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HYDROCARBON POTENTIAL OF THE LOWER KUSKOKWIM RIVER AREA, YUKON-KUSKOKWIM DELTA, SOUTHWEST ALASKA

by

C.G. Mull, T.K. Bundtzen, and R.R. Reifenstuhl

August 1995

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By C. G. Mull, T.K. Bundtzen, and R.R. Reifenstuhl

ABSTRACT

Regional geologic mapping and geophysical surveys in western Alaska indicate that the Yukon-Kuskokwim delta area is underlain by a thin section of non-marine Tertiary rocks that unconformably overlie a thick section of the Cretaceous Kuskokwim Group, which consists dominantly of graywacke deposited as turbidites in a basin adjacent to active orogenic uplifts. Basement rocks consist of pre-Cretaceous metasedimentary and meta-igneous rocks. Both the Kuskokwim Group and the basement rocks are intruded by numerous small mafic igneous intrusive bodies of Tertiary age. In the upland areas that flank the Yukon-Kuskokwim delta area, the Kuskokwim Group and basement rocks are intensely deformed by thrust faults and major regional strike-slip faults; much of this deformation probably occurred during the early Tertiary.

A detailed airborne magnetic survey of an 1,800 sq. mi. area in the lower Kuskokwim River area southwest of Bethel suggests that the rocks in the subsurface beneath that part of the Yukon-Kuskokwim delta are similar to those in the exposed upland areas. Magnetic basement in the project area ranges from about 14,000 to a depth of about 28,000 feet. The most prominent features on the map are a large number of relatively high amplitude circular to linear magnetic anomalies that probably represent small extrusive bodies and plug-like intrusions and dikes that rise to within 1,300 ft of the surface and intrude the Cretaceous and basement rocks. The magnetic data suggest a number of high angle faults that appear to break the area into a series of uplifted and downdropped horst and graben type blocks; five anticlinal uplifts cut by intrusions are also interpreted. In addition, four weak anomalies or "structural disturbances" of unknown origin are mapped.

Geochemical data from outcrops in the flanking upland areas and from the deep Napatuk Creek #1 well in the Kuskokwim delta area show that the Tertiary and Cretaceous rocks have a relatively small amount of total organic matter that is dominantly cellulosic, these rocks are classified as weak gas source or nonsource rocks. Neither the Tertiary nor the Cretaceous rocks have any appreciable amount of amorphous kerogen and they are not considered to be oil-prone source rocks. The thin Tertiary section is thermally immature, and the small amount of organic material contained in it is not a source of thermogenic gas. Regional thermal effects from the orogenic events and from the igneous intrusions have affected all of the Cretaceous sedimentary section. In the Napatuk Creek well, the Cretaceous rocks are thermally mature for generation of oil to about 5,000 ft, and for generation of thermogenic gas to about 9,000 feet. The deeper part of the Cretaceous section in the well is thermally overmature.

The Cretaceous rocks are composed of abundant volcanic rock fragments and other ductile grains and contain abundant clay matrix and calcareous cement. This results in low porosity and permeability, and the Cretaceous section is considered to have little reservoir potential. In contrast to the Cretaceous, the thin Tertiary section is undercompacted; the sandstones may have porosity but lack effective seals for hydrocarbon traps.

Evaluation of the geology in the lower Kuskokwim River area suggests that the probability of occurrence of small gas or oil accumulations is low. Exploration for small hydrocarbon traps in the area will require acquisition of reflection seismic data and drilling of exploratory wells. The high cost of exploration, combined with the adverse geological factors render the lower Kuskokwim River area a risky exploration objective for either gas or oil.

INTRODUCTION

The hydrocarbon potential of the Yukon-Kuskokwim delta area in southwestern Alaska has been of interest for many years, beginning with the 1957 discovery of commercial hydrocarbons on the Kenai Peninsula in southcentral Alaska. Recognition of the presence of oil and gas in lowland areas in Alaska led to immediate investigation of other apparent depositional basins in Alaska, including the Yukon-Kuskokwim delta. This modern delta is composed entirely of Quaternary alluvial sediments mantled by tundra and innumerable shallow lakes. A few bedrock exposures of Tertiary igneous rocks rise above the tundra and Quaternary cover in the western part of the delta, but most of the delta area contains no bedrock exposures. The interpretation of the subsurface geology in the lower Kuskokwim River area is thus based upon extrapolation of mapping data from adjacent mountain areas both southeast and northwest of the delta, from geophysical profiling, and from a deep exploratory well drilled 70 miles west of Bethel. The southwestern part of the Yukon-Kuskokwim delta in the vicinity of Bethel is commonly referred to as the "Bethel Basin", implying an area of relatively thick sediment deposition. However, evaluation of the regional geology of western Alaska discussed in this report suggests that the term "Bethel Basin" is a misnomer; the term is not used here beause it conveys erroneous implications concerning the thin Tertiary sediments in the area.

Scientific exploration of the geological framework of the lower Kuskokwim River area of western Alaska began with work by the U.S. Geological Survey (USGS) in the late 1890's (Spurr, 1900) and has continued sporadically to the present day with work by the USGS (Cady and others, 1955; Hoare, 1961; Miller and Bundtzen, 1994) and the Alaska Division of Geological and Geophysical Surveys (DGGS) (Bundtzen and Laird, 1991; Bundtzen and others, 1992; Bundtzen and Gilbert, 1993).

The early surface geological studies by the USGS in the Yukon-Kuskokwim area were augmented by airborne magnetic profiles (Dempsey and others, 1957) and by reconnaissance gravity data acquired in 1967, 1973, and 1977 (Barnes, 1977). Hydrocarbon exploration by major oil companies began in the Yukon-Kuskokwim delta area in the early 1960's and reconnaissance surface geologic studies in western Alaska are known to have been conducted by several major oil companies, including Shell Oil Company, Amoco Production Company, and Atlantic Richfield Company. Based upon reconnaissance geology and the USGS airborne magnetic profiles, a deep unsuccessful exploratory well, Napatuk Creek #1, was drilled to a depth of 14,890 feet in 1961 by PanAmerican Petroleum Company (now Amoco).

In the 1970's, reconnaissance reflection seismic surveys were carried out by at least two companies (Shell Oil Company and Atlantic Richfield Company), and a gravity survey and magnetotelluric survey in the Bethel area was conducted by Shell Oil Company in conjunction with its seismic survey. Mobil Oil Company is also reported to have carried out a reconnaissance gravity survey (D.P. Barnes, oral communication, 1995). In the 1980's, the USGS, as part of its National Uranium Evaluation Program (NURE), flew a more detailed airborne magnetic survey in the area.

Continued interest in hydrocarbon exploration in some of the relatively unexplored areas of Alaska has resulted sporadically in additional studies by the oil industry aimed at further evaluation of the hydrocarbon potential of the Yukon-Kuskokwim delta region of western Alaska. This has included geochemical and paleontologic analyses of drill cuttings from the Napatuk Creek well. Analysis of the available data from the exploration in western Alaska has resulted in assessments by the U.S. Geological Survey and Minerals Management Service suggesting that the Yukon-Kuskokwim area and other interior basins of Alaska, as well as the adjacent offshore areas in the Bering Sea have relatively low potential for the occurrence for major hydrocarbon accumulations (Dolton and others, 1981; Mast and others, 1989; Magoon and Kirschner, 1990. A regional appraisal of the petroleum potential by Powers (1993) estimated fair

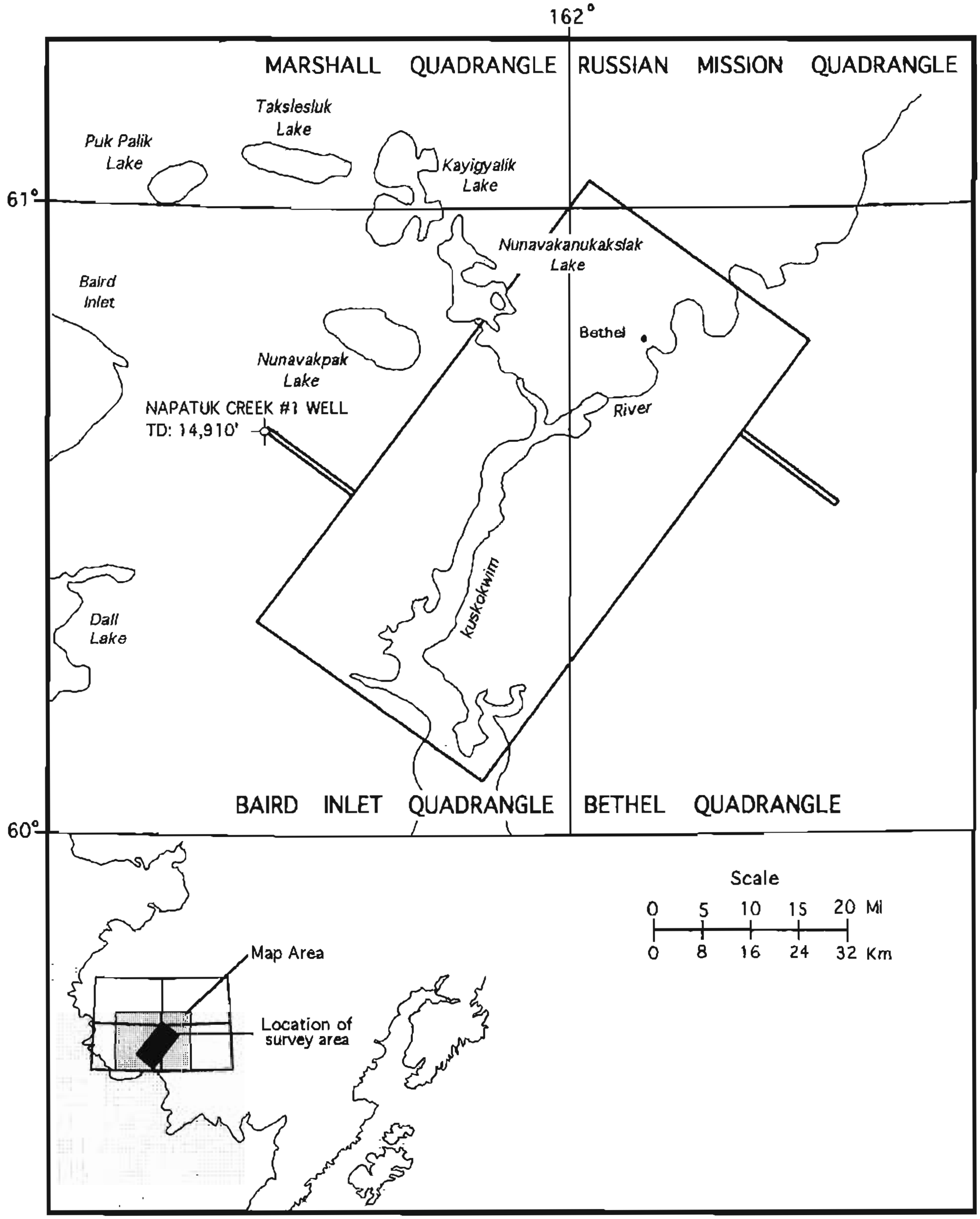


Fig. 1. Index map to the lower Kuskokwim River showing area of 1994 airborne magnetic survey.

to good gas potential in the Tertiary basins of Alaska for local usage, but this appraisal is not applicable to the lower Kuskokwim River area.

The need for more economical energy supplies in remote areas of western Alaska has resulted in continued interest in the evaluation of the potential for small natural gas accumulations that might be of significance if located close to remote communities. The Calista Corporation has acquired geological and geophysical data from public agencies and industry sources and has continued interest in exploration for natural gas in the lower Kuskokwim River area. The available gravity and airborne magnetic data were combined in 1992 for an interpretation of depth to basement and an evaluation of the hydrocarbon potential of the Bethel Basin in an unpublished undated report by Earthfield Technology, Inc. to Calista Corporation.

In 1994 the Alaska Department of Community and Regional Affairs funded a detailed aeromagnetic study of an 1,800 mi^2 area of the lower Kuskokwim River area (fig. 1) in a contract administered by the Alaska Department of Natural Resources, Division of Geological and Geophysical Surveys. The data, maps, and interpretations resulting from this survey have been prepared and discussed by Geonex Aero Surveys (1994, 1995a, and 1995b).

The report that follows summarizes and discusses the available surface and subsurface geological data and and integrates those data with the results of the aeromagnetic survey. It provides an updated discussion of the potential for occurrence of small gas accumulations that might be developed as a local energy source in the lower Kuskokwim River area. This appraisal is a subjective evaluation of the hydrocarbon potential of the area based upon the regional geological and geophysical data and the detailed geophysical data. No numerical assessments or computer simulations of resource potential have been made using these data

REGIONAL GEOLOGIC FRAMEWORK

Rock units flanking the Bethel Basin area of southwestern Alaska are broadly subdivided into three groups by age and history: 1) Pre-accretionary, Proterozoic-to-Paleozoic continental margin rocks; 2) pre- and syn-accretionary mainly Mesozoic rocks of northern Bristol Bay and Kilbuck Mountains; and 3) post-accretionary, sedimentary overlap assemblages and volcanic and plutonic rocks (fig. 2). The pre-accretionary rocks can be further subdivided into rocks of: 1) terranes of continental or 'cratonal' affinity; 2) oceanic crust or subduction zone complexes; 3) island arc and related flyschoid sequences; and 4) syn-accretionary granitic plutons of the Nyac suite.

