techniques, contained rare *Cibicides* sp. and *Cenosphaera* spp., which suggests deposition in a marine environment. The sample contained 0.17 percent organic carbon with a thermal-alteration index of 2+ to 3- on visual kerogen, which consisted of abundant woody and coaly material and rare herbaceous material.

LOCALITY 16

Sample 49-GB-78 was collected from the top of a hill 1 mile west of St. Mary's airport in sec. 25, T. 23 N., R. 77 W., where a subhorizontal sandstone mapped as calcareous sandstone of Cretaceous age by Hoare and Condon (1966) crops out. We consider this exposure part of the Shaktolik Group. This sandstone is flaggy, gritty, fine to coarse grained, calcareous, and medium-gray N5. The sample tested 7.2 percent porosity and 1.76 millidarcies permeability.

LOCALITY 17

Samples 47- and 48-GB-78 were collected from a quarry at the crest of the road across Andreafsky Mountain between St. Mary's airport and St. Mary's village in sec. 29, T. 23 N., R. 76 W., where overturned, interbedded sandstone and shale, which have been mapped as noncalcareous sandstone of Cretaceous age by Hoare and Condon (1966), crop out. We consider these outcrops part of the Shaktolik Group. The stratigraphically lowest unit in this exposure is a massive, medium-dark-gray N4, fine sandstone 4 to 6 feet thick, which contains abundant well-rounded cobble- to small boulder-size shale rip-ups and has load features on its base. Stratigraphically above this massive sandstone is a 60-foot section of 2- to 15-inch cross-laminated beds that grade from very fine sandstone at their bases to siltstone at their tops. The sandstone is medium-dark-gray N4 and the siltstone is dark-gray N3. These graded beds contain well-rounded cobble- to small boulder-size shale rip-ups and some burrows and commonly have load features on their bases. The graded beds are stratigraphically overlain by dark-gray N3 silty shale. Calcareous cannonball concretions are common in the sandstone, and flattened concretions are common in the shale. Carbonaceous plant debris is also common. A sandstone sample tested 0.9 percent porosity and 0.07 millidarcy permeability. A shale sample, which contained insufficient paleontological material for determination of age or depositional environment, contained 0.39 percent organic carbon with a thermal-alteration index of 2 to 2+ on visual kerogen, which consisted of abundant woody and coaly material and common herbaceous material.

LOCALITY 23

Samples 66-to 68-IP-78 were collected from a small outcrop at the southwest corner of Nash Harbor in sec. 2, T. 1 N., R. 103 W., on Nunivak Island. These samples were mapped as part of a graywacke-siltstone sequence of Cretaceous age by Coonrad (1957) and consist of hard, black N1, splintery shale. One sample contained 0.54 percent organic carbon and had a thermal-alteration index of 4- to 4 on visual kerogen, which consisted of abundant woody and coaly material and common herbaceous material. A sample collected for micropaleontological analysis was barren, but another sample contained a sparse palynomorph population that was indeterminate of age and indicated a probable nonmarine depositional environment.

LOCALITY 24

Samples 63- to 65-IP-78 were collected from a small outcrop overlain by volcanic flows along the southern shore of Nash Harbor in sec. 5, T. 1 N., R. 102 W., on Nunivak Island. These samples were mapped as part of a graywacke-siltstone sequence of Cretaceous age by Coonrad (1957) and consist of hard, grayish-black N2 mudstone that exhibits hackly fracture. A geochemical sample contained 0.87 percent organic carbon and had a thermal-alteration index of 3+ to 4- on visual kerogen, which consisted of abundant woody and coaly material with minor herbaceous material. A micropaleontological sample was barren, but another sample contained pollen suggestive of Cretaceous age and deposition in a marine environment.

LOCALITY 26

Samples 20-, 21-, and 23- to 26-TF-78 were collected from an outcrop along a ridge crest in the northern part of the Eek Mountains in sec. 5, T. 1 S., R. 64 W. These samples are of gray mudstone and pebble to cobble conglomerate in which quartz, andesite, and green mudstone constitute the majority of clasts. The exposure was mapped as conglomeratic facies of the Kuskokwim Group by Hoare and Coonrad (1959). Two sandstone samples contained 0.52 and 0.16 percent organic carbon and had thermal-alteration indices of 2 to 2+ and 3+ on visual kerogen, which consisted of abundant woody and coaly material with minor herbaceous material. One palynological and three micropaleontological samples were barren.

LOCALITY 27

Samples 31- and 32-IP-78 were collected along the north side of Kagati Lake in sec. 28, T. 3 S., R. 63 W., from an outcrop mapped as Gemuk Group by Hoare and Coonrad (1961). These samples are of well-indurated, medium-dark-gray N4 siltstone. One sample tested 1.9 percent porosity and 48 millidarcies permeability, but these values may be unrepresentatively high because of the presence of horizontal fractures. The other sample contained 0.14 percent organic carbon with a thermal-alteration index of 2 to 2+ on visual kerogen, which consisted of abundant woody and common herbaceous material.

LOCALITY 28

Samples 21- to 30-IP-78 were collected from the top of a hill in sec. 12, T. 4 S., R. 64 W., where rock mapped as Gemuk Group by Hoare and Coonrad (1961) crops out. Lithologies exposed at this location include well-indurated, light-olive-gray 5Y 5/2, fine to medium sandstone; well-indurated dark-gray N3 to grayish-black N2 argillite (which is generally thin bedded and locally cherty); and brecciated, dark-gray N3 micrite. A sandstone sample tested 2.1 percent porosity and 0.07 millidarcy permeability. Two geochemical samples contained 0.06 and 0.07 percent organic carbon with thermal-alteration indices of 3 to 3+ on visual kerogen, which consisted of abundant herbaceous with lesser woody and coaly material. Palynological examination of two samples was indeterminate of age or depositional environment, and one micropaleontological sample was barren. A sparse foraminiferal population in another sample was indeterminate of age, but a probable marine depositional environment was indicated.

PETROGRAPHY

Seventy-four samples from measured stratigraphic sections and spot localities were studied petrographically. Eleven samples were from the Gemuk Group in the Yukon River and Toklik stratigraphic sections and the Kagati Lake area. Thirty were from the Kuskokwim Group in the Great Ridge stratigraphic section. Sixteen were from the Shaktolik Group in the area between St. Marys on the Yukon River and Koyuk on Norton Bay. Fifteen samples were from outcrops of undifferentiated Cretaceous rocks in the Nunivak Island and Nelson Island I stratigraphic sections and the Kuzilvak Mountains area. The remaining two were from an exposure of Tertiary rocks south of Unalakleet.

Framework clasts in all the samples are predominantly lithic or quartzose grains. Samples from younger rock units tend to be more quartzose than samples from older rock units. Framework grains from Gemuk Group samples are composed primarily of lithic fragments (63 to 85 percent) and contain less than 7 percent quartzose clasts. Framework clasts in samples from the Shaktolik and Kuskokwim Groups contain from 8 to 68 percent quartzose grains, among which chert is quite common in the Kuskokwim Group samples. Feldspar ranges from 16 to 35 percent of the framework clasts in samples from the Shaktolik Group but does not exceed 17 percent in any of the Kuskokwim Group samples. The framework clast compositions of samples from exposures of undifferentiated Cretaceous rocks partially overlap the framework clast compositions of samples from the Gemuk, Kuskokwim, and Shaktolik Groups. A maximum of 37 percent of the framework clasts in the undifferentiated Cretaceous samples are quartzose, whereas lithic grains make up at least 56 percent of the framework clasts in these same samples. The two Tertiary samples contain at least 70 percent quartzose grains, 21 percent lithic grains, and no more than 9 percent feldspar among their framework clasts. Framework clast compositions for 20 samples for which point counts were made are presented as figure 8 and in table 7.

Quartzose grains are primarily monocrystalline with straight to moderately undulatory extinction in the samples from the Gemuk Group, but schistose polycrystalline quartz grains are common in the Shaktolik Group, Kuskokwim Group, and Tertiary samples, and chert grains are common in Kuskokwim Group samples.

Plagioclase is the principal feldspar in all the samples. Intermediate plagioclase, which is generally twinned according to the albite law and zoned and variably unaltered to moderately kaolinitized or sericitized, is common in all the samples and is the only feldspar observed in the Gemuk Group samples. Untwinned albite is common in the Shaktolik Group samples, Kuskokwim Group samples, and the Tertiary samples and is the predominant feldspar in many such samples.

