$7.40

Public-data File 86-73

PALEOENVIRONMENTAL AND TECTONIC CONTROLS IN THE MAJOR COAL BASINS OF ALASKA

By

Roy D. Merritt

Alaska Division of
Geological and Geophysical Surveys

August 1986

THIS REPORT HAS NOT BEEN REVIEWED FOR TECHNICAL CONTENT (EXCEPT AS NOTED IN TEXT) OR FOR CONFORMITY TO THE EDITORIAL STANDARDS OF DGGS.

794 University Avenue, Basement
Fairbanks, Alaska 99709

PALEOENVIRONMENTAL AND TECTONIC CONTROLS IN THE MAJOR COAL BASINS OF ALASKA

by

Roy D. Merritt

Alaska Division of Geological and Geophysical Surveys

Fairbanks, Alaska

ABSTRACT

The general physiographic and geologic setting, lithostratigraphy, structural geology and regional tectonism, and depositional environments are summarized for six major coal-forming basins in Alaska---Susitna, Matanuska, Bering River, Nenana, Chignik Bay-Herendeen Bay, and Northern. Alaska's Cretaceous and Tertiary bituminous to subbituminous coals are found in all physiographic regions of the State and may underlie as much as 8.5 percent of its land area. Continental Tertiary deposits are widely distributed and contain the majority of the subbituminous coals. Cretaceous formations contain the majority of the bituminous coals and more often have been influenced by marine waters during their evolution.

Depositional factors and related constraints are expected to play an important role in future mine planning and pre-development site investigations in the coal subbasins of the Susitna lowland. Depositional modeling will probably not greatly assist future mine planning in the Matanuska Valley because of the fairly complex geologic structure in the region. Similarly, a better understanding of the depositional environments in the Bering River basin will probably not greatly support exploration and development planning there because of the very complex geologic structure. Improved depositional modeling should be important though for future mine planning in the Nenana, Chignik Bay-Herendeen Bay, and Northern basins. Ultimately, other limiting factors such as location with respect to tidewater and potential export markets, coal quality considerations, resource base, permafrost distribution, infrastructure and port development, technological advances, and economics may determine the minability of Alaska's vast coal resources.

INTRODUCTION TO ALASKA'S COAL BASINS

Coal is found in all physiographic regions of Alaska, and geologic formations containing coal deposits may underlie as much as 8.5 percent of Alaska's land area (figure 1). Alaska's coal resources are estimated to range from 2.0 to over 5.5 trillion short tons and may constitute the most important asset in Alaska's energy future. These deposits could ultimately prove to make up half of the United States coal resource base and up to 15 percent of the world resource base. The total energy (Btu) equivalent of the coal in Alaska surmounts by many magnitudes that present in all the oil that will ultimately flow from the State. Coal is known to occur in over half of the 153 quarter-million scale quadrangles of Alaska. However, due to the present poor definition of Alaska's coal resources, identified coal resource figures are low compared to projected total coal resources. Total identified coal resources amount to nearly 170 billion short tons. The coal resources of the six major Alaskan coal basins to be discussed in this paper are summarized in table 1, and outcrop photographs of representative seams are shown in figure 2.

Figures 1,2; table 1--NEAR HERE

Although the majority of Alaska's coals are of bituminous and subbituminous ranks, anthracite is found locally in the Bering River and Matanuska fields. In general, 60 percent of Alaska's coal is bituminous and 40 percent subbituminous (McGee and Emmel, 1979). The coals exhibit variable moisture and ash contents, but almost universally show very low sulfur contents (table 2).

Table 2--NEAR HERE

GENERAL DEPOSITIONAL REGIME FOR ALASKA'S COAL BASINS

Most Alaska coal basins formed during the Cretaceous and Tertiary periods. However, coals of the Lisburne or Point Hope field are Mississippian, and the bituminous coal beds in the Nation River Formation are of probable Pennsylvanian age. Figure 3 places the major coal-bearing formations of Alaska on a geologic-age continuum diagram. Correlations of the many Cretaceous and Tertiary units are very crude, and the exact stratigraphic relationships of many of the near age-equivalent units are presently unknown.

Figure 3--NEAR HERE

Continental Tertiary deposits are widely distributed throughout Alaska (table 3). Most of the basins had been raised above the sea by Tertiary time, and hence few had significant marine influences during coal deposition. However, more commonly the Cretaceous coal-bearing formations of Alaska have been marine-influenced.

Table 3--NEAR HERE

The trends in the physical and chemical coal characteristics previously reported widely in the literature for other basins with similar settings in the United States are comparable to those observed in Alaska's coal basins. Coals formed in continental settings in Alaska tend to be more discontinuous laterally, range widely in thickness (thin lenses to beds over 30 m), contain variable but often relatively high mineral matter and ash contents (predominantly silica and kaolinite), but are extremely low in sulfides and the trace elements often associated with them. Alaska coals from marine-influenced paleoenvironments, by contrast, show generally opposite or dissimilar trends in coal characteristics from those formed in continental settings.

SUSITNA LOWLAND

GENERAL PHYSIOGRAPHIC AND GEOLOGIC SETTING

The entire Cook Inlet-Susitna lowland Tertiary province is about 515 km long by 130 km wide (figure 4). The Susitna lowland portion of the province encompasses about 13,000 km^2. The lowland is bounded by the arcuate Alaska Range on the north and west, the Talkeetna Mountains on the east, and Cook Inlet on the south. Surface elevations of the lowlands increase from sea level at Cook Inlet northward to about 300 m. Isolated uplands of intrusive and pre-Tertiary rocks rise to 1,200 m above the surrounding lowlands.

The Susitna lowland includes northern Cook Inlet, and is in fact a northwestern extension of the Cook Inlet Tertiary basin. Barnes (1966) terms the area the Beluga-Yentna region. The Castle Mountain fault, a major northeast-trending discontinuity separates upper Cook Inlet (on the south) and the Susitna lowland (on the north). Most stratigraphic studies on the Cook Inlet petroleum province terminate at the fault; however, important coal deposits in the Beluga area lie on both sides of the fault zone.

Figure 4--NEAR HERE

The central Susitna lowland is a broad, relatively flat to slightly irregular terrain that increases in relief toward the foothills. Schmoll and Yehle (1978) classify the physiographic and geologic features of the Beluga area into 1) high mountains and foothills of Mesozoic and lower Tertiary metamorphic and igneous rocks; 2) an adjacent plateau underlain primarily by Tertiary coal-bearing rocks with a generally thin and discontinuous cover of Quaternary-Tertiary(?) glacial deposits; and 3) lowlands underlain by thick Quaternary deposits---principally of estuarine and fluvial origin---that are separated from the plateau by major escarpments.

Large glaciers nearly reach the margins of the Susitna lowland. During Pleistocene time, at least five glaciations affected the lowland (Karlstrom, 1964; Nelson and Reed, 1978) and evidence indicates that ice filled upper Cook Inlet to present elevations of over 1,200 m (Karlstrom, 1965, p. 115). Retreat of glaciers from the Susitna lowland left a landscape dominated by glacial and glaciofluvial landforms including fluted moraines, drumlins, kettle lakes, ponds, marshes, bogs, and scoured bedrock (Karlstrom, 1965). Valley features created by periglacial activity and mass movement include talus slopes, landslides, avalanche chutes, and rock glaciers. Fluvial processes continue to modify the floor of the lowland.

TERTIARY LITHOSTRATIGRAPHY

The current stratigraphic nomenclature for the Tertiary coal-bearing strata of the Susitna lowland was first proposed by Calderwood and Fackler (1972) for the Cook Inlet basin (figure 5). Because of the thickness and complexity of the Tertiary sedimentary sequence, they changed the 'Kenai Formation' originally adopted by Dall and Harris (1892) to the Kenai Group, and recognized that it contains five distinct formations: West Foreland, Hemlock Conglomerate, Tyonek, Beluga, and Sterling. Most of the major oil fields of the Cook Inlet region produce from the Hemlock Conglomerate (Magoon and Claypool, 1981), and past petroleum exploration in the region has yielded valuable stratigraphic information. Oil or gas has been produced from all formations of the Kenai Group (Calderwood and Fackler, 1972).

Figure 5--NEAR HERE

The Kenai Group represents clastic fore-arc basin deposits of both early and late Cenozoic tectonic cycles (Fisher and Magoon, 1978; Schmoll and others, 1981). The rocks display many characteristics of a continental fluvial system. They are nondeltaic except for local lacustrine deltas, and appear ---particularly the Tyonek Formation---to be products of a sinuously meandering fluvial regime. Lateral migration produced fining-upward sequences, and rapid lateral and vertical changes in lithology are common. Channel deposits are characteristically coarse-grained sediments; fine-grained rooted siltstones, shales, and thin coals represent interfluve sediments. Levees flanking channels are typically fine-grained sandstone and siltstone. Sedimentary structures, other than cross-stratification in coarser-grained units are rare on natural exposures.

Sediments of the Kenai Group in the Susitna lowland were shed mostly from plutonic and metamorphic sources in the tectonically active Alaska Range and Talkeetna Mountains. The model of Kirschner and Lyon (1973) consists of a broad intermontane trough confined by borderlands of low to moderate relief in warm to temperate climatic conditions. They divide the deposition of the Kenai Group of the Cook Inlet basin into three phases based on the lithologic and mineralogic character of the sediments: 1) an Oligocene-Miocene transgressive phase; 2) a brief late Miocene culmination (stillstand); and 3) a Pliocene regressive phase. The West Foreland Formation, Hemlock Conglomerate, and the lower part of the Tyonek Formation were deposited during the transgressive phase. The late Miocene culmination was characterized by a transitional period of low-energy sedimentation during which the siltstones, carbonaceous shales, and coals in the upper part of the Tyonek Formation and the lower part of the Beluga Formation were deposited. All of the factors related to coal formation---plant growth, basin subsidence, sediment supply, compaction, and interaction of the ground water table---must have been favorable at this time. The upper part of the Beluga Formation and the Sterling Formation were deposited during the Pliocene regressive phase.

Exposures of the Kenai Group are confined to the basin rim (foothills of the Alaska Range) and to isolated, usually steep walls of incised and largely inaccessible stream canyons in the lowlands. Tertiary rocks are usually overlain by Pleistocene glacial drift or stream alluvium, which veil the underlying formations. The contact between Tertiary and Quaternary sediments is difficult to discern in many areas since it is often masked by deep weathering or buried. Coal-bearing outcrops are widely distributed but discontinuous and highly weathered. Spatial relationships are difficult to observe because of the lack of continuous exposures. Without the essential subsurface control, the horizontal migration of individual facies is not well documented.

STRUCTURAL GEOLOGY AND REGIONAL TECTONISM

The Susitna lowland is an embayment of the Cook Inlet back-arc basin or intermontane half-graben (figure 6). Kelly (1963) concluded it is separated from the Cook Inlet basin by a partially buried ridge of granitic rocks. The major synclinal axis of the Cook Inlet basin bifurcates northward with one arm extending into the Yentna region and the other extending northeastward into the Matanuska Valley. These pull-apart extensional basins or rift valleys are typically filled with continental deposits and are characterized by a large number of discontinuous coal seams.

Figure 6—NEAR HERE

Payne (1955) recognized five arcuate Mesozoic tectonic elements in south-central Alaska: 1) Chugach Mountains geosyncline, 2) the Seldovia geanticline, 3) the Matanuska geosyncline, 4) the Talkeetna geanticline, and 5) the Alaska Range geosyncline (figure 6). The Shelikof Trough, which includes the Susitna lowland, is a Cenozoic structure superimposed on these Mesozoic geanticlines and geosynclines. During widespread orogeny at the end of the Cretaceous period, the Talkeetna Mountains restricted part of the Matanuska geosyncline and became the eastern boundary of Shelikof Trough (Gates and Gryc, 1963).

According to Hackett (1976a), the Tertiary basins of the upper Cook Inlet region represent a system of tilted horsts and grabens produced by extensional fragmentation of a pre-Tertiary basement. He postulated (p. 13) substantial translational and rotational block movements in south-central Alaska during late Cretaceous and early Tertiary times, caused by a change from normal to oblique subduction between major plate boundaries. Continued oblique rifting during the middle and late Tertiary further accentuated these basins.

Bouguer gravity highs in the southern Susitna lowland correlate with exposures of pre-Tertiary basement rocks, whereas lows indicate areas underlain by Tertiary Kenai Group sedimentary rocks. The Beluga and Yentna basins are characterized by steep gravity gradients and low Bouguer anomalies indicating the presence of large basement discontinuities forming deep tectonic basins. The regional gravity gradient over the upper Cook Inlet region infers a gradual westward thickening of the earth's crust (Barnes, 1976; Hackett, 1977).

Relief on the pre-Tertiary basement surface generates the larger anomalies over the lowland (Hackett, 1977).

A major structural discontinuity consisting of the Bruin Bay fault, the Moquawkie magnetic contact, and that part of the Castle Mountain fault east of the Theodore River divides the Susitna lowland into a deeper southeastern segment and a shallower northwestern segment. The southeastern portion subsided more rapidly than the northwestern part during the accumulation of Kenai Group strata. North of the Castle Mountain fault, the Kenai Group is typically less than 600 m thick, whereas in the southern Susitna lowland it is commonly less than 3,000 m (Grantz and others, 1963; Wolfe and others, 1966; Calderwood and Fackler, 1972; Hartman and others, 1972).

These major high-angle reverse faults and small-scale high-angle block faults within the Susitna lowland have definitely offset the coal deposits. Most of the stratigraphic studies of the Cook Inlet petroleum province terminate south of the Castle Mountain fault. However, important coal leases in the Beluga basin are on both sides of the fault zone. The ultimate effect of these on future coal exploration and development has not yet been fully ascertained. Downthrown blocks commonly localize channeling and result in the erosion of coal seams. However, the faulting has served to localize certain blocks favorable for coal mining, as in the Chuitna River coal subfield of the Beluga area, which occurs near the surface in an upthrown block of the Tyonek Formation.

The major faults of the Cook Inlet region have acted to control the development and general configuration of basinal depocenters. In addition to coal, these thick sedimentary rock sequences may hold some potential for oil and gas resources as well (Hackett, 1976b). The Susitna lowland contains several subbasins within the main basin all of which have shared a similar tectonic and sedimentologic history. However, each contains a variable number and thickness of coal beds.

DEPOSITIONAL ENVIRONMENTS OF KENAI GROUP COALS

Source areas adjacent to the basins of the Susitna lowland were rejuvenated during the late Cretaceous and early Tertiary. Periodic or gradual uplift converted areas of the basinal flood plains into widespread coal-forming environments by late Oligocene to middle Miocene time when the Tyonek Formation was deposited (figure 7). Vegetal and woody materials accumulated and peats formed in these stagnant depositional areas. The ground-water table gradually rose, precluding 'drowning' of the developing peat swamps, and the sediment supply was restricted, which also promoted peat formation.

Figure 7--NEAR HERE

The rate of subsidence varied from area to area in the Susitna lowland. Rapid subsidence would have initiated the accumulation of clastics. However, gradual subsidence with periodic stillstands resulted in the formation of coal swamps in paleotopographic lows between flood events. At any one time, peat (or coal) was probably forming in relatively small areas of the region, as illustrated by the lack of extensive lateral continuity of the seams. Coal-seam partings also show the nonuniformity of conditions over the Susitna lowland, and indicate that lateral shifting of swamps and other subenvironments occurred with time.

Most of the stratigraphic sequences within the Tyonek Formation of the Kenai Group display fining-upward texture. Although some locales display cyclic characteristics, they are not cyclothems in the classic sense. A typical full cyclic sequence includes (from bottom to top) conglomerate, often an immature petromict; pebbly, very coarse-grained sandstone; medium- to coarse-grained sandstone; fine-grained sandstone; fine-grained sandstone interbedded with shale and siltstone; underclay, carbonaceous shale, or siltstone; and coal. As expected, a complete cycle is extremely rare because of erosion and truncation. Full sequences are predicted to occur nearer the depositing channel (Duff and others, 1967).

These cycles result from shifts of channels and sediment deposition across an alluvial plain as indicated by lithologic relationships. The coarser basal units represent lateral-accretion deposits that commonly are cross-bedded. The upper finer-grained units represent overbank and lake or swamp deposits. As proposed, the flow-regime intensity progressively decreases upward through the section. The cycles witness relative quiescent periods (tectonic lulls) during the Tertiary when large areas of the basinal flood plains were coal-forming swamps that alternated with periods of uplift, relative rapid basin subsidence, and the influx of clastics. In general, the Tertiary was a time of widespread but discontinuous coal formation in the Susitna lowland. Conditions conducive to coal formation were most favorable during the late Oligocene to middle Miocene during the deposition of the Tyonek Formation.

MATANUSKA VALLEY

GENERAL PHYSIOGRAPHIC AND GEOLOGIC SETTING

The Matanuska coal field lies in the valley of the Matanuska River at the head of Cook Inlet between the Talkeetna and Chugach mountain ranges of south-central Alaska (figures 1 and 8). The coal field varies from 9.5 to 13 km in width, is over 60 km long, and has an area over 500 km^2. The valley generally trends N. 70° E. and lies anywhere from 40 to 95 km northeast of tidewater. The lower Matanuska Valley (below Chickaloon) is about 160 km north of Seward (where Alaska's first coal export facility is being built), while the Anthracite Ridge district in the upper Matanuska Valley (above Chickaloon) is nearly 320 km from the coast at Seward. The Wishbone Hill district is located 65 km northeast of Anchorage. The Matanuska coal field is accessible by rail from either Seward or Anchorage, and is also transected by the Glenn Highway.

Figure 8--NEAR HERE

The Matanuska Valley connects the two broad physiographic regions of the Cook Inlet-Susitna lowland on the west and the great interior highland basin of the Copper River in the east. The Matanuska River itself originates near the southwest corner of the Copper River Plateau and flows for nearly 160 km generally along the south side of the coal field near the Chugach Mountains and eventually empties into Knik Arm, the northeasternmost branch of Cook Inlet. The rugged Chugach Mountains on the south side of Matanuska Valley include numerous peaks from 2000 to 3000 m high. Mountains of the southern Talkeetna Range rise rather abruptly also from the fairly deep depression of Matanuska Valley. The general maximum elevation in Matanuska Valley ranges from 1500 to 1800 m (Martin, 1906a; Paige and Knopf, 1907; Capps, 1927; Tuck, 1937; and Apell, 1944).