Terranes of continental or cratonal affinity include the Early Proterozoic Kilbuck and Idono terranes (Box and others, 1990; Miller and others, 1991), the Early Paleozoic to Triassic Farewell, Pingston, and Yukon-Tanana terranes (Bundtzen and Gilbert, 1983; Decker and others, 1994), and the Proterozoic(?) and Paleozoic Ruby terrane (Patton, 1978; Patton and others, 1984). These oldest rocks form fault-bounded belts that lie both northwest and southeast of the Bethel and Yukon-Kuskokwim delta area and are mapped as undifferentiated basement metamorphic rocks on figure 2.

Oceanic terranes and subduction complexes include the Devonian to Upper Jurassic Innoko and Angayucham terranes, which are complex ophiolite-chert-basalt complexes; and the Ordovician to Upper Jurassic Goodnews terrane subduction complex (Bundtzen and Miller, in press). These discontinuously outcropping terranes contain many magnetically suseptible, mafic volcanic and mafic-ultramafic intrusive rocks.

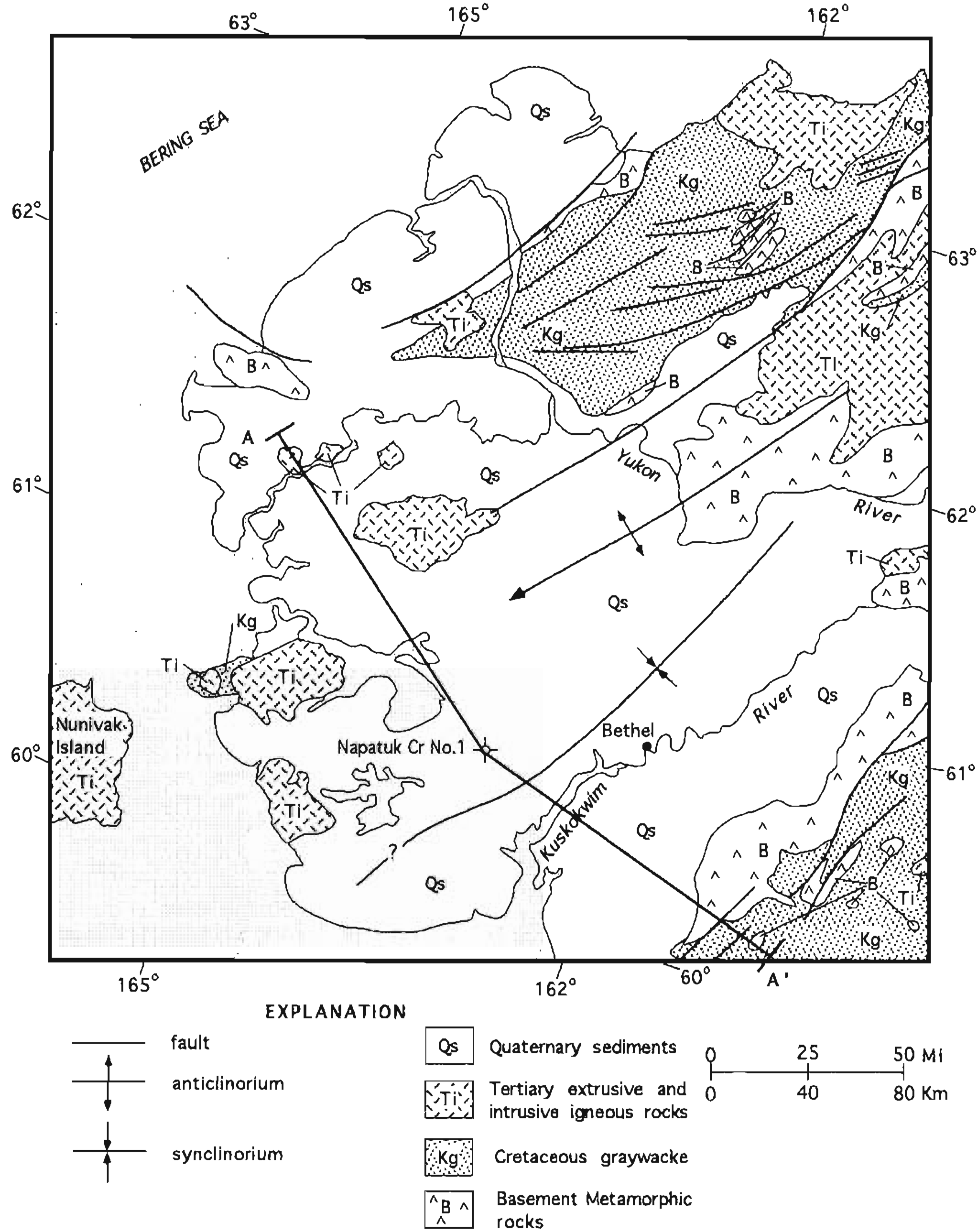


Fig. 2. Generalized geologic map of the Yukon-Kuskokwim delta area, modified from map by Kirschner, 1988. A-A' – line of cross section.

Island arc and related flysch deposits, which flank the Bethel area, include :1) the Koyukuk and enigmatic Portage terranes, which are Permian to Lower Cretaceous andesite tuff-dominated sequences exposed on the lower Yukon and Kuskokwim Rivers respectively; 2) the Jurassic to Cretaceous Nyac terrane, a andesite to basaltic andesite dominated section exposed in the Kilbuck Mountains, immediately east of the Bethel area; 3) the Togiak terrane, composed of Triassic to Lower Cretaceous volcanic and epiclastic rocks mainly exposed southwest of the Bethel area; and 4) the Kahiltna terrane, a turbidite dominated section exposed further to the southeast in the Mulchatna-Nushagak Rivers basins. These arc-related rocks--particularly the Nyac and Koyukuk-Portage terranes--probably form much of the basement in the Bethel and Yukon-Kuskokwim delta area since they strike more-or-less into the area from both the southwest and northeast. .

The fault-bounded pre-Cretaceous rocks are depositionally overlain by Cretaceous clastic rocks and subaerial volcanic rocks (fig. 2), and by Tertiary fluvial deposits that are not exposed in the lower Kuskokwim River area. In addition a wide variety of plutonic rocks intrude both the pre-Cretaceous terranes as well as the post-accretionary overlap assemblages.

The oldest overlap (post-accretionary) assemblage is a distinctly tuffaceous sandstone-siltstone sequence that probably correlates with rocks in the Yukon-Koyukuk basin north of the Bethel area (Patton and Box, 1989). These rocks are regarded as Early Cretaceous on the basis of Hauterivian to Barremian palynomorphs found in rocks in the Iditarod and Holycross quadrangles, and generally occur northwest of the main Kuskokwim Group rocks. The stratigraphic relationships between the rocks of the Yukon-Koyukuk Group and Kuskokwim Group to the southeast are unclear; two stages of the Cretaceous (Aptian and Albian), which span about 17 million years, apparently separate the time of deposition of the two groups.

Flysch dominated sedimentary rocks of the Upper Cretaceous Kuskokwim Group (Cady and others, 1955) dominate the post-accretionary bedrock units southeast of the Bethel area, , and probably underlies a large portion of the Yukon-Kuskokwim delta area. Age assignment of the Kuskokwim Group is based on a number of mainly Turonian mollusc collections throughout the central parts of the basin; a few Cenomanian, Coniacian, and Santonian fossils have also been recovered elsewhere. The Kuskokwim Group is a regionally extensive, basin-fill sequence that covers about 75,000 km^2 of southwest and west-central Alaska. The Kuskokwim Group consists primarily of marine turbidites deposited in a northeast trending elongate, fault-controlled basin; subordinate shallow-marine and fluvial strata were deposited along the margins of the basin (Bundtzen and Gilbert, 1983; Miller and Bundtzen, 1994; Box and others, 1993). Basinal turbidites, which consist of interbedded sandstone, siltstone, shale, and minor conglomerate (Facies A to E of Mutti and Ricci Lucchi, 1978) constitute the major part of the Kuskokwim Group. The sandstones are lithic rich and locally contain metamorphic, plutonic, sandstone, chert, limestone, and volcainic rock fragments. Nearly all of the sandstones contain abundant metamorphic and plagioclase feldspar grains, but some thin sections are notably rich in chert, limestone, and variable volcanic clasts suggesting variable source terranes (Miller and Bundtzen, 1994). Detrital modes can vary markidly both over short geographic distances and through stratigraphic intervals, making regional provenance correlations difficult. However it is clear that chert, limestone, metamorphic, and volcanic rocks were emergant at the time of Kuskokwim Group deposition.

The uppermost part of the Kuskokwim Group consists of relatively clean, quartzose sandstone, cross-stratified sandstone and siltstone, finely laminated shale, local leaf-rich beds, and minor coquina composed of brakish-to-nonmarine bivalves. Field relationships identified in the McGrath, Iditarod, and Medfra quadrangles northeast of the Bethel area strongly suggest that the quartz-rich upper section successively overlaps the basinal turbidite-dominated rocks in the form of an upward marine regression (Miller and Bundtzen, 1994; Bundtzen and others, 1992;

Patton and Box, 1989). Very minor, volcanic flows and tuffs of mainly intermediate compositionare interbedded in the shallow water quartz-rich facies of the Kuskokwim Group (Miller and Bundtzen, 1994).

The thickness of the Kuskokwim Group is poorly constrained. Cady and others (1955) believed that the Kuskokwim Group along the lower Kuskokwim River was over 15,000 meters thick, but recent geologic mapping has shown much of this 'type section' is repeated by overturned folds and thrust faults. Miller and Bundzen (1994) estimate a thickness of about 5,000 meters for the Kuskokwim Group in the central Iditarod quadrangle. Nearer the basin margin, the thickness is estimated to range from 2,100 to 2,400 meters. .

Granitic complexes of mid-Cretaceous age intrude pre-Cretaceous rocks in the Nyac area east of the Bethel area. These rocks are, in part, the lode source for extensive placer gold deposits mined there continuously since the early 1900's. Hornfels aureoles ranging from 1 to 2 km wide surround the granitic complexes of the Nyac area.

Volcano-plutonic complexes and granite porphyry dike and sill swarms of Late Cretaceous to early Tertiary age intrude and overlie the Kuskokwim Group and older lithologies. The best exposed and largest complexes include the Beaver, Russian, and Horn Mountains--the latter two of which crop out about 40 km northeast of the Bethel area--but many smaller bodies that range from 3 to 40 km^2 occur thoughout the Kuskokwim Mountains and undoubtedly occur in the Yukon-Kuskokwim delta area as well. The age of the volcano-plutonic complexes and granite porphyry sill swarms has been fairly well constrained to the time period 58-to-77 Ma (Miller and Bundtzen, 1994). The plutonic components of the complexes normally produce extensive hornfels aureoles ranging from the albite-epidote to hornblende hornfels metamorphic facies. The lateral extent of the hornfels aureoles from high-angle plutonic contacts normally ranges from 1 to 3 $km^{2,}$ however, much larger 100 km^2 hornfels zones frequently cap buried intrusions in the Iditarod and McGrath quadrangles northeast of the Bethel area.

Younger 5 to 45 Ma mafic volcanic rocks overlie the older rock units of southwest Alaska. These are mainly part of an extensive alkali-olivine basalt province best exposed in the St. Michaels and Nunivak Island areas; a 6 Ma old basalt plateau intrudes and overlies the Nixon Fork-Iditarod fault system northeast of Aniak (Bundtzen and Laird, 1991)

Regional structure of the lower Kuskokwim River area

Numerous high angle faults parallel the general northeast-trending structural grain of southwest Alaska. The most prominant among these include the Iditarod-Nixon Fork, Denali-Farewell, Goodnews, and Susalatna Faults ; many smaller high angle faults are not shown. Several workers suggest that about 88-to-92 km and 120 km of right lateral offsets have occurred along the Iditarod-Nixon and Denali-Farewell segments respectively since Late Cretaceous time. The Kanektok thrust fault displaces oceanic rocks of the Goodnews terrane over the high grade rocks of the Kilbuck terrane south of the Bethel area. Smaller thrust faults have been mapped displacing basinal turbidites over shallow water facies of the Kuskokwim Group.

Rock units have been deformed by folds as well as faults. Miller and Bundtzen (1994) and Box and others (1993) have both shown that pre-Tertiary rocks have been deformed by at least two periods of folds. The older period is marked by open to isoclinal, locally overturned folds with amplitudes ranging from 2-to-3 km and with generally northeast trending axes. The younger event refolds the northeast trending synclines and anticlines into broad, regional scale folds with amplitudes ranging from 20 to 40 km.

