

SCOMM

99:4

ISSUES CONCERNING COALBED METHANE DEVELOPMENT

MARKET

Cook Inlet has about a 10 to 12 year gas supply at current usage; CBM must compete with conventional gas. In rural areas, CBM must compete with current energy (usually diesel) source.

• COST

Large scale Alaska oil and gas development must compete in a world market--Independents and majors need to keep overhead down in order to make CBM projects economic. In rural communities, economics for CBM may be more favorable.

• REGULATIONS

AOGCC is currently revising drilling regulations, rig specifications, and bonding requirements to accommodate small-scale, low cost operations. Under their new regulations, permitting CBM wells should no longer be a problem. Other stratigraphic wells could still fall in a gray area as far as permitting is concerned.

ADEC requires a \$1,000,000 bond for exploratory drilling, however no bond is required for gas production wells. This bonding rule needs to be lowered for CBM exploratory wells to be more in line with the true environmental risks. Also, ADEC regulations make disposal of drilling wastes and all produced water expensive and difficult. Regulations are needed for easier disposal of nontoxic drilling wastes and produced water.

ADOG is currently revising royalty reduction statutes for low margin projects such as CBM and is looking for ways to streamline leasing procedures.

• OWNERSHIP

CBM ownership on state lands can be addressed on the leasing forms for both mining and oil and gas. Colorado is the only western state to do this and provides Alaska with an example. Ownership on private, native and federal acreage could still pose problems.



INTERGAS '95

May 15-19, 1995
The University of Alabama
Tuscaloosa, Alabama USA

ABSTRACT

Alaska's estimated coal reserves exceed 5.5 trillion short tons or nearly 1/2 of the U. S. total. Based on analysis performed during this study, I have concluded that these coals could contain up to 1,000 tcf of gas. Most of these coals range in age from Cretaceous to Tertiary and rank from bituminous to subbituminous. This study uses coal rank, present-day burial depth, seam thickness and structure as criteria to evaluate thirteen of Alaska's most promising coal basins. Much of the Cook Inlet, Susitna, North Slope, Middle Tanana, Nenana, Yukon Flats, North Aleutian, Seward Peninsula, and Copper River Basins contain thermally immature coals ($R_o < 0.5\%$) with low methane potential. The Upper and Lower Koyukuk, Kobuk, Gulf of Alaska, and the Alaska Peninsula Basins contain bituminous coals with moderate potential for local gas usage. Thermal maturity and coal isopach maps indicate that the Matanuska Valley area of the Cook Inlet Basin and the western foothills belt of the North Slope Basin contain abundant, bituminous, coalbeds up to 50 feet (15 m) thick. These coals have high potential for methane production at depths between 500 and 6,000 feet (150 and 1,800 m). Gas content of coal seams from the first core hole (AK-94CBM-1) drilled in the state to evaluate coalbed methane support this conclusion for the northern portion of Cook Inlet Basin. Coals penetrated by this well show increasing gas content with depth ranging from 63 scf/ton (1.96 cc/g) at 521 feet (159 m) to 245 scf/ton (7.66 cc/g) at 1,236 feet (377 m) on a dry, ash free basis.

INTRODUCTION

Alaska contains vast, lightly explored coal resources that underlie approximately 9% of the land area (Figure 1). Hypothetical coal resources exceed 5.5 trillion short tons, about half of the total United States coal resources [1]. Most of the coal is Cretaceous to Tertiary in age and bituminous to subbituminous in rank. The North Slope and Cook Inlet Basins contain both subbituminous and bituminous rank coals and constitute the largest coal resources in the state (Figures 1 and 2). The Upper and Lower Koyukuk, Kobuk, Alaska Peninsula and the Gulf of

Proceedings of the 1995 Unconventional Gas Symposium

The University of Alabama/Tuscaloosa
May 15-19, 1995

9501

Coalbed Methane Potential for Alaska and Drilling Results for the Upper Cook Inlet

T. N. Smith, State of Alaska, Department of Natural Resources, Division of Oil and Gas

Alaska Basins all contain bituminous coals (Figures 1 and 2). Subbituminous and lignite coals are found in the Susitna, Middle Tanana, Nenana, North Aleutian, Seward Peninsula and Copper River Basins (Figures 1 and 2).

Near-surface coal has been commercially utilized and studied in Alaska for over 100 years and most of the surface coal occurrences have been mapped and studied. Deep coal resources have received considerably less attention. This study focuses on the coal at deeper depths. Information from petroleum production and exploration wells, gravity surveys and surface studies are integrated to provide a coalbed methane resource estimate for Alaska and coalbed methane potential for Alaska's coal basins. Since gas content analyses are available only for the State of Alaska core hole (AK-94CBM-1) in Cook Inlet Basin, established indirect methods using data such as depth, rank and composition [2, 3 and 4] were used to estimate Alaska's coalbed methane resource. The available data suggests that Alaska's coal could contain over 1,000 trillion cubic feet (tcf) of gas. If only 10% is recoverable, the resource would triple the current proven conventional gas reserves for Alaska.

NORTHERN ALASKA PROVINCE

The Northern Alaska Province (North Slope)(Figure 3) contains the largest coal resource in Alaska with hypothetical reserves of 4 trillion short tons [1]. The coals underlie a 400 mile long by 150 mile (640 km by 240 km) wide area (approximately 60,000 square miles (154,000 sq km)). While coals range in age from Mississippian to Tertiary, the primary coal resources occur in the Lower Cretaceous Corwin Formation of the Nanushuk Group (Figure 4).

The North Slope is one of the most thoroughly explored basins in Alaska. Coal was exploited by whaling ships in the late 1800's along the Chukchi Sea coast and the first coal investigation was conducted by Collier [5] in 1906 in that same area. Early explorers also occasionally exploited natural oil seeps for fuel. Oil and gas exploration was initiated in 1919 by geologists of the U. S. Geological Survey and it was this early survey work that led to the

COALBED METHANE POTENTIAL FOR ALASKA AND DRILLING RESULTS FOR THE UPPER COOK INLET BASIN

establishment of the Naval Petroleum Reserve No. 4 (now National Petroleum Reserve in Alaska (NPRA)) in 1923. Between 1943 and 1953, early exploratory drilling by the Navy in NPRA found three oil and six gas accumulations. In 1967, the super giant Prudhoe Bay Field was discovered in the central North Slope by ARCO-Humble. This field is now expected to yield 12 billion barrels of oil and eventually over 23 tcf of gas.

The North Slope data base includes more than 350 oil and gas exploratory wells, 2,500 development wells and seismic data from near the Canadian border to the Chukchi Sea. Since NPRA was established, systematic geologic investigations have proceeded on the North Slope and the Brooks Range that include mapping and sampling the coals. Extensive coal studies have been done on Native lands in the area west of NPRA, where large, exploitable deposits are located near tidewater, but lack the infrastructure to commence mining operations.

Mississippian Coal

Mississippian coals are found in the Kapaloak Formation on the Lisburne Peninsula and in the regionally extensive Kekiktuk Formation (Figure 4). The Kapaloak Formation outcrops over a 45 mile (72 km) long belt trending north-south across the Lisburne Peninsula (Figure 3) and contains low-volatile bituminous to semianthracite coals up to 11 feet (3.4 m) thick. A minimum of 13 coal beds have been identified in outcrop along 2,200 feet (670 m) of measured section [6] that is extensively faulted and folded [7].

The presence of the Kekiktuk Formation has been documented across most of the North Slope. It has been described in detail from outcrops in the Brook Range [8] and is the primary petroleum reservoir at the Endicott Field located on the east side of the Prudhoe Bay Complex (Figure 3). In the Endicott Field, multiple, thick (greater than 10 feet (3 m)) coal seams with an average Ro of 0.6% occur at depths greater than 9,500 feet (2,900 m) (Figure 5). Several wells in NPRA have encountered coal beds as thick as 5 feet (1.5 m) in the Kekiktuk Formation [9]. Only minor, thin Kekiktuk Formation coal occurrences are found in the Brooks Range outcrop belt.

Coalbed Methane Potential. The structurally complex and high rank Kapaloak Formation coals on the Lisburne Peninsula may provide gas for local village or mining use. The Kekiktuk Formation coals are generally too deep to be viable for coalbed methane production.

Lower Cretaceous Coal

Most of the coal resources in Alaska are found in the Cretaceous Corwin and the Chandler Formations of the Nanushuk Group (Figure 4) [9]. Both the Corwin and Chandler Formations are dominantly nonmarine strata that were deposited in two separate, but simultaneous prograding delta systems (Corwin delta of western NPRA and Umiat delta of eastern NPRA) [10]. The Corwin

Formation contains abundant coal seams up to 20 feet (6 m) thick that underlie most of western and central NPRA and extend farther west under the Chukchi Sea [11]. These coal seams have been documented in outcrop along the Kukpowruk River [12] to the west of NPRA and in wells drilled in NPRA. The Kaolak -1 penetrated 255 feet (78 m) of coal in over 4,500 feet (1,370 m) of Nanushuk section and the Meade -1 encountered 130 feet (40 m) of coal in 2,000 feet (610 m) of Nanushuk Group section. Individual coal beds in these wells reach 20 feet (6 m) with up to 26 coal beds exceeding 5 feet (1.5 m) thick. Mapping by Sable and Stricker [9] shows that the coal-bearing interval lies between the surface and 6,000 feet (1,830 m) in western NPRA (Figure 5). In eastern NPRA, the Chandler Formation contains abundant coals similar to those found in the Corwin Formation. The coal-bearing interval of the Chandler Formation is less than 2,000 feet (610 m) deep (Figure 5). Coal rank increases from north to south, to the foothills of the Brooks Range, and also increases with depth. Most of the coal is high-volatile bituminous with a mean Ro of 0.7% [9].

Coalbed Methane Potential. The area of western NPRA, to the Chukchi Sea coast, has high coalbed methane potential and large possible gas reserves (Figure 5). These coals are in a relaxed tectonic stress regime. The area has been uplifted and stripped of overburden which may allow for open fractures and cleats. In the western NPRA area, the depth to the base of the Nanushuk Group coals exceeds 2,500 feet (760 m), placing a substantial portion of the coal section below permafrost. In eastern NPRA, most of the Nanushuk Group coals lie at depths less than 2,000 feet (610 m), placing them near or in the permafrost zone. It is currently uncertain what effects permafrost and cold temperatures will have on gas flow from these coals.

Upper Cretaceous and Tertiary Coal

The Upper Cretaceous Colville Group and the Tertiary Sagavanirktok Formation (Figure 4) contain substantial coal with coaly intervals and coal beds as thick as 50 feet (15 m) [13 and 14]. However, most beds are thinner and lower in rank than the Nanushuk Group coals. The rank of these coals range from lignite A to subbituminous B. The nonmarine Prince Creek Formation of the Colville Group occurs mostly in northeast Alaska and overlies the Nanushuk Group. The Sagavanirktok Formation conformably overlies the Colville Group [15] and occurs generally northeast of NPRA. In NPRA, distribution of the Sagavanirktok Formation is limited to the northeast corner and northern coastal areas, where it reaches a maximum thickness of 1,500 feet (460 m). East of NPRA, the formation thickens to over 7,000 feet (2,130 m) adjacent to the Arctic National Wildlife Refuge (ANWR) (Figure 3).

Coalbed Methane Potential. The Upper Cretaceous and Tertiary coals represent a large, low rank coal resource that probably contain large gas reserves. However, because of the low rank of these coals and cold subsurface

temperatures (permafrost), they have low potential for coalbed methane production.

COOK INLET-SUSITNA PROVINCE

With hypothetical resources exceeding 1.5 trillion short tons, the Cook Inlet-Susitna Province (Figures 2 and 6) constitute the second largest coal resource in the state. The province covers an area of approximately 14,000 square miles (36,000 sq km), which is bounded by the Kenai Mountains to the east, the Aleutian Range to the west, and extends north to the Alaska Range and the Talkeetna Mountains. Unlike many other areas of the state, portions of the Cook Inlet-Susitna Province are road accessible.

The first major commercial oil discovery in Alaska was made 16 miles (26 km) northeast of Kenai (Figure 6) at Swanson River Field in 1957. Subsequent oil and gas discoveries have produced over 1.2 billion barrels of oil and 5.5 tcf of gas. Seismic, well and production data from within the basin provide an extensive data base which greatly decreases coalbed exploration risk. Additionally, Cook Inlet oil and gas production has created an infrastructure which may enable near term gas development.

Cook Inlet Basin

The Cook Inlet Basin is located in the arc-trench gap between the volcanoes of the Alaska-Aleutian Range and the Aleutian trench. Over 25,000 feet (7,600 m) of Tertiary continental deposits unconformably overlie mostly marine Mesozoic rocks [16]. Although coal is found in the entire Tertiary section, the Oligocene to Miocene Tyonek and the Paleocene Chickaloon Formations (Figure 7) have the highest coalbed methane potential. The Tyonek Formation is widespread across Cook Inlet Basin. Large coal fields have been mapped where it crops out on the west side of Cook Inlet. The Chickaloon Formation is limited to the northeast portion of the Cook Inlet Basin.