The lithic fraction of framework clasts in Gemuk Group samples consists of vitrophyric, intersertal, and holohyaline volcanic grains; spherulitic and perlitic textures are developed in some holohyaline grains. In addition to holohyaline and hypocrystalline volcanic rock fragments, the lithic fractions of samples from the Shaktolik Group, Kuskokwim Group, and Tertiary contain holocrystalline volcanic rock fragments, mudstone grains, siltstone grains, and quartz-muscovite schist grains.

Framework clasts range from subangular to subrounded in Gemuk Group samples, from subangular to rounded in Shaktolik Group samples, from subangular to well rounded in Kuskokwim Group samples, and from angular to rounded in Tertiary samples. There is no apparent correlation between clast type and degree of roundness in any of the samples. Grain shapes in all the samples, except possibly sandy limestones, have been modified by ductile grain deformation attendant on compaction. Grain boundaries between volcanic rock fragments in Gemuk Group samples have commonly been obscured so that nondelimited volcanic clasts form a pseudomatrix in the samples.

It is evident from the types of framework clasts that the Gemuk Group samples were derived from a predominantly volcanic source terrane and that the other samples were derived from more varied source terranes in which sedimentary and metamorphic as well as volcanic rock types were abundant. A significant admixture of recycled sedimentary detritus is especially evidenced by the well-rounded quartz clasts in many Kuskokwim Group samples. The variability in and lack of correlation of roundness and grain type among framework clasts in samples from the Shaktolik Group, Tertiary, and undifferentiated Cretaceous exposures also suggest that clasts were recycled from older sedimentary sources.

Iron oxide, leucoxene, carbonate, clays, plagioclase, quartz, and zeolites were observed authigenic phases in the samples. Authigenic plagioclase was observed only in Gemuk Group samples, where it constitutes an early vein-filling material. Carbonate and authigenic quartz are present only as vein-filling phases in Gemuk Group samples. Iron oxide, clay, and zeolites are dispersed authigenic phases in the samples from the Gemuk Group. Iron oxide is present as a coating on clasts, and clay is present as an intergranular material and as an alteration product in clasts. Laumontite is the most common zeolite in Gemuk Group samples and appears to be present as a general replacement of clasts and intergranular material; other zeolites are present in some nonlaumontitized Gemuk Group samples as filling in intergranular spaces. Zeolite in intergranular spaces is invariably separated from clasts by clay, thus the clay is older than the zeolite.

Iron oxide, carbonate, clay, and quartz are present as authigenic phases in samples from the Shaktolik Group, Kuskokwim Group, and Tertiary and undifferentiated Cretaceous exposures. Zeolite is present in some Shaktolik Group samples. Carbonate is present as a replacement and as an intergranular cement, but the other authigenic materials appear to be present only as cements. Authigenic quartz is syntaxial to adjacent quartz clasts and generally

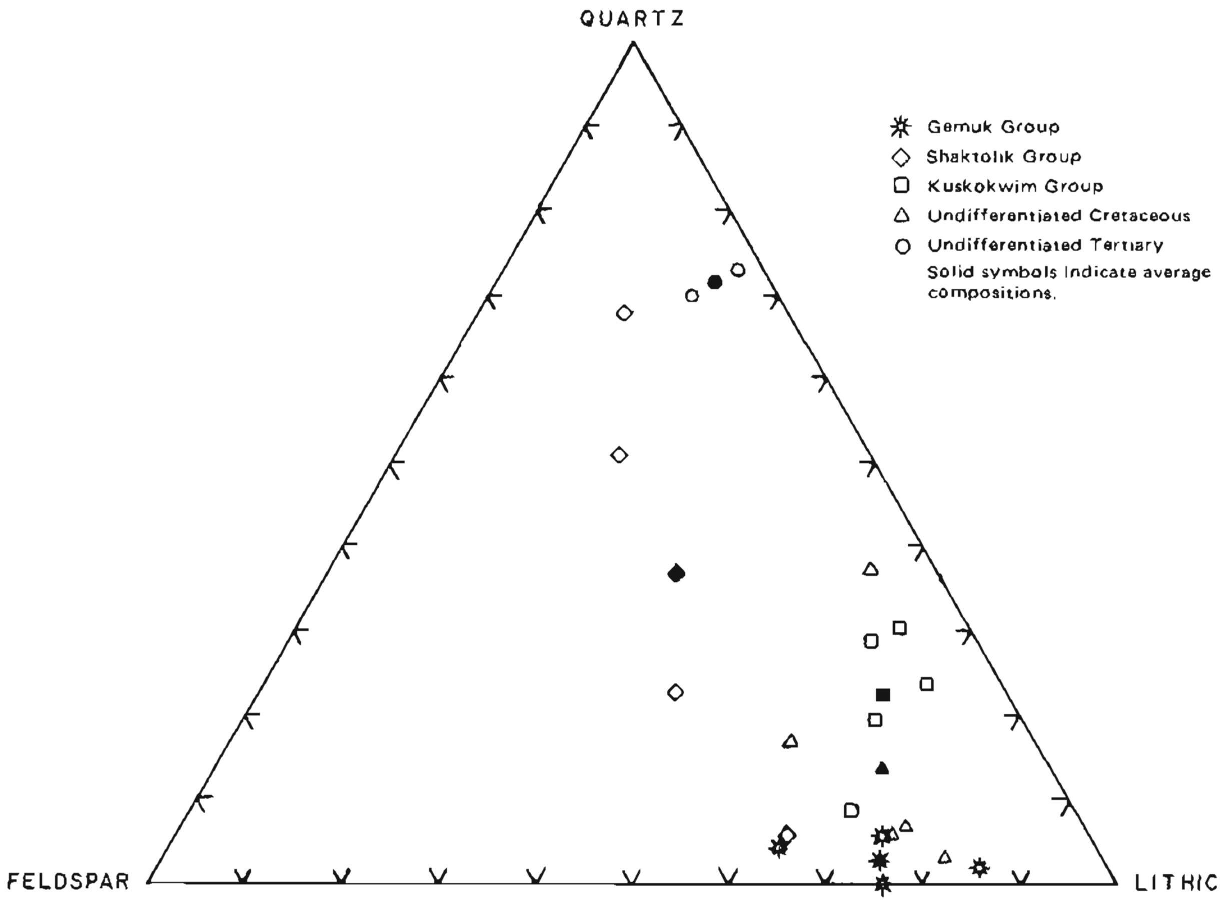


Figure 8. Framework grain compositions of point-counted sandstone samples from southwestern Alaska.

separated from them by a partial coat of authigenic clay. Iron oxide is the oldest and quartz or zeolite the youngest authigenic phase in the samples; where carbonate and authigenic clay are both present, carbonate is older. The amount of carbonate cement and degree of ductile grain deformation are inversely proportional; thus, carbonate cementation must have begun early in the burial of the rocks.

No visible porosity was observed in any of the samples. Inhomogeneity of packing, oversized and elongate intergranular areas, and floating and fractured clasts in the Shaktolik Group, Kuskokwim Group, and Tertiary samples suggest that authigenic cements may be filling secondary pores. Intergranular laumontite is inhomogeneously distributed in oversized areas that contain floating grains in Gemuk Group samples, but the common nebulosity of its contacts with pseudomatrix suggests a replacement origin without prior development of secondary porosity. The rock units as seen in the samples have little potential as petroleum reservoirs except in areas where extensive fracture porosity might exist. However, the probable past existence of secondary porosity in all rock units sampled except the Gemuk Group suggests that under appropriate subsurface conditions sufficient intergranular porosity for a petroleum reservoir might exist in the post-Gemuk Group rocks examined in this study.

CHARACTERISTICS OF POTENTIAL RESERVOIRS

GEOMETRY

Stratigraphic-section and spot-sample localities are widely separated geographically, and it is not surprising that rocks from the various localities were deposited in different environments or that potential reservoir sandstones are characterized by different geometries.

The Gemuk Group and much of the Shaktolik Group are characterized by rhythmically bedded sandstone, siltstone, and mudstone typical of deep-water turbidites. Sand bodies associated with turbidite deposition are commonly arrayed in channels, lobes, and sheets. Channels and lobes are generally associated with submarine fans, but sheet deposits can extend over a basin plane and may not be associated with any fan.

Submarine fan channels are many times as long as they are wide and several times as wide as they are thick. Sediment transport is generally through single, large channels near the apices of fans, but such channels grade to braided systems of smaller channels away from the apices. Potential reservoir sandstones deposited in channel environments will be elongated in a direction generally normal to the depositional strike.