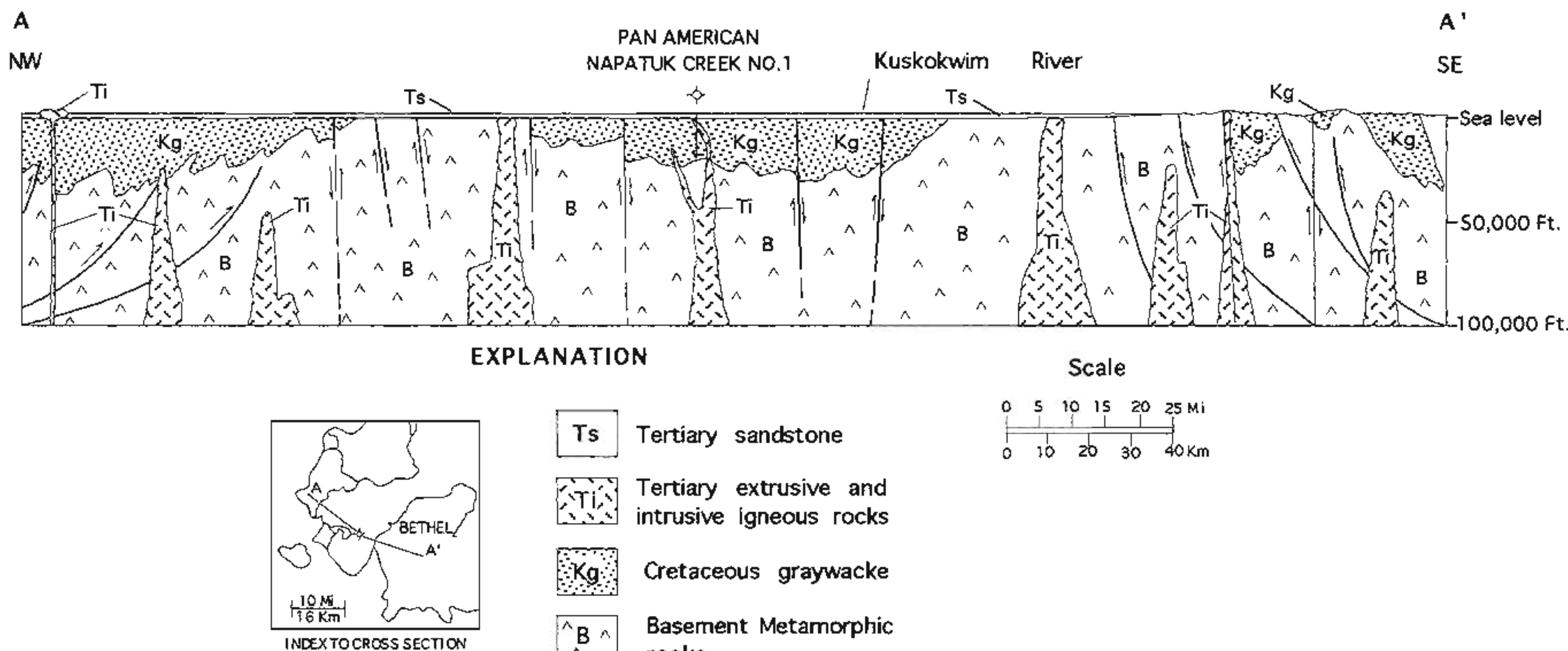


Fig. 3. Generalized cross section of Kuskokwim delta area, modified from section by C.M. Molenaar, Shell Oil Company, 1962. Gentle deformation in area of Napatuk Creek No. 1 well is indicated by poor seismic data and low dips in well. Structure in deformed belts to northwest and southeast is much more complex than shown. Thin Quaternary sediments not shown.

Structural elements mapped in the Bethel area can be explained within the framework of wrench-fault tectonics (Miller and Bundtzen, 1994). Two primary patterns observed in the area are the main wrench faults themselves (such as the Iditarod-Nixon Fork fault) and and en echelon folds with axial traces inclined toward the faults (Wilcox and others, 1973). Right-lateral wrench faults produce right-handed folds throughout the basin area. Local zones of extension and contraction can form along the strike-slip faults as the result of curvature along the faults. Hence, strike-slip tectonics explains not only structural setting, but basinal formation especially in post-accretionary time. The Kuskokwim Group was deposited in an elongate, probably strike-slip basin beginning in Late Cretaceous time. The basin probably continued to deepen while infilling took place. As the subsidence rate declined, the basin filled and the marine turbidites yielded upward to shallow water marine and nonmarine rocks. By latest Cretaceous time, compression led to formation of en- echelon folds followed by strike-slip faulting, which in turn led to both extensional and compressional stresses, depending on whether fault movement was convergant or divergant at the time. Emplacement of volcano-plutonic complexes, volcanic fields, and perhaps localization of the Tertiary deposition probably took place during intermittant periods of extension in the area of the lower Kuskokwim River. .

The inferred structural style of the lower Kuskokwim River area near Bethel is illustrated in figure 3, generalized from a diagrammatic cross section by C.M. Molenaar (Shell Oil Company, unpublished data, 1976). The area of the Napatuk Creek well is thought to be in a relatively undeformed part of a Cretaceous depositional basin flanked by opposing fold and thrust belts that severely deformed other parts of the basin. High angle faults within the relatively undeformed part of the basin are interpreted to be strike-slip faults related to the regional wrench faults discussed above.

SUBSURFACE GEOLOGY

Direct knowledge of the subsurface geology in the lower Kuskokwim River area is known from the results of the Napatuk Creek well. Drill data and logs from the well are on file with the Alaska Oil and Gas Conservation Commission, and copies are available from Riley's Data Share[1]. Paleontologic and geochemical analyses performed by industry on drill cuttings from the Napatuk Creek well are available from the Geologic Materials Center of the Alaska Division of Geological and Geophysical Surveys. (DGGS). Reports prepared on contract for the Calista Corporation, and additional industry interpretative data are on file and available for examination atCalista Corporation[2], and at DGGS.

Napatuk Creek #1

The Napatuk Creek #1 well (fig. 1) was drilled in 1961 to a depth of 14, 890 ft. by Pan American Petroleum Corporation (now AMOCO Petroleum). The well penetrated a sedimentary section consisting dominantly of sandstone and interbedded siltstone and shale with minor amounts of carbonaceous material; one thin interval of basaltic igneous rock was encountered. No visible hydrocarbon shows were noted in the drill cuttings, but no mud log to test for hydrocarbons in the drilling mud was run during the drilling of the well. Three drill stem tests recovered no hydrocarbons.

[1] 4608 N. Harvey Avenue, Oklahoma City, Oklahoma 73101. Phone (405) 848-4407.

[2] 601 W. Fifth Avenue, Suite 200, Anchorage, Alaska 99501)

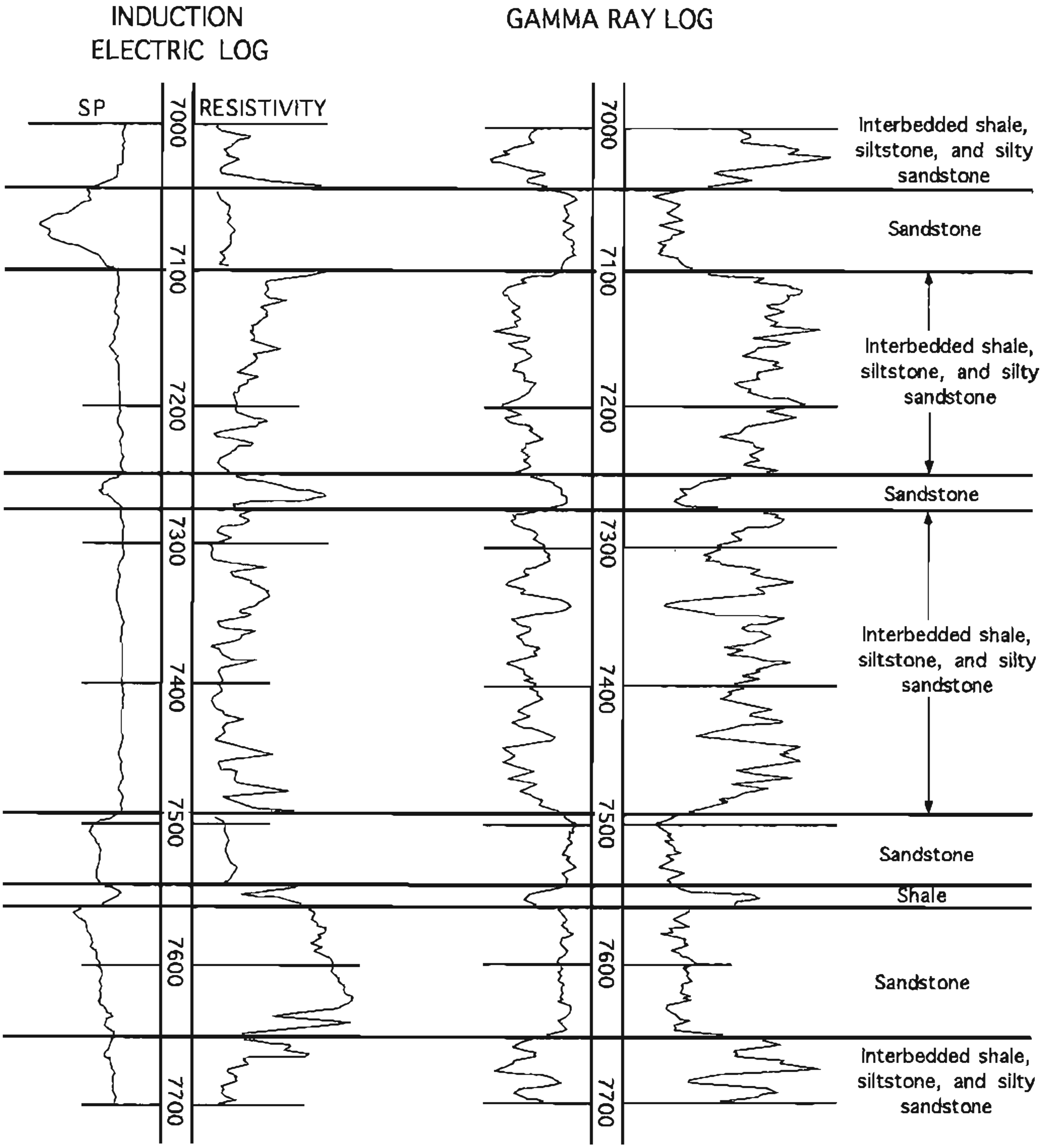


Fig. 4. Induction electrical log and gamma ray log of interbedded Cretaceous sandstones and shales at 7,000 ft. to 7,700 ft. in Napatuk Creek No. 1 well. Thinly interbedded shale, siltstone, and sandstone in interval 7,100 ft. to 7,480 ft. is characteristic of most of the Cretaceous section.

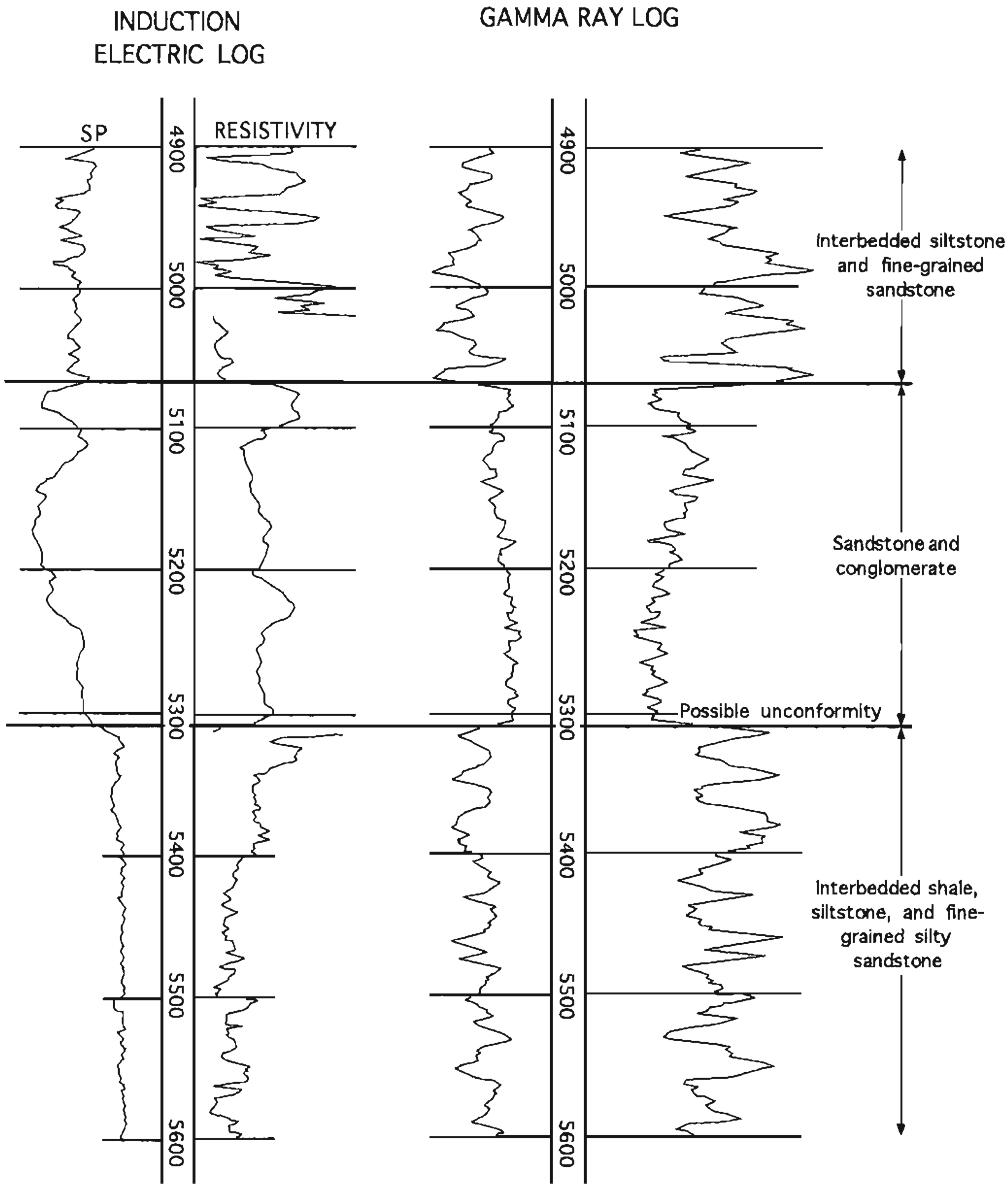


Fig. 5. Induction electrical log and gamma ray log of interval 4,900 ft. to 5600 ft. in Napatuk Creek No. 1 well showing thick Cretaceous sandstone and conglomerate unit overlying possible unconformity at 5,305 ft. Thinly interbedded shale, siltstone, and sandstones overlying conglomerate and sanstone are characteristic of most of the Cretaceous section in well.