Cook Inlet Basin forms a large trough with the basin axis located just west of Kenai and roughly paralleling the current shoreline (Figure 6). Because of post-depositional uplift of the basin margins, older rocks with higher thermal maturity are exposed on the basin margins, while rocks of similar age and thermal maturity occur at significant depths along the axis of the basin. For example, an Ro of 0.6% is reached at a depth of 15,000 feet (4,600 m) near the axis of the basin and at 5,000 feet (1,500 m) near the basin edge (Figure 6). Holocene uplift has brought the thick coals of the Tyonek and the Chickaloon Formations near the surface, making some of the onshore areas of the Cook Inlet basin attractive for coalbed methane exploration.

In 1994, the State of Alaska funded a core hole to sample Tyonek Formation coals near Wasilla, located in the northern portion of Cook Inlet Basin. The core hole (AK-94CBM-1) was drilled on a previously identified prospect [17] (Figure 8) located between the towns of Palmer and Houston and near roads and gas pipelines. In this area, the Tyonek Formation is estimated to have a total thickness in

excess of 4,000 feet (1,220 m) with cumulative coal thickness exceeding 100 feet (30 m). High-volatile bituminous coals are expected to be present at depths ranging from 500 to 6,000 feet (150 to 1,800 m).

AK-94CBM-1 was drilled to a total depth of 1,245 feet (380 m), continuously coring the Tyonek Formation from the surface casing shoe at 354 feet (380 m) to total depth. Eighteen seams of high-volatile C bituminous coal were encountered with the thickest being 6.5 feet (3.0 m) and a cumulative thickness of 41 feet (12.5 m). Thirteen of these coal seams were sampled for gas content using 38 gas desorption canisters. Gas content ranges from 63 scf/ton (1.96 cc/g) to 245 scf/ton (7.66 cc/g). Gas content and vitrinite reflectance generally increase with depth, while moisture decreases. Coal moisture contents are low, ranging from 9.02% at 521 feet (159 m) to 4.82% at 1,236 feet (377 m). Gas analyses show that carbon isotopes become slightly heavier with depth indicating an increase in the thermogenic/biogenic gas ratio. The range of -49.3 to -43.2 $\delta^{13}\text{C}$ for methane encountered here is indicative of coalbed gas that has both biogenic and thermogenic sources. Gas composition is 98% methane with minor amounts of CO_2 and N_2 . Due to cost constraints, the drilling program was designed solely to acquire coal samples for analysis and therefore the well was not flow tested. Porosity and permeability measurements have not been obtained. From visual analysis, coal cleat and fracture density is widely spaced with vertical fractures occurring 1 to 3 inches (2.5 to 7.6 cm) apart. Calcite coating was noted on some of the fracture surfaces which may lower effective permeability. Almost no fractures were noted in the clastic rocks. Figure 9 outlines the coal analyses from core samples for this well.

The coal-bearing Chickaloon Formation occurs only in the Matanuska Valley area north of Palmer (Figure 8). These coals have been mined from 1914 to 1968. Geologists with the Bureau of Mines and the U. S. Geological Survey [18] have mapped the extent of these coals in detail using outcrop, mining and core hole data. Most of the coal is confined to the upper 1,400 feet (426 m) of the Chickaloon Formation, which is greater than 3,000 feet (914 m) thick [18]. The coal in the Chickaloon Formation ranges in rank from high-volatile bituminous to anthracite. Coal beds up to 34 feet (10 m) thick and laterally continuous for up to 5 miles (8 km) have been mapped in faulted synclines that increase in structural severity to the east [18 and 19]. The presence of coalbed gas has been documented by mine explosions which occurred in 1937 and in 1957. In the 1937 incident, a violent methane and dust explosion in the Evan Jones Mine, located 12 miles (19 km) north of Palmer, killed 14 men. The 1957 incident was another methane and dust explosion in the same mine, killing 5 men.

Barnes and Payne [18] estimate that over half of the coal reserves lie beneath 1,000 to 2,000 feet (305 to 610 m) of overburden. Bituminous rank coal at shallow depths and the methane gas problems associated with mining combine

COALBED METHANE POTENTIAL FOR ALASKA AND DRILLING RESULTS FOR THE UPPER COOK INLET BASIN

to make the Matanuska Valley area highly prospective for coalbed methane production.

Coalbed Methane Potential. High gas content (up to 245 scf/ton at 1,200 feet (366 m) deep) and large coal resources (hypothetical coal resources exceeding 1.5 trillion short tons), indicate that Cook Inlet Basin contains large gas reserves. Conventional gas production, infrastructure and a local market make near term coalbed gas production possible. The uplifted margins of the basin constitute the best plays.

Cook Inlet coal is very similar to coal found in the Powder River Basin where economical flow rates have been accomplished. However, several significant questions need to be answered to determine the economics of coalbed production from within the basin. These include determination of production flow rates for gas as well as formation water.

Susitna Basin

The Susitna Basin underlies a lowland north of Cook Inlet between the Talkeetna Mountains to the east and the Alaska Range to the north and west (Figures 6 and 8). The Castle Mountain Fault and the Susitna Arch separates the shallower and younger Susitna Basin from the Cook Inlet Basin to the south (Figure 8). The dextral Castle Mountain Fault has offset Mesozoic rocks over 60 miles (97 km) and has almost a 2 mile (3.2 km) vertical throw [20]. The Tertiary coal-bearing section exceeds 13,400 feet (4,080 m) and consists of rocks equivalent to the Sterling, Beluga and upper part of the Tyonek Formations (Kirschner, unpublished report).

Nine exploratory wells have been drilled, plugged and abandoned in the basin, seven of which were drilled near the Castle Mountain Fault. The Trail Ridge -1 was drilled in a deeper part of the basin to 13,708 feet (4,178 m) and encountered Tyonek Formation coals with good gas shows from 11,700 feet to 13,708 feet (3,566 m to 4,178 m). The Tyonek Formation outcrops around the margins of the basin and contains subbituminous coal seams over 20 feet (6 m) thick. One reported seam on Sunflower Creek, located on the northwest side of the basin, measured 55 feet (16.8 m) thick [21].

Coals and sandstones north of the Castle Mountain Fault in the Houston area (Figure 8), where a small coal deposit was mined episodically between 1917 and 1952, appear to have high levels of gas. Five oil and gas exploration wells (Rosetta -1 through Rosetta -4A) and three U. S. Bureau of Mines (USBM) core holes drilled near Houston, encountered gassy coals (Figure 8). The USBM core holes, drilled in 1951, flowed small quantities of gas, possibly from coal seams. The Rosetta wells were drilled between 1954 and 1963 and encountered gas shows while drilling coals and sandstones. In spite of being plugged and abandoned, Rosetta -3 still has some gas escaping from around the surface casing. Some shallow water wells near the Castle Mountain Fault also flow small

quantities of gas. Gas analysis results are similar to those from the coals cored in AK-94CBM-1. Gas analyses from a water well located six miles (10 km) north of Wasilla, indicated the gas to be 98% methane, 2% N₂ and the carbon isotope for methane -46.4 δ¹³C.

Coalbed Methane Potential. Susitna Basin is a smaller, shallower extension of Cook Inlet Basin. Like Cook Inlet Basin, the uplifted basin margins constitute the best potential for gas targets. The area along the Castle Mountain Fault is also highly prospective. This basin lacks the infrastructure of roads and pipelines, however, gas could be exploited for local use or pipelines could be built to connect with the existing gas distribution system in the Cook Inlet Basin.

ALASKA PENINSULA PROVINCE

The Alaska Peninsula contains two distinct coal-bearing basins. Coals in the Cretaceous basin are bituminous rank and the Tertiary (North Aleutian Basin) coals are of bituminous, subbituminous and lignite ranks. The two coal basins have different structural and depositional histories and are separated by a regional angular unconformity. The Cretaceous coal accumulated in an arc-trench gap setting while most of the Tertiary coal-bearing deposits are in a back-arc setting [22].

Cretaceous Basin

All Cretaceous coal occurs in the Upper Cretaceous Coal Valley Member of the Chignik Formation [22]. The Chignik Formation subcrops from Wide Bay in the north to the Herendeen Bay-Pavlof Bay in the south, an area over 200 miles (322 km) long and 50 miles (80 km) wide (Figure 10). The strata is moderately folded and faulted with dips varying from 20 to 35 degrees. The Coal Valley Member is laterally discontinuous in this area. The thickest deposits are found near Herendeen Bay (1,250 feet (381 m)), while this member is absent at other localities. Coal deposition was also variable. An aggregate thickness of 26 feet (7.9 m) of coal [19] was found in one 200-foot (61 m) thick section in the Herendeen Bay area. Other sections within the area contain little coal [23]. Coal beds average 3 feet (0.9 m) thick (the thickest 8 feet (2.4 m)), contain 12 percent ash and have a high (90 percent) vitrinite content. The vitrinite reflectance values of these high-volatile bituminous coals range from 0.57% to 1.76% Ro.

In the subsurface, the Chignik Formation has been penetrated by at least four deep oil and gas wells (Figure 10). The Phillips, Big River A-1 penetrated 27 thin coal seams (maximum thickness of 6 feet (1.8 m) over a 1,345-foot (410 m) interval. The Pan Am, Hoodoo Lake Unit -2 encountered 18 thin coals (maximum thickness of 8 feet (2.4 m)) and the Cities, Painter Cr. -1 encountered 9 coal seams (maximum thickness of 9 feet (2.7 m)). Only the Pan Am, David River 1-A did not encounter any coal seams in the Chignik Formation. All the wells that encountered coals had excellent mudlog gas shows. Coal samples from the

Hoodoo Lake Unit -2 well at depths greater than 8,000 feet (2,438 m), and the David River 1-A at depths between 8,500 to 10,250 feet (2,590 to 3,124 m) (above the Chignik Formation in the overlying Tolstoi Formation) are high-volatile to low-volatile bituminous rank. The Cities Service, Painter Creek -1 encountered a medium-volatile bituminous coal at 1,018 feet (310 m) [24]. Coals of similar rank are found in outcrops at Chignik and Herendeen Bay, indicating that these areas have undergone considerable uplift since maximum burial. The permeability of the cleat system could be enhanced in the uplifted areas.

Coalbed Methane Potential. Cretaceous coal underlies a significant area of the Alaska Peninsula. The variability of the coal development and discontinuous nature of the thin coal beds make subsurface exploration for coalbed methane difficult, particularly for large scale operations. However, if a local energy source is the objective and large reserves and high productivity wells are not necessary, the Chignik Formation coals are viable gas targets for villages towns such as Chignik Lake and Chignik Lagoon.

Tertiary Coal

Alaska Peninsula Tertiary coal occurs in the Tolstoi (Paleocene to Eocene), Stepovak (Oligocene), and Bear Lake (Miocene) Formations. In general, the Bear Lake and Stepovak Formation coals are lignitic to subbituminous rank. Tolstoi Formation coals range from medium- to low-volatile bituminous rank. Most of the coal seams are less than 3 feet (0.9 m) thick. The Bear Lake Formation coals crop out in the area south of Herendeen Bay and on Unga Island (Figure 10). On the north side of the Alaska Peninsula, most of the Tertiary coal-bearing strata subcrop in an area which is over 250 miles (400 km) long and extends at least 35 miles (56 km) offshore to the North Aleutian Coast well in the North Aleutian Basin (Figure 10). Minor to good gas shows are associated with these coals. For example, the Gulf, Port Heiden Unit -1 shows greatly increased mudlog gas in the coaly section in the Bear Lake Formation from depths of 4,000 feet to 5,000 feet (1,219 m to 1,524 m). The mudlog gas levels increased from 20 ppm to over 250 ppm in some of the coal seams. Over this interval, the Port Heiden well encountered approximately 23 coal seams, most of which were less than 5 feet (1.5 m) thick. The David River 1-A well encountered Bear Lake Formation subbituminous coals at similar depths and the Hoodoo Lake Unit -1 penetrated lignitic coals to 5,000 feet (1,524 m) and subbituminous coals to the well's total depth of 8,049 feet (2,453 m) in the Stepovak Formation [24]. This trend is consistent to the north, where the General Petroleum, Great Basins -1 encountered immature rocks with an average Ro of 0.29% for the Bear Lake Formation and an average Ro of 0.51% for the Stepovak Formation. The Hoodoo Lake Unit -2 encountered a gassy coal section in the Tolstoi Formation between 5,800 feet and 6,500 feet (1,768 m and 1,980 m). Based on the mudlog, this well encountered coal seams to 20 feet (6 m) thick with good mudlog gas shows and trace oil shows. The coal is described as lignitic to subbituminous in rank and is shaly.

The rank of these coals must be higher than described in the mudlog since McLean [24] reports the vitrinite reflectance values average 1.15 % (medium-volatile bituminous) for this interval. Geophysical logs do not verify the thick coals noted on the mud log. This may be due to the shale interbeds and/or the nature of the shaly coal beds. The David River 1-A well encountered thin, high-volatile to low-volatile bituminous coal seams between the depths of 8,500 feet and 10,400 feet (2,590 m and 3,170 m) [24].

Coalbed Methane Potential. Structurally high areas where the Tolstoi Formation coals are found above 5,000 feet (1,524 m) in depth have the highest potential. Coal seams in the Bear Lake and Stepovak Formations are too low rank to have good gas potential.

GULF OF ALASKA PROVINCE

The Gulf of Alaska Province consists of the northern Gulf of Alaska onshore area of southern Alaska and is composed of amalgamated tectonic terranes that resulted from both Mesozoic and Cenozoic plate interactions [25]. The Tertiary coal-bearing rocks are found in the Yakutat terrane, the most recently arrived terrane. This terrane is presently moving north with the Pacific plate, colliding with and subducting beneath southern Alaska [26], subjecting the entire area to intense compressional stresses. The tectonism has caused the intense fold and fault deformation present in the Bering River Field [27].