The three major districts of the Matanuska Valley are Wishbone Hill, Chickaloon, and Anthracite Ridge. The Little Susitna field (figure 1), although considered by some as within the lower Matanuska Valley, contains coals of the Kenai Group that are more akin to those of the Susitna lowland. Five significant coal subbasins (subfields) have been distinguished in the Matanuska Valley---Eska-Moose, Young Creek, Castle Mountain, Chickaloon, and

Anthracite Ridge (Merritt and Belowich, 1984; figure 8). The Eska-Moose subbasin stretches from Moose Creek eastward to the valley of Eska Creek and essentially encompasses the Wishbone Hill region. The Young Creek subbasin is intermediate in position between the Eska-Moose and Chickaloon fields, and includes the coal deposits around Red Mountain. The deposits south of Castle Mountain and along the middle Kings River occupy the Castle Mountain subbasin, while the deposits south of the Matanuska River in the vicinity of Coal Creek are included in the Chickaloon subbasin. East of the Chickaloon subbasin, there are no significant coal-bearing outcrops until reaching the Anthracite Ridge subbasin.

LITHOSTRATIGRAPHY OF TERTIARY CHICKALOON FORMATION

The main Tertiary rock units of the Matanuska Valley are the Chickaloon, Wishbone and Tsadaka Formations, volcanic beds, and intrusive rocks (table 4). The Eska Conglomerate, which forms the main mass of Wishbone Hill, is an informal unit including the Wishbone and Tsadaka Formations. Barnes and Payne (1956) divided the Eska Conglomerate based on compositional differences in the conglomerate and the presence of an unconformity between them. The Chickaloon Formation is Paleocene to earliest Eocene in age, forms the base of the early Tertiary cycle, and is overlain unconformably by the Wishbone Formation. It contains an abundant flora, with fossil leaf impressions abundant in the roof rock of coal seams. An angular unconformity separates the Chickaloon Formation from the underlying Cretaceous Matanuska Formation, which makes up over a third of the bedrock outcrops of the Matanuska Valley (Grantz, 1964).

Table 4--NEAR HERE

The Chickaloon Formation is at least 900 m thick and contains up to 30 coal beds in the upper half of the unit (Conwell and others, 1982). All known coal deposits in the Matanuska Valley are included in the Chickaloon Formation, a unit that is more extensively outcropped north of the Matanuska River than south of it. Chickaloon Formation strata of the Matanuska Valley differ from Tertiary Kenai Group strata of the Susitna lowland in age (i.e., being older), in lithology and structure, in the presence of associated intrusives, and in the character and rank of the interstratified coal seams (Paige and Knopf, 1907). The general stratigraphic relations of the Chickaloon Formation with older rocks is complex. The unit appears to have undergone similar demation as the underlying Cretaceous rocks, and has been folded and faulted considerably since deposition. Sections of the Chickaloon Formation from different localities are difficult to correlate due to the numerous faults, and both the lenticularity and relative similarity in many of the beds.

The Chickaloon Formation consists of a monotonous sequence of shales, sandstones, coal seams, and thin conglomerate lenses. Shales are most abundant in the formation, but the proportion of sandstone is higher in the lower part of the unit. The numerous coal seams occur mainly in groups of three or more beds (Barnes and Payne, 1956). The character of coal, sandstone, and shale beds vary considerably both in thickness and texture within short distances. Thickness changes may have resulted largely by differential compaction. The shales are typically sandy, gray to dark bluish gray, feldspathic, fissile, some with thin coaly streaks and abundant organic matter, and interstratified with sandstones in regular beds. The sandstones are gray, hard, fairly well consolidated, lenticular, arkosic, with disseminated muscovite and abundant shale and other rock fragments, and thick-bedded in the lower part of the formation. Concretionary iron carbonate in nodules and thin lenses is common throughout the Chickaloon Formation. The unit resembles somewhat the Paleozoic coal measures of the Appalachian region (Paige and Knopf, 1907).

The coals of the Chickaloon Formation range in rank from subbituminous to anthracite. Generally, most coals of the lower Matanuska Valley are bituminous while those of the upper Matanuska Valley are semianthracite to anthracite. The coals of the Anthracite Ridge district have been upgraded because of regional deformation and contact with igneous intrusions.

STRUCTURAL GEOLOGY AND REGIONAL TECTONISM

The Matanuska Valley occupies a portion of the Mesozoic structural trough named the Matanuska geosyncline by Payne (1955). This trough is bounded by the Talkeetna and Seldovia geanticlines on the north and south respectively. The geologic history of the Matanuska geosyncline as a marine depositional trough ended by orogeny in Paleocene and Eocene time (Grantz, 1964) when an extensive continental sedimentary basin developed. By the end of the Eocene and the cessation of coal formation, the surrounding region was uplifted with thick deposits of gravel and sand laid down in the lower (western) reaches of the basin. A major period of uplift in the adjacent Chugach Mountains took place in the Miocene and Pliocene epochs (Kirschner and Lyon, 1973). Extensive faulting occurred in the Neogene with igneous rocks intruded into the sedimentary deposits in the Pliocene. Erosion and weathering has continued to carve and shape the geomorphology of the region since the Pliocene. The Matanuska River cut its present valley after extensive excavation by repeated advances and retreats of the Matanuska and other glaciers during the Pleistocene.

The Matanuska Valley is an extension of the Cook Inlet Tertiary basin and falls within the fore-arc terrane of the Alaska-Aleutian volcanic arc. Faulting in the region has resulted from intraplate strain caused by subduction of the Pacific plate beneath the convergent margin of the North American plate (Bruhn and Pavlis, 1981). The Matanuska basin narrows considerably toward the northeast where the coal-bearing Chickaloon Formation has undergone the greatest amount of compression. The Matanuska Valley is essentially a large graben, a structural basin 8 to 16 km wide and about 80 km long.

The coal-bearing sedimentary rocks of the region are bounded on the north by the large-scale, high-angle Castle Mountain fault system named by Barnes and Payne (1956), and on the south by the Border Ranges fault system. The Castle Mountain fault system separates the Matanuska Valley proper from the plutonic and metamorphic terrane of the Talkeetna Mountains to the north, and the Border Ranges fault system separates the valley from Jurassic to upper Cretaceous sedimentary, metasedimentary, and volcanic rocks of the Chugach Mountains to the south. In general, right-lateral separation has taken place along the Castle Mountain fault throughout Mesozoic and early Tertiary time and vertical separation since Oligocene time (Grantz, 1964).

Chickaloon Formation rocks are generally strongly to moderately folded, predominantly open but locally sharp and overturned, with steep dips and complex structures present throughout much of the Matanuska Valley. However, some tracts show a uniform dip for considerable distances. The strike of rocks in general are parallel to the easterly trend of Matanuska Valley. The strata are affected by a large number of faults with a small throw, often cutting the axes of folds. Transverse faults show predominant southeast dips and have undergone a greater amount of movement. In normal faults, the southeast block has generally moved down relative to the northwest block.

The dominant structural feature of the lower Matanuska Valley is the Wishbone Hill syncline, a canoe-shaped open fold that extends the full length of the district and is cut into blocks by several major transverse faults (Barnes and Payne, 1956). These north-trending faults may represent secondary shears related to deformation along the Castle Mountain fault system (Bruhn and Pavlis, 1981). The Wishbone Hill syncline strikes south 55° to 80° west, and its axis displays a plunge to the southwest of 10° to 25°. Coal beds crop out around the margins of the syncline, extend to considerable depths beneath Wishbone Hill, and occur within the Jonesville, Premier, Eska, and Burning Bed coal series. Past mining has been largely restricted to the moderately dipping north limb of the syncline.

In general, areas around Wishbone Hill of the lower Matanuska Valley, and Castle Mountain and Chickaloon of the central Matanuska Valley are less structurally disturbed than those around Anthracite Ridge, where the coal-bearing strata are folded east to west into a broad synclinal basin. Structure in the Chickaloon coal district is somewhat more complex than to the west, with faulting and igneous intrusives much more prevalent. The abundant exposures of the Chickaloon Formation along the gulches that drain the south flank of Anthracite Ridge aptly show that overturned folds are common in the area, faults are numerous, and the beds are intruded by both large and small sills and dikes.

DEPOSITIONAL ENVIRONMENTS OF CHICKALOON FORMATION COALS

An extensive fresh-water basin of deposition developed in the Matanuska Valley region in Paleocene and early Eocene time. A warm and temperate climate is inferred during this period based on the widespread fossil plants of the Chickaloon flora (Wolfe and others, 1966). The basin formed upon a surface of considerable relief with the basal Chickaloon Formation beds deposited in the lowest parts of the basin. Thus, the lowest Chickaloon Formation beds at any one location do not necessarily correspond in age with the basal strata at all other places. As the area of sedimentation broadened, successively younger portions of the formation were deposited upon the floor of the expanding basin. The recurrence of marshy conditions formed coal beds of moderate extent locally within the basin. Alternating periods of relatively weak and strong orogenic movements dictated the conditions prevalent across the basin. After the deposition of the Chickaloon Formation, a period of erosion followed, removing the top strata, and subsequently the unit was overlain unconformably by conglomerate of the Wishbone Formation (Capps, 1927).

The deposits of the Tertiary Chickaloon Formation include channel and near-channel conglomerates and sandstones, floodplain siltstones and silty claystones, stagnant lake claystones, and swamp deposits of coal, bone, and coaly claystone. In general, the Chickaloon Formation represents a fluvial, braided to meandering stream environment in the lower part, and a fluvial, meandering to paludal environment in the upper part (table 4). Second-order sedimentary cycles developed in the coal measures with each period of uplift initiating a new cycle of fairly rapid deposition. Accordingly, the first period was dominated by river sedimentation forming sandstone, conglomeratic at the base, which graded upward into finer clastics containing a few widely spaced coal beds. Relatively long-sustained regional swamp and stagnant-lake conditions developed subsequently during a period of quiescence when alternating beds of minable coal, bone, claystone, and intermediate lithologies formed (Payne, 1945; Clardy; 1978).

BERING RIVER BASIN

PHYSIOGRAPHIC AND GEOLOGIC SETTING

The Bering River coal basin is located in the Katalla district of the Controller Bay region and Gulf of Alaska Tertiary province, southeast Alaska (figure 9). Outcrops are scattered over some 180 km^2 of east-central Cordova and west-central Bering Glacier Quadrangles. The coal field is centered about 95 km southeast of Cordova on Prince William Sound and 19 km northeast of Katalla, lying between latitudes 60°15' and 60°30' N. and longitudes 143°45' and 144°20' W. The wedge-shaped field extends about 32 km east-west in an area north and northeast of Bering River and 3 to 10 km wide increasing toward the east. It is bounded on the north by the Martin River and Bering Glaciers of the Chugach Mountains, by Stellar and Bering Glaciers on the east, by the Gulf of Alaska on the south, and Bering Lake and the Copper River delta to the west. The belt extends northeastward from Bering Lake to the east side of the ridge culminating in Mt. Hamilton, to Shepherd Creek, to Carbon Creek and Kushtaka Ridge, to the basins of Trout, Clear, and Canyon Creeks, and to Carbon Mountain in the east. The coal field, thus, occupies a part of the foothill zone between the Chugach Mountains and the coast (Fisher and Calvert, 1914; Barnes, 1951; Sanders, 1976).

The relief of the region ranges from sealevel to about 1070 m, with most of the fault-controlled mountain ridges being about 600 m above sealevel. Two main types of physiographic development characterize the area---irregular, northeast-trending, densely forested rugged hills (for example, Carbon, Canyon Creek, Cunningham, and Kushtaka ridges) of moderate elevation and featureless

Figure 9--NEAR HERE

lowlands traversed by numerous small streams or occupied by arms of glaciers or by glacial lakes of considerable size (Fisher and Calvert, 1914). The glacially carved mountains and ridges, broad lowlands, and sediment-filled valleys all witness recent glaciation. The U-shaped valley of Shepherd Creek, a major stream on the west side of the field, drains Lake Charlotte, a morainal lake. Carbon Creek and its tributaries are steep-sided V-shaped canyons that indicate rapid post-glacial erosion. Kushtaka and First Berg are deep glacial lakes, whereas Bering Lake is a shallow tidal lake. Bering River is the trunk drainage of the field; its principal tributaries are Canyon, Stillwater, and Shepherd Creeks. Streams are often fault controlled with waterfalls to 30 m common (Fisher and Calvert, 1914; Sanders, 1976).

The Tertiary strata have been deposited on top of a basement complex of volcanic and metamorphic rocks. The best exposures of coals in this mountainous terrain are in eroded canyons, valley bottoms, and cliff faces (Fisher and Calvert, 1914).

LITHOSTRATIGRAPHY OF TERTIARY KUSHTAKA FORMATION

The Bering River coal field is delineated in general by the outcrop extent of the Kushtaka Formation (figure 9). The stratigraphy of the Kushtaka Formation and other Tertiary units of the eastern Gulf of Alaska are poorly understood. Sanders (1976), who has done the most recent and extensive coal resource evaluation of the area, failed to locate a measurable stratigraphic section in the Kushtaka Formation due to its extreme structural complexity. Basically, there appear to be at least three lower to middle Tertiary age formations that comprise an apparently conformable sequence---the Kushtaka, Tokun, and Katalla Formations (table 5). A fourth unit, the Stillwater Formation, formerly thought to form the base of the Tertiary sequence, is now believed to be at least partly age-equivalent with the Kushtaka Formation. The predominantly marine beds of the Stillwater Formation interfinger with and grade eastward into the predominantly nonmarine strata of the Kushtaka Formation. The Kushtaka Formation may be the oldest Tertiary formation exposed in the Bering River coal field (Miller, 1961).

Table 5--NEAR HERE

The lower Tertiary units include the Kushtaka and lower Tokun Formations, which are composed of well-indurated and complexly deformed rocks containing abundant Eocene plant fossil remains. The middle Tertiary (Oligocene to early

Miocene) units include the upper Tokun(?) and Katalla Formations, which hold up to 2,740 m of less indurated and less deformed rocks in the Katalla district. The Tokun Formation specifically is composed of gray to dark gray shale (mudstone, siltstone, and claystone) and gray to brownish-gray, fine-grained banded sandstone. The entire Tertiary sequence includes at least 6100 m of marine and continental sediments in this area. Although the exact thickness of the coal-bearing Kushtaka Formation is unknown, its total thickness is probably over 1000 m. In general, there are two main types of outcrops in the Katalla district---unconsolidated sediments of recent deposition occupying the lowlands, and the indurated and highly folded Tertiary shales, sandstones, coarse arkoses, and coals of the hills (Fisher and Calvert, 1914; Miller, 1961; Plafker, 1971; and Wheelabrator, 1983).

The Kushtaka Formation consists of alternating series of interbedded (intertonguing) graywacke; coarse, pebbly, feldspathic to arkosic, and commonly calcareous sandstone; siltstone; shale; claystone; and coal. The sandstones are micaceous and poorly sorted with crushed quartz and corroded feldspar grains. The coal-bearing strata are intruded by diabase and basalt dikes and sills (Fisher and Calvert, 1914).

Coal beds of the Katalla district are distributed throughout the entire thickness of the Kushtaka Formation and are restricted to it. The overlying Tokun Formation and the at-least-partially stratigraphically-equivalent Stillwater Formation are barren. Coals can be seen only in isolated outcrops, and it is impossible to ascertain the exact number of coal beds due to the complex structure and possibility of repetitions (Barnes, 1951; Sanders, 1976). Fisher and Calvert (1914) cited at least 22 coal beds over 0.9 m in thickness, but they also recognized that some may have been duplicated by folding and faulting. It appeared to them that the coal beds occurred in the sequence in three indefinite groups---a lower group of 8 moderately thick beds 30 to 250 m apart; a middle group of 9 beds in 120 m of strata; and an upper group of 5 beds, more widely spaced than in the middle group.

The coals of the Kushtaka Formation can be traced only over a short distance because of extreme lateral thickness changes. The lack of persistence is due both to structural deformation (squeezing, faulting, and truncation) and to stratigraphic thinning (Fisher and Calvert, 1914). Correlation is extremely difficult because of the faulting and folding often repeating sections and also due to the lack of diagnostic key beds. Although the coal beds are very discontinuous, they can be very thick locally, commonly found in large pods or lenses from 1.8 to 9 m, rarely to 18 m. The coals increase in rank from the western part of the field to the eastern part. They have been greatly devolatilized through low-grade regional metamorphism associated with the deformation of the area, and range in rank from high-volatile bituminous in the western part of the district, to low-volatile bituminous in the middle part, and to semi-anthracite and anthracite east of Canyon Creek. The coals are noncoking for the most part (Sanders, 1976).

STRUCTURAL GEOLOGY AND REGIONAL TECTONISM

The structure of the Bering River coal basin is complex and poorly understood. The complexity of the overall structure in the thick sequence of Tertiary sedimentary rocks increases from southwest to northeast. The intensity of folding grows progressively northeastward with the extreme northeast area of the basin greatly compressed. The magnitude of displacement of the numerous faults also appears to increase northward. The folding and faulting in the region is complicated by the local implacement of stocks, dikes, and sills and thermal metamorphism of surrounding sedimentary sequences.

The Katalla area of the eastern Gulf of Alaska is located at the boundary of Pacific and North American lithospheric plates, and hence has been subjected to intense dynamic stresses. Convergent plate motion is accomodated by underthrusting of the Pacific plate beneath the North American plate along the northwestward-dipping Aleutian subduction zone. This underthrusting results in compression of the overlying crust causing the folds, high-angle reverse faults and thrust faults that are manifest in the Bering River coal basin (Wheelabrator, 1983).

Tertiary rocks have been intensely folded and cut by many faults caused by uplift and compressive forces normal to the Chugach Mountain front. Pre-Tertiary rocks of the region have been subjected to both early and late Tertiary (to Quaternary) diastrophism culminating from two major orogenic episodes in early and late Cenozoic time. The Katalla area was subjected to a significant east-west component of compressive stress during early Tertiary (Paleogene) orogeny. Neogene tectonic activity involved consequent folding and faulting of bedrock materials, associated metamorphism with local igneous intrusions, and subsequent regional uplift in Quaternary and Holocene time. Glaciation has continued to sculpt the terrain, and mantle the area with morainal materials during prolonged glaciofluvial deposition (Miller, 1951; Plafker, 1971; Wheelabrator, 1983).

The Bering River basin can roughly be divided into structural provinces with Canyon Creek serving as a general boundary line. The western district is characterized by open and fairly regular folds striking northeast and dipping northwest with at least two major and several minor synclines. The eastern district, east of Canyon Creek, is more complex with folds in part overturned, locally complexly so, a complicated system of overthrust faults, and numerous dikes and sills of igneous rocks. The strata on first appearance seem to exhibit relatively uniform northwest dips, frequently at low angles. However, the structure is more raveled than the apparently uniform strike and monoclinal dip seem to indicate. It is actually characterized by close overturned folding in which the tightly compressed rocks are bent back on themselves with opposite limbs of folds parallel. The axes of many of the individual folds are broken by faults causing further repetition of beds (Martin, 1906b; Barnes, 1951).