Most of the coarser sediment coming through fan channels is deposited in lobes that are located at the ends of the channels. Shale beds, which form part of most classical turbidite sequences, are generally not present. A typical submarine fan lobe may be about 15 miles in diameter and 300 feet thick (Walker, 1978).

Sheet turbidite sandstone beds may extend over a large area, but are generally only a few inches thick and separated from each other in vertical sequence by equally extensive shale beds. Basin-plain sheet turbidite sandstone beds may merge into lobes laterally.

The Kuskokwim Group, part of the Shaktolik Group, and the undifferentiated Cretaceous and Tertiary rocks examined were deposited in shallow marine and nonmarine environments. Fluvial channel sandstones, which display elongate meandering morphologies, are present in the nonmarine parts of these rock units, and such channel sandstones are generally elongate normal to the depositional strike and paleoshoreline. Shallow-marine sandstones in these rock units may be expected to have the tabular geometry typical of sand bodies deposited as beaches, offshore bars, barrier islands, and spits. Widths of such tabular bodies are commonly 50 to 1000 times their thicknesses (Krynine, 1948).

QUALITY

Seventy-two samples were analyzed for porosity and permeability (table 4). Porosities ranged from 0.2 to 8.1 with an average of 2.9 percent. However, if two fractured samples with permeabilities of 6.31 and 48 millidarcies and a Tertiary sample with a permeability of 48 millidarcies are excluded, permeabilities range from 0.01 to 2.07 with an average of 0.19 millidarcy. These values are all very low.

HYDROCARBON SOURCE ROCKS AND BASIN MATURITY

A total of 69 samples were processed for C 15+ soxhlet extraction and deasphaltening by Geochem Laboratories, Inc. Table 3 shows a listing of these samples. When the nonhydrocarbons (precipitated asphaltene and nitrogen, sulfur, and oxygen compounds) are subtracted from the total extract, not a single sample contained more than 300 ppm hydrocarbons, the generally accepted threshold level for a petroleum source rock. The extracted hydrocarbons ranged from 6 to 99 ppm and averaged 48 ppm. Fifty-eight samples were not processed for complete liquid chromatography because of the lean amount of nC5 soluble in the C15+ total solvent extractable bitumen.

Except for one sample, organic carbon ranged from 0.05 to 1.05 percent; only 13 samples contained more than 0.5 percent carbon, the normally accepted minimum organic carbon threshold level for hydrocarbon source rocks. The one sample with higher organic carbon content was from the Shaktolik Group south of Beeson Slough and about 20 miles north of Unalakleet. It contained an exceptionally high value of 4.3 percent organic carbon and was taken from a unique and very thin bed.

In general, the suite of samples processed indicates that the hydrocarbon source-rock potential is very low in areas adjacent to the sampling sites. Many of these data are from coastal exposures and tend to downgrade the adjacent OCS area with respect to hydrocarbon source potential.

Visual kerogen in the 69 geochemical samples collected ranged from 1+ to 4 in thermal-alteration index; most samples were in the 2- to 3+ range (table 2). This range is considered to be representative of the ability of the kerogen to produce either "wet" or "dry" associated hydrocarbons, depending on kerogen type. Kerogen in the samples is overwhelmingly dominated by herbaceous, woody, and coaly material; thus, generated hydrocarbons are expected to be "dry" and gaseous. However, the sparseness of the organic content indicates only a slight possibility of the occurrence of any commercial hydrocarbons adjacent to the sampling sites.

CONCLUSIONS

Tabular deep- and shallow-marine and elongate marine and nonmarine sand bodies, some of which exceed 100 feet in thickness, are common in the outcrops examined. Similar sandstone bodies should exist in the adjacent offshore areas of Norton Sound and Kuskokwim Bay. However, the low reservoir quality that has resulted from diagenetic changes in the sandstone samples studied suggests that potentially productive levels of porosity and permeability in their offshore equivalents depend on the existence of secondary porosity. The task in predicting the locations of potential reservoirs in such offshore equivalents is more a matter of delimiting where secondary porosity may have developed and been preserved than of locating sand bodies.

Although thermal-alteration indices indicate that most of the geochemical samples are in the upper immature to mature range of thermal maturity and therefore capable of having generated hydrocarbons, the amount of organic carbon present in most of the samples was less than the 0.5 percent normally considered the minimum threshold level for hydrocarbon source rocks. Because the overwhelming majority of visual kerogen in the samples comprises "dry" gas precursors, the beds sampled are most likely to have produced only minor, noncommercial amounts of "dry" gas. Of course, different types and greater amounts of organic material may have collected in rocks in submerged lands adjacent to the study area, but our work onshore does not give cause for optimism.

In summary, the discovery of hydrocarbons in commercial quantities in the Norton Sound-Kuskokwim Bay area depends on the existence of potential reservoir and source rocks of better quality in offshore areas than are present onshore. However, very little of the Tertiary fill in the offshore basins is exposed onshore; thus, a sizable part of the stratigraphic column in the offshore basins was not tested in this study.

REFERENCES CITED

Cady, W.M., Wallace, R.E., Hoare, J.M., and Webber, E.J., 1955, The central Kuskokwim region, Alaska: U.S. Geological Survey Professional Paper 268, 132 p.

Cass, J.T., 1959a, Reconnaissance geologic map of the Norton Bay Quadrangle, Alaska: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-286, scale 1:250,000, 1 sheet.

Cass, J.T., 1959b, Reconnaissance geologic map of the Unalakleet Quadrangle, Alaska: U.S. Geological Survey Miscellaneous Geologic Investigations Map I:288, scale 1:250,000, 1 sheet.

Coonrad, W.L., 1957, Geologic reconnaissance in the Yukon-Kuskokwim delta region, Alaska: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-223, scale 1:500,000, 1 sheet.

Hoare, J.M., 1961, Geology and tectonic setting of lower Kuskokwim-Bristol Bay region, Alaska: American Association of Petroleum Geologists Bulletin, v. 45, p. 594-611.

Hoare, J.M., and Condon, W.H., 1966, Geologic map of the Kwiguk and Black Quadrangles, western Alaska: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-469, scale 1:250,000, 1 sheet, with accompanying text (7 p.).

_____1971, Geologic map of the Marshall Quadrangle, western Alaska: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-668, scale 1:250,000, 1 sheet, with accompanying text (6 p.).

Hoare, J.M., and Coonrad, W.L., 1959a, Geology of the Bethel Quadrangle, Alaska: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-285, scale 1:250,000, 1 sheet.

_____1959b, Geology of the Russian Mission Quadrangle, Alaska: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-292, scale 1:250,000, 1 sheet.

Hoare, J.M., and Coonrad, W.L., 1961, Geologic map of the Goodnews Quadrangle, Alaska: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-339, scale 1:63,360, 1 sheet.

Krynine, P.D., 1948, The megascopic study and field classification of sedimentary rocks: Journal of Geology, v. 56, p. 130-165.

Patton, W.W., Jr., 1973, Reconnaissance geology of the northern Yukon-Koyukuk province, Alaska: U.S. Geological Survey Professional Paper 774-A, 17 p.

Patton, W.W., Jr., and Miller, T.P., 1968, Regional geologic map of the Selawik and southeastern Baird Mountains Quadrangles, Alaska: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-530, scale 1:250,000, 1 sheet.

Sainsbury, C.L., Coleman, R.G., and Kachadoorian, R., 1970, Blueschist and related greenschist facies rocks of the Seward Peninsula, Alaska: U.S. Geological Survey Professional Paper 700B, p. B33-B42.

Smith, P.S., and Eakin, H.M., 1911, A geologic reconnaissance in southeastern Seward Peninsula and the Norton Bay-Nulato region: U.S. Geological Survey Bulletin 449, 146 p.

Walker, R.G., 1978, Deep-water sandstone facies and ancient submarine fans: models for exploration for stratigraphic traps: American Association of Petroleum Geologists Bulletin, v. 62, p. 932-966.

Table 1. *Sample numbers cross-referenced to quadrangle maps, township, range, and stratigraphic unit.*

[Letters designate sample collector: GB, Bolm; TF, Flett; WM, Lyle; JM, Morehouse; IP, Palmer.]