Most of the coal in the Gulf of Alaska Province is found within the Eocene to Early Oligocene Kulthieth Formation [28 and 26]. The coals found in the Bering River Field area (Figure 11) are low-volatile bituminous to meta-anthracite and occur in deformed lenses up to 60 feet (18 m) thick. The coal seams are lenticular both from intense structural deformation and stratigraphic thinning (27) (Merritt, 1986). Coal seams up to 6 feet (1.8 m) thick are found in the Duktoth River District in the Robinson Mountains about 50 miles (80 km) east of the Bering River Field (Figure 11). Thin coal seams are encountered over a much broader and less deformed area in the subsurface from the Bering River field to the Yakutat Bay area, however, none of the thick coal seams found at the Bering River field have been encountered in the subsurface. Onshore exploratory wells (Figure 11) encountered both coal-bearing fluvial and marine strata based on the presence of sparse outer neritic to upper bathyal benthic microfauna in the Kulthieth Formation [29]. Reconstruction of the Kulthieth depositional system indicates that a series of deltas probably deposited sediments directly into a deep marine basin with rapid lateral changes in paleobathymetry [25].

Coalbed Methane Potential. The coals in the Gulf of Alaska Province are subject to intense compressional stress and severely deformed. These coals may be too metamorphosed and compressed to be viable gas targets. However, suitable coalbed methane plays may be found in structurally less deformed areas between the Bering River Field and the coast line.

YUKON-KOYUKUK PROVINCE

The Yukon-Koyukuk Province of western interior Alaska is characterized by maturely-eroded and heavily-vegetated terrain with most of the coal found in outcrops along the Yukon, Koyukuk, and Kobuk Rivers. Three poorly defined coal basins (Upper Koyukuk, Lower Koyukuk, and Kobuk) (Figure 12) have been identified in this province by Merritt and Hawley [1]. Cretaceous and Tertiary volcanic and sedimentary rocks [30] were deposited in a highly mobile basin complex subject to repeated volcanism and plutonism [31]. Up to 25,000 feet (7,620 m) of Cretaceous sedimentary rocks have been documented in this province [31]. This assemblage consists of marine volcanic graywacke and mudstone turbidites overlain by a westward prograding assemblage which includes coal-bearing deltaic deposits at least 10,000 feet (3,048 m) thick [32]. Patton [31] concluded the coal-bearing beds were deposited along a broad shallow trough extending along the eastern margin of the province.

Upper Koyukuk Basin

The thickest coal seams in the Yukon-Koyukuk Province are found in the Tramway Bar Field in the Upper Koyukuk Basin. The Tramway Bar Field is located 35 miles (56 km) above Bettles on the Middle Fork of the Koyukuk River (Figure 12). At this field, three coal seams with thicknesses of 17.5 feet, 3 feet and less than 1 foot (5.3, 0.9, and 0.3 m) have been mapped. These coals are steeply dipping, high-volatile B bituminous, with 38% ash and 6% moisture content [33]. Although these are the only significant coal outcrops in the Upper Koyukuk Basin, abundant coal float has been reported on the John River north of Bettles [34].

Coalbed Methane Potential. The Upper Koyukuk Basin contains bituminous rank coals that could provide gas for local use. Widely scattered outcrops, little surface data, lack of continuity of coal seams, and the structural complexity of the area make drilling targets very elusive.

Lower Koyukuk Basin

Lower Koyukuk Basin coals consist primarily of scattered coal occurrences between Ruby and Anvik on the Yukon River [35] (Figure 12). However, coals in this basin possibly extend much farther south than Anvik as bituminous coals have been reported on the lower Yukon River and Kuskokwim Rivers and Nelson and Nunivak Islands [34]. Between 1890 and 1903, some of these coal occurrences were mined to supply fuel for the steam-powered boats of the Yukon River. The area near Nulato supported several small scale mines in what is now referred to as the Nulato Field. These coals are typically thin (less than 4 feet (1.2 m) thick), high-volatile C bituminous and occur in the Late Cretaceous Kaltag Formation [36]. The thickest coal seam, an 11-foot (3.4 m) bed, is located 12 miles (19 km) upriver from Galena [37]. Thin coal seams were reported at this location by Collier [35] and Chapman [38].

In 1960, the Nulato Unit -1 was drilled to 12,000 feet (3,658 m) and is the only deep well to be drilled in this basin. This well was drilled on a north-east trending surface anticline and penetrated only Cretaceous rocks, yielding little information on the coal-bearing section. Sample descriptions indicate only minor coal was encountered and cores show dips greater than 60 degrees and abundant fractures and brecciation. The entire succession is over mature with respect to oil generation [39] with vitrinite Ro values ranging from 2.62% near the surface to over 4.0% at 6,100 feet (1,859 m) measured depth.

Coalbed Methane Potential. The entire area has undergone moderate to severe structural deformation with some of the coal seams sheared and dipping at steep angles. The complex structure, combined with very limited outcrop control, make predicting reservoir continuity and drillable targets impossible. Gas from bituminous coals for local village usage along the lower Koyukuk and Yukon Rivers may be obtained provided viable drilling targets can be delineated.

Kobuk Basin

Kobuk Basin coals consist of scattered, high-volatile C bituminous occurrences along a 120 mile (193 km) stretch of the Kobuk River between Kiana and Kobuk [21] (Figure 12). Some of these coals were sampled by Clough and others [40] on the west end of the known coal deposition in the Hockley Hills-Singauruk River (near Kiana) areas. Clough and others [40] noted some coal seams up to 6 feet (1.8 m) thick with most of the coal thickness less than 2 feet (0.6 m). Ash contents are high, reaching values of 60%. While the area is slightly less deformed than the Upper and Lower Koyukuk Basins, bed dips exceeding 40 degrees are common. Because of the lack of well and seismic data, no subsurface information on the extent of coal beds is available in this area.

Coalbed Methane Potential. The Kobuk basin lacks the outcrop and subsurface data (well and seismic) to fully evaluate the gas potential of its coals. However, bituminous coals in the basin may be viable exploration targets if they can be demonstrated to subcrop near villages now dependent on imported oil for heating and electricity.

NENANA PROVINCE

The Nenana coal trend is located north of the Alaska Range and includes fields located in the Minchumina, Middle Tanana, and Nenana Basins (Figure 13). These Tertiary coal bearing basins form a discontinuous belt from the Jarvis Creek Field near Big Delta on the east, through Healy, Lignite Creek, and Suntrana Coal Fields in the central portion, to the Farewell-Little Tonzona area (Minchumina Basin) to the southwest. The entire trend extends over 200 miles (320 km) and is over 30 miles (50 km) wide. The coals in these areas are mostly Oligocene to Miocene in age and are subbituminous C or B in rank.

Minchumina Basin

The Minchumina Basin is probably a complex of small, extensional basins [41]. Scattered Tertiary nonmarine sedimentary rocks crop out along stream valleys and river bluffs adjacent to the Alaska Range on the eastern edge of the basin. No subsurface data is available in this area and therefore mapping the lateral extent of coals is problematic. Most outcrops lie along the Farewell Fault Zone and are steeply [42]. The Farewell Fault separates the Minchumina Basin from the Alaska Range. To the west, away from the Farewell Fault, it is conceivable that the dips of these rocks could flatten into the subsurface. Coals in this area range from subbituminous A to high-volatile C bituminous and ash content ranges from 4% to over 26%. Seam thicknesses up to 20 feet (6 m) and multiple coal seams over 3 feet (0.9 m) thick have been mapped [43]. One subbituminous coal seam over 100 feet (30 m) thick has been reported from the Farewell-Little Tonzona Field [44].

Coalbed Methane Potential. The Minchumina Basin contains coal similar to that found in Cook Inlet Basin. Known coal occurrences dip steeply along the major dextral faults in the area. Without subsurface control, the extent and depth to these Tertiary coals is unknown and locating viable coalbed methane targets will be difficult. If found, the coalbed gas could be a useful fuel for local village use.

Nenana Basin

The Nenana Basin contains over 3,000 feet (914 m) of nonmarine Tertiary coal-bearing rocks which unconformably overlie Precambrian and Paleozoic metamorphic rocks. The Nenana Basin is the most explored of the three basins in the Nenana Province and contains a large coal resource (Figures 2 and 13) with coal seams up to 60 feet (18 m) thick. Most of the coal in this basin is subbituminous and is comparable in overall quality to coals found in the Cook Inlet and Wyoming's Powder River Basins [27]. Although the Healy Creek, Suntrana, and Lignite Creek Formations of the Usibelli Group all have significant coal deposits, most exploitable coal is contained within the Suntrana Formation [27]. The Lignite (Hoseanna) Creek Field near Healy is the only active coal mine in Alaska. Here, multiple coal seams that average 20 feet (6 m) thick are being mined from the Suntrana Formation.

Coalbed Methane Potential. The Nenana Basin contains thick coals that are similar to those found in Cook Inlet Basin. If the gas contents are comparable to those in Cook Inlet Basin, these coals could be good gas objectives. This basin contains coalbed methane targets located along the state's road system between Nenana and Healy and in the Big Delta area.

Middle Tanana Basin

The Middle Tanana Basin lies just north of the Nenana Basin and contains about 10,000 feet (3,050 m) of late Cenozoic fill [45 and 41]. Two oil and gas exploratory

wells have been drilled in the Middle Tanana Basin. The Unocal, Nenana -1 and the Arco, Totek Hills -1 (Figure 13) were drilled near the margin of the basin. These wells drilled through the Tertiary section, encountering metamorphic basement rocks at 2,090 feet (789 m) and 3,163 feet (963 m) respectively. Both wells encountered coal, with the Totek Hills -1 well encountering numerous coal seams up to 10 feet (3 m) thick. The nonmarine Tertiary sequence in this basin penetrated by these wells consists of the Usibelli Group, which has been described from outcrops in the Nenana Basin to the south. Coals penetrated by both wells produced only minor mudlog gas shows. Cutting descriptions for the wells indicate the coals to be lignite to subbituminous and the section to be poorly to moderately consolidated. Higher rank coals could be encountered in the deeper parts of the Middle Tanana Basin. Stanley and others [46] estimate the top of the oil window (Ro of 0.6%) to be at depths exceeding 4,500 feet (1,370 m).

Coalbed Methane Potential. Wells in the Middle Tanana Basin encountered lignite to subbituminous coal. Higher rank (high-volatile bituminous) coal is projected to be below 4,500 feet (1,370 m) and is probably too deep for good coalbed methane production. Geologically, the low-rank coals are poor to moderate methane drainage targets, although the basin's proximity to the large Fairbanks market makes it attractive from an economic perspective.

NORTHERN YUKON PROVINCE

The Northern Yukon Province encompasses lower to middle Tertiary coal-bearing sedimentary rocks found in the Eagle and Rampart Troughs and the Yukon Flats Basin (Figure 13). Outcrops are scarce in this region occurring only in recently eroded bluffs and stream cutbanks. The area extends west over 400 miles (640 km) from the Canadian border along the Yukon River. Coal rank for the area ranges from lignite A to subbituminous C, though a few localities containing bituminous coal have been reported [47].

Eagle Trough

The Eagle Trough (Tintina Trench) is a northwest-trending basin that lies along the Tintina Fault Zone (Figure 13). This basin is estimated to contain as much as 9,500 feet (3,000 m) of Tertiary fill [48] in the vicinity of the Tintina Fault Zone. The basin contains subbituminous coals, although some coals have been tectonically upgraded in rank near the Tintina Fault Zone [47]. Although coal seams thicker than 30 feet (9 m) have been reported, most seams have a thickness less than 3 feet (0.9 m). In outcrop, many coal beds are highly fractured and steeply dipping [34].

Coalbed Methane Potential. The Eagle Trough contains mainly subbituminous coals which may be too low in rank to be good gas prospects. Gas for local use may be

COALBED METHANE POTENTIAL FOR ALASKA AND DRILLING RESULTS FOR THE UPPER COOK INLET BASIN

found in areas near faulting where the coal rank is higher and coal fractures may be better developed.

Rampart Trough

The Rampart Trough is a southwest-trending basin that lies along the Kaltag Fault. Tertiary fill in the trough is estimated to be as much as 6,500 feet (2,000 m) [41] (Figure 13). Coals found in the basin are dominantly subbituminous in rank and generally less than 5 feet (1.5 m) thick. Most of the mapped coal occurrences in the Rampart Trough are found adjacent to the Kaltag Fault and are very tectonically disturbed [47]. As in the Eagle Trough, some of the coals are bituminous in rank due to tectonic rank upgrading along major faults.

Coalbed Methane Potential. The Rampart Trough coals have low gas potential because of their low rank (subbituminous). Near faulting, where coals are fractured and have a higher rank, coalbed methane targets may be more attractive.