Twelve cores were taken at intervals between 3,121 ft. and 14,472 ft.. Measurments made on bedding or apparent bedding observed in the cores suggest that the rocks encountered in the well are relatively flat lying. Core dips (Pan American Petroleum, unpublished report, 1962) are summarized below:

Core #3: 5,745–5,751 ft., 10° dip, rated as good.
Core #10: 13,029–13,044 ft., appears to be nearly flat dip.
Core # 11: 14,458–14,472 ft., appear to be flat dips.

Lithology

With the exception of one interval of igneous rock, the Napatuk Creek well penetrated an entirely clastic sedimentary section. The wire-line logs and drill cutting descriptions suggest that most of the section consists of interbedded sandstone, siltstone, and shale. The log character on the induction, sonic, and gamma ray logs suggests that most of the sandstones are relatively thin intervals that contain numerous shale and siltstone interbeds (fig. 4). A few 20 to 100 ft.-thick sandstone intervals between 5,000 ft. and 7,600 ft. consist of massive sandstone that apparently contains fewer fine-grained interbeds than elsewhere in the section (fig. 5). A 230 ft.-thick interval from 5,070 ft..to 5,305 ft. consists of massive sandstone and conglomerate that contains clasts of granite, metasediments, schist, and slate (Pan American Petroleum, unpublished data, 1962).

Sandstones throughout the well are gray to light-gray, very-fine to medium grained, poorly sorted, arkosic, and commonly micaceous graywacke with abundant clay matrix. A few coarse grained sandstones are present. To a depth of 4796 ft.samples are commonly described as carbonaceous with thin coaly stringers. Below 5300 ft. the sandstones contain lesser amounts of coaly material, but plant debris is apparently present, and shales and silts are commonly lignitic. Twelve cores were taken at intervals between 3121 and total depth at 14, 910; the sandstones in all these cores are described as tight, with very poor to no visible porosity (Pan American Petroleum, unpublished report, 1962). Core analysis of 11 samples from core #3 (3,121-3141 ft.) showed porosities ranging from 1.5% to a maximum of 8.5%, and permeability entirely <0.5md.

A short core was taken of the top of a 30 ft.-thick diabase sill encountered at 4796 ft.. Although no other diabase was noted in the sample descriptions, the log character suggests the possibility of thinner igneous bodies interbedded with sediments to a depth of 5070 ft., at the top of the thick massive conglomerate interval.

Examination of the wireline logs does not suggest that any of the sandstones in the well contain porosity. The induction (IES), sonic, and gamma ray logs show intervals at 5070-5095 ft., 7040-7100 ft.. and 7490-7545 ft. in which thick massive sandstones appear to lack shaly interbeds. However, the micro log does not indicate any zones of porosity even in these thicker sandstone intervals.

Petrology

A suite of 19 thin sections cut from cores taken from 11 cored intervals between 3121 and 14,910 ft. were examined and point counted by R.R. Reifenstuhl (Appendix 1). In the upper part of the well, the sandstones to a depth of 5760 ft. are poorly sorted lithic sandstone (fig. 6A). From 7518 to 14,890 ft., quartz and feldspar are more abundant, and the sands are generally moderately well sorted feldspatholithic or quartzose lithic sandstone (fig. 6B). In addition to quartz and feldspar, lithic rock fragments, volcanic rock fragments, chert, slate, and white mica are common in many of the samples. Abundant carbonate alteration is present in all of the rocks represented in the thin sections. Porosity throughout the samples examined is very low (<3%), and was reduced by a high percentage of ductile grains, mechanical compaction, and pressure solution.

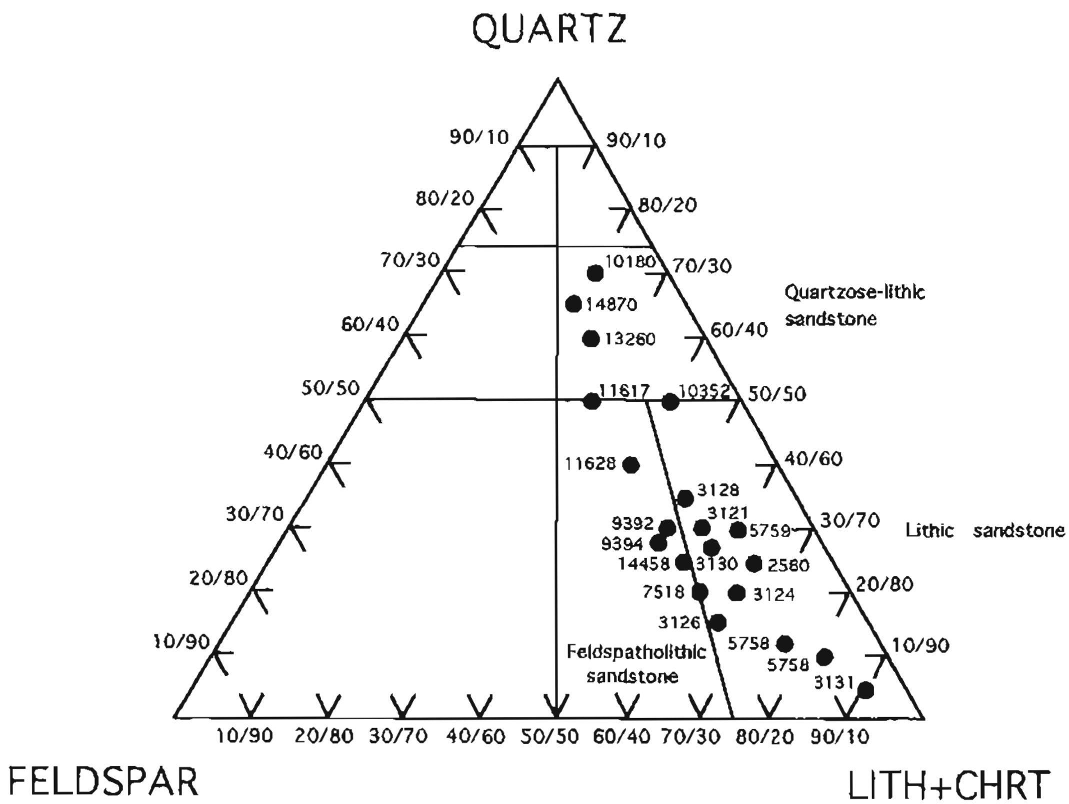


Fig. 7. Ternary diagram illustrating composition of compositionally immature sanstones in cores from Cretaceous rocks in Napatuk Creek No. 1 well. Petrography by R.R. Reifenstuhl. Lithic grains include abundant volcanic rock fragments and altered carbonate grains. Carbonate cement is abundant.

Point count data plotted on ternary QFL (quartz-feldspar-lithic) diagrams suggest that the rocks in the upper part of the well were derived from a volcanic source terrane (fig.7). In the lower part of the well, the rocks appear to have been derived to have been derived from a terrain that contained abundant granitic and low-grade metamorphic rocks.

Paleontology

Fossils recovered from the Napatuk Creek well suggest that the well penetrated about 2000 ft. of Tertiary rocks above a section of Cretaceous rocks that probably extends to the total depth of the well. Paleontologic data from the well is contained in unpublished reports by Mobil Oil Company, 1981, Dr. Hideyo Haga, Micropaleo Consultants Inc., 1994, and Dr. Robert Spicer, 1994. The dating from these reports is summarized below:

Palynology

Mobil Oil Company, unpublished report, 1981.

Depth	Age	Fossils
120–760 ft.	Pleistocene	Diatoms
760–1240 ft.	Pliocene	Diatoms
1,240–1,560 ft.	Late Miocene-Early Pliocene	Diatoms
1,560–2,040 ft.	Indeterminate	Indeterminate diatoms, marine
2,040–5,100 ft.	Lower to Upper Cretaceous,	(Barremian to Turonian), abundant spores
5,100–14,890 ft.	Indeterminate	Barren

Dr. Hideyo Haga, Micropaleo Consultants, Inc., oral communication, 1994.

2,040–5,100 ft.	Lower to Upper Cretaceous (Albian to Cenomanian)	Based upon evaluation of faunal list reported by Mobil Oil.

Paleobotany

Dr. Robert Spicer, Oxford University, oral communication to Dr. S.R. Box, 1994.

5,700 ft.	Late Cretaceous (Late Cenomanian-Turonian)	Plant fossils
5,800 ft.		
8,644 ft.		
8,651 ft.	Late Cretaceous (Late Cenomanian)	Plant fossils
8,676 ft.		
10,195 ft.		

Megafossils:

Pan American Petroleum Corp, unpublished report, 1962

10,204 ft.	Indeterminate age	Internal pelecypod mold
14,740–14,750 ft.	Probably Cretaceous	Inoceramus prisms

Discussion:

Although the palynology reports include forms that range into the Early Cretaceous, the occurrence of Late Cretaceous (Late Cenomanian) plant fossils at 10,195 ft.in the well suggest that the rocks at total depth are no older than late Early Cretaceous (Albian). These data indicate that the Cretaceous rocks in the Napatuk Creek well and in the adjacent parts of the Bethel area are correlative with the Kuskokwim Group of Late Cretaceous age.

Geochemistry

The hydrocarbon source rock potential of a sedimentary section is typically dependent upon quantity and type of kerogen (organic material) contained in shales, and upon the thermal history of the rocks. No analyses to determine the organic richness of the shales are available for the Napatuk Creek well. However, visual examination of the kerogen observed in the samples

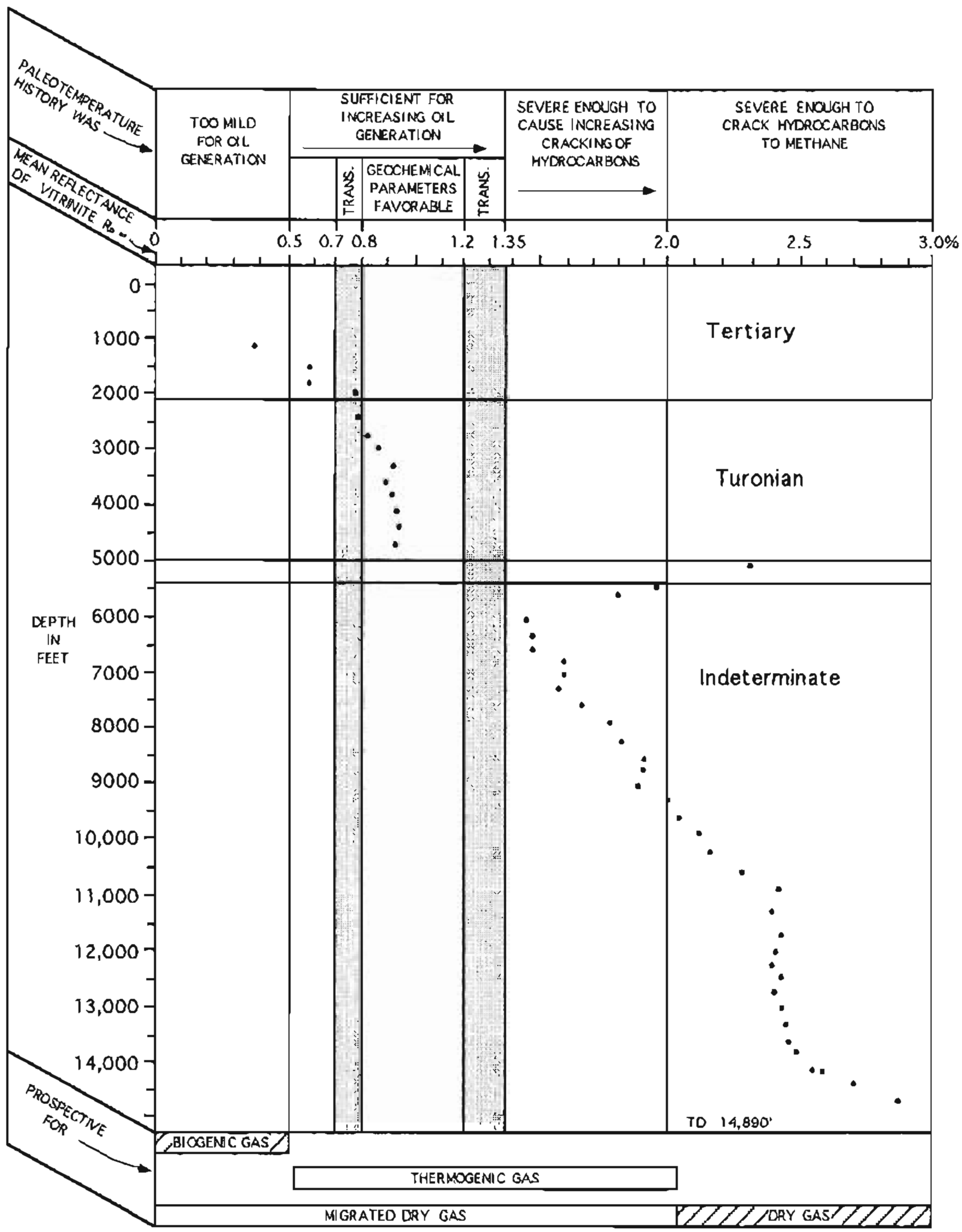


Fig. 8. Plot showing thermal maturity determined by vitrinite reflectance (Ro) from Napatuk Creek No. 1 well. Modified from unpublished data by Mobil Oil Company, 1981. Note abrupt increase in thermal maturity at 5,000 ft.

from the Napatuk Creek well revealed that the dominant kerogen type is cellulosic (Mobil Oil, unpublished report, 1982). Cellulosic, woody, or herbaceous type kerogen is commonly considered to be the capable of generating gaseous hydrocarbons if present in sufficient quantities and subjected to adequate burial and thermal heating. Kerogen of this type is not normally a source of any significant amount of oil.