Locality	Quadrangle map, Alaska series, (scale 1:250,000)	Sec.	T.	R.	Sample	Stratigraphic unit
1	Selawik	22,	9N,	6W	39-GB-78	Undifferentiated Tertiary
2	Norton Bay	25,	9S,	11W	43 to 45-GB-78	Shaktolik Group
3	"	12,	15S,	12W	54 to 57-GB-78	"
4	"	12,	17S,	12W	53-GB-78	"
5	Unalakleet	1,	19S,	11W	9 to 10-GB-78	"
6	"	4,	19S,	10W	13 to 14-GB-78	"
7	"	36,	18S,	10W	11 to 12-GB-78	"
8	"	8,	18S,	8W	7 to 8-GB-78	"
9	"	28,	20S,	11W	32 to 35-GB-78	Undifferentiated Tertiary
10	"	33,	20S,	11W	29 to 30-GB-78	Shaktolik Group
11	"	13,	21S,	12W	24 to 28-GB-78	"
12	St. Michael	34,	26S,	22W	22 to 23-GB-78	"
13	"	32,	27S,	19W	2 to 3-GB-78	"
14	Marshall	30,	22N,	83W	17 to 20-IP-78	Undifferentiated Cretaceous
					24-TF-78	
					28 to 29-TF-78	
15	Kwiguk	21,	23N,	77W	50 to 52-GB-78	Shaktolik Group
16	"	25,	23N,	77W	49-GB-78	"
17	"	29,	23N,	76W	47 to 48-GB-78	"
18	Russian Mission	11,	18N,	69W	1 to 16-IP-78	Gemuk Group
19	"	25,	18N,	69W	39 to 44-JM-78	"
		30,	18N,	68W	71 to 87-WL-78	"
20	Nunivak Island	28,	7N,	89W	1 to 23-WL-78	Undifferentiated Cretaceous
21	"	31,	7N,	89W	24 to 37-WL-78	"
22	"	13,	3N,	100W	33 to 62-IP-78	"
23	"	2,	1N,	103W	66 to 68-IP-78	"
24	"	5,	1N,	102W	63 to 65-IP-78	"
25	Bethel	31-32,	1S,	67W	1 to 38-JM-78	Kuskokwim Group
					45 to 49-JM-78	"
		34-36,	1S,	68W	2 to 19-TF-78	"
					38 to 70-WL-78	"
26	"	5,	1S,	64W	20 to 26-TF-78	"
27	Goodnews Bay	28,	3S,	63W	31 to 32-IP-78	Gemuk Group
28	"	12,	4S,	64W	21 to 30-IP-78	"

Table 2. *Summary of organic carbon content and visual kerogen data.*

[Determinations by Geochem Laboratories, Inc., Houston, Texas. Two numbers in "organic carbon" column indicate sample was run twice to test repeatability of analysis. TAI: scale from 1 (unaltered) to 4 (severely altered); underlined number indicates dominant rank of alteration. Kerogens listed in order of decreasing abundance: predominant (60-100%); secondary (20-40%); trace (1-20%). Al, algal; Am, amorphous-sapropel; C, coal; H, herbaceous-spore/cuticle; H*, degraded herbaceous; W, woody; U, unidentified material. A hyphen between kerogen types indicates subequal abundance. Kerogen types enclosed in parentheses following Am are recognizable degraded constituents of the amorphous population. Minor constituents of the trace population are indicated in parentheses following the code for the more abundant trace kerogen types.]

Locality	Sample	Organic carbon (%)	Visual kerogen data: Type	Visual kerogen data: Thermal alteration index (TAI)
		Gemuk Group		
18	1-IP-78	0.08	H;-;-	1+ to 2-
	1-IP-78	0.05	W;-;H	2- to 2
	6-IP-78	0.08	Am(Al);-;H	1+
	8-IP-78	0.10	Am(Al)-H;-;-	2-
	10-IP-78	0.05	H;Am-W;-	2- to 2
	16-IP-78	0.08	H; Am (Al)	1+
19	41-JM-78	0.07	H-W;C;-	2 to 2+
	44-JM-78	0.59	W-C;H;-	2 to 2+
	71-WL-78	0.12	H;W;-	2
	76-WL-78	0.08	H-W;-;-	2- to 2
	80-WL-78	0.08	W;H;C	2 to 2+
	82-WL-78	0.18	H-W;-;C	2
	86-WL-78	0.14;0.24	H;W;-	2- to 2
27	32-IP-78	0.14	W;H;-	2 to 2+
28	22-IP-78	0.06	H;-;W-C	3 to 3+
	25-IP-78	0.07	H;W;C	3 to 3+
		Shaktolik Group		
2	44-GB-78	0.41	H-W;-;C	2- to 2
3	56-GB-78	4.30	W-C;H;-	3+
5	10-GB-78	0.18	W-C;H;-	3- to 3
6	14-GB-78	0.21	H;W-C;-	3- to 3
7	12-GB-78	0.61	H-W-C;-;-	2 to 2+
8	8-GB-78	0.18	W-C;H;-	3- to 3
10	30-GB-78	0.38	W-C;H;-	3- to 3
11	25-GB-78	0.37	H-W-C;-;-	3- to 3
12	23-GB-78	0.10	W-C;H;-	2 to 2+
13	3-GB-78	0.45	W-C;-;H	3 to 3+
15	50-GB-78	0.17	W-C;-;H	2+ to 3-
17	48-GB-78	0.39;0.32	W-C;H;-	2 to 2+

Table 2. (cont.)

Locality	Sample	Organic carbon (%)	Visual kerogen data: Type	Visual kerogen data: Thermal alteration index (TAI)
		Kuskokwim Group		
25	4-JM-78	0.48	W-C;H;-	2+ to 3-
	6-JM-78	0.56	W-C;-;H	2 to 2+
	10-JM-78	1.02	H-W-C;-;-	2 to 2+
	15-JM-78	0.29	W-C;H;-	2 to 2+
	25-JM-78	0.25;0.30	W-C;H;-	2 to 2+
	35-JM-78	0.49	H;W-C;-	2 to 2+
	47-JM-78	0.48	H;W;C	2 to 2+
	8-TF-78	0.40	W-C;-;H	2+ to 3-
	12-TF-78	0.56	H;W-C;-	2 to 2+
	17-TF-78	0.60	H;W-C;-	2- to 2
	38-WL-78	0.92	W-C;H;-	2 to 2+
	42-WL-78	0.70	W-C;H;-	2 to 2+
	46-WL-78	0.51	W-C;-;H	2 to 2+
	52-WL-78	1.05	H-W-C;-;-	2 to 2+
	55-WL-78	0.65;0.63	H;W-C;-	2
	60-WL-78	0.26	H-W-C;-;-	2 to 2+
	64-WL-78	0.58	H-W-C;-;-	2 to 2+
26	20-TF-78	0.52	W-C;-;H	2 to 2+
	24-TF-78	0.16	W-C;-;H	3+
		Undifferentiated Cretaceous		
14	20-IP-78	0.10	H;-;C	4- to 4
	29-IP-78	0.29	H;W-C;-	4- to 4
20	3-WL-78	0.11	W;H;-	2 to 2+
	7-WL-78	0.08	W;-;H-C	2 to 2+
	9-WL-78	0.07	W-C;H;-	2+ to 3-
	13-WL-78	0.15	W;-;H-C	2
	16-WL-78	0.38	H-W;-;C	2 to 2+
	19-WL-78	0.10	W-C;H;-	2 to 2+
	21-WL-78	0.09	W-C;H;-	2+
21	24-WL-78	0.19	H-W-C;-;-	2 to 2+
	27-WL-78	0.08	W-C;-;H	2 to 2+
	31-WL-78	0.12;0.18	W;H;Am-C	2 to 2+
22	33-IP-78	0.27	W-C;H;-	3- to 3
	36-IP-78	0.12	W-C;H;-	2+ to 3-
	39-IP-78	0.28	W-C;-;H	3- to 3
	44-IP-78	0.18	W-C;-;H	3- to 3
	49-IP-78	0.19	W-C;-;H	3- to 3
	53-IP-78	0.28;0.28	W-C;H;-	3- to 3
	56-IP-78	0.15	W-C;-;H	2+ to 3-
	59-IP-78	0.18	W-C;-;H	3+ to 4-
23	66-IP-78	0.54	W-C;H;-	4- to 4
24	63-IP-78	0.87	W-C;-;H	3+ to 4-

Table 3. *Geochemical analyses of C_{15+} extracted material in rock.*

[Determinations by Geochem Laboratories, Inc., Houston, Texas. All values in parts per million. NSO's are nitrogen-sulfur-oxygen derivatives. Fifty-eight samples were not subjected to complete analysis due to the small amount (0.01 gm) of nC_5 soluble in the C_{15+} total solvent extractable bitumen.]