Yukon Flats Basin

Covering over 8,500 square miles (22,000 sq km), the Yukon Flats Basin is the largest Tertiary basin in Interior Alaska [47] (Figure 13). The basin is a half-graben complex with about 2 to 3 miles (3 to 5 km) of nonmarine Tertiary fill [49]. The only subsurface control in this large basin is a proprietary oil company seismic survey, shallow core holes, and a 1,200-foot (366 m) core hole drilled in 1994 at Fort Yukon by the U. S. Geological Survey. Bedrock outcrops are rare with the only exposures found along the margins of the basin. These limited exposures indicate coal-bearing rocks probably underlie most of the Yukon Flats Basin. Barker and Goff [47] report augering about 20 feet (6 m) of coal with a rank from lignite A to subbituminous B. The USGS Fort Yukon well encountered a 21+ feet (6.4 m), Middle Miocene, lignitic coal bed at a depth of 1,260 feet (384 m) (Gary Stricker, personnel communication, 1994). The core sample released a significant amount of gas when brought to the surface. This resulted in the termination of drilling (Tom Ager, personnel communication, 1994).

Coalbed Methane Potential. The known coals of Yukon Flats Basin are too low in rank for good gas production. However, higher rank coals found closer to the surface along the uplifted basin margins may have high gas potential.

SEWARD PENINSULA PROVINCE

Lignite and subbituminous coal-bearing rocks of Cretaceous and Early Tertiary age occur in isolated, structurally controlled coal fields on the Seward Peninsula [50] (Figure 12). Some of the coal beds are impressive in thickness reaching 80 feet (24 m) at Chicago Creek Field and 180 feet (55 m) at Grouse Creek [7]. The Tertiary section at Chicago Creek Field is generally less than 200 feet (61 m) thick and unconformably overlies quartz-mica

schist of lower Paleozoic or Proterozoic age. Lignite beds in the Unalakleet area are generally less than 2 feet (0.6 m) thick and also dated as early Tertiary [31].

Both the Socal, Cape Espenberg -1, drilled on the north side of the Seward Peninsula, and the Socal, Nimiuk Point -1, drilled south of Kotzebue (Figure 12), penetrated a coal-bearing section in the Selawik Basin. The coal-bearing section penetrated by the wells is Upper Pliocene to lower Pleistocene in age [51] and thermally immature with Ro values less than 0.4%, distinguishing it from the Paleocene coals found in outcrop at Chicago Creek Field [52]. These wells reached total depth in schistose metasediments and marble that likely correlate with pre-Mississippian schists and marble exposed on the Seward Peninsula. Both wells failed to penetrate the Cretaceous and early Tertiary coal-bearing rocks that outcrop on the Seward Peninsula, possibly indicating that the Seward Peninsula coal-bearing strata occurs as local, isolated basins.

Coalbed Methane Potential. Coals in the Seward Peninsula, Selawik, and Unalakleet areas are too low in rank for good gas production.

OTHER COAL-BEARING AREAS

Southeast Alaska

High-volatile B Bituminous [53] coal occurs near Angoon on the Kootznahoo Inlet (Admiralty Island) throughout an area of about 40 square miles (100 sq km) [54] (Figure 1). The coals are high sulfur, dirty, discontinuous and thin. The prominent structural dip of the rocks in the area is 45 degrees to the southeast. Coal with similar characteristics crops out near Murder Cove at the southern tip of Admiralty Island. Small, isolated outcrops of Tertiary lignite also are present on Prince of Wales, Kuiu, and Kake Islands [34].

Coalbed Methane Potential. The Kootznahoo Inlet coals on Admiralty Island are the only coals in southeast Alaska that hold even low gas potential. However, these coals are thin, discontinuous, dirty and structurally complex, making them unlikely targets.

Copper River

The Copper River Basin (Figure 11) occupies a lowland area in south-central Alaska between the Talkeetna and the Wrangell Mountains. Coal occurs throughout the 3,000 feet (914 m) of nonmarine Tertiary sedimentary basin fill. The coals penetrated in the wells and found in outcrops on the basin margins are lignites. Ten exploratory oil and gas wells have been drilled in the basin. The thickest Tertiary section penetrated in the northeast portion of the basin by Salmon Berry Lake -1 and Rainbow Federal -1 and -2 wells (Figure 11). A high thermal gradient on the eastern side of the basin near the Neogene and Quaternary Wrangell Mountain volcanoes may be present and upgrade the rank of coal in this area. However, coal outcrops in the Wrangell Mountains (Figure 11) are reported to be lignite [1] and Ro

values of Tertiary sediments are generally less than 0.4% in the eastern portion of the basin near the Wrangell Mountains.

Coalbed Methane Potential. The Copper River Basin coals are too low in rank to have good gas potential.

DISCUSSION

Neither a proven reserve base or an export market for coalbed methane has been established in Alaska. However, preliminary analysis suggests that coalbed methane represents a huge, untapped state resource. As Alaska's conventional oil and gas reserves decline, it is critical to locate and identify and catalog potential deposits that can contribute to long term growth. In addition, identifying future energy resources is essential for land use planning.

This report's evaluation of Alaska's coalbed methane potential is based primarily upon the current limited knowledge of the basins and is calibrated with analogs from producing coalbed methane basins, primarily in the lower 48 states. It must be noted, however, that coal is a complex, heterogeneous material that defies simple analysis and comparisons. Predictions of Alaska's coalbed methane potential is fraught with pitfalls and ultimately only exploration drilling and long term well testing can provide definitive results.

For large scale coalbed methane production (involving several tcf) to take place in Alaska, it will have to compete with other gas sources for export to Pacific Rim markets. The economics involved with using coalbed methane as a local energy source may be much more favorable. Alaska's remote communities are currently dependent on large deliveries of diesel fuel for heating and electrical generation. Some areas pay the equivalent of \$10 to \$15 per mcf in fuel costs. The potential for spills during water-borne transportation of petroleum products is well known, and regulators are making it increasingly expensive. Additionally, using gas for local consumption would eliminate the large oil storage facilities (large enough to sustain the village through the entire winter) that each village must maintain, thus eliminating the potential for oil spills and pollution of ground and surface water. Wells producing 30 mcf per day, that in other situations would be uneconomic, could fill the energy needs of many of Alaska's rural communities.

CONCLUSIONS

Alaska's enormous coal resources provide many opportunities for coalbed methane exploration. Both Northern Alaska (North Slope) and Cook Inlet-Susitna Provinces contain thick coal sequences that hold large coalbed methane resources. The onshore areas in the Matanuska Valley and the uplifted basin margins of Cook Inlet Basin provide the highest potential for near term, large scale coalbed methane development. Large scale coalbed methane development on the North Slope is currently not

feasible due to a lack of infrastructure. Bituminous coals in the Upper and Lower Koyukuk, Kobuk, Gulf of Alaska and Alaska Peninsula Basins could provide gas for the rural communities that depend on diesel fuel for power generation. Subbituminous and lignite coals in the North Slope, Cook Inlet, Susitna, Middle Tanana, Nenana, Yukon Flats, North Aleutian, Seward Peninsula and Copper River Basins could provide more opportunities for gas production provided hydrologic conditions and gas contents are suitable.

ACKNOWLEDGMENTS

The author is especially grateful to Michael Pritchard, State Division of Oil and Gas, for preparing all the illustrations in this paper. Thanks to Mark Myers, Don Krouskop, Tim Ryherd, and James Hansen, all from the State Division of Oil and Gas, and Mike Belowich, Consultant, for their review of the manuscript. Thanks to Dave Lappi, Lapp Resources, Inc., for his help and interest in the project from pulling core at the well site to review of this manuscript. Thanks to Matt McCullough and Brad Penn, Marathon Oil Co., and Eric Graven, Unocal, for their help. Thanks to the State of Alaska for providing the funds and time necessary to complete this project and to the U. S. Geological Survey drilling crew (Art Clark, Dan Sweeney, Dean Bohn and Todd Hunter) for all their help and expertise. Special thanks to Don Church for allowing his land to be the drilling site. And finally to my wife, Deborah, for her help and support.

REFERENCES CITED

1. Merritt, R. D. and Hawley, C. C., 1986, Map of Alaska's coal resources: Alaska Division of Geological and Geophysical Surveys Special Report 37, 1 sheet, scale 1:2,500,000.
2. Kim, A. G., 1976, Estimating methane content of bituminous coalbeds from absorption data: U. S. Bureau of Mines Report of Investigations 8245, 22 p.
3. McFall, K. S., Wicks, D. E., Kelso, B. S., Sedwick, K., and Brandenburg, C., 1987, An analysis of the coal and coalbed methane resources of the Piceance Basin, Colorado: SPE/DOE 16418.
4. King, G. R., and Ertekin, T. M., 1989, A survey of mathematical models related to methane production from coal seams, part 1-Empirical and equilibrium sorption models, in The 1989 Coalbed Methane Symposium, Proceedings- University of Alabama, Tuscaloosa, April 17-20, 1989: School of Mines and Energy Development, Gas Research Institute, U. S. Mine Safety and Health Administration, and Geological Survey of Alabama, p. 125-138.
5. Collier, A. J., 1906, Geology and coal resources of the Cape Lisburne region, Alaska: U. S. Geological Survey Bulletin 278, 54 p.
6. Tailleux, I. L., 1965, Low volatile bituminous coal of Mississippian age on the Lisburne Peninsula, Northwestern Alaska: U. S. Geological Survey Professional Paper 525B, p. B34-B38.

COALBED METHANE POTENTIAL FOR ALASKA AND
DRILLING RESULTS FOR THE UPPER COOK INLET BASIN

7. Eakins, G. R., 1986, Investigations of coal resources in northwest Alaska, 1980-1985, in Rao, P. D., ed., Focus on Alaska's Coal '86; Proceedings of the Conference: University of Alaska at Fairbanks, Mineral Industry Research Laboratory Report 72, p. 250-265.
8. LePain, D. L., Crowder, R. K., and Wallace, W. K., 1994, Early Carboniferous transgression on a passive continental margin: Deposition of the Kekiktuk Conglomerate, northeastern Brooks Range, Alaska: American Assoc. of Petroleum Geologists Bulletin, v. 78, p. 679-699.
9. Sable, E. G., and Stricker, G. D., 1987, Coal in the National Petroleum Reserve in Alaska (NPRA); Framework geology and resources, in Tailleir, I. L., and Weimer, R., eds., Alaskan North Slope geology: Society of Economic Paleontologists and Mineralogists and Alaska Geological Society Book 50, p. 195-216.
10. Ahlbrandt, T. S., Huffman, A. C., Fox, J. E., and Pasternak, Ira, 1979, Depositional framework and reservoir quality studies of selected Nanushuk Group outcrops, North Slope, Alaska, in Ahlbrandt, T. S., ed., Preliminary geologic, petrologic, and paleontologic results of the study of Nanushuk Group rocks, North Slope, Alaska: U. S. Geological Survey Circular 794, 163 p.
11. Tailleir, I. L., and Brosge, W. P., 1975, Coal resources of northern Alaska may be nation's largest, in Rao, P. D., and Wolff, E. N., eds., Focus on Alaska's coal '75, Proceedings of the Conference held at the University of Alaska, Fairbanks, October 15-17, 1975: Mineral Industry Research Laboratory Report No. 37, p. 219-226.
12. Warfield, R. S., and Boley, C. C., 1969, Sampling and coking studies of several coal beds in the Kokolik River, Kukpowruk River, Cape Beaufort areas of Arctic Alaska: U. S. Bureau of Mines Report of Investigations 7321, 58 p.
13. Brosge, W. P., and Whittington, C. L., 1966, Geology of the Umiat-Maybe Creek region, Alaska: U. S. Geological Survey Professional Paper 303-H, p. H501-H638.
14. Molenaar, C. M., Kirk, A. R., Magoon, L. B., and Huffman, A. C., 1984, Twenty-two measured sections of Cretaceous-Lower Tertiary rocks, eastern North Slope, Alaska: U. S. Geological Survey Open-File Report 84-695, 19 p.
15. Detterman, R. L., Reiser, H. N., Brosge, W. P., and Dutro, J. T., Jr., 1975, Post-Carboniferous stratigraphy, northeastern Alaska: U. S. Geological Survey Professional Paper 886, 46 p.
16. Calderwood, K. W. and Fackler, W. C., 1972, Proposed stratigraphic nomenclature for Kenai Group, Cook Inlet basin, Alaska: American Assoc. of Petroleum Geologists Bulletin, v. 56, p. 739-754.
17. Smith, T. N., and Clough, J. G., 1993, Coalbed methane potential for Alaska: 1993 American Assoc. of Petroleum Geologists Annual Convention Program, abs., p. 184.
18. Barnes, F. F., and Payne, T. G., 1956, The Wishbone Hill District, Matanuska coal field, Alaska: U. S. Geological Survey Bulletin 1016, 85 p.
19. Alaska's high-rank coals, 1993: State of Alaska, Div. of Geological and Geophysical Surveys Information Circular 33, 36 p.
20. Detterman, R. L., Plafker, G., Hudson, T., Tysdal, R. G., and Pavoni, N., 1974, Surface geology and Holocene breaks along the Susitna segment of the Castle Mountain fault, Alaska: U. S. Geological Survey Miscellaneous Field Studies Map MF-618, scale 1:24,000.
21. Sanders, R. B., 1980, Coal resources of Alaska: in Rao, P. D., and Wolff, E. N., eds., Focus on Alaska's coal '80, Proceedings of the Conference held at the University of Alaska, Fairbanks: Mineral Industry Research Laboratory Report No. 50, p. 11-31.
22. Burk, C. A., 1965, Geology of the Alaska Peninsula-- island arc and continental margin: Geological Society of America Memoir 99, pts. 1-3, 250 p.
23. Merritt, R. D., and McGee, D. L., 1986, Depositional environments and resource potential of Cretaceous coal-bearing strata at Chignik and Herendeen Bay, Alaska Peninsula: Sedimentary Geology, v. 49, p. 21-29.
24. McLean, Hugh, 1977, Organic geochemistry, lithology, and paleontology of Tertiary and Mesozoic rocks from wells on the Alaska Peninsula: U. S. Geological Survey Open-File Report 77-813, 63 p.
25. Turner, R. F., Risley, D. E., Martin, G. C., Lynch, M. B., Flett, T. O., Larson, J. A., and Horowitz, W. L., 1992, Geologic report for the Gulf of Alaska planning area: OCS Report MMS 92-0065, 302 p.
26. Plafker, George, 1987, Regional geology and petroleum potential of the northern Gulf of Alaska continental margin, in Scholl, D. W., Grantz, A., and Vedder, J. G., eds., Geology and resource potential of the continental margin of western North America and adjacent ocean basins - Beaufort Sea to Baja California: Houston, Texas, Circum-Pacific Council for Energy and Mineral Resources, Earth Science Series, v. 6, p. 229-268.
27. Merritt, R. D., 1986, Paleoenvironment and tectonic controls in major coal basins of Alaska, in Lyons, P. C., and Rice, C. R., eds., Paleoenvironment and tectonic controls in coal-forming basins of the United States: Geological Society of America, Special Paper 210, p. 173-200.
28. Winkler, G. R., and Plafker, G., 1981, Preliminary geologic map of the Cordova and Middleton Island quadrangles, Alaska: U. S. Geological Survey Open-File Report 81-1164, scale 1:250,000.
29. Rau, W. W., Plafker, G., and Winkler, G. R., 1983, Foraminiferal biostratigraphy and correlations in the Gulf of Alaska Tertiary province: U. S. Geological Survey Oil and Gas Investigations Chart OC-120, 11 p., 3 plates.
30. Patton, W. W., Jr., and Box, S. E., 1989, Tectonic setting of the Yukon-Koyukuk basin and its borderlands, western Alaska: Journal of