Thermal maturity:

The thermal maturity of the rocks in the Napatuk Creek well has been evaluated by by vitrinite reflectance analysis (Ro) (fig. 8) and thermal alteration index (TAI) analysis (Mobil Oil Company, unpublished report, 1982). The results of the vitrinite reflectance (Ro) (fig.8) and the thermal alteration index (TAI) analyses are summarized below:

Vitrinite reflectance:

Depth	Ro	Thermal maturity	Max. temp.
60 to 2130 ft.	< 0.7	Immature	< 80° C
2,130 to 2,700 ft.	0.7 to 0.8	Transitional mature	80° C
2,700 to 5,100 ft.	0.78 to 0.95	Mature	90° C
5,100 to 9,500 ft.	1.4 to 2.0	Very mature	200° C
9500 to 14,870 ft	2.0 to 3,8	Overmature	200° to 400° C

TAI analysis:

Depth	TAI	Thermal maturity	Max. temp.
120 to 2,040 ft.	1 to 1+	Immature	< 50° C
2,040 to 6,030 ft.	2+ to 3-	Mature	65° C to 80 ° C
6,030 to 14,890 ft.	3+	Overmature	> 200 ° C

Discussion of thermal maturity

Evaluation of the thermal maturity of the section penetrated in the Napatuk Creek well shows that the rocks above 2,000 ft. in the well are immature and have not been subjected to sufficient burial and heating for kerogen contained in the rocks to generate thermogenic hydrocarbons. Between about 2,000 and 5,000 ft. the rocks are thermally mature and capable of generating gas if sufficient cellulosic kerogen (organic material) is present. Below 5,000 ft., the thermal maturity of the rocks increases abruptly from Ro 0.95 to >1.4 and are thermally very mature to overmature. Rocks at this stage of maturity have generated any possible hydrocarbons that might have been resulted from maturation of their kerogen, and any hydrocarbons that are trapped and have not migrated out of the area will be affected by thermal cracking so that only some dry gas (methane) will remain. The reported abundance of cellulosic kerogen in the sediment indicates that only gas is likely to have been generated, if sufficient kerogen was present in the section at the time of deposition. Below 9,500 ft. in the well, the rocks have Ro >2.0, and range up to Ro 3.8; these rocks are thermally overmature and capable of containing only dry gas.

Drill stem tests:

Four drill stem tests (DST's) were run on the Napatuk Creek well (Pan American Petroleum, unpublished report, 1962). A test of the bottom of the hole was unsuccessful. A test of interval 9,368–9,406 ft. built up to a good blow that then died. The test recovered slightly salty water, which indicates that some formation fluids flowed into the well. Two tests of interval 5,754–7,180 ft. had an initial blow of air from the well bore, which died by the end of the tests. Only drilling mud was recovered. In the series of tests, the slight blows that rapidly died. and low pressures recorded indicate that the rocks tested are probably quite tight and have little porosity or permeability.

Hydrocarbon source rock potential of Napatuk Creek well

Examination of samples from the Napatuk Creek well shows that the rocks throughout the Cretaceous section contain cellulosic kerogen. If present in sufficient quantities, this type of kerogen, derived from terrigenous organic sources, is generally considered to be a source of only gas; liquid hydrocarbons are not generated in any quantity by cellulosic kerogen. Although the rocks in the Napatuk Creek well have not been analyzed for total organic carbon (TOC), correlative Cretaceous rocks from the Kuskokwim Mountains southeast of Bethel have been analyzed by Lyle and others (1982) who reported that analyses of 19 samples showed 8 samples with < 0.5% TOC, 9 samples with 0.5 to 0.9% TOC, and 2 samples with 1.02 to 1.05% TOC. Commonly, shales with > 1% total organic carbon are considered to be potential source rocks, and shales with >2% TOC is considered to be excellent source rocks, if they have been subjected to sufficient burial and thermal heating to cause thermal maturation of the organic material to form hydrocarbons. Rocks with < 1% total organic carbon are considered to be non- source rocks. The data suggest that the Cretaceous rocks in the Napatuk Creek well are probably dominantly non-source to very low grade gas source rocks.

Discussion

Evidence from the lithology, paleontology, thermal maturation, and character of the wire line logs in the Napatuk Creek well discussed above suggest a possible stratigraphic sequence boundary or unconformity at 5,305 ft. Although there is no apparent change in the sandstone composition above and below 5,300 feet, an abrupt change in log character at 5,305 ft. coincides with the base of a 235 ft.-thick massive sandstone and conglomerate unit that contains clasts of granite, schist, and other metasedimentary rocks. This depth also coincides with an abrupt increase in thermal maturity.

Paleontologic data concerning a possible unconformity at about 5,300 ft. are inconclusive. The data indicate that the rocks both above and below this horizon are Late Cretaceous age, but lack sufficient precision to show the presence of any significant time gap at this horizon. Palynomorphs are present in the rocks down to 5,100 ft. and the rocks below are barren, but this may be due to destruction of palynomorphs by the regional thermal effects. Plant fossils are reported only from below 5,700 ft, and the sample descriptions report that coaly material is less abundant below 5,300 ft.

Collectively, these data suggest a change in the depositional environment at 5,300 ft. The thick conglomerate and sandstone interval can be interpreted as a basal conglomerate that forms a stratigraphic sequence boundary that may represent an unconformity. The abrupt increase in thermal maturation in the underlying section suggests that the lower section was subjected to thermal effects that did not affect the overlying rocks. The available data suggest that this unconformity or change in depositional regime occurred sometime in Late Cretaceous time, possibly in the Turonian, about 90 million years before present.

GEOPHYSICAL SURVEYS

Several geophysical surveys have been conducted in the area of the Yukon-Kuskokwim delta by governmental agencies and by the oil industry. These surveys have been carried out both for reconnaissance regional framework control and more detailed studies for specific exploration objectives. These studies include airborne magnetic studies, gravity surveys, and reflection seismic surveys. Magnetotelluric data are also reported to have been collected by Shell Oil Company, but these data are not available.

Reflection seismic surveys

Reflection seismic surveys of the lower Kuskokwim River area by Shell Oil Company and by Atlantic Richfield Company have resulted in reconnaissance seismic lines up the Kuskokwim

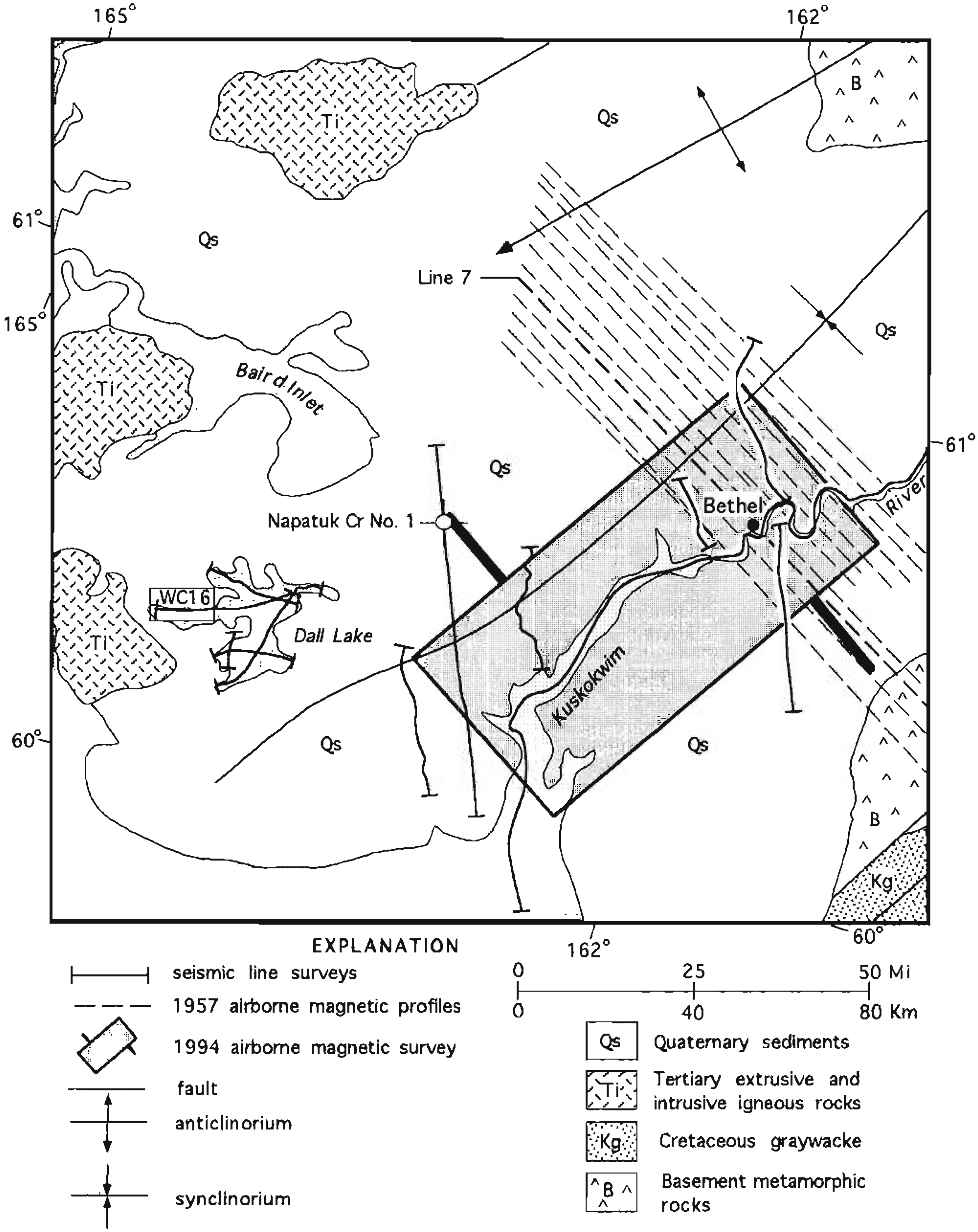


Fig. 9. Map showing location of oil industry seismic lines, USGS reconnaissance airborne magnetic lines (Dempsey and others, 1957), and area of 1994 airborne magnetic survey in lower Kuskokwim River area.

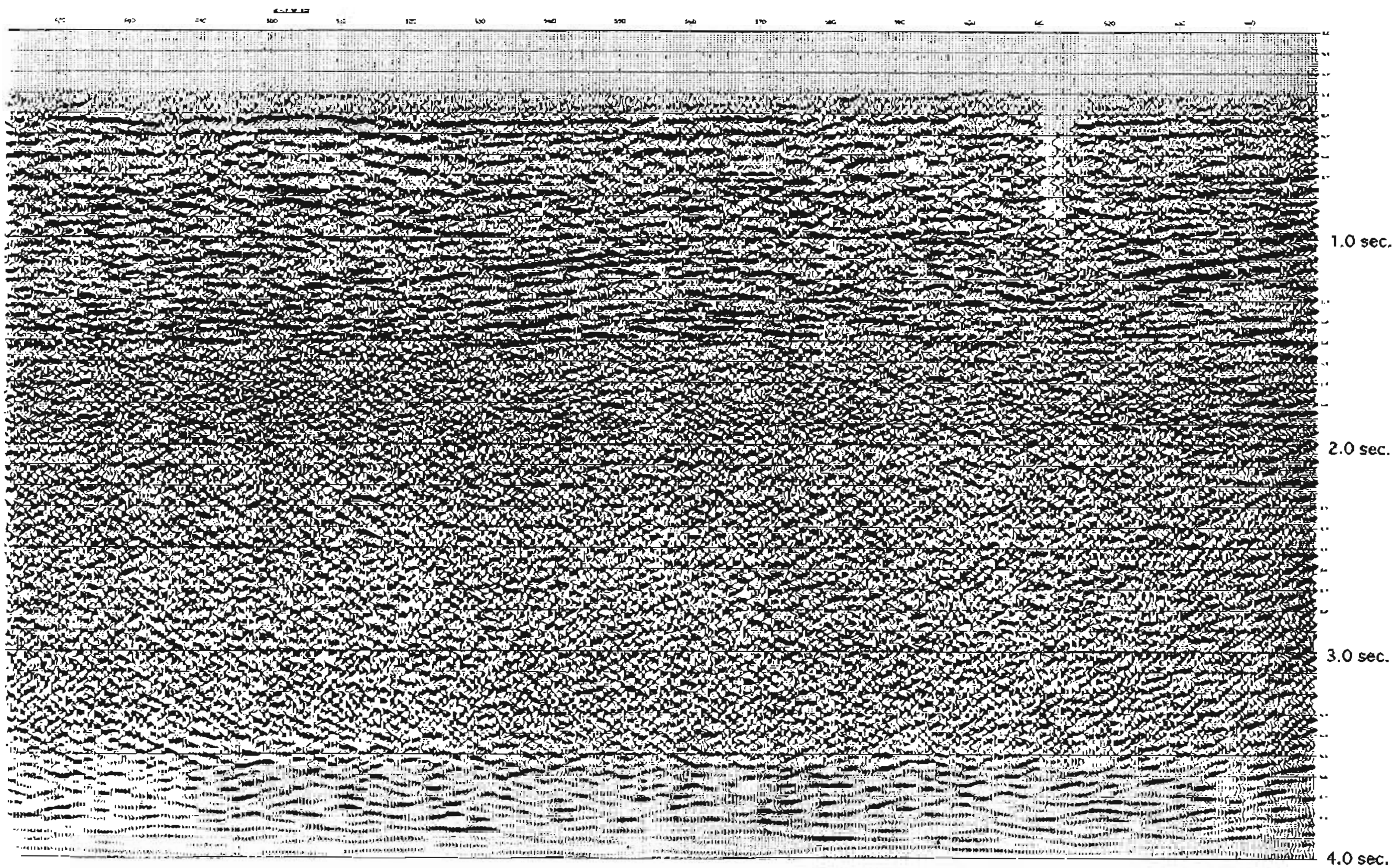


Fig. 10. Portion of seismic line WC16 in Dall Lake showing reflection continuity in Cretaceous section deformed by probable thrust and high angle faults. Base of Cretaceous section is at about 10,000 ft.