			Hydrocarbons (H)			Nonhydrocarbons (N)				
Locality	Sample	Total extract (H+N)	Paraffin-naphthene	Aro-matic	Total	Sulfur	Precip. asphaltene	Eluted NSO's	Noneluted NSO's	Total
				Gemuk Group						
18	1-IP-78	117	--	--	--	--	94	--	--	--
	4-IP-78	170	--	--	--	--	135	--	--	--
	6-IP-78	150	--	--	--	--	118	--	--	--
	8-IP-78	155	--	--	--	--	115	--	--	--
	10-IP-78	96	--	--	--	--	50	--	--	--
	16-IP-78	168	--	--	--	--	122	--	--	--
19	41-JM-78	109	--	--	--	--	73	--	--	--
	44-JM-78	110	--	--	--	--	73	--	--	--
	71-WL-78	128	--	--	--	--	72	--	--	--
	76-WL-78	194	--	--	--	--	124	--	--	--
	80-WL-78	144	--	--	--	--	115	--	--	--
	82-WL-78	292	46	26	72	--	163	50	7	220
	86-WL-78	115	--	--	--	--	84	--	--	--
27	32-IP-78	125	--	--	--	--	78	--	--	--
28	22-IP-78	134	--	--	--	--	90	--	--	--
	25-IP-78	271	18	6	23	72	138	26	12	248
				Shaktolik Group						
2	44-GB-78	618	21	77	98	--	374	111	35	520
3	56-GB-78	211	--	--	--	--	162	--	--	--
5	10-GB-78	121	--	--	--	--	112	--	--	--
6	14-GB-78	94	--	--	--	--	70	--	--	--
7	12-GB-78	127	--	--	--	--	86	--	--	--
8	8-GB-78	86	--	--	--	--	61	--	--	--
10	30-GB-78	98	--	--	--	--	75	--	--	--
11	25-GB-78	140	--	--	--	--	96	--	--	--
12	23-GB-78	81	--	--	--	--	73	--	--	--
13	3-GB-78	140	--	--	--	--	97	--	--	--
15	50-GB-78	62	--	--	--	--	56	--	--	--
17	48-GB-78	183	--	--	--	--	130	--	--	--

Table 3. (cont.)

		Total	Hydrocarbons (H)			Nonhydrocarbons (N)				
Locality	Sample	extract (H+N)	Paraffin-naphthene	Aro-matic	Total	Sulfur	Precip. asphaltene	Eluted NSO's	Noneluted NSO's	Total
				Kuskokwim Group						
25	4-JM-78	100	--	--	--	--	79	--	--	--
	6-JM-78	281	--	--	--	--	183	--	--	--
	10-JM-78	191	--	--	--	--	107	--	--	--
	15-JM-78	170	--	--	--	--	96	--	--	--
	25-JM-78	220	--	--	--	--	164	--	--	--
	35-JM-78	229	--	--	--	--	145	--	--	--
	47-JM-78	205	--	--	--	--	107	--	--	--
	8-TF-78	280	--	--	--	--	212	--	--	--
	12-TF-78	338	9	51	60	--	224	49	6	278
	17-TF-78	411	8	56	64	--	280	57	10	347
	38-WL-78	226	--	--	--	--	147	--	--	--
	42-WL-78	276	9	53	62	--	164	43	8	215
	46-WL-78	193	--	--	--	--	142	--	--	--
	52-WL-78	933	7	11	18	--	723	93	100	915
	55-WL-78	370	5	65	70	--	199	92	9	300
	60-WL-78	359	8	63	71	--	203	72	13	288
	64-WL-78	292	10	46	56	--	172	51	13	236
26	20-TF-78	124	--	--	--	--	88	--	--	--
	24-TF-78	91	--	--	--	--	51	--	--	--
				Undifferentiated Cretaceous						
14	20-IP-78	126	--	--	--	--	75	--	--	--
	29-TF-78	316	--	--	--	--	260	--	--	--
20	3-WL-78	119	--	--	--	--	90	--	--	--
	7-WL-78	199	--	--	--	--	125	--	--	--
	9-WL-78	88	--	--	--	--	55	--	--	--
	13-WL-78	79	--	--	--	--	48	--	--	--
	16-WL-78	242	--	--	--	--	144	--	--	--
	19-WL-78	153	--	--	--	--	117	--	--	--
	21-WL-78	104	--	--	--	--	63	--	--	--
21	24-WL-78	294	11	34	45	--	132	83	34	249
	27-WL-78	235	--	--	--	--	165	--	--	--
	31-WL-78	824	--	--	--	--	773	--	--	--
22	33-IP-78	117	--	--	--	--	69	--	--	--
	36-IP-78	109	--	--	--	--	74	--	--	--
	39-IP-78	185	--	--	--	--	92	--	--	--
	44-IP-78	134	--	--	--	--	106	--	--	--
	49-IP-78	116	--	--	--	--	59	--	--	--
	53-IP-78	161	--	--	--	--	112	--	--	--
	56-IP-78	142	--	--	--	--	84	--	--	--
	59-IP-78	195	--	--	--	--	161	--	--	--
23	66-IP-78	222	--	--	--	--	181	--	--	--
24	63-IP-78	100	--	--	--	--	76	--	--	--

Table 4. *Porosity and permeability.*

[Determinations by Chemical & Geological Laboratories of Alaska, Inc. "F" in the permeability column indicates sample is fractured.]

Locality	Sample	Effective porosity (%)	Horizontal permeability (millidarcies)
		Gemuk Group	
18	3-IP-78	7.6	0.40
	13-IP-78	4.7	0.31
	14-IP-78	6.7	0.30
19	39-JM-78	7.5	2.07
	43-JM-78	1.0	0.03
	75-WL-78	0.2	0.01
	79-WL-78	4.3	0.07
	84-WL-78	5.5	6.31 (F)
	85-WL-78	3.9	0.04
27	31-IP-78	1.9	48 (F)
28	21-IP-78	2.1	0.07
		Shaktolik Group	
2	45-GB-78	2.7	0.07
3	54-GB-78	1.1	0.05
	55-GB-78	0.2	0.06
4	53-GB-78	1.2	0.05
5	9-GB-78	3.6	0.30
6	13-GB-78	2.0	0.08
7	11-GB-78	2.1	0.09
8	7-GB-78	2.2	0.14
10	29-GB-78	1.2	0.08
11	27-GB-78	8.1	0.12
12	22-GB-78	2.9	0.08
13	2-GB-78	2.5	0.15
15	51-GB-78	0.4	0.05
	52-GB-78	5.1	2.04
16	49-GB-78	7.2	1.76
17	47-GB-78	0.9	0.07

Table 4. (cont.)

Locality	Sample	Effective porosity (%)	Horizontal permeability (millidarcies)
		Kuskokwim Group	
25	1-JM-78	1.3	0.07
	5-JM-78	1.9	0.08
	9-JM-78	2.2	0.10
	14-JM-78	1.4	0.08
	24-JM-78	3.3	0.10
	28-JM-78	3.0	0.10
	29-JM-78	2.8	0.10
	34-JM-78	3.2	0.06
	38-JM-78	2.2	0.11
	45-JM-78	1.5	0.08
	49-JM-78	3.6	0.09
	3-TF-78	1.9	0.24
	4-TF-78	1.8	0.13
	5-TF-78	2.3	0.05
	6-TF-78	3.4	0.08
	7-TF-78	1.4	0.02
	11-TF-78	0.5	0.02
	15-TF-78	2.4	0.03
	16-TF-78	2.9	0.03
	41-WL-78	3.5	0.04
	45-WL-78	2.2	0.02
	49-WL-78	1.5	0.03
	51-WL-78	1.7	0.03
	58-WL-78	1.9	0.03
	59-WL-78	1.3	0.03
	67-WL-78	1.6	0.04
	68-WL-78	3.0	0.05
	69-WL-78	2.4	0.04
	70-WL-78	1.1	0.03
		Undifferentiated Cretaceous	
14	17-IP-78	0.2	0.05
	18-IP-78	0.3	0.06
	19-IP-78	0.4	0.05
	28-TF-78	4.9	0.01
20	5-WL-78	7.2	0.21
	6-WL-78	2.8	0.02
21	30-WL-78	5.4	0.50
	34-WL-78	4.7	0.06
	35-WL-78	5.8	0.13
	36-WL-78	7.4	0.04
	37-WL-78	6.3	0.08
22	42-IP-78	2.2	0.06
	48-IP-78	2.5	0.05
	52-IP-78	5.2	0.06
	62-IP-78	5.6	0.13
		Undifferentiated Tertiary	
9	34-GB-78	6.1	1.49
	35-GB-78	6.9	48

Table 5. *Summary of micropaleontological age and environment data.*

[Determinations by Anderson, Warren & Associates, Inc., San Diego, California. Frequency symbols used: R, rare; F, frequent; C, common; A, abundant.]