- Geophysical Research, vol. 94, no. B11, p. 15,807-15,820.
31. Patton, W. W., Jr., 1973, Reconnaissance geology of the northern Yukon-Koyukuk Province, Alaska: U. S. Geological Survey Professional Paper 774-A, p. A1-A17.
 32. Patton, W. W., Jr., 1966, Regional geology of the Kateel River quadrangle, Alaska: U. S. Geological Survey Misc. Geol. Inv. Map I-437, scale 1:250,000.
 33. Rao, P. D., 1986, Characterization and evaluation of washability of Alaskan coals, fifty selected seams from various coal fields: U. S. Department of Energy Final Technical Report - September 30, 1976 to February 28, 1986 (DOE/PC/62695-T5); University of Alaska at Fairbanks Mineral Industry Research Laboratory Report no. 75, p. 184.
 34. Barnes, F. F., 1967, Coal resources of Alaska: U. S. Geological Survey Bulletin 1241-B, 36 p.
 35. Collier, A. J., 1903, The coal resources of the Yukon, Alaska: U. S. Geological Survey Bulletin 218, 71 p.
 36. Martin, C. G., 1926, Mesozoic stratigraphy of Alaska: U. S. Geological Survey Bulletin 776, p. 396-410.
 37. Goff, K. M., and Barker, J. C., 1988, Nulato coalfield: Alaska Division of Geological and Geophysical Surveys Report of Investigations, in press.
 38. Chapman, R. M., 1963, Coal deposits along the Yukon River between Ruby and Anvik, Alaska, in Contributions to Economic Geology of Alaska: U. S. Geological Survey Bulletin 1155, p. 18-29.
 39. Johnsson, M. J., 1992, Vitrinite reflectance and conodont color alteration index data from Alaska (computer file): U. S. Geological Survey Open-file Report 92-409.
 40. Clough, J. G., Eakins, G. R., and Menge, M., 1983, Preliminary report on the Hockley Hills-Singauruk River coal occurrence: Alaska Division of Geological and Geophysical Surveys Public-data File 83-3.
 41. Kirschner, C. E., 1988, Map showing sedimentary basins of onshore and continental shelf areas, Alaska: U. S. Geological Survey Miscellaneous Investigations Series, Map I-1873, scale 1:2,500,000.
 42. Sloan, E. G., Shearer, G. B., Eason, J. E., and Almquist, C. L., 1981, Reconnaissance survey for coal near Farewell, Alaska, in Rao, P. D., and Wolff, E. N., eds., Focus on Alaska's Coal '80: University of Alaska at Fairbanks Mineral Industry Research Laboratory Report 50, p. 152-170.
 43. Solie, D. N., and Dickey, D. B., 1982, Coal occurrences and analyses, Farewell-White Mountain area, southwest Alaska: Alaska Division of Geological and Geophysical Surveys Open-file Report 160, 17 p., 1 sheet.
 44. Player, Gary, 1976, The Little Tonzona coal bed near Farewell, Alaska; an important extension of the coal field north of the Alaska Range: Gary Player ventures consultant report, Anchorage, 10 p.
 45. Barnes, D. F., 1961, Gravity low at Minto flats, Alaska: U. S. Geological Survey Professional Paper 424-D, p. D254-D257.
 46. Stanley, R. G., McLean, Hugh, and Pawlewicz, M. J., 1989, Petroleum source potential and thermal maturity of the Tertiary Usibelli Group of Sumtrana, Alaska, in Dover, J. H., and Galoway, J. P., eds., Geologic studies in Alaska by the U. S. Geological Survey, 1989: U. S. Geological Survey Bulletin 1946, p. 65-76.
 47. Barker, J. C., and Goff, K. M., 1986, Coal resources within the Yukon Drainage, interior Alaska, in Rao, P. D., ed., Focus on Alaska's Coal '86; Proceedings of the Conference: University of Alaska at Fairbanks, Mineral Industry Research Laboratory Report 72, p. 336-349.
 48. Cady, J. W., and Weber, F. R., 1983, Aeromagnetic map and interpretation of magnetic and gravity data, Circle quadrangle, Alaska: U. S. Geological Survey Open-file Report 83-170C.
 49. Magoon, L. B., and Krischner, C. E., 1990, Alaska onshore national assessment program--Geology and petroleum resource potential of six onshore Alaska provinces: U. S. Geological Survey Open-file Report 88-450T, 47 p.
 50. Hudson, Travis, 1977, Preliminary geologic map of the Seward Peninsula, Alaska: U. S. Geological Survey Open-file Report 77-167A, scale 1:1,000,000.
 51. Turner, D. L., and Olson, D. L., 1978, Preliminary paleontology report, Standard Oil Company of California, Cape Espenberg No. 1 well and Nimiuk Point No. 1 well, Kotzebue Sound--Selawik Basin Area: U. S. Minerals Management Service internal report.
 52. Decker, John, Robinson, M. S., Clough, J. G., and Lyle, W. M., 1988, Geology and petroleum potential of Hope and Selawik basins: Alaska Division of Geological and Geophysical Surveys Public-data File Report 88-1, 41 p.
 53. Cooper, H. M., Snyder, N. H., Abernathy, R. F., Tarpley, E. C., and Swingle, R. J., 1946, Analyses of mine, tippie, and delivered samples, in Analyses of Alaska coals: U. S. Bureau of Mines Technical Paper 682, p. 19-69.
 54. Latham, E. H., Pomeroy, J. S., Berg, H. C., and Loney, R. A., 1965, Reconnaissance geology of Admiralty Island, Alaska: U. S. Geological Survey Bulletin 1181-R, p. R1-R48.

Figure 1. Alaska coal basins and coal occurrences [1].

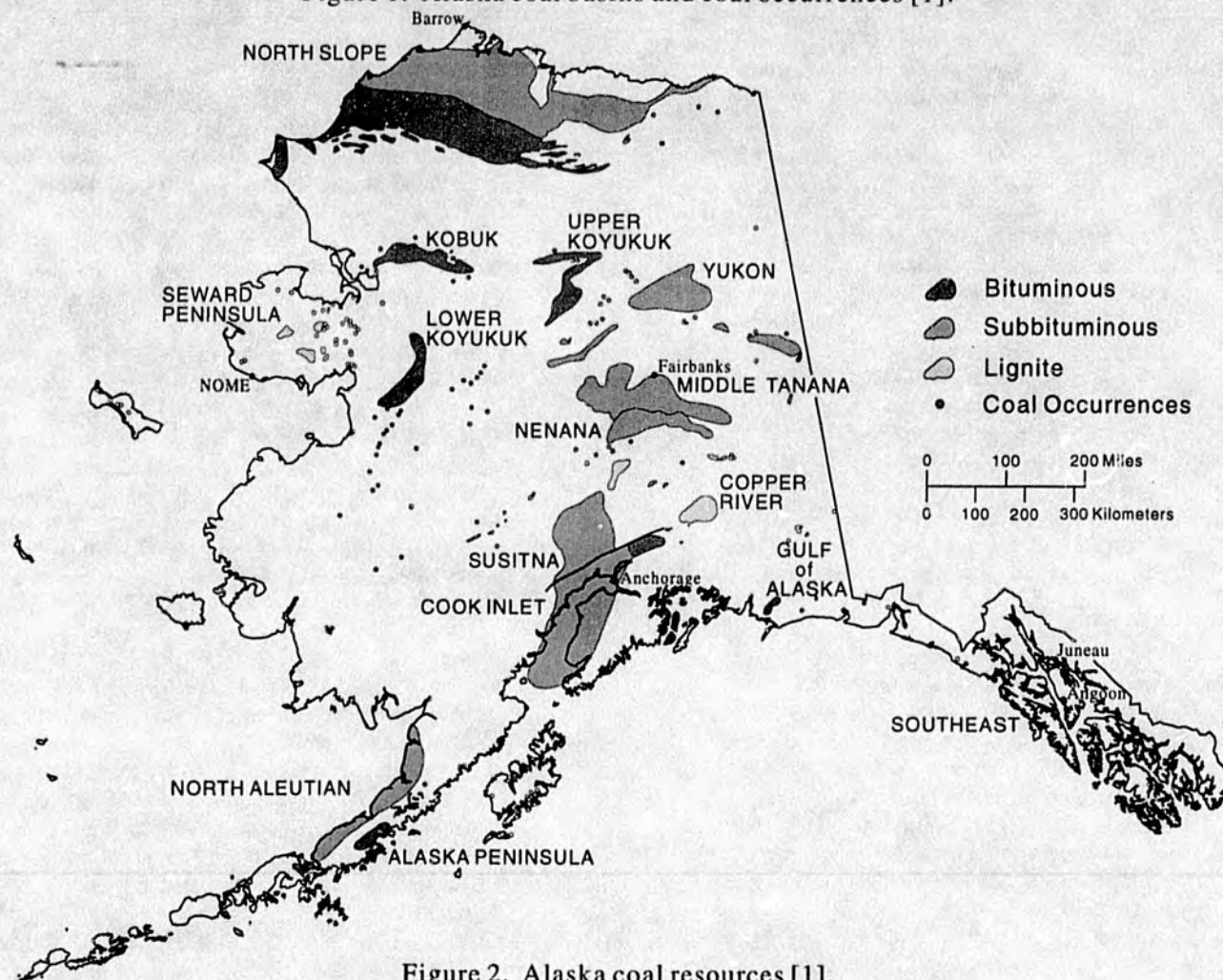


Figure 2. Alaska coal resources [1].

<u>RANK OF COAL</u>	<u>BASIN</u>	<u>HYPOTHETICAL RESOURCES</u> (Billion short tons)
BITUMINOUS COAL		
	North Slope	2,500
	Cook Inlet	500*
	Alaska Peninsula	3
	Gulf of Alaska	4
	Upper and Lower Koyukuk	1
	Kobuk	1
SUBBITUMINOUS COAL		
	North Slope	1,500
	Cook Inlet	1,000
	Nenana	15
	Susitna	3
	Tanana	45
	Yukon	1
	North Aleutian	No Estimate
LIGNITE COAL		
	Copper River	No Estimate
	Seward Peninsula	0.1

*Includes subsurface for Cook Inlet Basin from well data and Matanuska field coals.