Sanders (1976) describes the complex series of folds as highly distorted, greatly compressed, isoclinal, chevron-like, and incorporated into an imbrication of bedding plane faults. He envisions a model wherein the competent strata of the overlying Tokun Formation acting against the assumed competent strata of the Stillwater Formation set up a shear couple within the relatively incompetent Kushtaka Formation. The Tokun Formation was forced over the lower block of Stillwater Formation creating a thrust relationship between these units. The compression and shortening was absorbed by the incompetent Kushtaka Formation as a whole. In essence, Kushtaka Formation strata was crushed and squeezed out between the adjacent competent Tokun and Stillwater Formations.

Major regional structural features include the Carbon Creek anticline and a number of northward- to northwestward-dipping thrusts. At least four known large magnitude high-angle reverse faults traverse the area of the Bering River coal field from northwest to southeast. Faults of lesser dimension, some with throws of less than 100 m to 200 m, are also prevalent. Both the major and minor faults are generally vertical or steep with north to west dips and the footwall on the south and east sides. Others show opposite dip-slip displacement or a large component of lateral displacement. The amount of displacement has not been accurately determined on any of the faults. The closely spaced folds and tightly compressed anticlines and synclines of the Bering River basin trend northeastward with some of the folds overturned to the southeast. Beds throughout the coal field dip from 20° to 80°, commonly at 60° or more, but average 40°. Pre-Quaternary rocks generally dip to the northwest and strike northeast, but vary locally (Martin, 1908; Miller, 1951; Barnes, 1951; and Wheelabrator, 1983).

Tectonic deformation has progressively elevated the rank of the coal eastward with the increased compression. Shearing, crushing, and small-scale faulting may have affected the overall character of the coal more than the major folding and faulting. The coal occurs in very thick pockets to discontinuous lenses and is typically of a friable nature. Slickensides are prevalent in the more competent strata, whereas crushing is extensive along bedding planes in less competent strata. Crushing was most common in coal beds with shearing planes highly developed. The shearing has also caused the introduction of additional impurities. The complex structure of the Bering River coal basin is the most important factor bearing on the potential economic value of the coal deposits, and ultimately must be unraveled in order to determine the true future potential of the large aggregate coal resource of the region (Barnes, 1951).

DEPOSITIONAL ENVIRONMENTS OF KUSHTAKA FORMATION COALS

Detailed modeling of the depositional environments of the Kushtaka and other Tertiary formations of the eastern Gulf coast of Alaska has not been developed mainly because of the complex structure and stratigraphic relationships existent within the rock units. In general, both marine and nonmarine sediments are known to exist.

The lower Tertiary sedimentary sequence includes the Stillwater Formation(?), the Kushtaka Formation, and the lower Tokun Formation. These shallow marine to continental sedimentary rocks contain abundant coal in the eastern Katalla district. The lower Tertiary sequence contains a late Paleocene to late Eocene and possibly early Oligocene fauna and flora and was deposited in a subtropical to temperate environment. The Kushtaka Formation contains an abundant Eocene plant fossil flora and thick carbonaceous deposits that formed in stagnant coal swamps 50 million years ago. The Stillwater Formation, principally a marine siltstone, interfingers with and grades eastward into the entirely fresh-water deposits of the Kushtaka Formation. The middle Tertiary sedimentary sequence includes strata of the upper Tokun and Katalla Formations that were deposited in moderately deep to deep marine waters of a temperate environment. The Tokun Formation was deposited on the Kushtaka Formation with little break in sedimentation but witnessing a gradual transition to deeper marine water upward through its section. Subsequently, the Katalla Formation was conformably deposited on the Tokun Formation, and represents deep marine sediments (Miller, 1961; Plafker, 1971).

Since unraveling the complex structure of the Kushtaka Formation will ultimately prove to be the key limiting factor to future coal development in the Bering River basin, it is uncertain that a better understanding of the paleodepositional regime would allow circumvention of the aforementioned more essential prerequisite.

NENANA BASIN

GENERAL PHYSIOGRAPHIC AND GEOLOGIC SETTING

The general location of the Nenana basin of interior Alaska is shown in figure 1 along with the other major coal fields and occurrences throughout the State. The region falls within the Alaska Range physiographic province (Wahrhaftig, 1965), and encompasses an area over 6500 km^2. Outcrops of the coal-bearing group are restricted to an area less than 2500 km^2. The belt of Tertiary coal-bearing rocks extends for about 225 km along the north-central flank of the Alaska Range and is up to 50 km wide. The deposits are centered in an area about 95 km southwest of Fairbanks and 320 km north of Anchorage. The Nenana basin occupies a large area of the foothills belt between the Nenana and Delta Rivers, south of the Tanana Flats and north of the Alaska Range. The Nenana trend continues 240 to 320 km southwest of the Nenana basin proper and includes the coal-bearing rocks of the Farewell (Little Tonzona) field (figure 1).

Lignite Creek and Healy Creek are the most important of the structurally similar series of disconnected subbasins that form the Nenana basin (figure 10). The others include (from west to east)——western Nenana, Rex Creek, Tatlanika Creek, Mystic Creek, Wood River, West Delta, East Delta, and Jarvis Creek. These relatively shallow coal subbasins are generally aligned east-west parallel to the structural trend of the foothills belt of the Alaska Range.

The Nenana basin is a region of diverse physiographic features. The rugged alpine ridges of the Alaska Range generally trend east-west, with numerous peaks within the range attaining altitudes over 3,000 m. Mt. Hayes has an altitude of 4200 m, and Mt. McKinley, the highest mountain peak in North America, has an altitude of about 6200 m and lies southwest of the main coal fields. The outer ridges of the foothills belt in the Nenana basin descend downward to the Tanana Flats, which is a lowland of slight relief with a width of about 50 km. The northward extent of the coal belt beneath the Tanana Flats is unknown.

Figure 10—NEAR HERE

LITHOSTRATIGRAPHY OF THE TERTIARY COAL-BEARING GROUP

The Tertiary coal-bearing group of the Nenana basin is less than 900 m thick and was subdivided by Wahrhaftig and others (1969) into five formations (in ascending order): Healy Creek, Sanctuary, Suntrana, Lignite Creek, and Grubstake (figure 11). The folded and locally faulted strata are loosely to moderately consolidated and deeply incised. Locally thick sections are exposed along Healy and Lignite Creeks which are nearly complete. These stratigraphic sequences consist of cross-bedded sandstones, siltstones, soft-blue claystones (locally shaley), loosely-cemented conglomerates, gravel beds, and clean whitish quartzose grit interbedded with numerous coal beds.

The coal-bearing group is characterized by rapid lateral changes in lithologies and varying thicknesses in individual facies. Correlations of beds over distance is difficult. Volcanic ash partings, which can be utilized for correlation purposes, can be observed locally throughout the Nenana coal field. Coal and coaly shale occur in sandstones as wavy stringers and lenses. Fossilized tree trunks and other abundant plant remains are present (Wahrhaftig, 1958).

Coal-bearing sections sometimes have a basal conglomerate with pebbles of schist, angular quartz, quartzite, and chert. Sandstones are commonly composed of quartz and black chert, and locally have a 'salt-and-pepper' appearance. Cross-bedding is present in many of the sandstone and conglomerate sections of the coal-bearing group. Sandy shales and claystones often exhibit high chroma yellow or buff colors. Abundant mica occurs in sediments and was derived from underlying schists. Differential erosion in softer portions of sandstone beds result in mushroom-shaped rock bodies and castellated forms; these are also rarely found in coal beds of the region. Differentially-cemented calcium carbonate concretions to five feet in diameter occur in certain sections of the coal-bearing group (Wahrhaftig, 1958).

Figure 11--NEAR HERE

Dickson (1981) points to two lithologic changes during the deposition of portions of the coal-bearing group which indicate a general climatic cooling: 1) transition from dominantly kaolinitic clays of the Healy Creek Formation to montmorillonitic clays in the Suntrana Formation and above; and

2) pebbles in the Healy Creek and Suntrana Formations are more resistant than those of the arkosic Lignite Creek Formation. In addition, chemical weathering generally decrease from older to younger formations of the group.

STRUCTURAL GEOLOGY AND REGIONAL TECTONISM

The Tertiary coal-bearing group strata of the Nenana basin occur within a structurally similar series of disconnected subbasins isolated by faulting and folding along the northern flank of the Alaska Range. The fold axes of these relatively shallow warped basins are generally aligned east-west parallel to the structural trend of the mountains of the foothills belt and Alaska Range. Late Tertiary (Pliocene) uplifts in the Alaska Range resulted in elevation and tilting of certain structural blocks. In the intervening areas between the subbasins, the coal-bearing sequence has been eroded away. Precambrian-Paleozoic metamorphic rocks border and underlie the coal-bearing group; both the structure and stratigraphy of the region has been strongly influenced by the fringing metamorphic rocks.

Erosion of the Precambrian-Paleozoic basement surface continued into the middle Tertiary (late Oligocene) when deposition of the coal-bearing group began. A major unconformity occurs at the base of the Healy Creek Formation. Clastics shed from low to moderate highlands in the general vicinity of the western Yukon-Tanana Upland served as a sediment source for most of the coal-bearing group (Wahrhaftig, 1958). Deposition was generally continuous through the coal-bearing sequence but local unconformities exist at the base and top of the Sanctuary Formation, top of the Suntrana Formation, and top of the Grubstake Formation. By Pliocene time when the Nenana Gravel was deposited, the source of the clastics had shifted from the north to the south following rejuvenation in the Alaska Range.

Hackett and Gilbert (1983, personal communication) have outlined the existence of several major tectonic blocks across the north-central portion of the Alaska Range by gravity and magnetic surveys and structural evidence. These blocks are bounded on the north by the south edge of the Tanana Flats, on the south by the McKinley strand of the Denali fault system, on the west by the Teklanika River, and on the east by the West Fork of the Little Delta River and Yanert Glacier. They have evidence for a broad Bouguer gravity low greater than 12 milligals near Healy and for large density contrasts between the Tertiary coal-bearing sediments of the Healy Creek and Lignite Creek basins and the denser underlying Precambrian-Paleozoic basement rocks. The down-dropped tectonic blocks of Tertiary sedimentary rocks resting on the underlying heavier Paleozoic or older basement result in a low gravity anomaly along the trend of the synclinal axes of the Nenana basin to the east.

Both the Healy Creek and Lignite Creek coal deposits occur in synclinal structures. A near-vertical fault separates the two subbasins displacing the coal-bearing strata on the north side upward about 1500 m, bringing the coal beds close enough to the surface locally to create favorable strip-mining situations. Birch Creek Schist is also brought into direct contact with the Nenana Gravel in certain areas on the upthrown northern block (Wahrhaftig and Birman, 1954). Thorson (1978) cited evidence for late Quaternary recurrent movements on this fault.

The Healy Creek coal section occurs in a westward-plunging syncline with dips off the limbs ranging from 30° to 90°. Mining on Healy Creek in the past has been limited to the south limb which dips on the average at 45°. Near the east end of the Healy Creek subbasin and the axis of the faulted syncline, beds are near-vertical to slightly overturned, and drag folds and rolls are present locally (Wahrhaftig and Freedman, 1945; Conwell, 1972). The geologic structure of the Lignite Creek subbasin is dominated by several synclines and anticlines with typically gentler dips around 20°, but in places with broad open flexures having dips of 30° to 35° (Wahrhaftig and Birman, 1954). The hornblende dacite intrusion of Jumbo Dome has greatly affected the section adjacent to the flanks of the dome, and has caused significant structural adjustments and attitude changes within the Tertiary clastics.

DEPOSITIONAL ENVIRONMENTS OF TERTIARY COAL-BEARING GROUP COALS

The Tertiary coals of the Nenana basin formed in late Oligocene and Miocene epochs about 10 to 30 million years ago (Wolfe and others, 1980). These deposits are similar in age, structure, and sedimentologic character. They are products of terrestrial sedimentation, including fresh-water stream-laid, lacustrine, and poorly drained swamp deposits. They accumulated on an irregular, deeply weathered and eroded land surface (Precambrian Birch Creek Schist or other Paleozoic metamorphic rocks) which had been raised above the sea in Cretaceous time (Wahrhaftig, 1958; Wahrhaftig and others, 1969).

A number of coal-forming environments developed along what is now the north-central flank of the Alaska Range on a subsiding alluvial plain that shifted with time. Hence, the lateral continuity of units is generally poor.

Correlation is difficult and decreases with distance from the particular depositional system, as a fluvial channel.

Buffler and Triplehorn (1976) cite evidence for at least 23 fining-upward cycles of continental sedimentation in coal-bearing group strata near Healy. They believe that these cycles reflect both tectonic controls (uplift and subsidence) as well as sedimentary controls (lateral shifting of stream channels). Figure 12 is a generalized Healy Creek section illustrating the cycles and respective interpretations of their depositional environment.

Figure 12--NEAR HERE

Much of the following discussion of the conditions of deposition of the coal-bearing group is adapted from information in Wahrhaftig (1958).

The Healy Creek Formation is a fluvial sequence of conglomeratic sandstones interbedded with claystones and subbituminous coal. It was deposited during Healy Creek time (figure 13A) in late Oligocene and early Miocene epochs. The weathered schist basement on which it was deposited was a highly irregular surface with a hundred to several hundred meters of relief, resulting in a major unconformity. Densely vegetated coal swamps developed in nearly isotopographic lows on this irregular surface. Poorly drained swamps, ponds, sandy stream channels, levees and crevasse splays occurred over this lowland plain surrounded by forested uplands of moderate relief. Sediments carried by meandering streams across the swampy plains were derived mainly from the basement rock of these nearby hills particularly from quartz veins in the weathered schist. They are characterized by a diversity of source rocks. At certain intervals, the forests were either destroyed by fires or the hills laid barren and made susceptible to erosion and large landslides. Clastics washing into the coal swamps eventually closed off each coal-forming episode. Several localized basins of deposition formed in a region about 225 km long and 50 km wide.

Figure 13--NEAR HERE

Conditions in the depositional system have determined the sedimentologic character of the preserved rocks of the Healy Creek Formation. Variations in these local conditions of deposition have resulted in lenticular and intertonguing beds exhibiting rapid facies changes. Discontinuous sand sheets or mudflows often occur as splits in coal seams. Although coal beds of the Healy Creek Formation are locally thick, they maintain little lateral continuity.

The Sanctuary Formation is a locally thick claystone of probable lacustrine origin. It was deposited during Sanctuary time (figure 13B) in early to middle Miocene. The silt and clay that washed into this large shallow lake were derived apparently from sources different than the Healy Creek, possibly from basic igneous rocks in a fairly distant region. Prominent lacustrine deltas formed locally. The formation thickens somewhat to the south and southeast. During most of Sanctuary time, the lake was sufficiently deep to prevent the rooting of aquatic vegetation, but parts of the lake became restricted by late Sanctuary time and coal swamps began to form. However, very little coaly material has been preserved, and it is near the top of the formation.

The Suntrana Formation formed on a subsiding plain with scattered, fairly extensive, coal swamp development during Suntrana time in the middle Miocene (figure 13 C and D). Periods in which streams carried sheets of sand and gravel from northern source areas, i.e., uplift and subsidence (Suntrana time 1, figure 13C) alternated with periods in which most of the plain was a coal-forming swamp (Suntrana time 2, figure 13D). Important subenvironments included channels, levees, crevasse splays, forested plains (evidenced by coalified logs), and alluvial fans. Subsidence was greatest to the south, and the formation gradually thickens in this direction. Chert pebbles indicate a source near the western margin of the Yukon-Tanana Upland, perhaps from the Livengood Chert (Wahrhaftig, 1958).

Crosscurrent directions preserved in sandstones show a northerly provenance for the clastics washed into the subsiding basin during the periods of rapid erosion. Depositional conditions were much more uniform (than during Healy Creek time, e.g.) in the coal-forming periods, and this has produced more laterally continuous coal beds in the Suntrana Formation. Several depocenters with substantial thicknesses of coal developed toward the southern margin of the basin where subsidence was greatest. As the hills to the north were gradually lowered, and the sediment supply became more restricted, silts and clays were deposited. A period of renewed uplift would initiate another cycle of sedimentation.

Sediments of the Lignite Creek Formation were deposited in the same basin(s) as the Suntrana Formation during Lignite Creek time (figure 13 E and F) in middle Miocene. The pattern of deposition was similar to that of the Suntrana, and was to some degree also cyclic. Little or no significant break in deposition occurred, and sediments derived from the north poured into the subsiding basin at an increased rate (Lignite Creek time 1, figure 13E). Since the pebble lithologies are less resistant than those of the Suntrana Formation, they may have been derived from a less distant source area or different source unit, and/or after considerable rejuvenation of the source area (Wahrhaftig, 1958). Large alluvial fans developed on the sloping terrain between the subsiding basin and the highland source areas. The coal swamps that developed during Lignite Creek time 2 (figure 13F) were often inundated by flood waters depositing silts, sands, and gravel. Hence, coal seams of the Lignite Creek Formation are very lenticular and laterally discontinuous. The highlands to the north were eventually lowered by erosion depleting the supply of clastic materials. Shallow lakes formed locally and silts and clays were deposited.

The Grubstake Formation consists mainly of claystone and was deposited during the transition period (Grubstake time, figure 13G) in late Miocene which separates the derivation of clastic materials from northerly source areas (Suntrana and Lignite Creek times) and later on from southerly source areas (Nenana Gravel time). An unconformity separates the Lignite Creek and Grubstake Formations. Grubstake time was relatively unstable and depositional conditions shifted between large shallow lakes and broad alluvial plains. The old highlands to the north were lowered and new ones to the south began to rise. Local uplifts closed off rivers and the drainage was 'ponded' in the lowland. Lacustrine deltas locally splayed into the lakes. The unstable depositional conditions are reflected in the absence of coal and in the interbedded finer-grained sediments with relatively dark-colored sandstones and conglomerates.

The Nenana Gravel (time 13H) was derived from southerly source areas in the Pliocene and covered the coal-bearing sediments in a thick layer of coarse gravel with included cobbles and boulders.

CHIGNIK BAY AND HERENDEEN BAY BASINS

GENERAL PHYSIOGRAPHIC AND GEOLOGIC SETTING

Rocks of the upper Cretaceous Chignik Formation, Coal Valley Member, are exposed in a long, narrow belt on the Alaska Peninsula between Pavlof Bay at the southwest and Wide Bay at the northeast (figure 14). The two main coal fields of the region, Chignik Bay and Herendeen Bay, are about 160 km apart. The Coal Valley Member of the coal fields is not equally wide throughout its length but is restricted in width by marine embayments, other changes in the configuration of the Cretaceous beach line, and other variations in the sediment source. Rock outcrops of the Chignik Bay and Herendeen Bay areas include clastic volcanic and marine to nonmarine sediments of Jurassic and Cretaceous age that are intruded by Tertiary to Quaternary mafic dikes and sills and also large, intermediate composition multiphase intrusive bodies (Burk, 1965; McGee, 1979; Vorobik and others, 1981).