River and several onshore seismic lines northwest of the river (fig. 9). Most of the records have poor data quality, and generally lack consistent reflections that can be used to map structural and stratigraphic relationships with confidence. In some areas the limited data on the records show short segments of reflections that suggest gently dipping strata. An exception is a 12 mi east-west trending marine line (Line WC 16) in Dall Lake (fig. 10), 70 miles west of Bethel and 30 miles southwest of the Napatuk Creek #1 well. This is the only seismic line in which any significant amount of continuous reflectors are visible in the seismic records, but because it is some distance from the area of the airborne magnetic survey near the lower Kuskokwim River, it is of little help in evaluating the aeromagnetic data. The western end of the line contains good reflection continuity in the upper 1.4 sec. of data (approx. 10,000 ft.); the eastern end of the line also contains long reflection segments, but the continuity is not as good as in the west. Other seismic lines in Dall Lake lack consistent reflectors. The general absence of good reflections in the seismic records is probably the result of complicated structure in the subsurface, combined with the effects of poor energy transmission into the earth in the area of the land-based seismic lines.

Gravity surveys

Gravity data collected by Shell Oil Company in the lower Kuskokwim River area in 1974 have been digitized, combined with USGS public domain data (Barnes, 1977), and computer contoured in 1992 by Earthfield Technology, Inc. (n.d.). The Earthfield Technology Bouguer gravity map displays a prominent northeast-southwest trending gravity gradient that "correlates well with the total intensity (magnetic) map....". The lower Kuskokwim River area is characterized by several broad relative gravity lows with an amplitude of about 30-35 mgal. Although the only subsurface control is in the Napatuk Creek #1 well, it is assumed that these gravity minima coincide roughly with areas of thicker Tertiary sediment. The Napatuk Creek well was located near the lowest part of the most significant gravity minima in the area and encountered about 2,000 ft. of Tertiary sedimentary rock that is much more poorly consolidated than the underlying Cretaceous rocks.

Airborne magnetic surveys

Widely spaced northwest-southeast trending reconnaissance aeromagnetic profiles by the U.S. Geological Survey in 1957 (fig. 9) showed that part of the lower Kuskokwim River area near Bethel is underlain by rocks containing no significant magnetic anomalies (fig. 11). The data suggested that rocks with high magnetic susceptibility lay both northwest and southeast of the Bethel area.

More detailed airborne magnetic surveys flown by the USGS as part of the National Uranium Evaluation Program (NURE) were flown with a line spacing of 6 miles and tie line spacing of 12 miles. These data were digitally processed and combined with public domain data by Earthfield Technology, Inc. to produce a series of magnetic maps that include total intensity and vertical derivative maps of the lower Kuskokim River-Bethel area. The total intensity map is described Earthfield Technology Inc. (n.d., p. 6) as:

> "characterized by short wavelength, high frequency magnetic anomalies over a wide, northeast-southwest trending zone covering the central portion of the survey area which is associated with an area of thick intrusive and extrusive rocks which partially fill this portion of the basin. Northwest of this zone the data are relatively quiet with long wavelength anomalies indicating the Yukon Delta Basin area. The most striking feature however, is the large northeast-southwest trending magnetic gradient which cuts across the entire area. This gradient, which is almost certainly fault related, separates the ....volcanic rich area from the Bethel Basin proper, which appears to have very little volcanics present."

An interpretation of depth to magnetic basement produced by analysis of the magnetic data and integration of gravity and geologic data by Earthfield Technology, Inc. (n.d., p. 8) which

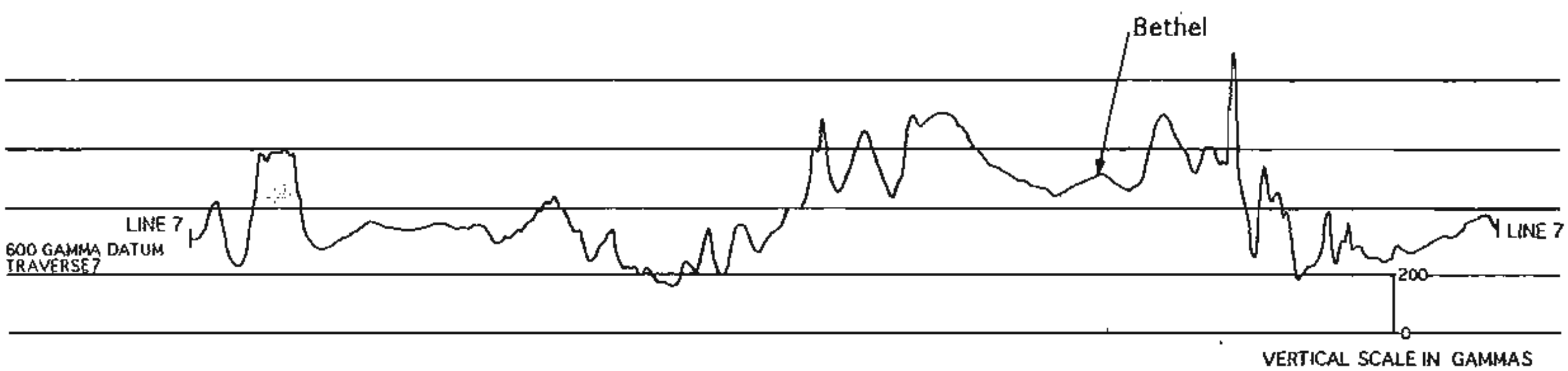


Fig. 11. Airborne magnetic profile line no. 7 (Dempsey and others, 1957) across lower Kuskowkim River area near Bethel, illustrating typical character of magnetic profiles. Sharp magnetic anomalies are indicative of buried igneous rocks. See fig. 9 for location of magnetic profile.

suggests that the area has large regions that appear to be essentially devoid of major volcanic or intrusive accumulations. Numerous faults or fault zones that can be mapped with the potential field data are also reported (p. 8). Throughout most of the area, depth to magnetic basement is interpreted to be between 18,000 and 26,000 ft. below sea level, but reaches 32,000 ft. in the southern part of the area.

1994 airborne magnetic survey

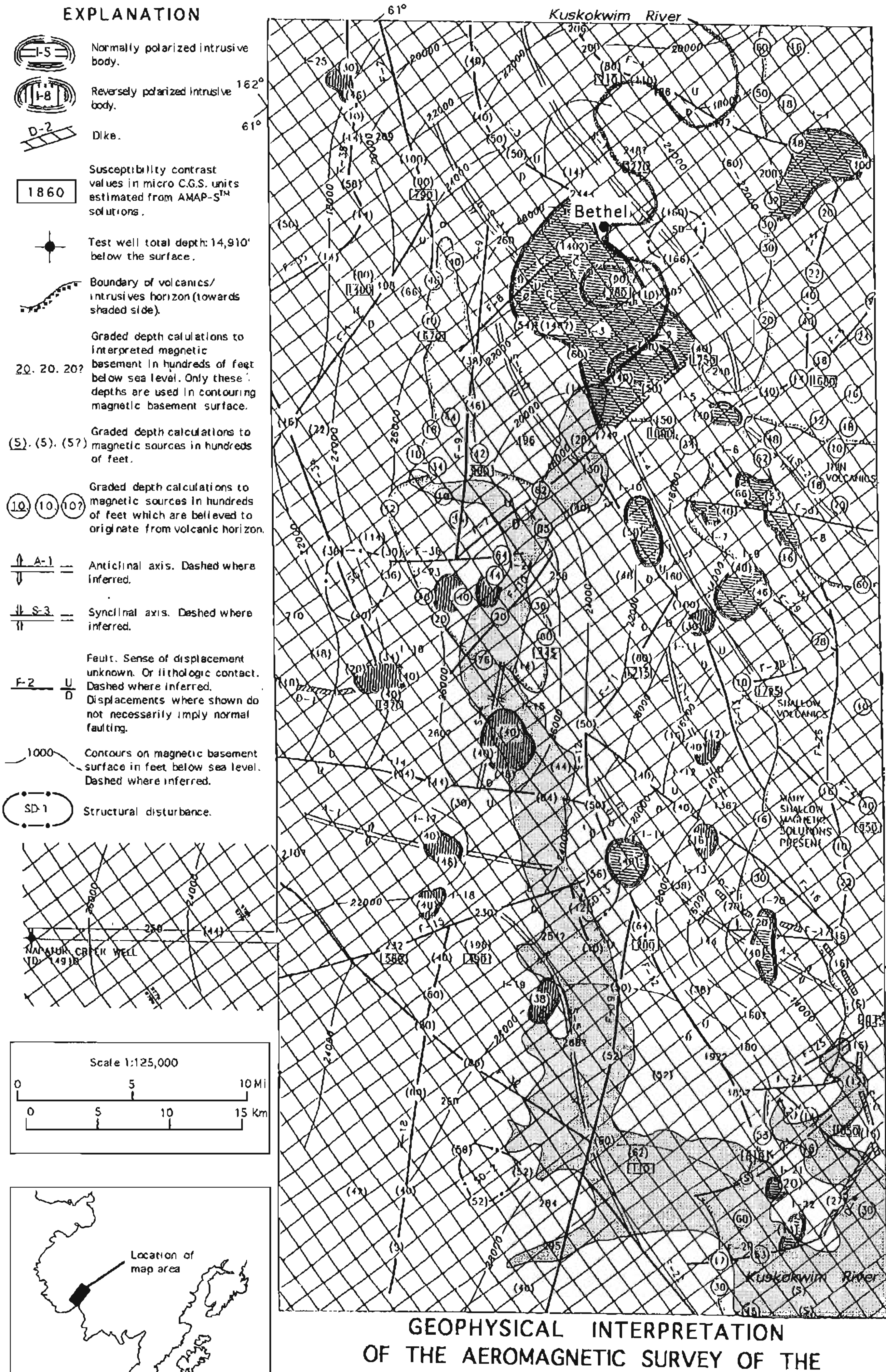
As a result of the analysis of the potential field data, a closely spaced airborne magnetic survey was recommended to localize areas of interest (Earthfield Technology, Inc., n.d. p.4). A high resolution aeromagnetic survey was flown by Geonex Aero Service, during the period of August 12-29, 1994 in an approximately 1,800 sq. mi area southwest of Bethel in the lower Kuskokwim River area (fig. 1). The data, maps, and interpretations resulting from this survey have been prepared and discussed by Geonex Aero Surveys (1994, 1995a, and 1995b).

The area selected for the survey was based upon an evaluation of the available gravity and magnetic data that seem to indicate a strong northeast-southwest trending fault zone southeast of the Kuskokwim River. The majority of the survey area was thought to lie in a basin area northeast of this inferred fault, and is tied to the Napatuk Creek #1 well to provide subsurface geologic control. An interpretation map and discussion of the aeromagnetic data (Geonex Aero Surveys, 1994) is summarized below.

The Geonex interpretation of the aeromagnetic data (fig. 11) indicates that magnetic basement in the project area ranges from about 14,000 ft. to about 28,000 ft.. The regional geology suggests that this basement consists of metasedimentary and metaigneous rocks and that it is overlain by graywacke and shale of the Cretaceous Kuskokwim Group. The interpretation indicates that the basement and overlying rocks are broken by a number of high angle faults, many of which have a general northeast-southwest trend; this trend is compatible with the trends indicated by the regional outcrop mapping. Throw on many of the faults shown on the aeromagnetic interpretation ranges from 2,000 ft. to over 4,000 ft.; a few of the faults are interpreted to extend to within 1,600 ft.of the ground surface, but many are 4,000 to 6000 ft. below the surface. The faults are interpreted to break the area into a series of uplifted and downdropped horst and graben type blocks. Based upon correlation with the Napatuk Creek well, it is likely that the faults cut the Kuskokwim Group in addition to the basement. Two areas cut by the faults are interpreted to contain relatively flat-lying volcanic rocks or sills that are probably within the Kuskokwim Group.

The aeromagnetic interpretation shows five anticlinal uplifts that apparently deform the basement and Cretacous rocks. In addition to the anticlinal axes, four "structural disturbances" are indicated. These are described as weak anomalies that are believed (Geonex Aero Services, 1994, p. 55) to "represent sedimentary structures such as minor uplifts, reefs, sand lenses, or domes...". No seismic data are available to further document or refine the interpretation of these weak anomalies.