Gemuk Group

Locality 18

2-JP-78: Radiolaria (silicified) (R). Orange-brown silty mudstone.

Age: Indeterminate
Environment: Probable marine

5-IP-78: Barren. Orange phosphatic(?) shale.

Age: Indeterminate
Environment: Indeterminate

7-IP-78: Barren. Orange-brown mudstone.

Age: Indeterminate
Environment: Indeterminate

9-IP-78: Barren. Orange-brown mudstone.

Age: Indeterminate
Environment: Indeterminate

11-IP-78: Barren. Orange-brown mudstone.

Age: Indeterminate
Environment: Indeterminate

15-IP-78: Barren. Dark-bluish-green chert.

Age: Indeterminate
Environment: Indeterminate

Locality 19

72-WL-78: Barren. Greenish-brown siliceous shale or chert.

Age: Indeterminate
Environment: Indeterminate

77-WL-78: *Cenosphaera?* spp. (C). Dark-orange-brown siliceous mudstone.

Age: Indeterminate
Environment: Possible open marine

81-WL-78 Barren. Greenish-gray iron-stained siliceous shale.

Age: Indeterminate
Environment: Indeterminate

83-WL-78: *Cenosphaera?* spp. (F), spicules (R). Multicolored siliceous shale or chert.

Age: Indeterminate
Environment: Possible open marine

Table 5. (cont.)

Gemuk Group (cont.)

87-WL-78: Barren. Dark-orangish-brown siliceous shale.

Age: Indeterminate
Environment: Indeterminate

Locality 28

23-IP-78: Barren. Black and brown siliceous shale or chert.

Age: Indeterminate
Environment: Indeterminate

26-IP-78: *Arenaceous* sp. (R), *Cenosphaera* spp. (R). Dark-gray to black sandy chert.

Age: Indeterminate
Environment: Probable marine

Shaktolik Group

Locality 2

43-GB-78: Barren. Orange-tan angular fine-grained sandstone.

Age: Indeterminate
Environment: Indeterminate

Locality 3

57-GB-78: *Eponides?* sp. (R). Black schist(?)

Age: Indeterminate
Environment: Possible marine

Locality 5

10-GB-78: Barren. Dark-yellowish-gray mudstone.

Age: Indeterminate
Environment: Indeterminate

Locality 6

14-GB-78: Barren. Black and brown muddy fine-grained sandstone.

Age: Indeterminate
Environment: Indeterminate

Locality 7

12-GB-78: Barren. Dark-gray micaceous shale.

Age: Indeterminate
Environment: Indeterminate

Locality 8

8-GB-78: Barren. Fecal pellets (C). Dark-gray to black sandy shale.

Age: Indeterminate
Environment: Indeterminate

Table 5. (cont.)

Shaktolik Group (cont.)

Locality 10

30-GB-78: Barren. Fecal pellets (F). Dark-gray micaceous shale.

Age: Indeterminate
Environment: Indeterminate

Locality 11

28-GB-78: Echinoid remains (R). Black sandy shale.

Age: Indeterminate
Environment: Possible marine

Locality 12

23-GB-78: Barren. Brownish-gray micaceous mudstone.

Age: Indeterminate
Environment: Indeterminate

Locality 13

3-GB-78: Barren. Black shale.

Age: Indeterminate
Environment: Indeterminate

Locality 15

50-GB-78: *Cibicides?* sp. (R), *Cenosphaera* spp. (R). Black sandy shale.

Age: Indeterminate
Environment: Probable marine

Locality 17

48-GB-78: Barren. Black shale.

Age: Indeterminate
Environment: Indeterminate

Kuskokwim Group

Locality 25

3-JM-78: Barren. Dark-brownish-gray micaceous mudstone.

Age: Indeterminate
Environment: Indeterminate

7-JM-78: Barren. Dark-brownish-gray micaceous mudstone.

Age: Indeterminate
Environment: Indeterminate

11-JM-78: Barren. Shell fragments (R). Black iron-stained shale.

Age: Indeterminate
Environment: Indeterminate

Table 5. (cont.)

Kuskokwim Group (cont.)

16-JM-78: Barren. Dark-gray sandy shale.

Age: Indeterminate
Environment: Indeterminate

26-JM-78: Barren. Black shale.

Age: Indeterminate
Environment: Indeterminate

36-JM-78: *Cenosphaera* sp. (R). Dark-brown muddy, fine-grained sandstone.

Age: Indeterminate
Environment: Possible marine

46-JM-78: Barren. Megaspores? (F), fecal pellets (F). Dark-brown to black sandy shale.

Age: Indeterminate
Environment: Indeterminate

9-TF-78: Barren. Black silty mudstone.

Age: Indeterminate
Environment: Indeterminate

13-TF-78: *Arenaceous* sp.? (R). Black siltstone.

Age: Indeterminate
Environment: Possible marine

18-TF-78: Barren. Black silty shale.

Age: Indeterminate
Environment: Indeterminate

39-WL-78: Barren. Black silty shale.

Age: Indeterminate
Environment: Indeterminate

43-WL-78: Barren. Fecal pellets (R). Dark-brown sandy shale.

Age: Indeterminate
Environment: Indeterminate

47-WL-78: Barren. Black silty shale.

Age: Indeterminate
Environment: Indeterminate

53-WL-78: Barren. Dark-brownish-gray to black muddy, very fine grained sandstone.

Age: Indeterminate
Environment: Indeterminate

56-WL-78: Barren. Black shale.

Age: Indeterminate
Environment: Indeterminate

Table 5. (cont.)

Kuskokwim Group (cont.)

61-WL-78: Barren. Dark-brown iron-stained silty shale.

Age: Indeterminate
Environment: Indeterminate

65-WL-78: Barren. Black siltstone or very fine grained sandstone.

Age: Indeterminate
Environment: Indeterminate

Locality 26

21-TF-78: Barren. Black fine-grained metasandstone.

Age: Indeterminate
Environment: Indeterminate

23-TF-78: Barren. Black shale.

Age: Indeterminate
Environment: Indeterminate

25-TF-78: Barren. Black iron-stained shale.

Age: Indeterminate
Environment: Indeterminate

Undifferentiated Cretaceous

Locality 20

4-WL-78: Barren. Dark-gray mudstone.

Age: Indeterminate
Environment: Indeterminate

8-WL-78: Barren. Yellow-orange phosphatic(?) shale.

Age: Indeterminate
Environment: Indeterminate

10-WL-78: Barren. Dark-brown silty mudstone.

Age: Indeterminate
Environment: Indeterminate

12-WL-78: Barren. Fecal pellets (A). Buff-tan mudstone.

Age: Indeterminate
Environment: Indeterminate

15-WL-78: Barren. Fecal pellets (F). Dark-greenish-gray shale.

Age: Indeterminate
Environment: Indeterminate

18-WL-78: Barren. Brownish-gray mudstone.

Age: Indeterminate
Environment: Indeterminate

Table 5. (cont.)

Undifferentiated Cretaceous (cont.)

22-WL-78: Barren. Dark-brownish-gray metasiltstone.

Age: Indeterminate
Environment: Indeterminate

Locality 21

25-WL-78: Barren. Fecal pellets (F). Dark-gray shale.

Age: Indeterminate
Environment: Indeterminate

28-WL-78: Barren. Dark-gray mudstone.

Age: Indeterminate
Environment: Indeterminate

32-WL-78: Barren. Dark-gray mudstone.

Age: Indeterminate
Environment: Indeterminate

Locality 22

34-IP-78: *Valvulineria?* sp. (R), fecal pellets (F). Dark-gray iron-stained mudstone.

Age: Indeterminate
Environment: Possible marine

37-IP-78: Barren. Fecal pellets (F). Dark-gray silty shale.

Age: Indeterminate
Environment Indeterminate

40-IP-78: Barren. Fecal pellets (C). Dark-gray sandy shale.

Age: Indeterminate
Environment: Indeterminate

45-IP-78: Barren. Fecal pellets (R). Dark-gray muddy siltstone.

Age: Indeterminate
Environment: Indeterminate

50-IP-78: Barren. Dark-gray silty shale.

Age: Indeterminate
Environment: Indeterminate

54-IP-78: Barren. Fecal pellets (F). Black shale.

Age: Indeterminate
Environment: Indeterminate

57-IP-78: Barren. Fecal pellets (C). Dark-gray silty shale.