Figure 14—NEAR HERE

Herendeen Bay is an arm of Port Moller and with it forms the only deep embayment in the Bering Sea side of the Alaska Peninsula. The Herendeen Bay field is about 560 km southwest of Kodiak and lies between latitudes 55°40' and 55°55' north and longitudes 160°37' and 160°56' west. The Alaska Peninsula in this area is nearly severed by deep indentations of the coast line; Port Moller and Herendeen Bay on the Bering Sea side and Portage and Stepovak bays on the Pacific side approach to within 13 km. The chain of mountains that forms the backbone of the Alaska Peninsula is the dominant physiographic feature of the region. The highest of the sharp and rugged peaks are 750 to 900 m in elevation. The Cretaceous coal-bearing strata here covers at least 100 km^2 (Paige, 1906; Resource Associates of Alaska, Inc., 1980).

Chignik Bay forms a broad indentation in the east coast, Pacific side, of the Alaska Peninsula, and is about 400 km southwest of Kodiak. The Chignik coal field comprises about 100 km^2 of coal-bearing strata of the Coal Valley Member of the Chignik Formation. It forms a northeast-trending belt about 40 km long and 1.5 to 5 km wide on the northwest shore of Chignik Bay (Martin, 1925; Resource Associates of Alaska, Inc., 1980).

LITHOSTRATIGRAPHY OF CRETACEOUS CHIGNIK AND ASSOCIATED FORMATIONS

Five Jurassic to Cretaceous sedimentary rock formations are exposed in the Herendeen Bay coal field, four in the Chignik Bay coal field. These include the Naknek and Staniukovich Formations, Herendeen Limestone in the Herendeen Bay area, the Chignik Formation (including the Coal Valley Member), and the Hoodoo Formation (figure 15). Each formation exhibits gradational, intercalating and interdigitating contacts with units above and below. This relationship has resulted from transgressional-regressional cycles operating in phase with uplift and subsidence caused by pulsating crustal plate convergence. The interdigitation between formations was further accentuated by deposition of primary clastic debris into depositional sites varying from subaerial to outer continental shelf marine (Vorobik and others, 1981).

Figure 15—NEAR HERE

The upper Cretaceous (Campanian to Maestrichtian) sedimentary rock sequence consists of the Chignik Formation with its middle clastic and coal-bearing Coal Valley Member and the black siltstones and shales of the Hoodoo Formation. The age of the rocks is based on palynomorphs, ammonites, inoceramids, and foraminiferids. Younger Tertiary and Quaternary sediments cover large areas of the Cretaceous belt where the Coal Valley Member is probably present in the subsurface (McGee, 1979; Mancini, 1977).

Burk (1965) states that the source of the upper Cretaceous rocks is problematic. The sandstones of the Chignik Formation are composed primarily of subangular to subrounded grains of feldspar and quartz suggestive of a plutonic source terrain. Some of the clasts in the Chignik Formation conglomerates appear to be Naknek argillites and erosion of the Naknek and adjacent formations probably provided some debris for the Chignik and Hoodoo Formations. The source area for the sedimentary rocks that comprise the Chignik and Hoodoo Formations that most clearly fits the available petrographic and paleocurrent data is to the north and northwest (Burk, 1965; Mancini and others, 1978; McGee, 1979).

The general succession of Cretaceous rocks in both the Chignik Bay and Herendeen Bay regions is underlain by the upper Jurassic Naknek Formation. This unit includes a monotonous sequence of hard, dense, fine-grained, and massive siltstones with pelecypods of Buchia, rare pectins, and gastropods. Gray, quartzo-feldspathic, belemnoid-bearing, fine-grained, arkosic sandstones and local thin conglomerates are interbedded in the siltstones (Burk, 1965; Vorobik and others, 1981).

The Jurassic and early Cretaceous Staniukovich Formation unconformably overlies upper Jurassic Naknek Formation rocks. The unit is over 300 m thick and is composed of distinctive light tan to brown-weathering interbedded sandstones, conglomerates, and siltstones with occasional interbeds of shale. In the Herendeen Bay field, the Staniukovich Formation is overlain unconformably by the Herendeen Limestone, but in the Chignik field is overlain unconformably or is in thrust contact with the Chignik Formation. The Herendeen Limestone is composed of light arenaceous, resistant, cross-bedded limestone and is about 250 m thick at its type locality, Herendeen Bay (Smith, 1939; McGee, 1979).

The Chignik Formation is the most significant late Cretaceous neritic to subaerial depositional sequence exposed in the Chignik Bay and Herendeen Bay regions. It includes sandstones, siltstones, claystones, and conglomerate units of upper and lower shallow marine sections that are separated by the deltaic sandstones and coals of the Coal Valley Member. Chignik Formation sandstone composition varies from quartz arenite to arkosic subgraywacke. The sandstones are greenish gray, gray, pink, and tan, and commonly exhibit trough cross-bedding, ripple lamination, and bioturbation. Inoceramus burrows, cephalopods and gastropods, and carbonaceous root, log, and other plant remains---including pollen, spores, and some phytoplankton---firmly indicate continental shelf deposition (McGee, 1979; Vorobik and others, 1981; Mancini and others, 1978).

Detterman (1978) reported three complete cycles and a part of a fourth represented in nearshore marine to nonmarine rocks of a Chignik Formation section on the northwest shore of Chignik Lagoon. The Chignik Formation in the vicinity of Port Moller is about 750 m thick, massively bedded, homogeneous, fine- to medium-grained sandstone interbedded with siltstone. The Chignik Formation section measured by Burk (1965) near Staniukovich Mountain is about 500 m thick. The upper 120 m consists of gray to tan friable sandstones and siltstones, commonly containing pelecypods and carbonaceous plant remains. The lower 380 m is the type section of the Coal Valley Member, which includes down-section 1) 120 m of medium gray to tan and brown conglomerate containing volcanic and chert clasts; 2) 150 m of gray-green sandstone and siltstone, locally very clayey and carbonaceous with rare thin and lenticular seams of coal; and 3) 105 m of sandstone, siltstone, claystone, and thin coal beds. The clastics of the basal section are predominantly light gray and tan, weathered to a mottled light brown, reddish brown, and tan. The sandstones are predominantly fine-grained and easily friable. No marine fossils were noted but numerous intervals contained abundant carbonaceous plant fragments (McGee, 1979; Mancini and others, 1978).

Coal Valley Member sediments are relatively well-sorted and stratified and contain abundant organic matter. The conglomerates of the Coal Valley Member contain subrounded pebbles and cobbles in a clayey sand matrix and beds 3 to 30 m thick. The quartzo-feldspathic sandstone beds are 1 to 3 m thick. Channeling and trough cross-bedding are common features in the basal part of the sandstone, whereas ripple and convolute laminations typify the upper part. The grain size also decreases upward in some sandstone beds. Siltstone beds average 2 m thick and are carbonaceous. The Coal Valley Member contains all the significant and potentially commercial coal deposits in the upper Cretaceous rocks of the Alaska Peninsula. The coal horizons are interbedded with carbonaceous claystone and sandstone, and individual coal seams vary greatly in thickness over short lateral distances. Correlations between individual coal seams is difficult and it is necessary to correlate carbonaceous coaly intervals (Mancini and others, 1978; McGee, 1979).

At the base of the Coal Valley Member, a 6 to 12 m thick distinctive arkosic to quartzose platform sandstone rests conformably on the lower Chignik green sandstones and conglomerates at Chignik Bay (figure 16). The thickest carbonaceous siltstones and coals were deposited upon this platform sandstone followed by quartzose and locally calcareous sand and thinner coal horizons. The Coal Valley Member appears to represent one of the only instances recorded where there was sufficient stability in the system for platform development. Increased distributary activity resulted in the development of an unconformity at the top of the Coal Valley Member (Vorobik and others, 1981).

The youngest Cretaceous formation exposed in the Chignik Bay and Herendeen Bay fields is the Hoodoo Formation. The Hoodoo Formation type section is southeast of Hoodoo Mountain and along the west side of Beaver Valley, Herendeen Bay field. It consists of over 300 m of black siltstone that is highly fractured and weathers into prismatic slivers. Minor interbeds of dark gray to black, well-bedded claystone, silty claystone, and fine-grained tan sandstone occur in the black siltstone. The siltstones and shales contain an outer neritic to bathyal foraminiferal assemblage and open-marine ammonoids and bivalves. The quartzo-feldspathic sandstone beds are fine- to medium-grained, poorly to moderately sorted, and contain graded bedding and convolute laminations. Burk (1965) noted the presence of coarse distributary conglomerates and concluded that these may be related to turbidite deposition on the outer shelf. Rare plant fragments and disseminated organic debris characteristic of deep water deposition are also present in the conglomeratic units (Mancini and others, 1978; McGee, 1979).

Figure 16--NEAR HERE

Burk (1965) conservatively estimated the thickness of the Hoodoo Formation in the vicinity of Port Moller to be 760 m. The Hoodoo Formation thickens rapidly to the south of Herendeen Bay and may represent deposition in an embayment and a longer period of deep water sediment accumulation. This is consistent with and supports a late Cretaceous transgression. The relationship between the Hoodoo Formation and the underlying Chignik Formation is not obvious in the field because there are few observable contacts and because the Hoodoo Formation is structurally complex. Where observed in the field, the upper Chignik Formation appears to be transitional into the Hoodoo Formation. This indicates that a regional transgressive event did occur but that it was preceded by the simultaneous deposition of the Coal Valley Member, Chignik and Hoodoo Formations (Mancini and others, 1978; McGee, 1979; Vorobik and others, 1981).

STRUCTURAL GEOLOGY AND REGIONAL TECTONISM

The structure of the Chignik Bay and Herendeen Bay coal fields has been dominated by convergent plate tectonics and arc-trench development, which have resulted in continuous uplift and erosion of plutonic rocks and subsequent deposition of marine and nonmarine arkose, claystone, and sandstone. Arc-building was initiated on the Aleutian margin by the emergence of an early Jurassic magmatic arc along the northern edge of the present Alaska Peninsula (figure 16). Moore and Connely (1977) identified three periods of magmatic arc and subduction complex activity and infer that plates were mobile from late Triassic to late Jurassic, early- to mid-Cretaceous, and late Cretaceous to Paleocene time. Although Burk (1965) and Moore and Connely (1977) have slightly differing views on the time of onset of convergence in the Alaska Peninsula region, the result of tectonism from Jurassic time onward is well recorded in the stratigraphic sections in the Chignik Bay and Herendeen Bay areas (Vorobik and others, 1981).

The general structure of the Chignik district is that of an intensely shattered mass in which the structural constituents consist of relatively small gently tilted blocks separated by faults or zones of shattering. The dominant trend of faults and major folds is subparallel to the long axis of the Alaska Peninsula, that is, generally slightly north of east (Martin, 1925; Resource Associates of Alaska, Inc., 1980).

The first of three major periods of deformation of upper Cretaceous Chignik Formation rocks in the Chignik Bay area involved penecontemporaneous small-scale, low-amplitude folding, deforming bedding at the time of deposition and causing small syndepositional faults and folds that disrupt the sediments in the lower but not upper Chignik Formation. The second deformational period subjected a majority of the Aleutian Range Jurassic and Cretaceous age sediments to intense compressional foreshortening. The most conspicuous structural feature of this period in the Chignik area is the Chignik anticline and overthrust complex. Moderately to highly deformed Jurassic-aged Naknek Formation rocks have been anticlinally arched and thrust southeastward over Cretaceous Chignik and Hoodoo Formations. The strike of the Chignik thrust and anticline is subparallel to the dominant structural trend throughout the Chignik area. Regional strike of bedding, fold axes and faults is N. 60° to 90° E., with bedding commonly dipping 15° to 20° to the south. The anticline plunges 5° to 10° to the northeast. The third deformational event involves local high-angle normal faults that are not subparallel to regional structural trends and often cuts older structures. These faults evidently resulted from late tensional adjustment within the Chignik rocks, post-dates the anticlinal arching, and is probably a brittle response to a shift in the compressional vector of the convergent plate motion (Vorobik and others, 1981).

The Chignik Formation and underlying older sedimentary rocks of an area in the Herendeen Bay coal field are folded into a syncline with the axes approximately paralleling the valley of Mine Creek but migrating slightly north in the eastern part of the drainage. The plunge of this structure is gentle and where measured less than 7°. The syncline is asymmetrical with the dip of the north limb ranging from 10° to 18° and on the south limb from 20° to 37°. The south limb is broken into blocks by at least three major faults which strike almost due north. On one of these faults, a coal bed has been displaced 75 m along the strike of the fault. Numerous minor faults paralleling the major fault systems have displacements to several meters. Most of the coal potential in this area lies on the north limb of this synclinal structure (Gates, 1944; McGee, 1979).

DEPOSITIONAL ENVIRONMENTS OF CRETACEOUS CHIGNIK AND ASSOCIATED FORMATIONS

The general environment of deposition of Chignik and time-equivalent Hoodoo Formations of the Alaska Peninsula is that of a fore-arc basin landward of the trench-slope break. The facies of the Coal Valley Member, Chignik Formation, and Hoodoo Formation are composed mainly of plutonic rock fragments, feldspar and quartz which suggest derivation from the eroding late Cretaceous arc front (Mancini, 1977).

Burk (1965) suggested that deposition of nonmarine sands of the Coal Valley Member through the nearshore sediments of the Chignik Formation and the deep-water marine Hoodoo Formation represents a marine transgression (figure 17). Mancini (1977) interpreted these units as approximately correlative sedimentary facies deposited in different environments of deposition: proximity to source in an alluvial fan, braided stream, and flood plain depositional environment for the conglomerates, quartzo-feldspathic sandstones, and coals of the Coal Valley Member; inner-neritic continental shelf (upper and lower shoreface deposits) for the sandstones and siltstones of the Chignik Formation; and outer-neritic continental shelf to bathyal continental slope for the deeper water, predominantly fine argillaceous sediments of the Hoodoo Formation. Both Burk (1965) and Mancini and others (1978) interpret the conglomerates and coarse sandstones incorporated in the Hoodoo Formation siltstones as turbidite deposits. McGee (1979) finds that this general facies model concept is supported in the field where nonmarine beds of the Coal Valley Member locally grade laterally into marine beds very similar to the upper part of the Chignik Formation.

The depositional environment of the lower part of the Coal Valley Member includes valley flat (floodplain cut by meandering distributary levees), paludal (swamp), and lacustrine (shallow lake) deposits. The increase in conglomerates in the upper part of the depositional sequence suggests that the distance to the source area was decreasing during the deposition of the upper part of the Coal Valley Member, or that the source area was more active and shedding coarse material forming coalescing alluvial fans in a piedmont environment. However, there is little evidence to suggest that the lower part of the Coal Valley Member was deposited in a piedmont environment, a terrain with higher stream gradients and characterized by: 1) a great range in particle size with wide and irregular distribution; 2) poorly sorted and stratified deposits; 3) rare fossils because of the stringent depositional conditions; 4) yellow and gray colors; and 5) materials that become finer with distance from the source (McGee, 1979).

Most of the coals in the Coal Valley Member were developed as the result of preservation of swamps developed on flat and gently sloping areas. Although the swamps were numerous, their lateral extents were limited. For the most part,

---

Figure 17--NEAR HERE

---

they are believed to be fresh-water swamps because of the low sulfur contents of the coals. However, there may have been development of marine swamps at or near the littoral zone essentially separating the Coal Valley Member from the marine Chignik Formation. There is little evidence to suggest that conditions were favorable for coal deposition during the onlap of Chignik sediments. The presence of rare thin coal seams, associated with estuarine, delta, and salt marsh deposition, in the Chignik Formation suggests both periods of hesitation during which peat areas were preserved by deeper burial and conditions that were never stabilized long enough for a thick peat section to accumulate. These discontinuous swamps developed in lagoons behind beach barriers or in restricted basins contained between interdistributary levees (McGee, 1979; Vorobik and others, 1981).

NORTHERN BASIN

GENERAL PHYSIOGRAPHIC AND GEOLOGIC SETTING

The Northern coal field of Alaska is delineated mainly by the outcrop belt of the Nanushuk Group of rocks which extend relatively unbroken from the sea cliffs at Cape Corwin on the west some 650 km eastward to the Sagavanirktok River of the eastern Arctic Slope (figure 18). Nanushuk Group exposures are typically better on the western Arctic Slope where stream channels have locally incised through 500 m of section. The coal field mainly occurs within three major physiographic provinces: 1) the mountainous Brooks Range rims the southern boundary; 2) the Arctic Foothills belt, where exposures of the Nanushuk Group are largely confined, is located north of this mountainous province; and 3) the Arctic coastal plain spans the remaining terrain to the Arctic Ocean. The Arctic Foothills province is characterized by treeless rolling hills, ridges, and valleys aligned east to west parallel to the mountain front, and broken by numerous northward-flowing streams and rivers. It is made up of a Southern Foothills section and a Northern Foothills section. The Southern Foothills section is hillier with both higher overall altitude (averaging 1200 m) and more local relief. The relief of the Northern Foothills section ranges from 60 to 300 m and altitudes average 180 m. The Arctic coastal plain is an extensive, nearly featureless tundra plain with numerous lakes and marshes and poorly developed streams (Martin and Callahan, 1978; Mull, 1979).

The National Petroleum Reserve in Alaska (NPRA) encompasses some 96,000 km^2 of the Arctic Slope of northern Alaska, and includes a large proportion of the coal resources of the Northern field and of Alaska as a whole. This broad region stretches from the crest of the DeLong Mountains in the Brooks

Range northward to the Arctic coast and from the lower Colville River westward to the Chukchi Sea. Abundant coal resources are also present both east and west of NPRA (Martin and Callahan, 1978).

Figure 18—NEAR HERE

LITHOSTRATIGRAPHY OF THE CRETACEOUS NANUSHUK GROUP

The coals of the Northern field occur in two sedimentary rock sequences—the Nanushuk Group of early Albian to Cenomanian age (early to late Cretaceous), which contains better quality coals, and the Colville Group of late Cretaceous age (figure 19). The base of the Cretaceous sequence is composed predominantly of marine shales, which grade upward to the marginal-marine and nonmarine coal-bearing rocks of the Nanushuk Group, and finally the intertonguing marine and nonmarine coal-bearing rocks of the Colville Group. The Nanushuk Group has been subdivided into formations based mainly on the marine and nonmarine character of the rocks. They have been successfully correlated by use of spore, pollen, and plant megafossil zonations in nonmarine facies and of dinoflagellate, foraminiferal, and limited faunal zonations in marine facies. In the western section of the Foothills belt, the Kukpowruk Formation comprises the lower marginal-marine facies of the Nanushuk Group and the Corwin Formation comprises the upper nonmarine facies. The type section for the Corwin Formation is at Corwin Bluff (Brosgé and Tailleur, 1971; Martin and Callahan, 1978; Ahlbrandt, 1979; and Stricker and Roehler, 1981). This unit contains the bulk of the coal resources of the Nanushuk Group. In addition to the numerous coal seams, the unit also contains fine- to coarse-grained sandstone, siltstone, claystone, carbonaceous shale, and coal.