The most prominent features on the map are a large number of relatively high amplitude magnetic anomalies that are circular to linear in form and probably represent small plug-like intrusions and dikes. These anomalies are most numerous in the northeastern part of the map area; the southwestern part of the area does not appear to contain intrusive rocks. A number of the plug-like bodies are interpreted to reach to within 2,000 to 4,000 ft. of the surface; one is interpreted to reach to within 1,300 ft.of the surface. Most of the plug-like intrusions range from 1 to 4 sq. mi. in area, however, one considerably larger body in the northeastern part of the area covers an area of about 45 sq.mi. The linear bodies, thought to be dikes, are interpreted to come to within 1,600 to 1,800 ft.of the surface. By analogy with the igneous body encountered in the Napatuk Creek well, it is likely that these dikes and plug-like intrusions are basaltic and intrude



GEOPHYSICAL INTERPRETATION
OF THE AEROMAGNETIC SURVEY OF THE
SOUTHEASTERN BETHEL BASIN, ALASKA
BY
GEONEX AERO SERVICES
1994

Fig. 12. Interpretation map of aeromagnetic data, reduced from map by Geonex Aero Services (1994), showing depth to magnetic basement, depth to faults, and shallow magnetic anomalies caused by intrusive and extrusive igneous rocks. Map indicates that depth to basement ranges from 14,000 ft. to 28,000 ft. Cretaceous sediments above magnetic basement are cut by a number of faults with significant displacement and intruded by numerous igneous bodies. Tertiary sediments up to about 2000 ft. thick probably unconformably overlie the faulted and intruded Cretaceous rocks. Anomalies designated SD-1 to SD-4 are of unknown origin.

much of the Cretceous section. Regionally in southwestern Alaska most of the intrusions range from 50 to 70 million years old (Late Cretaceous to early Tertiary).

Based upon the fact that many of the faults and intrusive bodies are probably no shallower than 1,600 to 2,000 ft., the shallow part of the sedimentary section is interpreted to be Tertiary age. This is compatible with the data from the Napatuk Creek well, which show about 2,000 ft. of relatively poorly consolidated Tertiary sediments.

HYDROCARBON POTENTIAL IN THE LOWER KUSKOKWIM RIVER AREA

Reservoir rocks

Data from the Napatuk Creek #1 well indicate that the Tertiary rocks of the lower Kuskokwim River area are dominantly nonmarine rocks that are compositionally and texturally immature. Such rocks tend to contain abundant fine grained matrix material that inhibits porosity. Owing to the fact that the Tertiary rocks in the lower Kuskokwim River area have not been deeply buried and compacted, adequate porosity and permeability may be present, but, this lack of compaction also prevents the formation of impermeable seals that are necessary to form effective hydrocarbon traps.

The regional data indicate that the Cretaceous rocks in the lower Kuskokwim River area are marine rocks deposited dominantly in an active turbidite depositional environment although some shallow marine and nonmarine deposits are recorded (Bundtzen and others, 1992; Miller and Bundtzen, 1994). The source areas for the Cretaceous sediments contained large amounts of recycled sedimentary and volcanic rocks and, because of the high rate of rapid sedimentation, contain large amounts of clay matrix. Under the conditions of active tectonics, deep burial and compaction that prevailed in the lower Kuskokwim River area, such rocks normally contain little porosity and permeability and are unlikely to form adequate reservoirs. More compositionally mature sub-lithic to quartzose sandstones that would be less affected by compaction are known along the flanks of the Cretaceous depositional basin, but these rocks are not known to be present in the lower Kuskokwim River area. For this reason, and the generally poor hydrocarbon source rock potential (discussed below), the petroleum potential of the Cretaceous rocks in the onshore interior basins of Alaska was not assessed by Powers (1989).

Hydrocarbon source rock potential

The Tertiary rocks in the lower Kuskokwim River area are relatively thin, dominantly nonmarine clastic rocks that are thermally immature, and contain only small amounts of organic material. These data suggest that the Tertiary section is not capable of generating gas in any significant quantity because at least 10,000 ft. of sedimentary fill is necessary for the formation of thermogenic gas (Powers, 1989.)

The regional data show that the Cretaceous rocks in the lower Kuskokwim River area are also low in organic content and are considered to be generally weak source to non-source rocks. The rocks are dominantly turbidites that contain large amounts of terrigenous material that dilutes the cellulosic gas-prone kerogen that was formed in the Cretaceous depositional basin.

Although the rocks are low in total organic content, the data suggest that the shallower part of the Cretaceous section in the subsurface of the lower Kuskokwim River area is within the zone of thermal maturity. An abrupt jump in thermal maturity apparently occurs at about 5,100 ft. in the Napatuk Creek well, so that in the underlying section the rocks are thermally overmature. Any migrated hydrocarbons trapped in the deeper part of the sedimentary section will have been subject to thermal cracking. Combined, the indications of low total organic content and generally high thermal maturity indicate that the hydrocarbon source rock potential of the Cretaceous in the lower Kuskokwim River area is generally low.

In some circumstances, biogenic gas can be generated at low temperatures by decomposition of organic material by anaerobic micro-organisms. This type of gas generation occurs in marine sediments at temperatures between 0 and 75°C (Rice and Claypool, 1981); this range is markedly lower than the temperature at which any significant amount of thermogenic methane is generated. This type of generation, however, is not likely to have occurred in the lower Kuskokwim River area, because the shallow Tertiary section contains dominantly nonmarine sediments that probably do not contain either coal or any significant amount of marine organic material. Powers (1989, p. A44) suggests that microbial gas may be trapped in the Alaskan Tertiary basins whenever an adequate seal in a trapping situation exists. However, as discussed above, in the lower Kuskokwim River area, the thin Tertiary sediments are undercompacted, and impermeable seals for trapping of migrated gas are unlikely.

SUMMARY AND CONCLUSIONS

Evaluation of the regional geologic history, stratigraphy, petrology, organic geochemistry, and geophysics suggests that the potential for discovery of commercial quantities of either liquid or gaseous hydrocarbons in the lower Kuskokwim River area is low. The nature of the Tertiary and Cretaceous depositional systems combined with the deformational and thermal history of the area is not compatible with the deposition and preservation of adequate hydrocarbon source beds or reservoir rocks.

The preserved rock sequence records rapid deposition of both nonmarine Tertiary rocks and Cretaceous rocks deposited largely as turbidites in a marine basin. The rocks in both of these depositional settings were derived from erosion of large areas of volcanic and low grade metasedimentary rocks that yielded large amounts of compositionally unstable and clay-rich sediment. With the exception of areas on the flank of the Cretaceous basin, the depositional history records little opportunity for winnowing of the sediment and development of deposits composed of compositionally mature stable sediments in which porosity and permaeability can be preserved after deep burial. However, the flank of the Cretaceous basin was far from the lower Kuskokwim River area, which seems to have been in the deep turbidite part of the basin.

Because of the large amount of terrigenous sediment in the nonmarine and largely turbidite depositional systems, the limited amount of organic material in the system is highly diluted by non-organic detritus. Terrigenous organic material is considered to be a source of gas rather than liquid hydrocarbons, but the generally low total organic content is considered to be a weak hydrocarbon source.

In the lower Kuskokwim River area, the deformational and burial history, combined with the widespread occurrence of shallow intrusive and extrusive igneous rocks has resulted in a high thermal regime. A large amount of the sedimentary section is thermally overmature and beyond the range at which hydrocarbons are preserved. Thus, even if the low amount of organic material in the sediment was capable of generating hydrocarbons, the high thermal effects that have affected most of the sedimentary section have probably resulted in destruction or dispersal of any hydrocarbon that was generated. At an earlier stage of their burial and maturational history, probably in the early Tertiary, the Cretaceous rocks in the lower Kuskokwim River area probably progressed through a stage in which they were at a level of thermal maturity in which organic material contained in them may have generated small amounts of gas. However, presence of the regional unconformity between the Tertiary rocks of probable Miocene age and the underlying Cretaceous rocks suggests that the Cretaceous rocks were deformed in the early Tertiary time. If gas was generated and migrated at this stage in the deformational and maturational history, it would have either migrated out of the region or, if retained in the system, would have been thermally "cooked".

Although the airborne magnetic data suggest that igneous intrusive bodies are less numerous southwest of the Napatuk Creek well, because of the apparent absence of adequate hydrocarbon source and reservoir rocks, the potential for either oil or natural gas is not enhanced. The potential for discovery of thermogenic natural gas in the lower Kuskokwim River area must be assessed as low based upon present knowledge. Powers (1989) suggested fair to good potential for biogenic gas for local usage in the interior Tertiary basins of Alaska. However owing to the absence of either marine organic material or coal in the nonmarine Tertiary sediments, the potential for biogenic gas in the lower Kuskokwim River area is also probably low.

Current knowledge of details of the subsurface structure in most of the lower Kuskokwim River area is limited, but the regional geology and the results of the airborne magnetic surveys suggest that faulted structures that might serve as traps may be present in the subsurface. However, exploration for the small amounts of natural gas that might have been generated and migrated into traps formed by fracturing of otherwise generally impermeable strata will be difficult and probably require expensive detailed reflection seismic surveys.

REFERENCES CITED

Barnes, 1977, Bouguer gravity map of Alaska: U.S. Geological Survey Geophysical Investigations Map GP-913, 1 sheet, scale 1:2,500,000.

Box, S.E., Moll-Stalcup, E.J., Wooden, J.L., and Bradshaw, J.Y., 1990, Kilbuck Terrane--Oldest known rocks in Alaska: Geology, vol. 18, p. 1219-1222.

Box, S.E., Moll-Stalcup, E.J., Frost, T.P., and Murphy, J.M., 1993, Preliminary geologic map of the Bethel and southern Russian Mission quadrangles, southwestern Alaska: U.S. Geological Survey MF-2226-A, one sheet, scale 1:250,000 ; 20 pages.

Bundtzen, T.K., and Gilbert, W.G., 1983, Outline of the Geology and Mineral Resources of the Upper Kuskokwim Region, Alaska, in Western Alaska geology and resource potential: Alaska Geological Society Symposium, Anchorage, Alaska, Proceedings, p. 101-117.

Bundtzen, T.K., and Laird, G.M., 1991, Geology and mineral resources of the Russian Mission C-1 quadrangle, southwest Alaska: Ak. Div. Geol. and Geophys. Surveys Prof. Report 109, 24 p., two sheets, scale 1:63,360 and 1:200..

Bundtzen, T.K., Miller, M.L., Laird, G.M., and Bull, K.F., 1992, Geology and mineral resources of the Iditarod mining district, Iditarod B-4 and eastern B-5 quadrngles, southwestern Alaska: Ak. Div. Geol. and Gephys. Surveys Prof. Report 97, 46 p., two sheets, scale 1:63,360 and 1:500 .

Cady, W.M., Wallace, R.E., Hoare, J.M., and Webber, E.J., 1955, The central Kuskokwim region, Alaska: U.S. Geol. Survey Prof. Paper 263, 131 pages.

Decker, John, Bergman, S.C., Blodgett, R.B., Box, S.E., Bundtzen, T.K., Clough, J.G., Coonrad, W.L., Gilbert, W.G., Miller, M.L., Murphy, J.M., Robinson, M.S., and Wallace, W.K., 1994, Geology of southwestern Alaska, in Plafker, George, and Berg, H.C., eds., The Geology of Alaska: Boulder, Colorado, Geological Society of America, The Geology of North America, vol. G-1, p. 285-310.

Dempsey, W.J., Meuschke, J.L., and Andreason, G.E., 1957, Profiles of Bethel Basin, Alaska: U.S. Geological Survey open-file map, 3 sheets, scale 1:250,000.

Dolton, G.L., and others, 1981, Estimates of undiscovered recoverable conventional resources of oil and gas in the United States: U.S. Geological Survey, Circular 860, 87pp.

Earthfield Technology, Inc., No date [1992?], Hydrocarbon potential summary and integrated potential fields data interpretation in the Bethel Basin, Alaska: Unpublished report prepared for the Calista Corporation, 11 p., 27 fig., 2 maps, scale 1:500,000.

Geonex Aero Services, 1994, High resolution aeromagnetic survey, southwestern Bethel basin, Alaska: Alaska Division of Geological & Geophysical Surveys, Public Data File report PDF 95-2 81 p., 1 sheet, scale 1:125,000.

Geonex Aero Services, 1995a, Total field magnetics of the southwestern Bethel Basin, Alaska: Alaska Division of Geological & Geophysical Surveys, Report of Investigations RI 95-1, 2 sheets, scale 1:125,000.

Geonex Aero Services, 1995b, Digital gridded data of total field magnetics of the southwestern Bethel basin, Alaska:Alaska Division of Geological & Geophysical Surveys, Public Data File report PDF 95-1, 1 PC disk compatible with Geosoft programs.

Hoare, J.M., 1961, Geology and tectonic setting of ther lower Kuskokwim-Bristol Bay region, Alaska: Am. Assoc. of Petrol. Geologists Bulletin, vol 45, no. 5, pp. 594-611.

Kirschner, C.E., 1988, Map showing sedimentary basins of onshore and continental shelf areas, Alaska: U.S. Geological Survey map MI-1873, 1 sheet, scale 1:5,000,000.

Kirschner, C.E., 1994, Map showing sedimentary basins in Alaska, in Plafker, George, and Berg, H.C., eds., The Geology of Alaska: Boulder, Colorado, Geological Society of America, The Geology of North America, vol. G-1, plate 7, scale 1:2,500,000.

Lyle, W.M., Palmer, I.F., Bolm, J.G., and Flett, T.O., 1981, Hydrocarbon reservoir and source rock characteristics from selected areas of southwestern Alaska: Alaska Division of Geological Surveys Professional Report 77, 34 pp, 7 plates.

Magoon, L.B., and Kirschner, C.E., 1990, Alaska Onshore National Asessment Program--Geology and petroleum resource potential of six onshore Alaska provinces: U.S. Geological Survey Open-file report 88-450-T, 47pp.

Mutti, E., and Ricci Lucchi, F., 1978, Turbidites of the northern Appennines--Introduction to facies analysis: International Geology Review, vol. 20, no. 2, p. 125-166.