Age: Indeterminate
Environment: Indeterminate

Table 5. (cont.)

Undifferentiated Cretaceous (cont.)

60-IP-78: Barren. Dark-gray sandy shale.

Age: Indeterminate
Environment: Indeterminate

Locality 23

67-IP-78: Barren. Black shale.

Age: Indeterminate
Environment: Indeterminate

Locality 24

64-IP-78: Barren. Fecal pellets (R). Black shale.

Age: Indeterminate
Environment: Indeterminate

Undifferentiated Tertiary

Locality 9

33-GB-78. Barren. Brown, slightly calcareous mudstone.

Age: Indeterminate
Environment: Indeterminate

Table 6. *Summary of palynological age and environment data.*

[Determinations by Anderson, Warren & Associates, Inc., San Diego, California. Frequency symbols used: R, rare; F, frequent; C, common; A, abundant.]

Gemuk Group

Locality 19

73-WL-78: Essentially barren of palynomorphs.

Age: Indeterminate
Environment: Indeterminate

78-WL-78: Undifferentiated bisaccates (R), *Juglans* sp. (single), tricolpate grain (single), *Micrhystridium* sp. (single).

Age: Probable Tertiary
Environment: Marginal marine(?)

Locality 28

24-IP-78: Probable surface contaminants: *Alnus* sp. (R), Pinaceae (R), *Lycopodiumsporites* sp. (R). Mainly black fusinitic material.

Age: Indeterminate
Environment: Indeterminate

27-IP-78: Probable surface contaminants: *Alnus* sp. (R), Pinaceae (R), unidentified tricolpate (single).

Age: Indeterminate
Environment: Indeterminate

Shaktolik Group

Locality 2

43-GB-78: Undifferentiated bisaccates (A), *Tsuga* sp. (F), *Lycopodiumsporites* sp. (R), *Alnus* sp. (R).

Age: Probable Neogene
Environment: Nonmarine

Locality 3

57-GB-78: Barren of palynomorphs. Woody and fusinitic material only.

Age: Indeterminate
Environment: Probable nonmarine

Locality 11

28-GB-78: Pinaceae (single, probable surface contaminant). Mainly woody and fusinitic material.

Age: Indeterminate
Environment: Probable nonmarine

Locality 15

50-GB-78: Barren of palynomorphs. Small recovery of fusinitic and woody material.

Age: Indeterminate
Environment: Probable nonmarine

Table 6. (cont.)

Shaktolik Group (cont.)

Locality 17

48-GB-78: Probable surface contaminants: *Laevigatosporites* sp. (R), *Betula* sp. (R). Mainly woody and fusinitic material.

Age: Indeterminate
Environment: Probable nonmarine

Kuskokwim Group

Locality 25

2-JM-78: Probable surface contaminants: Pinaceae (R), *Alnus* sp. (R), *Betula* sp. (R). Mainly woody and fusinitic material.

Age: Indeterminate
Environment: Probable nonmarine

8-JM-78: Probable surface contaminants: *Alnus* sp. (R), *Betula* sp. (R), *Sphagnum* sp. (R). Mainly woody and fusinitic material.

Age: Indeterminate
Environment: Probable nonmarine

12-JM-78: Poorly preserved indeterminate spores (R). Mainly woody and fusinitic material.

Age: Indeterminate
Environment: Probable nonmarine

17-JM-78: Probable surface contaminants: *Lycopodium* sp. (R), *Laevigatosporites* sp. (R), *Sphagnum* sp. (R). Mainly woody and fusinitic material.

Age: Indeterminate
Environment: Probable nonmarine

37-JM-78: Probable surface contaminants: *Lycopodium* sp. (R), *Laevigatosporites* sp. (R), *Sphagnum* sp. (R). Mainly woody and fusinitic material.

Age: Indeterminate
Environment: Probable nonmarine

10-TF-78: Barren of palynomorphs. Only woody and fusinitic material.

Age: Indeterminate
Environment: Probable nonmarine

14-TF-78: Organic recoveries similar to above with probable surface contaminants: *Alnus* sp. (F), *Laevigatosporites* sp. (R), *Sphagnum* sp. (R).

Age: Indeterminate
Environment: Probable nonmarine

19-TF-78: Organic recoveries similar to above with probable surface contaminants: *Alnus* sp. (F), *Laevigatosporites* sp. (R), *Sphagnum* sp. (R).

40-WL-78: Essentially barren of palynomorphs. Woody and fusinitic material only.

Age: Indeterminate
Environment: Probable nonmarine

Table 6. (cont.)

Kuskokwim Group (cont.)

44-WL-78: Poorly preserved, indeterminate spores and spore fragments (R).

Age: Indeterminate
Environment: Probable nonmarine

48-WL-78: Probable surface contaminants: *Sphagnum* sp. (R), *Laevigalosporties* sp. (R). Poorly preserved, indeterminate spores (R).

Age: Indeterminate
Environment: Probable nonmarine

54-WL-78: Probable surface contaminant: Pinaceae (R). Mainly woody and fusinitic material.

Age: Indeterminate
Environment: Probable nonmarine

62-WL-78: Probable surface contaminant: *Lycopodiumsporiles* sp. (R). Mainly woody and fusinitic material.

Age: Indeterminate
Environment: Probable nonmarine

66-WL-78: Probable surface contaminant: *Lycopodiumsporiles* sp. (R). Mainly woody and fusinitic material.

Age: Indeterminate
Environment: Probable nonmarine

Locality 26

26-TF-78: Barren of palynomorphs. Mainly fusinitic and woody material.

Age: Indeterminate
Environment: Probable nonmarine

Undifferentiated Cretaceous

Locality 20

2-WL-78: Poorly preserved indeterminate spores? (R).

Age: Indeterminate
Environment: Probable nonmarine

11-WL-78: *Spinidinium vestitum* sp. (F).

Age: Early Cretaceous (Albian)
Environment: Marginal marine

14-WL-78: Undifferentiated bisaccates (F), *Tsuga* sp. (R), *Ornamentifera echinata* (single).

Age: Cretaceous (probable Albian)
Environment: Probable nonmarine

20-WL-78: Undifferentiated bisaccate (R), probable surface contaminant: *Alnus* sp. (R).

Age: Indeterminate
Environment: Probable nonmarine

Table 6. (cont.)

Undifferentiated Cretaceous (cont.)

22-WL-78: Probable surface contaminants: *Sphagnum* sp. (R), *Laevigatosporites* sp. (R).

Age: Indeterminate
Environment: Probable nonmarine

23-WL-78: *Spinidinium vestitum* sp. (R).

Age: Early Cretaceous (Albian)
Environment: Marginal marine

Locality 21

26-WL-78: Undifferentiated bisaccates (C), *Deltoidospora* sp. (R), *Appendicisporites* sp. (single), *Spinidinium vestitum* sp. (R), *Deflandrea?* sp. (R).

Age: Early Cretaceous (Albian)
Environment: Marginal marine

29-WL-78: *Aequitriradites spinulosus* sp. (single), *Appendicisporites* sp. (single), *Cicatricosisporites* sp. (single), *Spinidinium vestitum* sp. (R).

Age: Early Cretaceous (Albian)
Environment: Marginal marine

33-WL-78: Undifferentiated bisaccates (C), *Cicatricosisporites* sp. (single), *Spinidinium vestitum* sp. (R), *Deflandrea?* sp. (R), *Cribroperidinium edwardsi* (single).

Age: Early Cretaceous (Albian)
Environment: Marginal marine

Locality 22

35-IP-78: Undifferentiated bisaccates (R), *Osmundacidites* sp. (R), poorly preserved indeterminate spores (F).

Age: Indeterminate
Environment: Probable nonmarine

38-IP-78: Poorly preserved indeterminate spores (R).

Age: Indeterminate
Environment: Probable nonmarine

41-IP-78: Undifferentiated bisaccates (R), *Lycopodiumsporites* (R), poorly preserved indeterminate spores (F).

Age: Indeterminate
Environment: Probable nonmarine

46-IP-78: Undifferentiated bisaccates (R).

Age: Indeterminate
Environment: Probable nonmarine

51-IP-78: Undifferentiated bisaccates (R).

Age: Indeterminate
Environment: Probable nonmarine

Table 6. (cont.)

Undifferentiated Cretaceous (cont.)

55-IP-78: Undifferentiated bisaccates (R), poorly preserved indeterminate spores (F).

Age: Indeterminate
Environment: Probable nonmarine

61-IP-78: *Deltoidospora* sp. (R).