The Nanushuk Group essentially forms a wedge-shaped rock unit. The coarsest nonmarine sediments and the trend of greatest thickness of the Nanushuk Group occurs in the proximal portion of the deltaic clastic wedge, which is counter to the normal trend in deltaic sedimentation. Thick sequences of Cretaceous sedimentary rocks were deposited in the Colville geosyncline. The probable source terrains for the Corwin delta sediments are the western DeLong Mountains, Lisburne Hills, and their offshore extensions. A significant depositional hiatus is indicated between Corwin Formation rocks and overlying rocks of the Colville Group by both structural relationships and the difference in the degree of induration. During this period of erosion, a substantial thickness of the Corwin Formation was removed (Martin and Callahan, 1978;

Callahan and Martin, 1981).

Figure 19--NEAR HERE

Data on the distribution and extent of coal beds of the Nanushuk Group is less detailed in the Foothills than in the Coastal Plain. The group forms a continuous subcrop beneath Pleistocene and Holocene deposits in the Coastal Plain. But in general, the outcrop area of the Corwin Formation is discontinuous with coal beds exposed only in the cutbanks of the larger streams and along sea cliffs at Corwin Bluff (Callahan and Martin, 1981).

The Cretaceous-aged sedimentary rock sequence is as much as 4600 m thick in the southern NPRA adjacent to the Brooks Range but thins northward to about 900 m near Barrow. The thickness of the Nanushuk Group alone decreases from southwest to northeast from over 3300 m at Corwin Bluff to zero in the eastern NPRA. The Corwin Formation comprises the entire thickness of the Nanushuk Group exposed at Corwin Bluff but decreases to about 1200 m thick in the west-central NPRA. The original thickness of the Corwin Formation does not seem to have been preserved in any of the depositional basins. Most stratigraphic sections represent only the lower part of the original thickness of the Corwin Formation. The Colville Group unconformably overlies the Nanushuk Group in the eastern NPRA and reaches a maximum thickness of about 900 m (Brosgé and Tailleur, 1971; Callahan and Martin, 1981).

The majority of the coal resources of the Northern field are contained in the nonmarine facies of the Nanushuk Group, primarily in the middle portion of the clastic wedge, and stratigraphically in the upper half of the sequence widely separated from the underlying marginal-marine facies, indicating deposition considerably inland from the sea. This contrasts significantly with the pattern found in other western United States Cretaceous deltaic and paralic coals, where they are normally found in the first 30 m of nonmarine section above the marine facies. The thicker coal seams are in the upper part of the Corwin Formation, while the coals of the lower part of the Corwin Formation are relatively thin. The sulfur content of the latter coals is relatively higher and more erratic than coals higher in the Corwin Formation. Coals of the Colville Group in the eastern NPRA are of poorer quality, and are considerably less abundant than coals in the Nanushuk Group (Weimer, 1977; Martin and Callahan, 1978).

STRUCTURAL GEOLOGY AND REGIONAL TECTONISM

The structure of the Cretaceous coal-bearing and associated rocks of the Northern field is characterized by folding and faulting along east to west axes generally paralleling the Brooks Range. The intensity of the deformation decreases northward from the mountains; gentle open folding and little faulting characterizes the Coastal Plain, whereas greater structural complexity and steeper dips are found in the Foothills. The Nanushuk Group strata exhibit a general homoclinal dip to the south of about 9 m to a km in the Coastal Plain. The Corwin Formation of the Nanushuk Group in the Foothills occupies the central parts of the numerous broad but relatively simple synclinal basins separated by tightly folded, east to west anticlines. Most of these anticlines are complicated by high-angle reverse faults or north-directed thrust faulting in the Kukpowruk Formation (Martin and Callahan, 1978; Callahan and Martin, 1981).

Lower Cretaceous sedimentation on the North Slope reflects the uplift of the Brooks Range and attendant deposition in a marine basin along the north flank of this range. Downwarping and sedimentation appear to have taken place concurrently with, and probably as a result of the northward-directed thrust faulting that accompanied the uplifting of the mountain range to the south. The thermal maturity of the rocks suggests a greater depth of burial, uplift, and erosion in the Foothills than in the Coastal Plain. Portions of the Nanushuk Group rocks were removed by erosion, especially in the Foothills belt and the eastern Arctic. Thus, tectonic disturbance has greatly affected the ultimate distribution and rank of coal beds between the Foothills and the Coastal Plain on the Arctic Slope of northern Alaska (Carter and others, 1977; Martin and Callahan, 1978; and Ahlbrandt, 1979).

DEPOSITIONAL ENVIRONMENTS OF NANUSHUK GROUP COALS

Ahlbrandt and others (1979) developed a deltaic sedimentation model, later refined by Callahan and Martin (1981; figure 20), to reconstruct depositional environments and facies represented by the Kukpowruk and Corwin Formations. These two formations make up the Nanushuk Group in the Foothills and Arctic Coastal Plain of the western North Slope. This regressive depositional sequence is locally over 3300 m thick and includes marine, transitional, and nonmarine intervals. Other rocks in the western

Brooks Range and Lisburne Peninsula were uplifted and eroded with the resulting detritus progressively deposited in the Colville Trough, a foredeep that developed north of but generally concurrent with the Brooks Range uplift. The Nanushuk Group was deposited as a clastic wedge that prograded (time transgressively) to the north and northeast resultantly causing the Cretaceous shoreline to migrate in the same direction. Nanushuk Group rocks thin and become increasingly more marine in character northeastward away from their source in the Brooks Range (Detterman, 1973; Martin and Callahan, 1978; Ahlbrandt and others, 1979; Stricker and Roehler, 1981).

At least two river-dominated deltas that began to develop in early Cretaceous time are hypothesized for onshore Nanushuk Group rocks---the Corwin delta in the west and the Umiat delta in the central North Slope (Ahlbrandt, 1979). The Corwin delta prograded northeasterly across the western North Slope including areas now under the Chukchi Sea. Progradation in the west was nearly continuous with only minor local marine transgressions. A major depocenter for the Nanushuk Group was in the area of Corwin Bluff. Here, Nanushuk Group rocks are the oldest, thickest, contain the coarsest material, and have the most nonmarine assemblage of any rocks on the western North Slope. The Torok, Kukpowruk, and coal-bearing Corwin Formations are interpreted as having formed in prodelta, delta-front and delta-plain environments respectively. The Torok Formation includes marine shales of Albian age over which the deltaic and interdeltaic sediments of the Nanushuk Group prograded (Ahlbrandt, 1979; Ahlbrandt and others, 1979; Stricker and Roehler, 1981).

Figure 20--NEAR HERE

The lithologies, fossils, and primary sedimentary structures indicate that the Corwin Formation was deposited as part of the large, high-constructional Corwin delta that prograded northeastward across the western portion of the North Slope of Alaska. Coals higher in the Corwin Formation may have formed in backswamp areas between stream channels in an upper delta plain or flood plain environment, where thicker peat accumulations were possible because of the greater channel stability and more prolific plant growth. The general low sulfur content of these coals suggests isolation from brackish water influences. These stratigraphically higher and thicker coals (up to 9 m) tend to thin and split over short distances. Post-depositional tectonism and erosion evidently removed intervals of the upper-delta plain and alluvial deposits. Numerous coal beds of intermediate thickness (2 to 3 m) and continuity (to 10 km) in the central Corwin Formation developed on platforms underlain by abandoned channels and splay deposits in the middle delta-plain environment. Coals of this transition zone may ultimately prove to have the best commercial potential. The higher sulfur content of the thinner and more discontinuous coals of the lower Corwin Formation suggests peat deposition in interdistributary bays in the lower (more seaward) part of the delta system that were subjected to periodic exposure to salt and brackish water (Stricker and Roehler, 1981; Callahan and Martin, 1981).

RELATIONSHIP OF PALEOENVIRONMENTAL AND TECTONIC CONTROLS TO THE ULTIMATE COAL-RESOURCE DEVELOPMENT POTENTIAL IN MAJOR COAL BASINS OF ALASKA

Limited depositional modeling in the Susitna lowland has resulted in a general improved understanding of the nature of continental fluvial coal deposits of the Tertiary Kenai Group. Depositional factors and related constraints are expected to play an important role in future mine planning and pre-development site investigations in the coal basins of the Susitna lowland. Although structural problems may locally complicate mining, they are not expected to be significant compared to other basins in Alaska. In general, world-class coal mines are possible in the Susitna lowland. Large-scale surface mines to 15 million short tons per year production are planned, and even larger mines are feasible. The coal resource base of this region is not a limiting factor. Because of its strategic location relative to tidewater, it is envisioned that coal fields of the Susitna lowland will serve as a major future source of steam coal for Far-Eastern countries.

Overall, it is not believed that depositional modeling of the fluvial meandering to paludal deposits of the upper part of the Tertiary Chickaloon Formation will assist future mine planning significantly in the Matanuska Valley. Unraveling the fairly complex geologic structure will be more beneficial in the long term. The geologic structure and limited resource base will severely restrict the size of coal mines in this region. Large-scale operations (over 1 million short tons per year as used here) are not practical in the Matanuska coal field. The deposits are important though, since they contain the only known bituminous coals within the Railbelt region of Alaska.

The chief limiting factor to coal development in the Bering River coal field is the complex geologic structure. A better understanding of the depositional environments of the continental Tertiary Kushtaka Formation might minimally assist in an improved knowledge of coal character but probably not greatly support exploration and development planning. The complex geologic structure in the field will severely constrain the size of future mine operations. It is believed that the coal deposits will serve as a source for high quality specialty or metallurgical coal, or low-ash carbon raw material.

Improved depositional modeling of the Tertiary continental-fluvial coal-bearing group strata in the Nenana basin should be important for future mine planning in this region. Structure again may be a local complicating factor, but in general is not expected to be a severe limiting constraint to mine development. The resource base of the Nenana basin will not be a limiting factor to further coal development, although future mine size will unlikely exceed 5 million short tons per year. The coal fields of this region will serve as an increasingly important source of steam coal both for Alaska and Pacific-rim nations. Export of coal from the Usibelli Coal Mine, Inc. of the Nenana basin to South Korea will begin in late 1984.

The Chignik Bay and Herendeen Bay basins contain many thin seams of coal in cyclic nearshore marine and nonmarine deposits of the late Cretaceous Chignik Formation that have been mined in previous years, but it is believed that both the coal character and resource base may be limiting factors to future development. Coal character and bed thickness in these areas suggest that thick coals with large lateral extent will probably not be encountered in the Cretaceous coal-bearing strata anywhere on the Alaska Peninsula. Thick coal accumulations cannot be expected to occur in covered areas if depositional environments were the same elsewhere in the upper Cretaceous. However, this should not preclude the possibility of developing small mines. Any potentially commerciable coal in the two areas are found in the interval from the base of the Coal Valley Member of the Chignik Formation upward to the base of the first massive conglomerate (McGee, 1979).

The development of a deltaic sedimentation model for the coal-bearing Cretaceous Nanushuk Group rocks of the Northern field has already allowed for a greater understanding of coal character and ultimate development potential for the different facies of the unit. In general, intermediate thickness and continuity coals of the transition zone between upper and lower delta plain deposits may prove to have the best future commercial potential. Thicker seams of the upper delta-plain deposits exhibit poor lateral continuity, and seams of the lower delta-plain environment are higher in sulfur and generally of unminable thickness. The coal resource base of the Northern field is definitely not a limiting factor to future development. Indeed, it comprises one of the largest coal deposits in the world. However, mining in permafrost will undoubtedly be the most formidable challenge to coal mine development in the Northern coal field of Alaska.

ACKNOWLEDGMENTS

I thank Charles L. Rice of the U.S. Geological Survey, Reston, Virginia and Ross G. Schaff of the Alaska Division of Geological and Geophysical Surveys (DGGS), Anchorage for their encouragement to produce this paper. I also thank Gary Anderson of Nerco Minerals Company, Fairbanks for allowing me to utilize proprietary information from unpublished coal reports on the Chignik Bay and Herendeen Bay coal fields, and Don L. McGee of DGGS for permitting me use of his unpublished paper on the same regions. Michael A. Belowich drafted the text figures in the report, and Karen Pearson lent cartographic assistance during figure preparation.

REFERENCES CITED

Ahlbrandt, T.S., 1979, Introduction to geologic studies of the Nanushuk Group, 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, p. 1-4.

Ahlbrandt, T.S., Huffman, A.C., Jr., 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, p. 14-31.

Apell, G.A., 1944, Moose Creek district of Matanuska coal fields, Alaska: U.S. Bureau of Mines Report of Investigations 3784, 36 p.

Barnes, D.F., 1976, Bouguer gravity map of Alaska: U.S. Geological Survey Open-file Report 76-70, scale 1:2,500,000, 1 sheet.

Barnes, F.F., 1951, A review of the geology and coal resources of the Bering River coal field, Alaska: U.S. Geological Survey Circular 146, 11 p.

__________, 1966, Geology and coal resources of the Beluga-Yentna region, Alaska: U.S. Geological Survey Bulletin 1202-C, p. C1-C54, scale 1:2,500,000, 1 sheet.

Barnes, F.F., and Payne, T.G., 1956, The Wishbone Hill district, Matanuska coal field, Alaska: U.S. Geological Survey Bulletin 1016, 88 p.

Brosgé, W.P., and Tailleur, I.L., 1971, Northern Alaska petroleum province, in Future petroleum provinces of the United States--their geology and potential: American Association of Petroleum Geologists Memoir 15, v. 1, p. 68-99.

Bruhn, R.L., and Pavlis, T.L., 1981, Late Cenozoic deformation in the Matanuska Valley, Alaska; three-dimensional strain in a forearc region : Geological Society of America Bulletin, v. 92, no. 5, p. 282-293.

Buffler, R.T., and Triplehorn, D.M., 1976, Depositional environments of continental Tertiary deposits, central Alaska, in Miller, T.P., ed., Recent and ancient sedimentary environments in Alaska: Alaska Geological Society, Anchorage, p. H1-H10.

Burk, C.A., 1965, Geology of the Alaska Peninsula---island arc and continental margin; part 1--text: Geological Society of America Memoir 99, 250 p.

Calderwood, K.W., and Fackler, W.C., 1972, Proposed stratigraphic nomenclature for Kenai Group, Cook Inlet basin, Alaska: American Association of Petroleum Geologists Bulletin, v. 56, no. 4, p. 739-754.

Callahan, J.E., and Martin, G.C., 1981, Coal occurrences of the Nanushuk Group, western Arctic Alaska—an update, in Rao, P.D., and Wolff, E.N., Focus on Alaska's coal '80, Proceedings of the conference, University of Alaska, Fairbanks, October 21-23, 1980: University of Alaska Mineral Industry Research Laboratory Report 50, p. 32-50.

Capps, S.R., 1927, Geology of the upper Matanuska Valley, Alaska: U.S. Geological Survey Bulletin 791, 88 p.

Carey, S.W., 1958, The tectonic approach to continental drift--a symposium: Hobart, University of Tasmania, Geology Department, p. 177-355.

Carter, R.D., Mull, C.G., Bird, K.J., and Powers, R.B., 1977, The petroleum geology and hydrocarbon potential of Naval Petroleum Reserve No. 4, North Slope, Alaska: U.S. Geological Survey Open-file Report 77-475, 61 p.

Clardy, B.I., 1978, Stratigraphy of the Matanuska-Susitna area, northeastern Cook Inlet basin, Alaska: Louisiana Land and Exploration Company, Western Division, Denver, unpublished industry report, 15 p.

Conwell, C.N., 1972, Alaskan coals: Society of Mining Engineers, AIME Transactions, v. 252, no. 3, p. 279-282.

Conwell, C.N., Triplehorn, D.M., and Ferrell, V.M., 1982, Coals of the Anchorage Quadrangle, Alaska: Alaska Division of Geological and Geophysical Surveys Special Report 17, 8 p., scale 1:250,000, 4 sheets.

Dall, W.H., and Harris, G.D., 1892, Correlation papers--Neocene: U.S. Geological Survey Bulletin 84, p. 232-268.

Detterman, R.L., 1973, Mesozoic sequence in Arctic Alaska, in Arctic geology: American Association of Petroleum Geologists Memoir 19, p. 376-387.

______________, 1978, Interpretation of depositional environments in the Chignik Formation, Alaska Peninsula, in Johnson, K.M., ed., The United States Geological Survey in Alaska, accomplishments during 1977: U.S. Geological Survey Circular 772-B, p. B62-B65.

Dickinson, K.A., and Campbell, J.A., 1978, Epigenetic mineralization and areas favorable for uranium exploration in Tertiary continental sedimentary rocks in southcentral Alaska, a preliminary report: U.S. Geological Survey Open-file Report 78-757, 13 p.

Dickson, R.K., 1981, Uranium mineralization in the Nenana coal field, Alaska, in Short notes on Alaskan geology: Alaska Division of Geological and Geophysical Surveys Geologic Report 73, p. 37-42.

Duff, P. McL. D., Hallam, A., and Walton, E.K., 1967, Cyclic sedimentation: Amsterdam, Elsevier Publishing Co., 280 p.

Fisher, C.A., and Calvert, W.R., 1914, Geology of the Bering River field and its relations to coal mining conditions, in Report on coal in Alaska for use in the United States Navy: 63rd Congress, 2nd Session, House of Representatives Document 876, p. 29-50.

Fisher, M.A., and Magoon, L.B., 1978, Geologic framework of lower Cook Inlet, Alaska: American Association of Petroleum Geologists Bulletin, v. 62, no. 3, p. 373-402.

Gates, G.O., 1944, Part of Herendeen Bay coal field, Alaska: U.S. Geological Survey Open-file Report 2, 5 p.

Gates, G.O., and Gryc, G., 1963, Structure and tectonic history of Alaska, in Childs, O.E., and Beebe, B.W., eds., Backbone of the Americas: American Association of Petroleum Geologists Memoir 2, p. 264-277.

Grantz, Arthur, 1964, Stratigraphic reconnaissance of the Matanuska Formation in the Matanuska Valley, Alaska: U.S. Geological Survey Bulletin 1181-I, 33 p.

Grantz, Arthur, Zietz, Isidore, and Andreasen, G.E., 1963, An aeromagnetic reconnaissance of the Cook Inlet area, Alaska: U.S. Geological Survey Professional Paper 316-G, p. 117-134.

Hackett, S.W., 1976a, Speculative tectonic evolution of the Cenozoic Shelikof trough, southcentral Alaska, in Short notes on Alaskan geology--1976: Alaska Division of Geological and Geophysical Surveys Geologic Report 51, p. 13-17.

__________, 1976b, Regional gravity gradient of Beluga basin and adjacent area, Cook Inlet region, southcentral Alaska: Alaska Division of Geological and Geophysical Surveys Open-file Report 100, 38 p.