Miller, M.L., and Bundtzen, T.K., 1994, Generalized geologic map of the Iditarod quadrangle, Alaska, showing potassium-argon, major oxide, trace element, fossil, paleocurrent, and archeological sample localities: U.S. Geological Survey Map MF-2219-A, one sheet, scale 1:250,000, 48 pages.

Miller, M.L., Bradshaw, J.Y., Kimbrough, D.L., Stern, T.W., and Bundtzen, T.K., 1991, Isotopic evidence for early Proterozoic age of the Idono Complex, west-central, Alaska: Journal of Geology, vol. 99, no.1, p. 209-223.

Patton, W.W. Jr., 1978, Juxtaposed continental and oceanic-island arc terranes in Medfra quadrangle, in Johnson, K.M., ed., U.S. Geological Survey Circular 772-B, p. B38-39.

Patton, W.W. Jr., and Box, S.E., 1989, Tectonic setting of the Yukon-Koyukuk basin and its borderlands, western Alaska: Journal of Gephysical Research, vol. 94, no. B11, p. 15,807-15,820.

Patton, W.W., Jr., Moll, E.J., Lanphere, M.A., and Jones, D. L., 1984, New age data for the Kaiyuk Mountains, west-central Alaska, in Coonrad, W..L., and Elliott, R.L., eds., the United States Geological Survey in Alaska: Accomplishments during 1981: U.S. Geological Survey Circular 868, p. 30-32.

Mast, R.F., and others, and Martin, P.E., and others, 1989, Estimates of undiscovered conventional oil and gas resources in the United States--A part of the nation's energy endowment, by U.S. Geological Survey and Minerals Management Service: United States Government Printing Office, 44p.

Powers, R. B., 1993, Petroleum eexploration plays and resource estimates, 1989, Onshore United States---Region 1, Alaska; Region 2: U.S. Geological Survey Bulletin 2034-A, p. 1-70.

Rice, D.D. and Claypool, G.E., 1981, Generation, accumulation, and resource potential of biogenic gas: American Association of Petroleum Geologists Bulletin, v ol. 65, no. 1, p. 5-25.

Spurr, J.E., 1900, A reconnaissance in southwestern Alaska in 1898, : U.S. Geological Survey 18th Annual Report, part 7, p. 31-264.

Wilcox, R.E., Harding, T.P., and Seely, D.R., 1973, Basic wrench fault tectonics: American Association of Petroleum Geologists, vol. 57, no. 1, p.74-96.

NAPATUK #1 WELL

Petrographic analysis of 19 thin sections
5/4/94 R.R. Reifenstuhl

THIN SECTION (number is well depth)	ROCK TYPE AND COMMENTS
2560-2570	**Lithic sandstone**, fine-grained, subangular, poorly sorted, very highly carbonate altered, no porosity
3121-3122	**Lithic sandstone**, fine-grained, subangular, poorly sorted, very highly carbonate altered, trace hornblende, no porosity
3124-3125	**Lithic sandstone**, fine-grained, angular, poorly sorted, highly carbonate altered (30%), white mica 2-3%, layered appearance from micas, trace porosity
3126-3127	**Lithic sandstone**, very fine and fine grained, poorly sorted, angular and subangular, carbonate alteration, carbonate (siderite?) cement, trace white mica
3128-3129	**Lithic sandstone**, very fine and fine grained, poorly sorted, angular, carbonate-altered, carbonate (siderite?) cement (20%), abundant volcanic rock fragments (VRF), trace white mica, hornblende, no porosity
3130-3131	**Lithic sandstone**, very fine and fine grained, poorly sorted, angular, carbonate-altered, carbonate (siderite?) cement (20%), abundant VRF, white mica (4%), 0 porosity
3131-3132	**Lithic sandstone**, fine grained, poorly sorted, angular, carbonate-altered, carbonate (siderite?) cement (15%), abundant VRF (60%), slate or phyllite, trace white mica, hornblende
4798-4799	**Diabase**, medium-grained (1-5 mm), plagioclase-hornblende-pyroxene-bearing, very altered to calcite+chlorite+clinozoisite+iron oxides+white mica
5120-5130	**Diabase**, medium-grained (1-5 mm), plagioclase-hornblende-pyroxene-bearing, very altered to calcite+chlorite+clinozoisite+iron oxides+white mica
5758-5759	**Lithic sandstone**, fine grained, moderately sorted, angular, carbonate-altered, carbonate (siderite?) cement, abundant VRF, slate or phyllite, trace white mica, glaconite(?), 1-3% porosity
5758-5759A	**Lithic sandstone**, very fine grained and fine grained, poorly sorted, subangular, carbonate-altered, carbonate (siderite?) cement, abundant VRF, slate or phyllite, trace white mica, hornblende
5759-5760	**Lithic sandstone**, fine grained and very fine grained, moderately sorted, angular, carbonate-altered, carbonate (siderite?) cement, abundant VFR, 10-15% chert, slate or phyllite, trace white mica,
7518-7518	**Lithic to feldspatholithic sandstone**, medium grained, poorly sorted, angular, carbonate-altered (20%), carbonate cement, abundant VFR, chert, slate or phyllite, trace white mica, 2-3% porosity
9392B	**Feldspatholithic sandstone**, medium grained, poorly sorted, sub-angular, carbonate-altered (20%), carbonate cement, abundant VFR, chert, slate or phyllite, white mica 2-3%, 2-3% porosity, granitoid-low grade slate, phyllite source
9394B	**Feldspatholithic sandstone**, medium grained, poorly sorted, sub-angular, carbonate-altered (20%), carbonate cement, sutured grain boundaries, abundant VFR, chert, slate or phyllite 5-10%, white mica 5%, porosity 1%, granitoid-low grade slate-phyllite source

10180-10190	**Quartzose lithic sandstone**, fine-grained, moderately sorted, angular and sub-angular, carbonate altered, carbonate cement, chert, slate or phyllite, white mica 1%, porosity 1%, more quartz than rocks above
10352	**Quartzose lithic sandstone**, medium-grained, moderately sorted, sub-angular, carbonate altered, carbonate cement, chert, slate or phyllite, white mica 1%, porosity 1%, more quartz than rocks above, granitoid-low grade slate, phyllite source
11617	**Quartzose lithic sandstone**, fine-grained, moderately sorted, sub-angular, carbonate altered, carbonate cement, chert, slate or phyllite, white mica 1%, porosity 1%, more quartz than rocks above, granitoid-low grade slate, phyllite source
11628-11630	**Quartzose lithic sandstone**, fine-grained, moderately sorted, sub-angular, carbonate and sericite altered, carbonate cement, chert (15%), slate or phyllite, white mica 1%, porosity 1%, K-spar with Microcline twinning, pressure solution of feldspars, more quartz than rocks above, granitoid-low grade slate, phyllite source
13260-13280	**Quartzose lithic sandstone**, fine-grained, moderately sorted, sub-angular, carbonate altered, carbonate cement, chert, slate or phyllite, white mica 1%, porosity 1%, more quartz than rocks above, granitoid-low grade slate, phyllite source
14458	**Feldspatholithic sandstone**, medium to fine-grained, moderately sorted, sub-angular, carbonate altered, carbonate cement, chert, slate or phyllite, white mica 1%, porosity 1%,
14870-14890	**Quartzose lithic sandstone**, fine-grained, moderately sorted, sub-angular, carbonate altered, carbonate cement, chert, slate or phyllite, white mica 1%, porosity 1%, more monocrystalline quartz than rocks above, granitoid-low grade slate, phyllite source

GENERAL COMMENTS

All samples are highly altered to carbonate, and to a lesser degree the non quartzose clasts are altered to sericitic white mica.

All samples contain carbonate cement: calcite and lesser siderite(?), consequently the porosity is very low (about 1-4%)

All sandstone below 7500 feet are Lithic sandstone, with volcanic clasts to 60%, and lesser chert, and low grade metamorphic rock fragments

Sandstone from 9,000 feet are less lithic-rich (Feldspatholithic) than sands above, and transitional to the more quartz-rich sand in the 10,000 to 14,000 range

Five of the seven samples below 10,000 feet are the most quartz-rich (Quartzose-lithic sandstone), and the maximum quartz content is 30% (mostly monocrystalline)

There is a 2,600' sample-gap between 3100' and 5758", where the diabase sill(?) occurs, yet no obvious petrographic break was found in the sample record

Below 9,000' the provenance for the sandstone is a granitoid-low grade slate and phyllite terrane: the mid Cretaceous age granites and low-grade metamorphic rocks of the Ruby terrane

Provenance for sands in the upper well were volcanic-rock dominated: derived from a volcanic source terrane. There are no indicators of syndepositional volcanism in these basin samples.

Porosity is very low, and permeability is probably equally low. Porosity was reduced by the high percentage of ductile grains, highly soluble grains, mechanical compaction, and pressure solution. Calcite precipitation has occurred between grain boundaries and within grains, and locally as poikilotopic crystals.

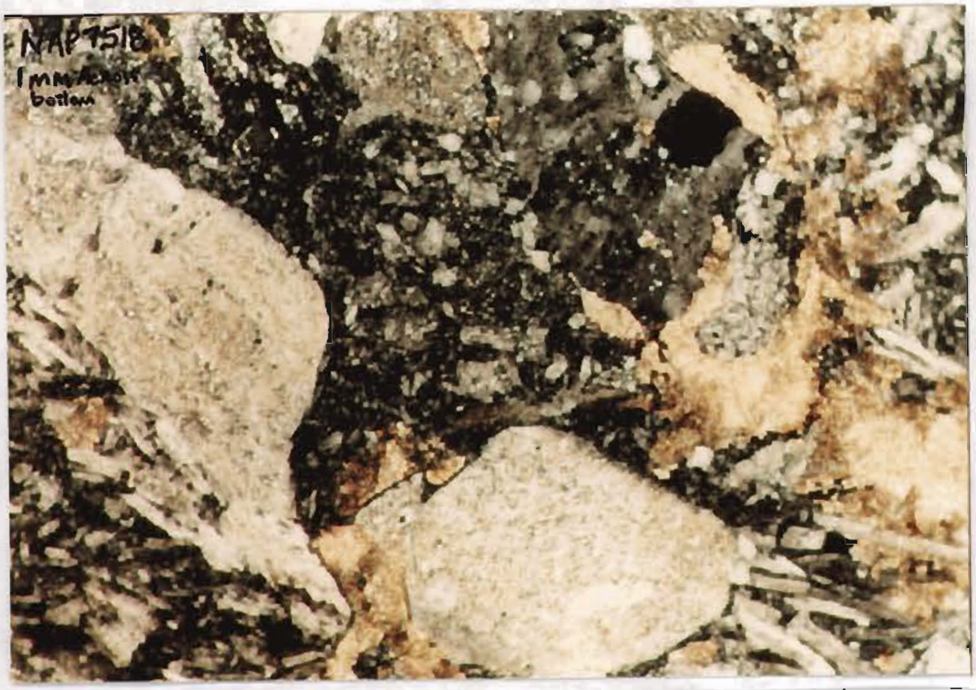


Fig. 6A. Photomicrograph of lithic sandstone at 7,518 ft in Napatuk Creek #1. Sand grains consist of altered carbonate, chert, abundant volcanic rock fragments, phyllite, and trace of white mica, cemented by carbonate. Volcanic arc and metamorphic provanance. Petrography by R.R. Reifenstuhl..

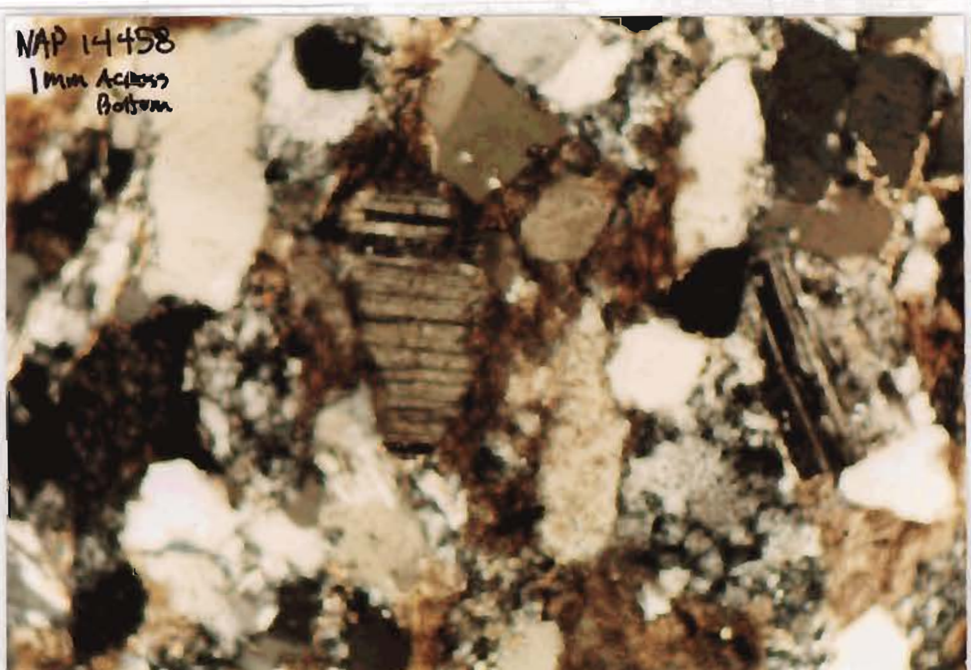


Fig. 6B Photomicrograph of feldspatholithic sandstone at 14,458 ft. in Napatuk Creek #1. Sand grains consist of quartz, chert, altered carbonate, phyllite, and trace of white mica, with carbonate cement. Granitic and metamorphic provenance. Petrography by R.R. Reifenstuhl..