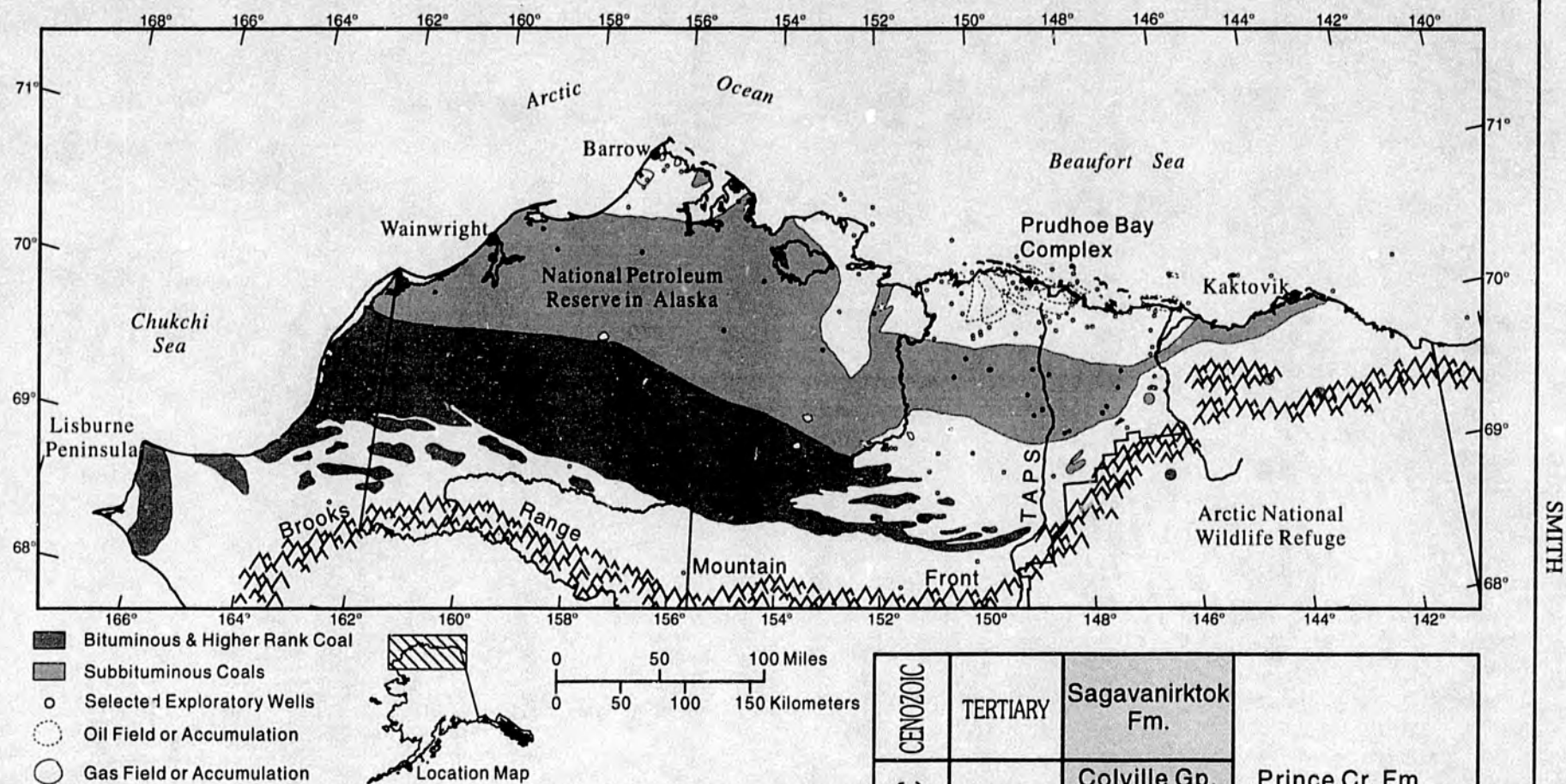


Figure 3. Extent of Northern Alaska Province (North Slope) coals [1].

CENOZOIC	TERTIARY	Sagavanirktok Fm.	Prince Cr. Fm. Corwin Fm.
MESOZOIC	CRETACEOUS	Colville Gp.	
		Nanushuk Gp.	
		Kuparuk Fm.	
	JURASSIC	Kingak Fm.	
TRIASSIC	Sadlerochit Gp.	Kekiktuk Fm. Kapaloak Fm.	
PERMIAN	Lisburne Gp.		
PENN.			
MISS.	Endicott Gp.		
DEVONIAN			

Figure 4. North Slope generalized stratigraphic column.

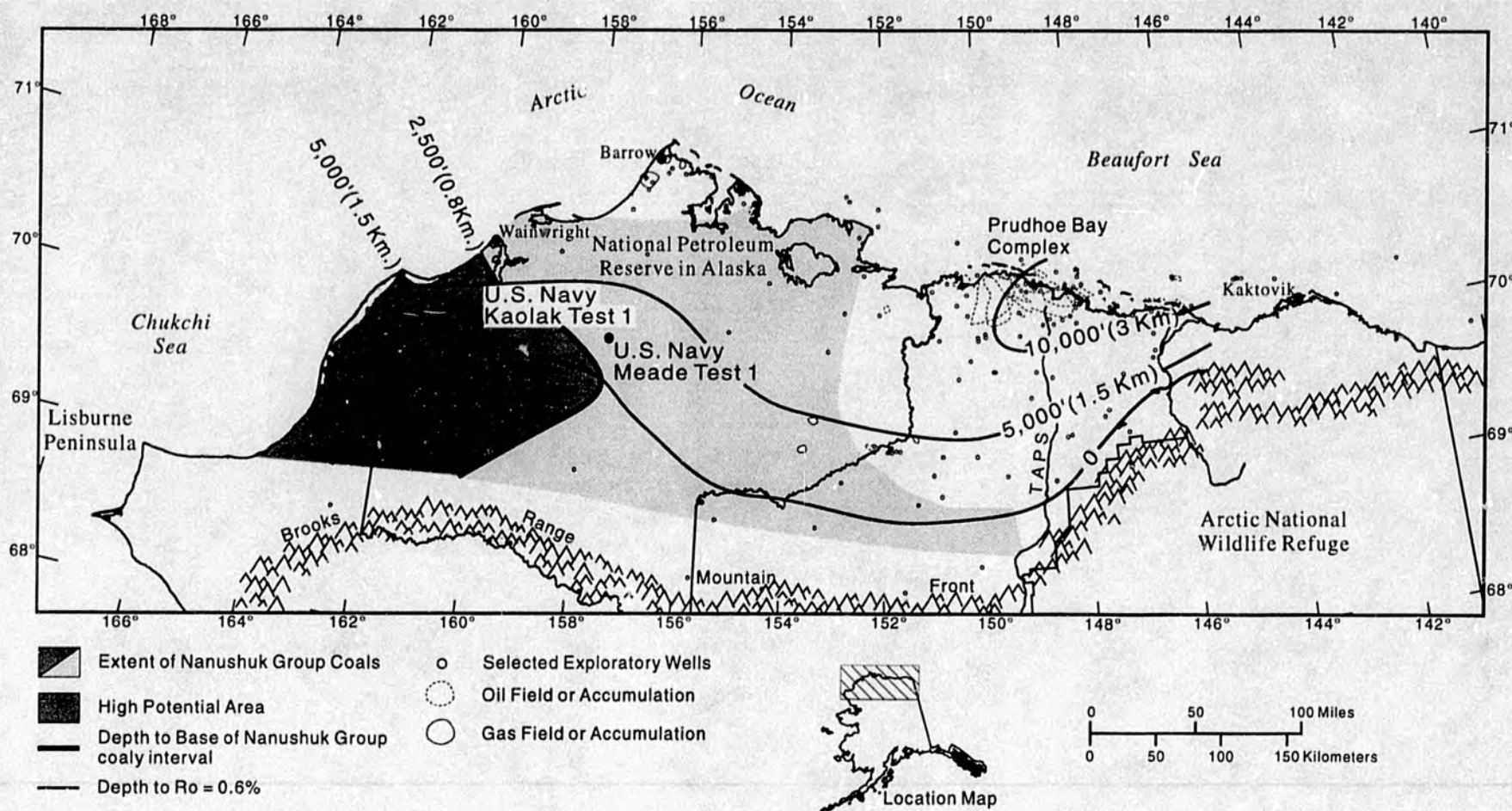


Figure 5. Extent of Nanushuk Group coals [9] and area of high coalbed methane potential.

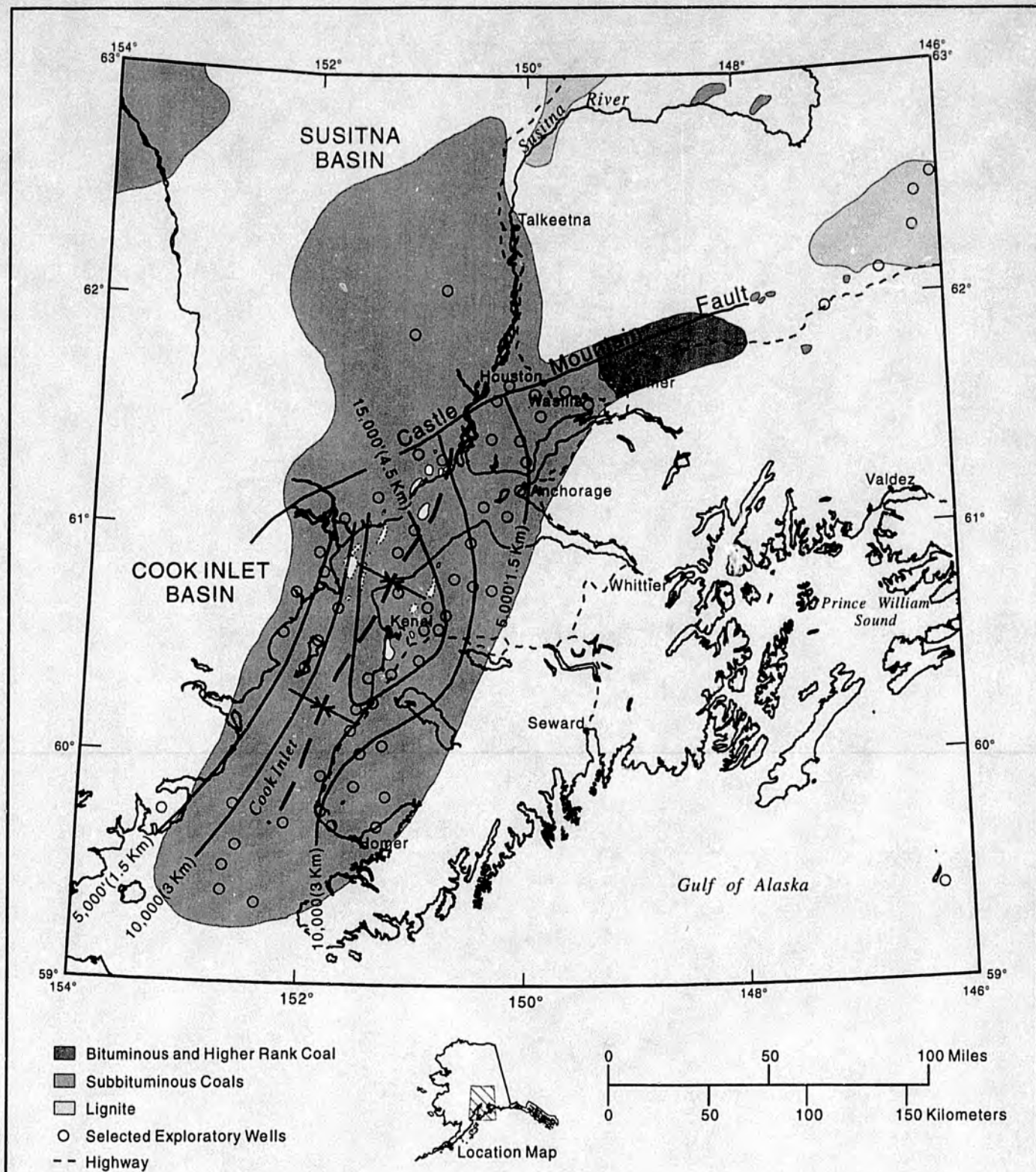


Figure 6. Extent of Cook Inlet-Susitna Province coals [1] showing the basin axis and contours showing depth to $R_o = 0.6\%$.

COALBED METHANE POTENTIAL FOR ALASKA AND DRILLING RESULTS FOR THE UPPER COOK INLET BASIN

TERTIARY	PLIOCENE	Sterling Fm.	subC to hvBb, beds > 50' thick
	MIOCENE	Beluga	
		Tyonek Fm.	
	OLIGOCENE	Hemlock	
	EOCENE	W. Foreland	hvBb and higher, beds to 34' thick
		Chickaloon Fm.	

Figure 7. Cook Inlet generalized stratigraphic column.