__________, 1977, Gravity survey of Beluga basin and adjacent area, Cook Inlet region, southcentral Alaska: Alaska Division of Geological and Geophysical Surveys Geologic Report 49, 26 p.

Hartman, D.C., Pessel, G.H., and McGee, D.L., 1972, Preliminary report on the stratigraphy of the Kenai Group, upper Cook Inlet, Alaska: Alaska Division of Geological and Geophysical Surveys Special Report 5, 11 plates.

Hite, D.M., 1976, Some sedimentary aspects of the Kenai Group, Cook Inlet, Alaska, in Recent and ancient sedimentary environments in Alaska: Alaska Geological Society, Anchorage, p. I1-I23.

Karlstrom, T.N.V., 1964, Quaternary geology of the Kenai lowland and glacial history of the Cook Inlet region, Alaska: U.S. Geological Survey Professional Paper 443, 69 p.

______________, 1965, Resumé of the Quaternary geology of the upper Cook Inlet area and Matanuska River valley, in Péwé, T.L., ed., Guidebook to the Quaternary geology, central and southcentral Alaska (VII INQUA Congress): Alaska Division of Geological and Geophysical Surveys, p. 114-141.

Kelly, T.E., 1963, Geology and hydrocarbons in Cook Inlet basin, Alaska, in Childs, O.E., and Beebe, B.W., eds., Backbone of the Americas--a symposium: American Association of Petroleum Geologists Memoir 2, p. 278-296.

Kirschner, C.E., and Lyon, C.A., 1973, Stratigraphic and tectonic development of Cook Inlet petroleum province, in Pitcher, M.G., ed., Arctic geology: American Association of Petroleum Geologists Memoir 19, p. 396-407.

McConkey, W., Lane, D., Quinlan, C., Rahm, M., and Rutledge, G., 1977, Alaska's energy resources; final report, phase 1, v. 2, Inventory of oil, gas, coal, hydroelectric and uranium resources: Alaska Division of Energy and Power Development, Anchorage, p. 133-216.

McGee, D.L., 1979, Depositional environments and resource potential of Cretaceous coal-bearing strata at Chignik Bay and Herendeen Bay, Alaska Peninsula: Alaska Division of Geological and Geophysical Surveys unpublished report, 41 p.

McGee, D.L., and Emmel, K.S., 1979, Alaska coal resources: Alaska Division of Geological and Geophysical Surveys unpublished report, 26 p.

Magoon, L.B., and Claypool, G.E., 1981, Petroleum geology of Cook Inlet basin--an exploration model: American Association of Petroleum Geologists Bulletin, v. 65, no. 6, p. 1043-1061.

Mancini, E.A., 1977, Alaska Peninsula late Cretaceous fore-arc deposition: American Association of Petroleum Geologists Bulletin, v. 61, no. 5, p. 811.

Mancini, E.A., Deeter, T.M., and Wingate, F.H., 1978, Upper Cretaceous arc-trench gap sedimentation on the Alaska Peninsula: Geology, v. 6, no. 7, p. 437-439.

Martin, G.C., 1906a, Preliminary statement on the Matanuska coal field (Alaska), in Brooks, A.H., Mineral resources of Alaska, report on progress of investigations in 1905: U.S. Geological Survey Bulletin 284, p. 88-100.

____________, 1906b, Distribution and character of the Bering River coal, in Brooks, A.H., and others, Report on progress of investigations of mineral resources of Alaska in 1905: U.S. Geological Survey Bulletin 284, p. 65-77.

__________, 1908, Geology and mineral resources of the Controller Bay region, Alaska: U.S. Geological Survey Bulletin 335, p. 65-112.

__________, 1925, The outlook for petroleum near Chignik, in Brooks, A.H., and others, Mineral resources of Alaska, report on progress of investigations in 1923: U.S. Geological Survey Bulletin 773, p. 209-213.

Martin, G.C., and Callahan, J.E., 1978, Preliminary report on the coal resources of the National Petroleum Reserve in Alaska: U.S. Geological Survey Open-file Report 78-1033, 23 p.

Merritt, R.D., and Belowich, M.A., 1984, Coal geology and resources of the Matanuska Valley, Alaska: Alaska Division of Geological and Geophysical Surveys Report of Investigations 84-24, 64 p., scale 1:100,000, 3 plates.

Miller, D.J., 1951, Preliminary report on the geology and oil possibilities of the Katalla district, Alaska: U.S. Geological Survey Open-file Report 50, 66 p.

__________, 1961, Geology of the Katalla district, Gulf of Alaska Tertiary province, Alaska: U.S. Geological Survey Open-file Report 206, scale 1:96,000, 2 sheets.

Miller, R.D., and Dobrovolny, Ernest, 1959, Surficial geology of Anchorage and vicinity, Alaska: U.S. Geological Survey Bulletin 1093, 128 p.

Moore, J.C., 1974, The ancient continental margin of Alaska, in Burk, C.A., and Drake, C.L., eds., The geology of continental margins: New York, Heidelburg, Berlin, Springer-Verlag, p. 811-815.

Moore, J.C., and Connelly, William, 1977, Mesozoic tectonics of the southern Alaska margin, in Talwani, Manik, and Pitman, W.C., eds., Island arcs, deep sea trenches, and back arc basins: American Geophysical Union, Maurice Ewing Series, v. 1, p. 71-82.

Mull, C.G., 1979, Nanushuk Group deposition and the late Mesozoic structural evolution of the central and western Brooks Range and Arctic Slope, 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, p. 5-13.

Nelson, S.W., and Reed, B.L., 1978, Surficial deposits, Talkeetna Quadrangle, Alaska: U.S. Geological Survey Miscellaneous Field Studies Map MF-870-J, scale 1:250,000, 1 sheet.

Paige, Sidney, 1906, The Herendeen Bay coal field, in Brooks, A.H. and others, eds., Report on progress of investigations of mineral resources of Alaska in 1905: U.S. Geological Survey Bulletin 284, p. 101-108.

Paige, Sidney, and Knopf, Adolph, 1907, Reconnaissance in the Matanuska and Talkeetna basins, in Brooks, A.H. and others, eds., Mineral resources of Alaska, report on progress of investigations in 1906: U.S. Geological Survey Bulletin 314, p. 104-115.

Payne, T.G., 1945, Stratigraphic and structural features, lower Matanuska Valley coal field, Alaska [abs.]: Economic Geology, v. 40, no. 1, p. 93.

__________, 1955, Mesozoic and Cenozoic tectonic elements of Alaska: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-84, scale 1:5,000,000.

Plafker, George, 1971, Possible future petroleum resources of Pacific-margin Tertiary basin, Alaska, in Cram, I.H., ed., Future petroleum provinces of United States—their geology and potential: American Association of Petroleum Geologists Memoir 19, v. 1, p. 120-135.

Resource Associates of Alaska, Inc., 1980, Literature review and status of Chignik and Herendeen Bay coal fields, southern Alaska Peninsula: Unpublished industry report, 15 p.

Sanders, R.B., 1976, Geology and coal resources of the Bering River field, in Rao, P.D., and Wolff, E.N., Focus on Alaska's coal '75, Proceedings of the conference, University of Alaska, Fairbanks, October 15-17, 1975: University of Alaska School of Mineral Industry, Mineral Industry Research Laboratory Report 37, p. 54-58.

Schmoll, H.R., and Yehle, L.A., 1978, Generalized physiography and geology of the Beluga coal field and vicinity, southcentral Alaska: U.S. Geological Survey Circular 772-B, p. B73-B76.

Schmoll, H.R., Chleborad, A.F., Yehle, L.A., Gardner, C.A., and Pasch, A.D., 1981, Reconnaissance engineering geology of the Beluga coal resource area, southcentral Alaska, in Rao, P.D., and Wolff, E.N., eds., Focus on Alaska's coal '80: Alaska Coal Conference, 2nd, Fairbanks, 1980, Proceedings, University of Alaska Mineral Industry Research Laboratory Report 50, p. 92-110.

Smith, P.S., 1939, Areal geology of Alaska: U.S. Geological Survey Professional Paper 192, p. 28, 31, 51-66.

Stricker, G.D., and Roehler, H.W., 1981, Deltaic coals and sediments of the Cretaceous Torok, Kukpowruk, and Corwin Formations in the Kokolik-Utukok region, National Petroleum Reserve in Alaska, in Rao, P.D., and Wolff, E.N., Focus on Alaska's coal '80, Proceedings of the conference, University of Alaska, Fairbanks, October 21-23, 1980: University of Alaska Mineral Industry Research Laboratory Report 50, p. 61.

Thorson, R.M., 1978, Recurrent late Quaternary faulting near Healy, Alaska: Alaska Division of Geological and Geophysical Surveys Geologic Report 61, p. 10-14.

Tuck, Ralph, 1937, The Matanuska coal field, Alaska [abs.]: Washington Academy of Science Journal, v. 27, no. 8, p. 359-360.

Vorobik, J.L., Farnstrom, H.E., Cantrell, C.L., Jaworski, M.J., and Beeson, D.C., 1981, Exploration and evaluation of the coal potential of Bristol Bay Native Corporation lands in the Chignik area, Alaska: Resource Associates of Alaska, Inc., unpublished industry report, 5 v.

Wahrhaftig, Clyde, 1958, Lithology and conditions of deposition of the formations of the coal-bearing group in the Nenana coal field: U.S. Geological Survey unpublished report, 93 p.

________________, 1965, Physiographic divisions of Alaska: U.S. Geological Survey Professional Paper 482, 52 p.

Wahrhaftig, Clyde, and Birman, J.H., 1954, Stripping-coal deposits on lower Lignite Creek, Nenana coal field, Alaska: U.S. Geological Survey Circular 310, 11 p.

Wahrhaftig, Clyde, and Freedman, Jacob, 1945, Coal deposits in the valley of the Healy River, Alaska: U.S. Geological Survey War Minerals Report, 8 p.

Wahrhaftig, Clyde, Wolfe, J.A., Leopold, E.B., and Lanphere, M.A., 1969, The coal-bearing group in the Nenana coal field, Alaska: U.S. Geological Survey Bulletin 1274-D, p. D1-D30.

Weimer, R.J., 1977, Stratigraphy and tectonics of western coals, <u>in</u> Murray, K.D., ed., Geology of Rocky Mountain coal, Proceedings of the 1976 symposium, Golden, Colorado: Colorado Geological Survey Department of Natural Resources, Resource Series No. 1, p. 9-27.

Wheelabrator Coal Services Company, 1983, Assessment of the feasibility and implementation of port and transportation system alternatives for the Bering River coal field; phase 1 report prepared for the city of Cordova, Alaska, p. 5.4-5.17.

Wolfe, J.A., Hopkins, D.M., and Leopold, E.B., 1966, Tertiary stratigraphy and paleobotany of the Cook Inlet region, Alaska: U.S. Geological Survey Professional Paper 398-A, 29 p.

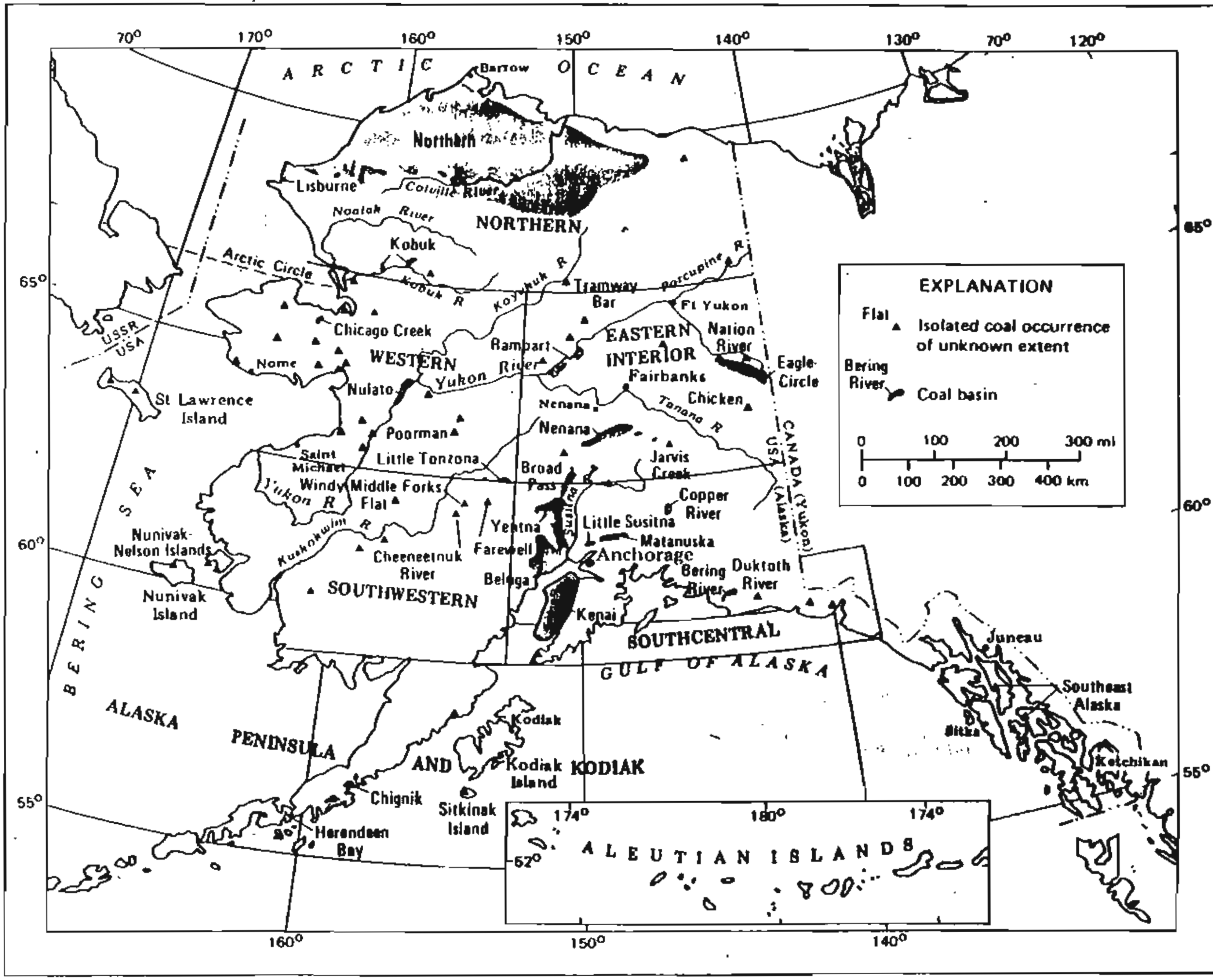
Wolfe, J.A., Hopkins, D.M., Leopold, E.B., and Tanai, Toshimasa, 1980, The Miocene Seldovia Point flora from the Kenai Group, Alaska: U.S. Geological Survey Professional Paper 1105, 52 p.

LIST OF FIGURES

bearing group of the Nenana basin. No particular scale or specific area is implied. Refer to text for discussion. The ancestral mountains of C and E represent potential source areas of clastics near the northern part of the present Tanana Flats or western end of the Yukon-Tanana Upland. The ancestral mountains to the south on H represent uplifts in the Alaska Range.

14. Distribution and extent of upper Cretaceous Chignik Formation coal-bearing rocks on the Alaska Peninsula, and the general configuration of the late Cretaceous tectonic framework and subduction complex (modified from Burk, 1965; Mancini and others, 1978).
15. Stratigraphy of the upper Jurassic and Cretaceous sedimentary rocks of the Alaska Peninsula (modified from Burk, 1965; Moore, 1974; and Mancini and others, 1978).
16. Schematic block diagram of the late Cretaceous paleogeography in the Chignik area. The subduction zone-trench complex was offshore to the southwest (from Vorobik and others, 1981).
17. General depositional sequence of the Cretaceous Chignik and Hoodoo Formations: A--deposition of the Chignik Formation, Coal Valley Member, and the Hoodoo Formation time-equivalent sequence; B--transgressive onlap of Cretaceous seas with subsequent deposition of upper Chignik and Hoodoo facies. The assumed source area is now less active and may be farther away (from McGee, 1979).
18. Distribution and extent of coal-bearing rocks of northern Alaska showing coal rank and isopachs for the Nanushuk Group (modified from Callahan and Martin, 1981).
19. General stratigraphic nomenclature and correlation diagram for the coal-bearing Nanushuk and Colville Groups (from Ahlbrandt and others, 1979).
20. Generalized deltaic sedimentation model for the Corwin and Kukpowruk Formations (from Callahan and Martin, 1981). Note coal character for the different subenvironments.