Age: Indeterminate
Environment: Probable nonmarine

Locality 23

68-IP-78: Undifferentiated bisaccates (R), poorly preserved indeterminate spores (R).

Age: Indeterminate
Environment: Probable nonmarine

Locality 24

65-IP-78: Undifferentiated bisaccates (C), *Osmundacidites?* sp. (R), *Deltoidospora?* sp. (R). *Odontochitina operculata?* sp. (R), poorly preserved.

Age: Possibly Cretaceous
Environment: Possible marine

Undifferentiated Tertiary

Locality 1

39-GB-78: Probable surface contaminant: *Laevigatosporites* sp. (R).

Age: Indeterminate
Environment: Indeterminate

Locality 9

33-GB-78: Undifferentiated bisaccates (A), *Tsuga* sp. (A), *Lycopodiumsporites* sp. (R), *Laevigatosporites* sp. (R), *Alnus* sp. (A), *Betulaceae* sp. (F), *Boisduvalia* sp. (single).

Age: Neogene
Environment: Nonmarine

Table 7. *Petrographic data*

Locality	Sample	Rock type	Framework clast composition: Quartz and chert (%)	Feldspar (%)	Rock fragments and pseudomatrix (%)	Authigenic material (%)	Paragenesis of authigenic phases	Remarks
					Gemuk Group			
18	13-IP-78	Fine to medium sandstone	- -	24	76	24	Iron oxide, laumontite	Pseudomatrix; laumontite is replacement.
19	43-JM-78	Very fine sandy mudstone	2	13	85	- -	- -	Pseudomatrix; weakly foliated.
	85-WL-78	Medium to coarse sandstone	6	21	73	17	Clay, zeolite	Pseudomatrix.
28	21-IP-78	Fine sandstone	4	33	63	2	Clay	Pseudomatrix.
	Average		3	22.75	74.25	10.75		
					Shaktolik Group			
7	11-GB-78	Medium sandstone	23	34	43	11	Carbonate, clay, quartz	Ductile grain deformation; carbonate is replacement.
11	27-GB-78	Medium sandstone	68	17	15	2	Carbonate	Ductile grain deformation; carbonate is replacement.
12	22-GB-78	Very fine to fine sandy limestone	51	26	23	56	Carbonate	Carbonate is largely replacement.
15	52-GB-78	Fine to coarse sandstone	6	31	63	17	Iron oxide, clay, laumontite	Ductile grain deformation; weakly foliated; clay and laumontite are replacements and cements.
	Average		37	27	36	21.5		
					Kuskokwim Group			
25	24-JM-78	Calcareous medium to coarse sandstone	29	11	60	9	Carbonate	Ductile grain deformation; carbonate is sparry cement.
	28-JM-78	Medium to coarse sandstone	20	15	65	8	Clay, quartz	Ductile grain deformation.
	5-TF-78	Very fine sandstone	24	8	68	<1	Clay, quartz	Ductile grain deformation; weakly foliated.
	16-TF-78	Medium sandstone	31	7	62	<1	Clay, quartz	Ductile grain deformation.
	49-WL-78	Calcareous medium to coarse sandstone	9	23	68	17	Carbonate, clay	Ductile grain deformation; carbonate is replacement and sparry cement.
	Average		22.6	12.8	64.6	7		
					Undifferentiated Cretaceous			
14	18-IP-78	Fine to coarse sandstone	6	20	74	6	Carbonate, clay, quartz	Ductile grain deformation; carbonate and clay are replacements.
20	5-WL-78	Medium to very coarse sandstone	3	16	81	16	Clay	Ductile grain deformation.
21	30-WL-78	Calcareous medium to coarse sandstone	17	25	58	33	Carbonate	Ductile grain deformation; carbonate is sparry cement and replacement.
22	42-IP-78	Fine sandy limestone	37	7	56	73	Carbonate	Carbonate is sparry cement and replacement.
	52-IP-78	Calcareous very fine to medium sandstone	7	18	75	15	Clay, carbonate	Ductile grain deformation; carbonate is sparry cement and replacement.
	Average		14	17.2	68.8	28.6		
					Undifferentiated Tertiary			
9	34-GB-78	Silty to medium sandy limestone	73	3	24	66	Carbonate	Carbonate is sparry cement.
	35-GB-78	Fine sandstone	70	9	21	16	Carbonate, chlorite, quartz	Ductile grain deformation except in carbonate-cemented areas; carbonate cement is sparry.
	Average		71.5	6	22.5	41		

STAFF

Ross G. Schaff, State Geologist

W.W. Barnwell and W.G. Gilbert, Deputy State Geologists

D.D. Adams, Geological assistant
M.D. Albanese, Geological assistant
R.D. Allely, Geological assistant
M.A. Armstrong, Publications specialist
M.R. Ashwell, Minerals laboratory technician
B.G. Baldwin, Clerk typist
E.E. Becia, Planner
T.A. Benjamin, Chemist
D.L. Bertossa, Geological assistant
J.M. Bird, Clerk-typist
M.E. Brown, Land management officer
T.K. Bundtzen, Geologist
C.D. Burgess, Clerk-typist
L.E. Burns, Geological assistant
S.J. Carrick, Hydrologist
S.L. Chambers, Clerk-typist
M.S. Christy, Geologist
R.A. Clay, Hydrologist
J.G. Clough, Geological assistant
E.J. Collazzi, Geological assistant
R.A. Combellick, Geologist
P.L. Coonrod, Secretary
N.W. Crosby, Operation's research analyst
C.L. Daniels, Publications specialist
N.L. Dann, Clerk-typist
J.N. Davies, Geologist
L.L. Dearborn, Hydrologist
J.E. Decker, Geologist
J.T. Dillon, Geologist
R.G. Dixon, Archaeologist
G.R. Eakins, Geologist
S.V. Garbowski, Geologic information technician
D.E. Gibson, Archaeologist
J.J. Hansen, Geophysicist
S.B. Hardy, Geological assistant
M.W. Henning, Geologist
B.S. Hurtig, Systems analyst
C.E. Holmes, Archaeologist
M.G. Inghram, Hydrologist
R.W. Ireland, Geologist
S.A. Jacques, Cartographer
J.T. Kline, Geologist
S.L. Klingler, Archaeologist
R.W. Kornbrath, Geologist
K.J. Krause, Geologist
D.L. Krouskop, Geophysicist
G.M. Laird, Cartographer
E.M. Lamey, Administrative assistant
G.E. LaRoche, Geological assistant
F.L. Larson, Publications specialist
T.A. Little, Geologist
W.E. Long, Hydrologist
W.M. Lyle, Geologist
C.L. Mahan, Accounting technician
R.A. Mann, Clerk
G.D. March, Geologist
M.A. Maurer, Hydrologist
G.A. McCoy, Hydrologist
D.L. McGee, Geologist
R.D. Merritt, Geologist
J.F. Meyer, Geophysicist
G.W. Mishler, Archaeologist
W.H. Mitchell, Jr., Geological assistant
M.A. Moorman, Geologist
R.J. Motyka, Geologist
C.G. Mull, Geologist
J.A. Munter, Hydrologist
D.J. Mursch, Clerk-typist
J.N. Newgaard, Accounting technician
C.R. Nichols, Geologist
K.S. Pearson, Cartographer
G.H. Pessel, Geologist
F.H. Pitts, Administrative officer
M.K. Polly, Mineral laboratory technician
M.E. Pritchard, Cartographer
S.E. Rawlinson, Geologist
J.W. Reeder, Geologist
D.R. Reger, Archaeologist
R.D. Reger, Geologist
V.L. Reger, Clerk-typist
M.S. Robinson, Geologist
L.C. Schell, Cartographer
R.D. Shaw, Archaeologist
J.A. Sigler, Clerk
T.E. Smith, Geologist
T.N. Smith, Geologist
D.J. Solie, Geologist
D.R. Stein, Chemist
R.O. Stern, Archaeologist
C.H. Stevenson, Geologic information technician
M.J. Stroebele, Clerk-typist
A.G. Sturmann, Drafting technician
R.W. Stuvek, Land management technician
B.A. Syvertson, Clerk-typist
C.A. Ulery, Geological assistant
R.G. Updike, Geologist
N.C. Veach, Chemist
R.D. Wallace, Operations research analyst
J.L. Weir, Clerk-typist
S.M. Weum, Geophysicist
D.M. Wietchy, Land management officer
B.K. Wilson, Geological assistant
M.A. Wiltse, Chemist
G.M. Zartman, Clerk