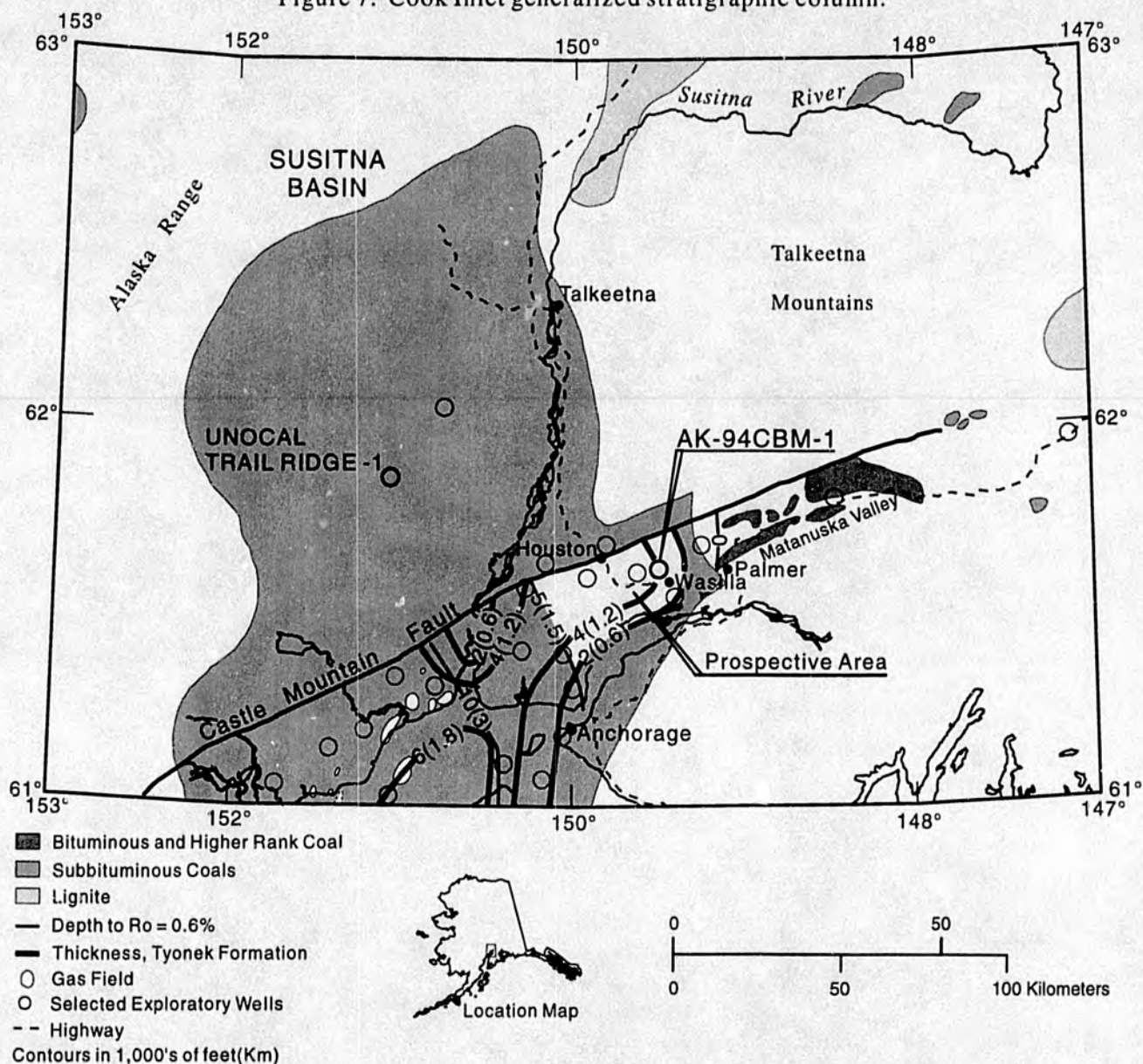


Figure 8. Extent of Susitna and upper Cook Inlet coals [1] showing Tyonek Formation thickness, depth to $R_o = 0.6\%$ and prospective area for Tyonek Formation coals.

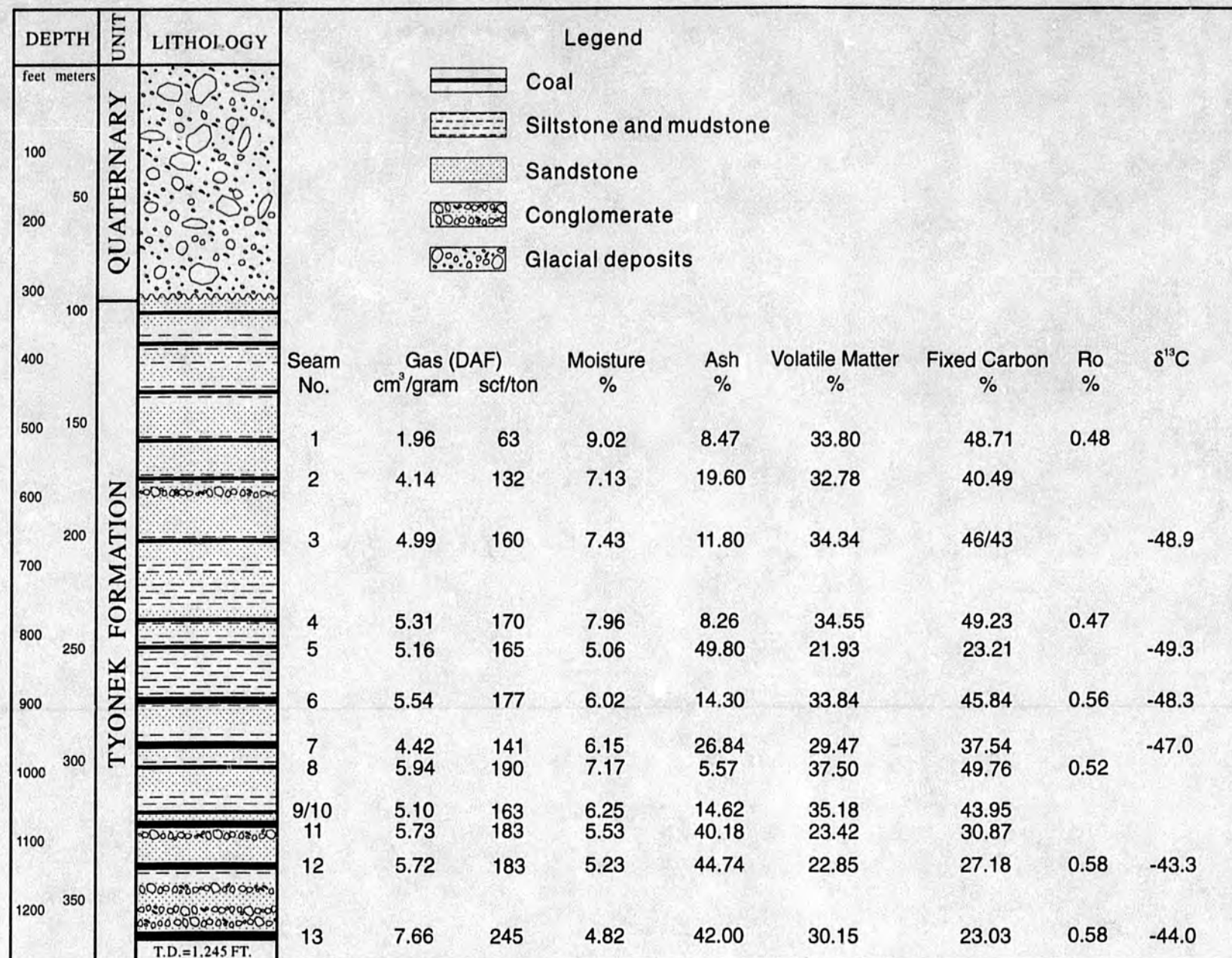


Figure 9. Coal analyses for AK-94CBM-1.

COALBED METHANE POTENTIAL FOR ALASKA AND DRILLING RESULTS FOR THE UPPER COOK INLET BASIN

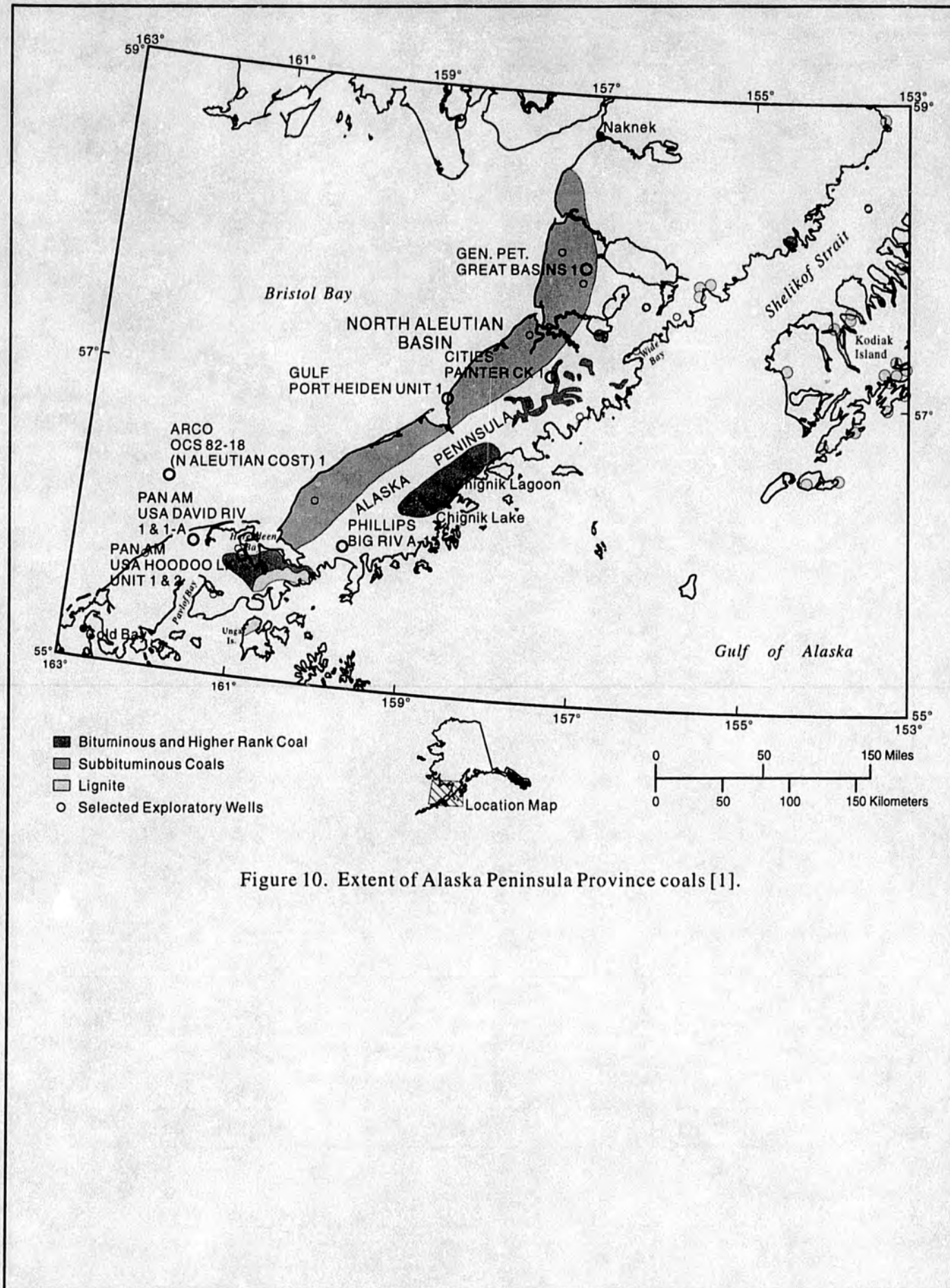


Figure 10. Extent of Alaska Peninsula Province coals [1].

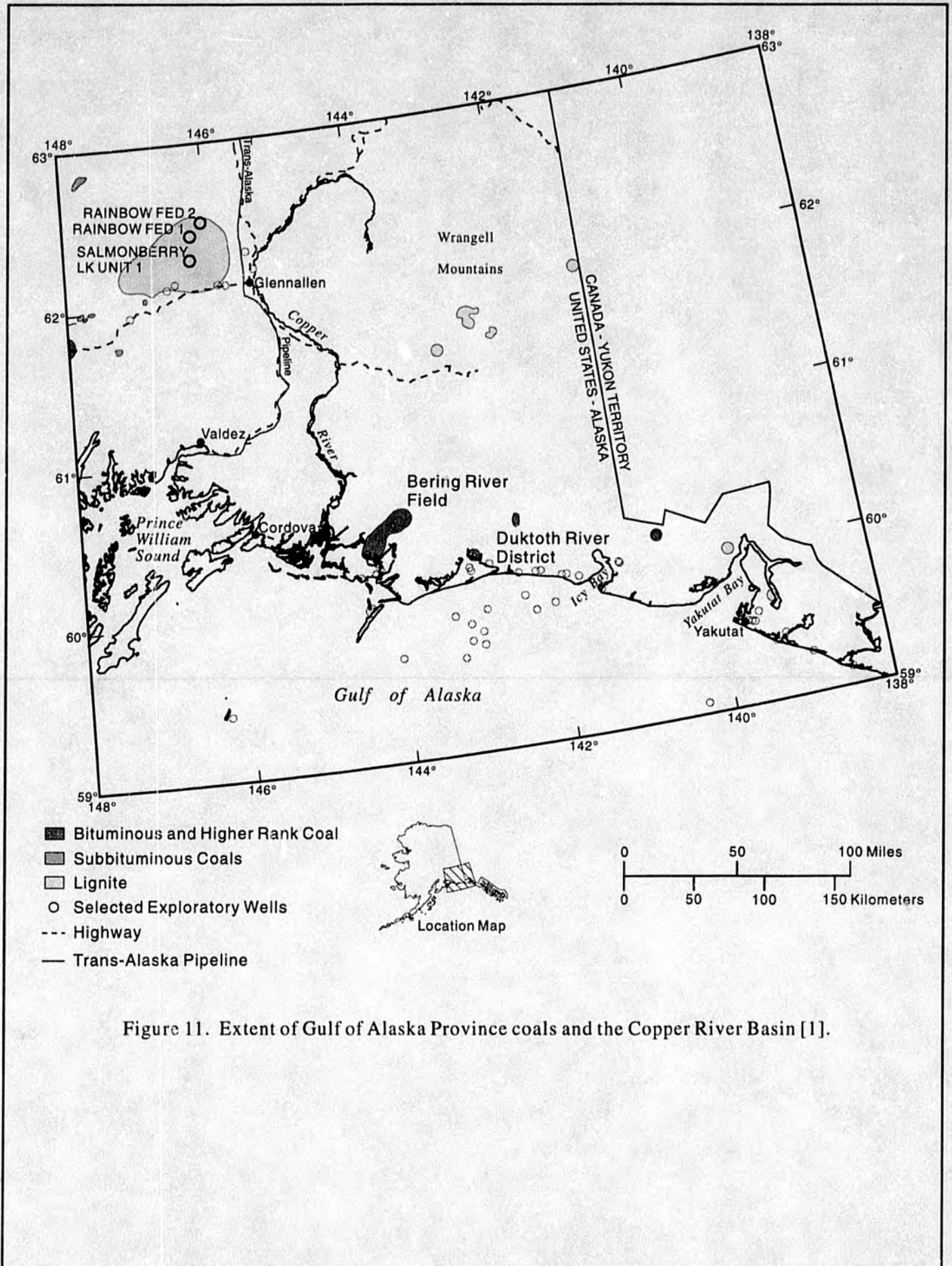


Figure 11. Extent of Gulf of Alaska Province coals and the Copper River Basin [1].