51

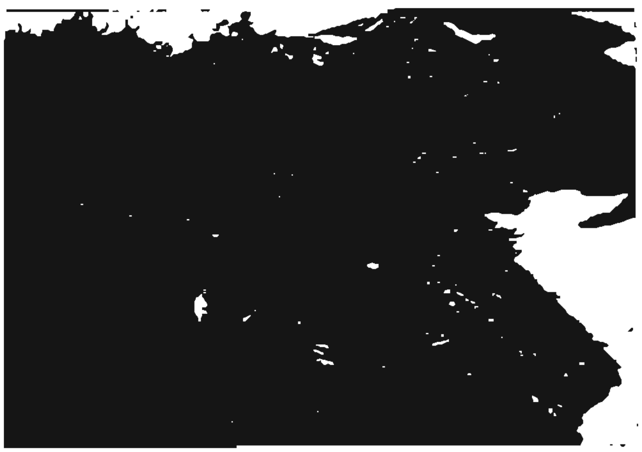


ARCTIC OCEAN
Barrow
Northern
Lisburne
Colville River
Noatak River
NORTHERN
Kobuk
Arctic Circle
Kobuk R
Koyukuk R
Porcupine R
Tramway Bar
Ft Yukon
USSR
USA
Chicago Creek
WESTERN
Nome
Rampart
River
EASTERN
INTERIOR
Nation River
Eagle-Circle
Fairbanks
Yukon
Nulato
St Lawrence Island
Nenana
Chicken
Tanana R
Poorman
Little Tonzona
Saint Michael
Jarvis Creek
Broad Pass
Yukon R
Windy
Middle Forks
Flat
Copper River
Kuskokwim R
Yentna
Little Susitna
Matanuska
Nunivak-Nelson Islands
Cheeneetnuk River
Farewell
Anchorage
Beluga
Bering River
Duktoth River
SOUTHWESTERN
Nunivak Island
Kenai
SOUTHCENTRAL
CANADA (Yukon)
USA (Alaska)
GULF OF ALASKA
BERING SEA
ALASKA PENINSULA AND KODIAK
Kodiak
Kodiak Island
Chignik
Sitkinak Island
Herendeen Bay
Juneau
Southeast Alaska
Sitka
Ketchikan
ALEUTIAN ISLANDS
EXPLANATION
Flat
Isolated coal occurrence of unknown extent
Bering River
Coal basin
0 100 200 300 mi
0 100 200 300 400 km

Figure 1

A. Brown Seam, Tyonek Formation, upper Chuitna River, Beluga Field.

B. Wishbone Hill seams, Chickaloon Formation, Matanuska Field.

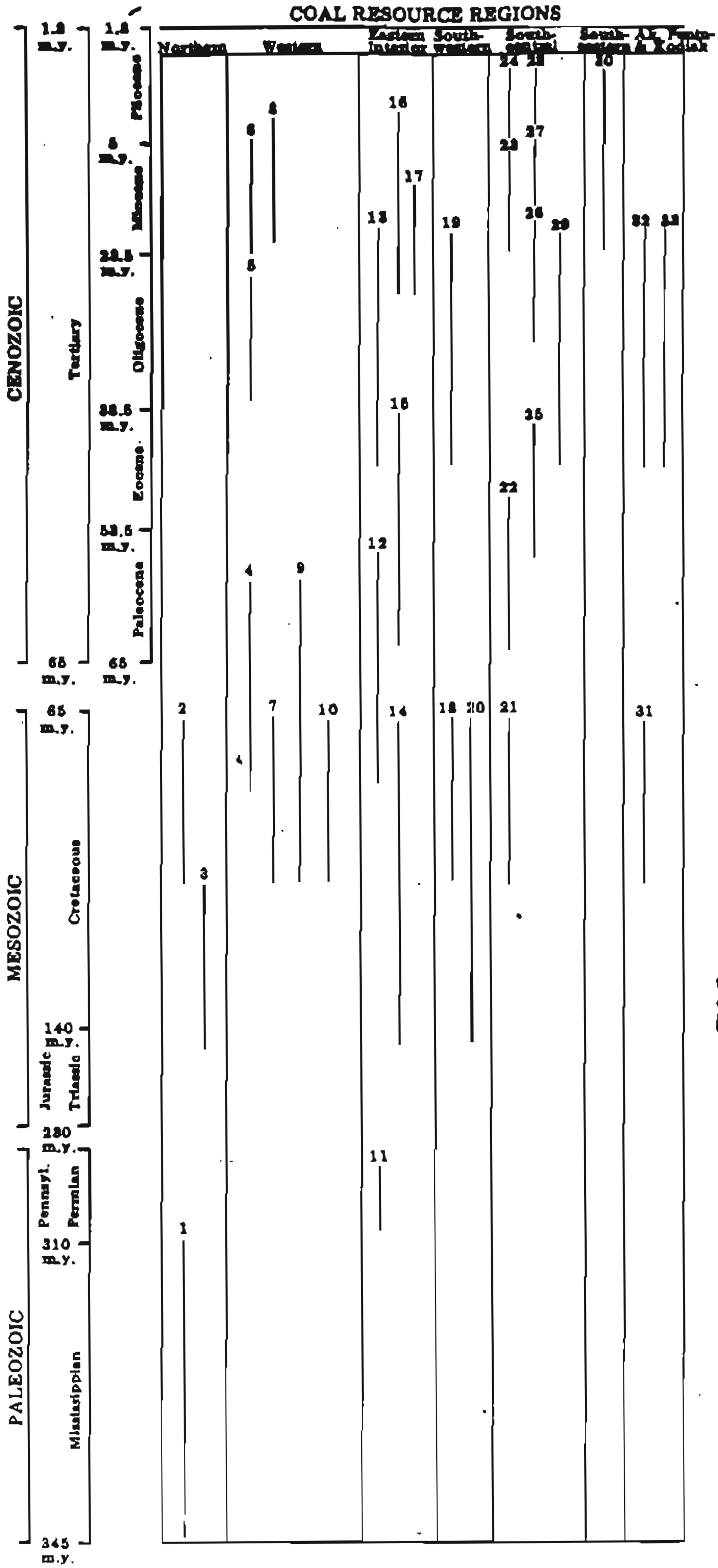


C. Queen Vein, Kushtaka Formation, Bering River Field (courtesy R.B. Sanders).

D. Sheep — Moose Creeks seam, Suntrana Formation, Nenana Field.

E. Mine Harbor seams, Chignik Formation, Herendeen Bay Field.

F. Kukpowruk River seam, Corwin Formation, (courtesy J.E. Callahan).



EXPLANATION

1. Kapaloak Formation, Lisburne Group
Lisburne Field
2. Bergman Group (upper member)
Kobuk Field, Tramway Bar
3. Corwin Formation, Nanushuk Group
Arctic Coastal Plain and Foothills Province
4. Coal-bearing formation, Chicago Creek
Kugruk River Field
5. Coal-bearing formation
St. Lawrence Island
6. Coal-bearing formation
Palisades, Yukon River
7. Kaltag Formation, Nulato (Lower Yukon) Field, Koyukuk Basin
8. Coal-bearing formation, Kobuk
Hodzana Highlands
9. Kaltag and Nulato Formations
Koyuk and Unalakleet
10. Coal-bearing formation, Selawik Basin and Southeast Baird Mountains
11. Nation River Formation
Nation River
12. Coal-bearing formation
Eagle-Circle Field
13. Coal-bearing formation
Costello Creek
14. Coal-bearing formation
Tanacross, Upper Tanana Basin
15. Coal-bearing formation, Rampart (Yukon-Tanana) Field
16. Coal-Bearing Group, Nenana Field
Healy Creek, Suntrana, Lignite Creek Formations
17. Healy Creek (Other?) Formation(s)-
Jarvis Creek Field
18. Coal-bearing formation
Innoko Lowland, Flat and Poorman
19. Coal-bearing formation, Farewell (Little Tonzona) Field
20. Kuskokwim Group, Eek River, Yukon-Kuskokwim region, Nunivak-Nelson Islands
21. Coal-bearing formation
Talkeetna Mountains
22. Chickaloon Formation
Matanuska Valley
23. Frederika Formation, McCarthy area, Copper River Basin
24. Coal-bearing formation
Broad Pass Field
25. Kulthieth Formation
Malaspina and Yakataga districts
26. Tyonek Formation
27. Beluga Formation
28. Sterling Formation
Kenai Group - Susitna Lowland, Kenai Fields
29. Kushtaka Formation, Bering River Field, Chugach Mountains
30. Coal-bearing formation(s)
Coast Mountains, Southeast Alaska
31. Chignik Formation, Chignik and Herendeen Bay Fields
32. Coal-bearing formation(s), South and east of Herendeen Bay, Unga Island
33. Coal-bearing formation,
Sitkinak and Tugidak Islands

Figure 3

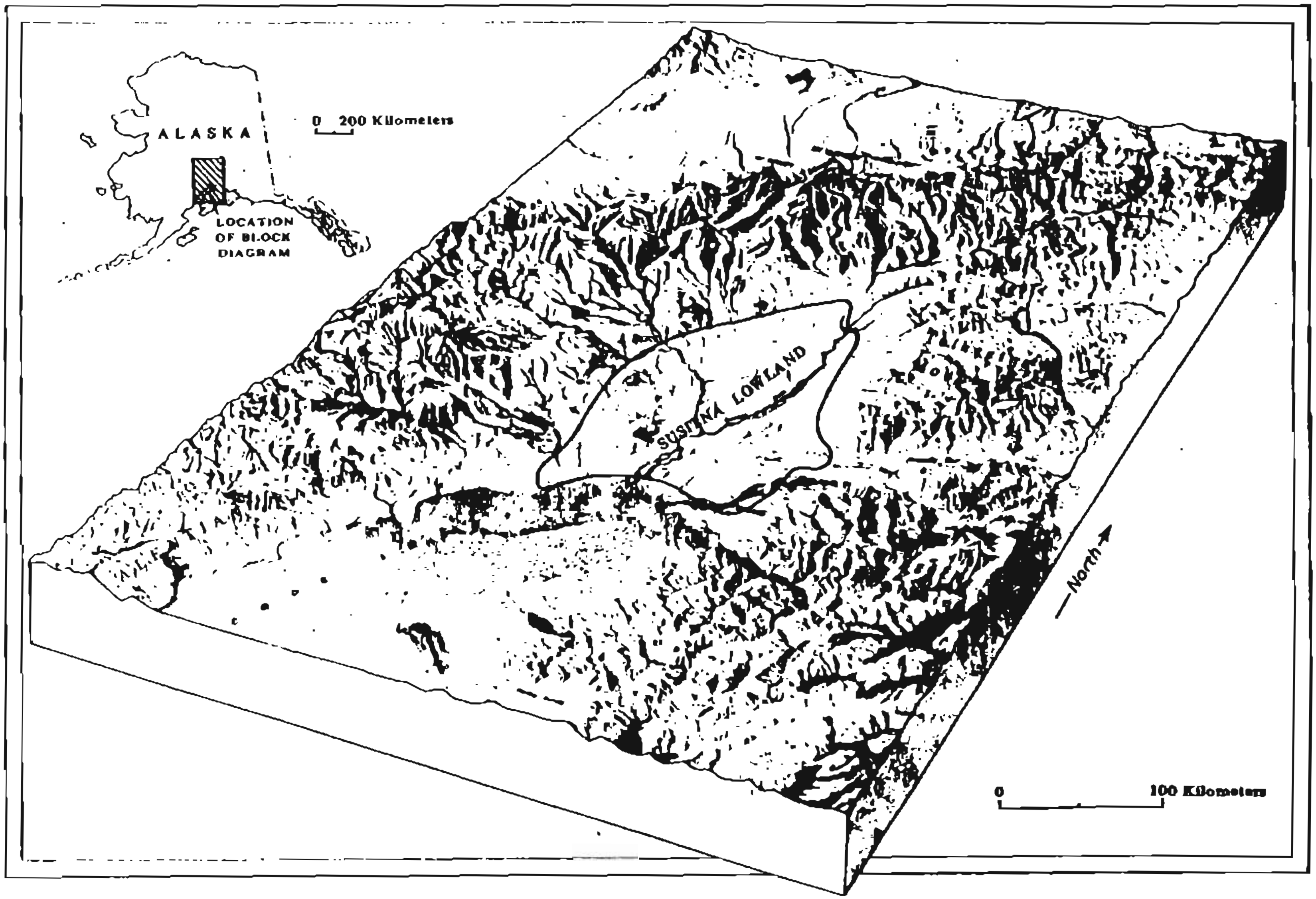

ALASKA
0 200 Kilometers
LOCATION OF BLOCK DIAGRAM
SUSITNA LOWLAND
North
0
100 Kilometers

Figure 4

SYSTEM	SERIES	GROUP	FORMATION	DESCRIPTION
CENOZOIC	QUATERNARY		Alluvium and glacial deposits	
	TERTIARY	KENAI GROUP	Sterling Formation	Massive sandstone and conglomerate beds with occasional thin lignite beds
			Beluga Formation	Claystone, siltstone, and thin sandstone beds; thin subbituminous coals beds
			Tyonek Formation	Sandstone, claystone, and siltstone interbeds and massive subbituminous coal beds
			Hemlock Conglomerate	Sandstone and conglomerate
			West Foreland Formation	Tuffaceous siltstone and claystone, scattered sandstone and conglomerate beds
		Rests unconformably on older Tertiary, Cretaceous, and Jurassic rocks		

Figure 3

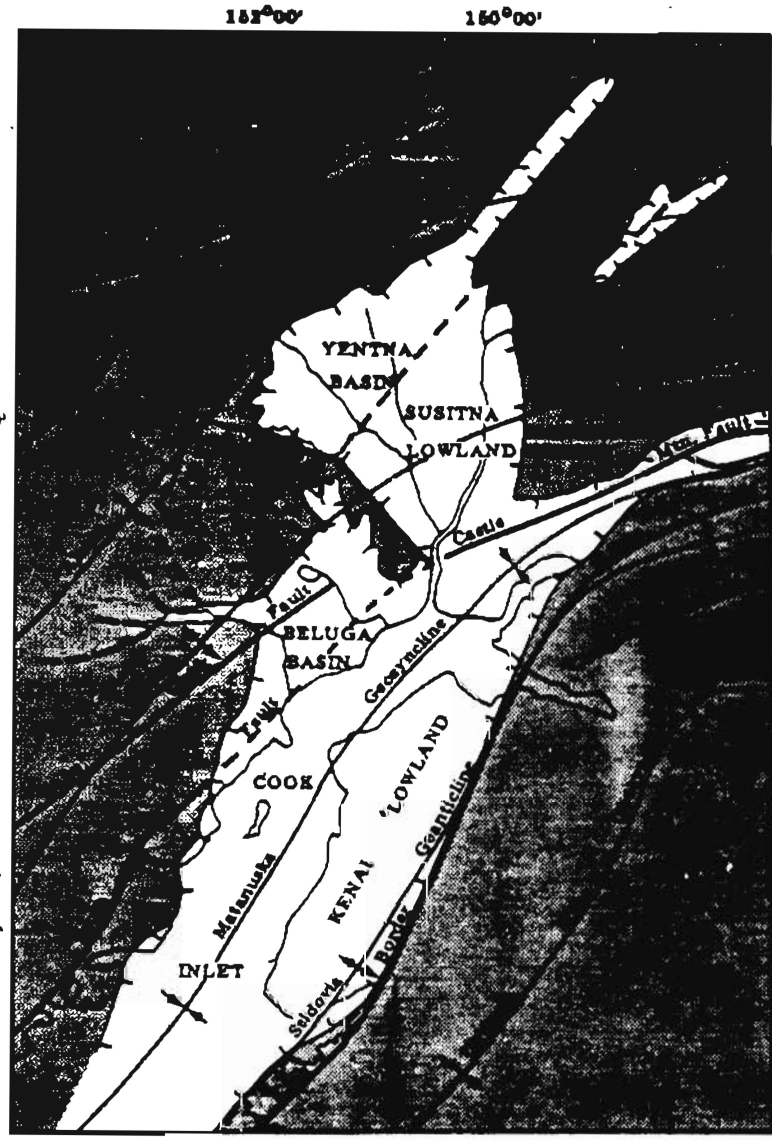
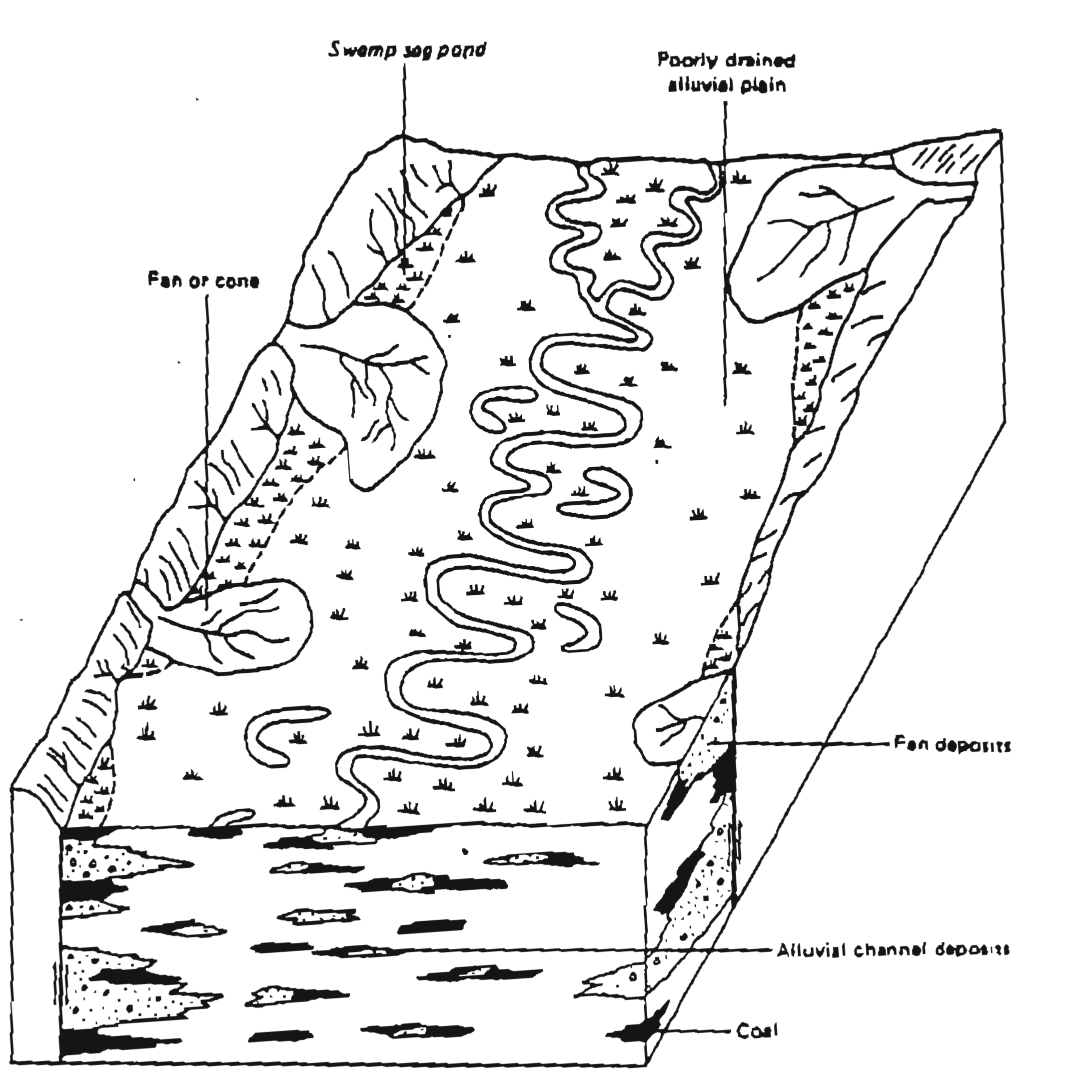
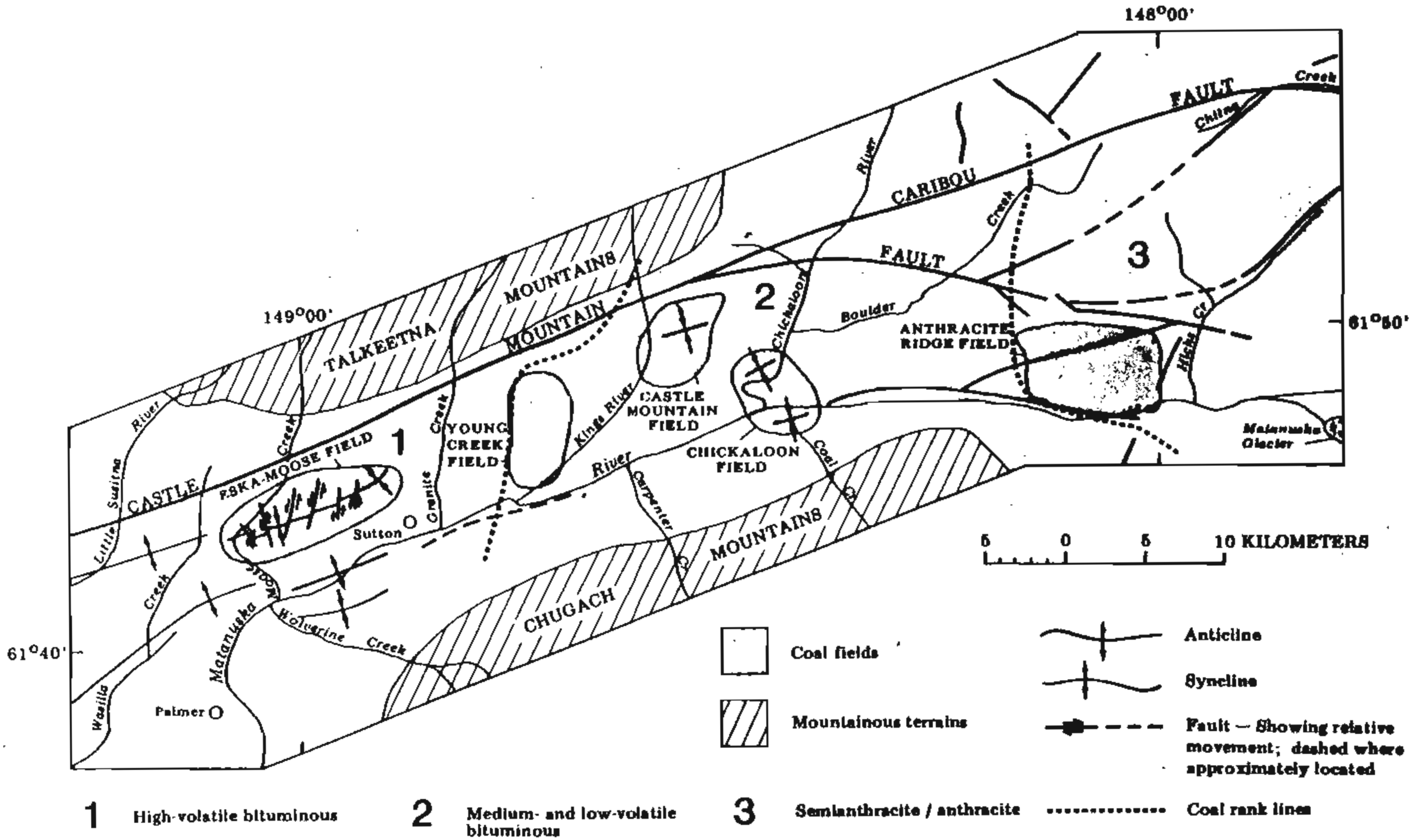