COALBED METHANE POTENTIAL FOR ALASKA AND
DRILLING RESULTS FOR THE UPPER COOK INLET BASIN

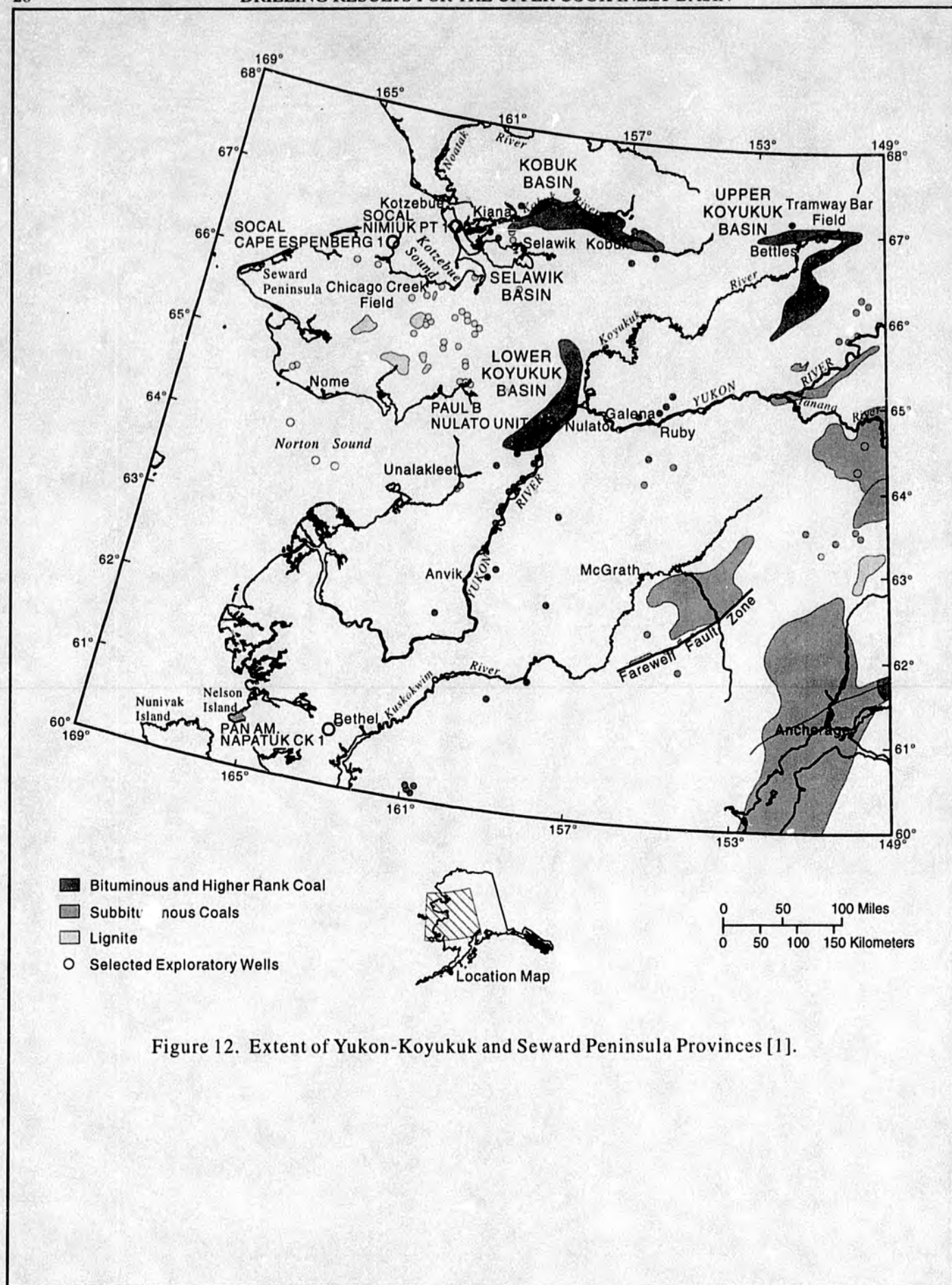


Figure 12. Extent of Yukon-Koyukuk and Seward Peninsula Provinces [1].

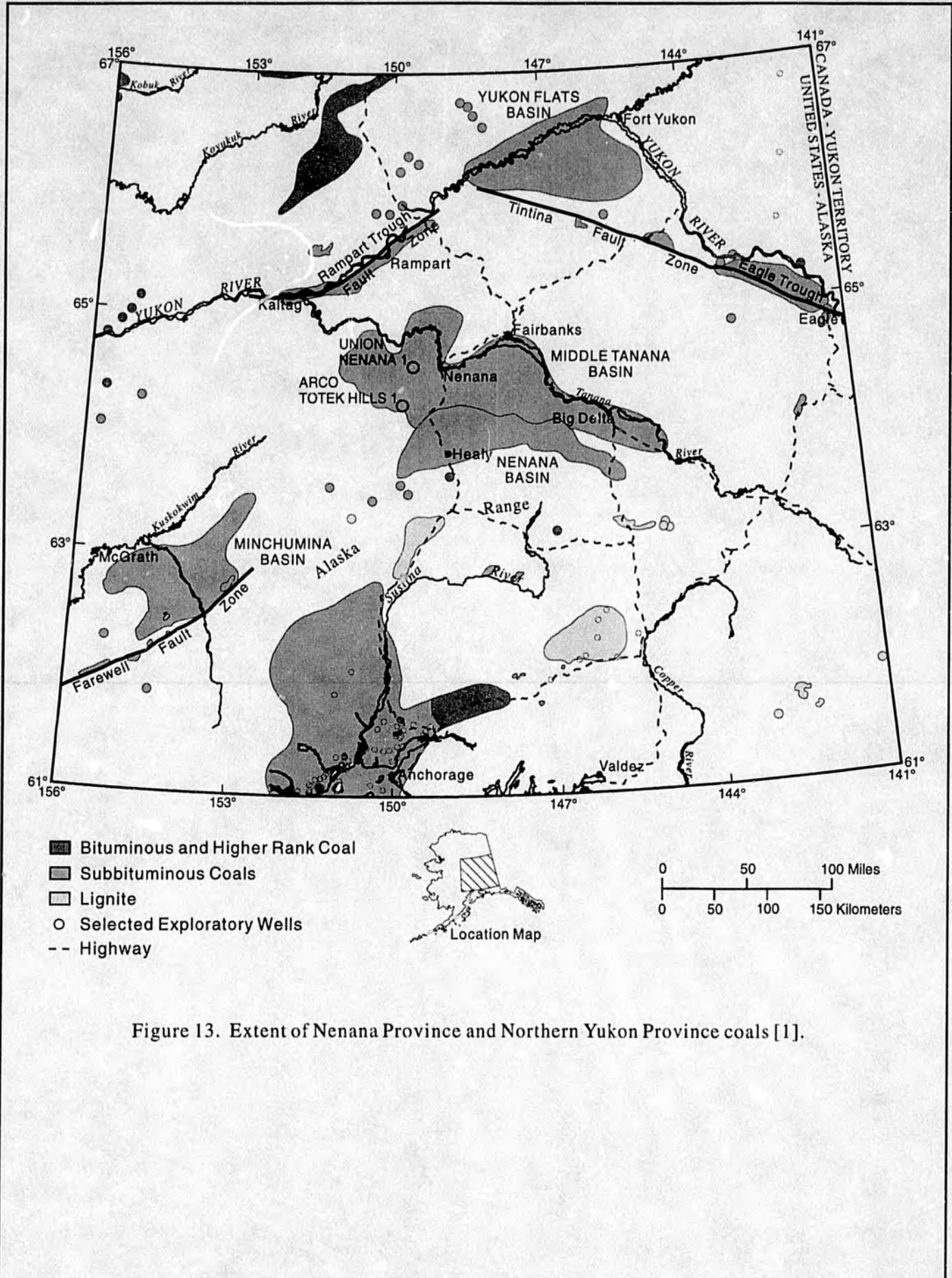


Figure 13. Extent of Nenana Province and Northern Yukon Province coals [1].

Coalbed Methane Summary

History.

Methane from coal seams is nothing new. Coal miners considered it a nuisance to mining operations. They found ways to produce it as early as the turn of the century in the US through drill holes to prevent mining accidents.

Compared to conventional gas production, production from coalbeds is very new. In the early 70's, US Bureau of Mines and US Steel started a program to produce methane before coal was mined, drilling the first coalbed methane wells in Alabama in 1971. Commercial production also began in Alabama in the Black Warrior basin in 1980.

The Windfall Profit Act of 1980 through the nonconventional fuel tax credit has greatly added to the current activity in developing this resource. The credit was about 90 cents per 1000 cf (mcf) in 1991 and slowly goes up each year with 1992 receiving 93.6 cents per mcf. Wells drilled after 1993 do not receive this credit.

What is coalbed methane?

Coalbeds are both sources and reservoirs for the gas formed from coalification-- the process of converting organic material from peat, lignite, subbituminous, bituminous, and finally anthracite. Through these stages both biogenic (swamp gas) and thermogenic gases, primarily methane, are produced. Once the coal is saturated with gas, the gas migrates to the associated sediments, as is probably the case in Cook Inlet where at least the shallower gas reservoirs were probably sourced from the coals.

The coals can store high concentrations of the methane, as much as 3 to 4 times that of a sandstone reservoir under similar conditions. This is due to the extremely high internal surface area of the coal.

Gas is stored in both microporosity where it is absorbed within the molecular structure and micropores and macro- porosity, fractures and cleats similar to that of a conventional sandstone reservoir.

How is it produced?

The absorbed gas stored in the coal matrix or micropores, desorbs and diffuses through the coal. The gas migrates to the large pores and into the cleat and fracture system and finally into the well bore. In order to get this to happen, the pressure is lowered on the coal by removing the water, usually by pumping. Once a pressure gradient is established, methane then can diffuse into the fracture system and finally into the well bore.

A negative decline is usually established where water production starts out high and gradually lowers and gas production increases until the production decline finally occurs. Typical wells are projected to be long lived, 20-40 years.

Production rates and potential.

Two basins produce most of the US coalbed methane, although production is expanding to many other coal basins across the US. The San Juan in Colorado-New Mexico and Black Warrior in Alabama, where the first coalbed methane wells were drilled, account for over 95% of current production. The San Juan is the largest producer having produced 436 bcf from 2,087 producing wells. Total reserves are 50 TCF. US potential recoverable reserves exceed 500 TCF.

Coals have generally lower production rates than sandstone reservoirs because coal has smaller fractures and pore space which impede the flow of fluids and gases to the well bore. Typical wells in the San Juan basin produce 100,000 to 400,000 CFPD with some as high as 5 to 20 million CFPD. This compares with average Cook Inlet production rates in sandstone reservoirs of 6 million and individual Walakapa wells are projected to produce 1-2 million CFPD.

Evaluation.

The first step in the evaluation program is to review available well and geologic data to select well locations and to design data collection programs. These data include structure and stratigraphic maps, thermomaturity, drilling records, logs, well tests, production records, gas content information, and fracture studies.

The next step in the evaluation is to collect gas content and permeability data from the first well or wells drilled. Gas content is quantified with conventional core, pressure core, sidewall core, and drill cuttings samples. The permeability of the fracture system is quantified with drill stem tests. Open hole logging of the well is also necessary.

Upon completion of the well, it is necessary to determine the coal gas storage capacity and the properties of the coal and non-coal rocks from core analyses. Natural fracture geometry is further quantified.

The final step in the evaluation is to combine all the above data and analyses to predict gas and water production. Completion methods and reservoir stimulation programs can then be designed.

Potential for Alaska.

Hypothetical coal reserves for Alaska exceed 5.5 trillion short tons or nearly 1/2 of the United State's coal reserves. These coals could contain up to 1,000 TCF of gas. About 9% of Alaska is underlain by subbituminous to bituminous coal that is found in many parts of the state. The areas of higher rank coals in a "relaxed" structural setting have the highest potential. The Matanuska Valley area of Cook Inlet, the foothills belt along the North Slope, and the Alaska Peninsula are promising areas, however further study of all the coal basins is needed to evaluate this resource. See "Coalbed Methane Potential for Alaska and Drilling Results for the Upper Cook Inlet" by T. N. Smith for more information.

Issues that effect coalbed methane development?

Market--Cook Inlet has about 10 to 12 years gas supply at the current consumption. CBM will have to compete with conventional gas to be marketable.

Cost--Drilling and production costs must be kept low in order for the lower volume CBM wells to compete conventional gas.

Regulations--Drilling and production regulations need changes to allow for the drilling of low cost, shallow wells.

Bonding--Bonding needs to be at levels that closer reflect the environmental and mechanical risks of CBM operations.

Ownership--CBM ownership must be clearly stated in leases and statutes to avoid conflicts between mining and oil and gas interests.