152°00'
150°00'
62°00'
60°00'
YENTNA
BASIN
SUSITNA
LOWLAND
Castle
Fault
BELUGA
BASIN
Geosyncline
COOK
LOWLAND
KENAI
Geanticline
Matanuska
INLET
Seldovia
Border

Figure 6


Swamp sag pond
Poorly drained
alluvial plain
Fan or cone
Fan deposits
Alluvial channel deposits
Coal

Figure



148°00'
149°00'
61°50'
61°40'
TALKEETNA MOUNTAINS
CASTLE MOUNTAIN
CARIBOU FAULT
FAULT
CHUGACH MOUNTAINS
ESKA-MOOSE FIELD
YOUNG CREEK FIELD
CASTLE MOUNTAIN FIELD
CHICKALOON FIELD
ANTHRACITE RIDGE FIELD
Sutton
Palmer
Matanuska Glacier
Little Susitna River
Wasilla Creek
Matanuska River
Moose Creek
Wolverine Creek
Granite Creek
Kings River
Carpenter Cr.
Chickaloon River
Coal Cr.
Boulder Creek
Chitina Creek
Hicks Cr.
1
2
3
5 0 5 10 KILOMETERS
Coal fields
Mountainous terrains
Anticline
Syncline
Fault — Showing relative movement; dashed where approximately located
Coal rank lines
1 High-volatile bituminous
2 Medium- and low-volatile bituminous
3 Semianthracite / anthracite

Figure 8

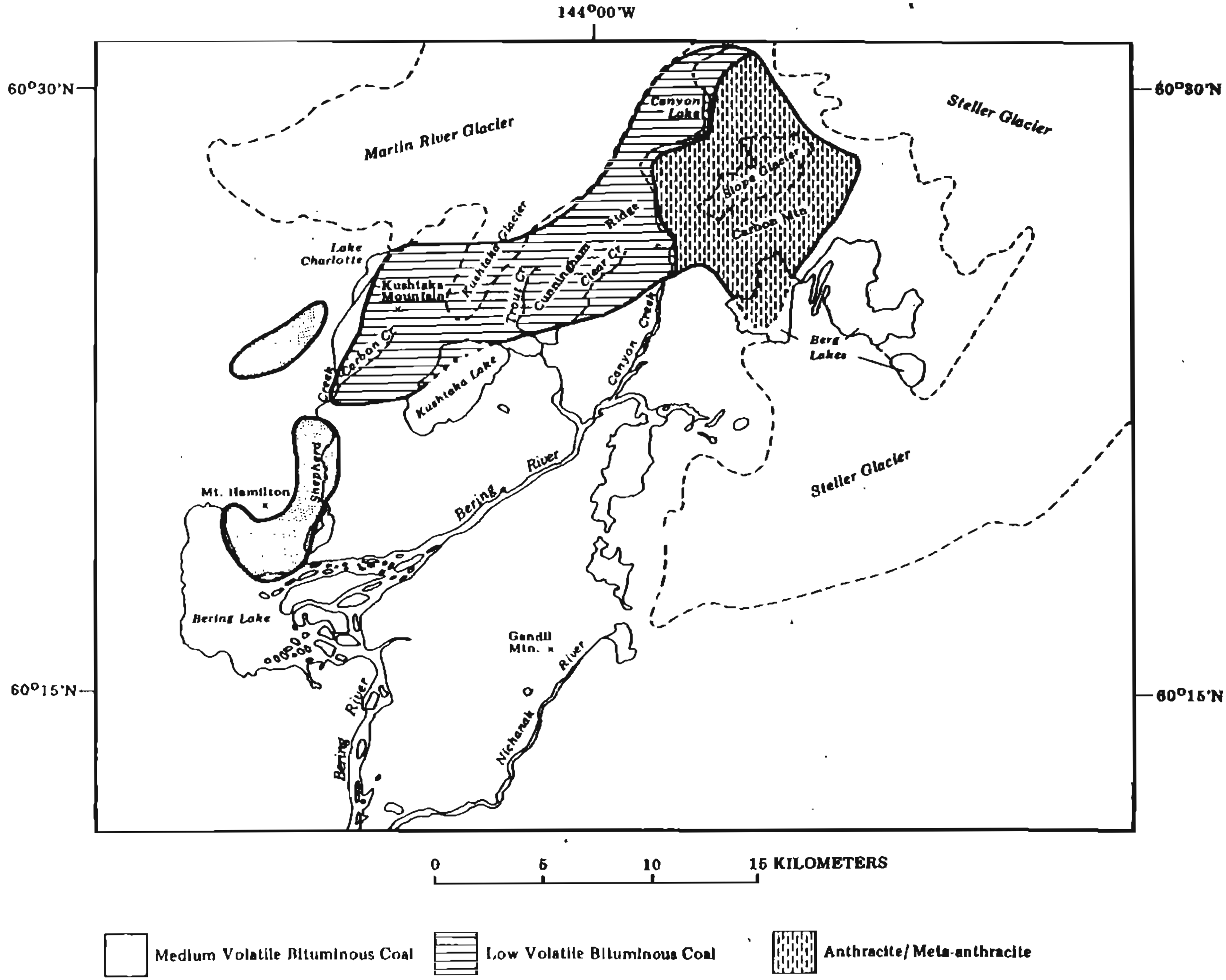

144°00'W
60°30'N
60°15'N
Martin River Glacier
Steller Glacier
Canyon Lake
Slope Glacier
Carbon Mtn
Ridge
Lake Charlotte
Kushtaka Glacier
Kushtaka Mountain
Trout Cr.
Cunningham
Clear Cr.
Carbon Cr.
Creek
Kushtaka Lake
Canyon Creek
Berg Lakes
Mt. Hamilton
Shepherd
Bering River
Bering Lake
Gandil Mtn.
Nichawak River
0
5
10
15 KILOMETERS
Medium Volatile Bituminous Coal
Low Volatile Bituminous Coal
Anthracite/Meta-anthracite

Figure 9

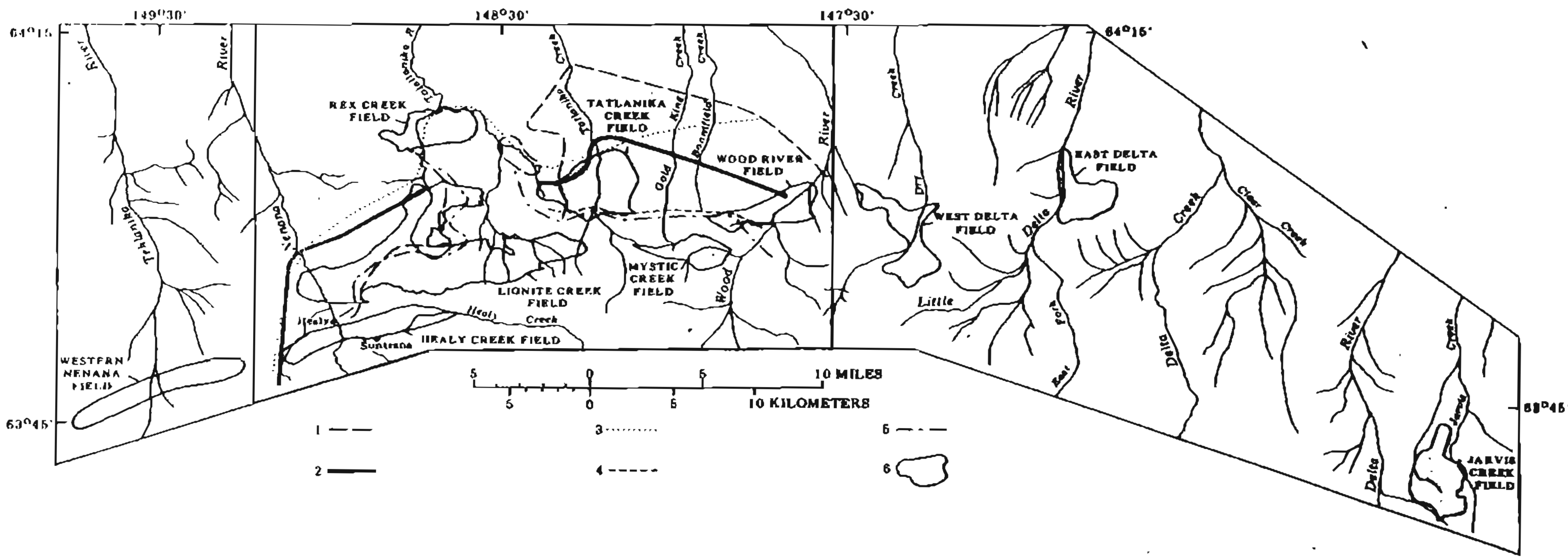

149°30'
148°30'
147°30'
64°15'
63°45'
REX CREEK FIELD
TATLANIKA CREEK FIELD
WOOD RIVER FIELD
LIGNITE CREEK FIELD
MYSTIC CREEK FIELD
HEALY CREEK FIELD
WESTERN NENANA FIELD
WEST DELTA FIELD
EAST DELTA FIELD
JARVIS CREEK FIELD
Suntrana
Healy Creek
Tekanika
Nenana
Gold King Creek
Bonnifield Creek
Wood River
Little Delta
East Fork
Delta Creek
Clear Creek
Delta River
10 MILES
10 KILOMETERS
1
2
3
4
5
6

Figure 10

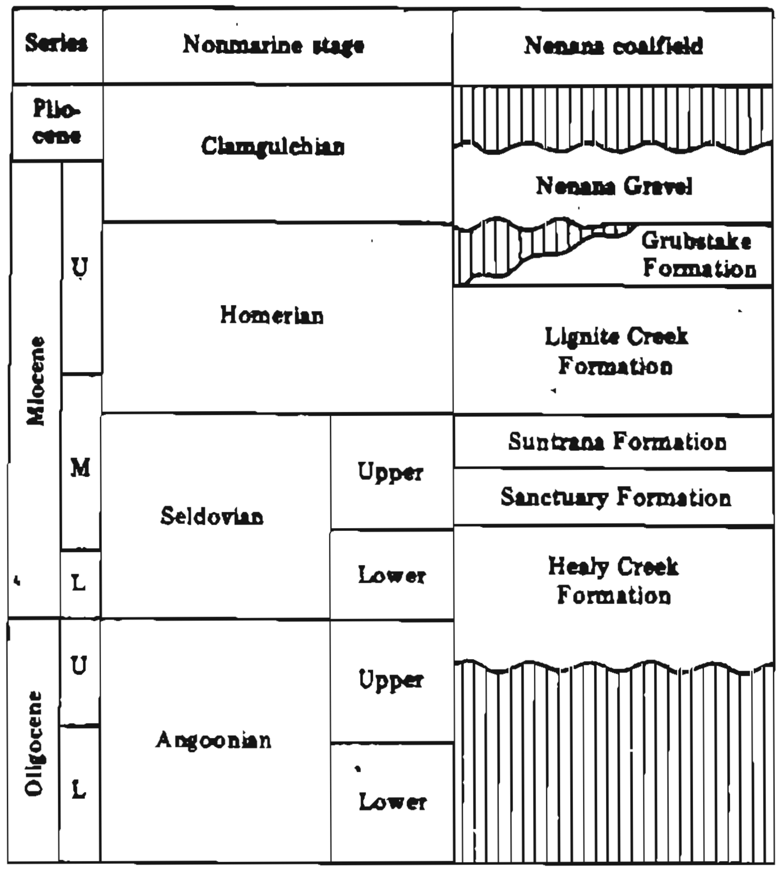
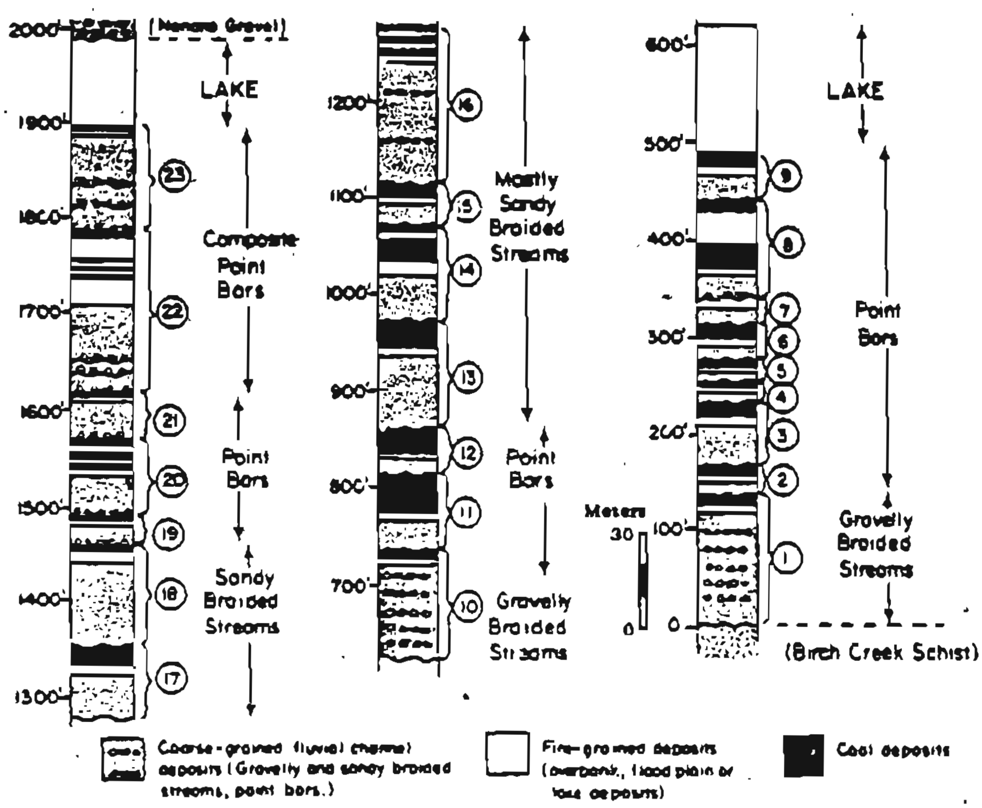
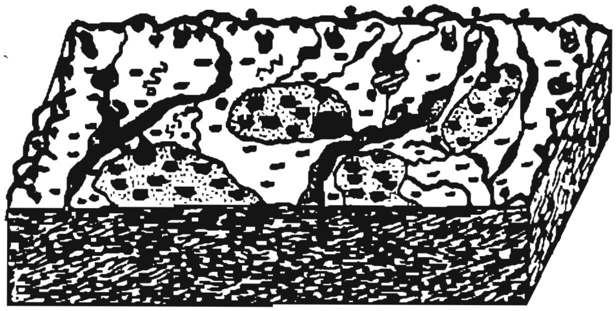

Series
Nonmarine stage
Nenana coalfield
Plio-cene
Clamgulchian
Nenana Gravel
Miocene
U
Homerian
Grubstake Formation
Lignite Creek Formation
M
Seldovian
Upper
Suntrana Formation
Sanctuary Formation
L
Lower
Healy Creek Formation
Oligocene
U
Angoonian
Upper
L
Lower

Figure 11

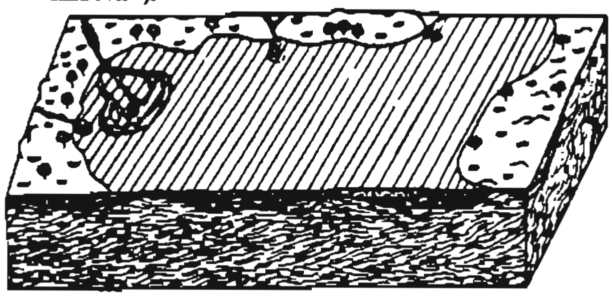


2000'
(Nenana Gravel)
LAKE
1900'
23
1800'
Composite Point Bars
1700'
22
1600'
21
Point Bars
20
1500'
19
Sandy Braided Streams
1400'
18
17
1300'
1200'
16
1100'
15
Mostly Sandy Braided Streams
14
1000'
13
900'
12
Point Bars
800'
11
700'
10
Gravelly Braided Streams
Meters
30
0
600'
LAKE
500'
9
400'
8
7
Point Bars
300'
6
5
4
200'
3
2
100'
Gravelly Braided Streams
1
0
(Birch Creek Schist)
Coarse-grained fluvial channel deposits (Gravelly and sandy braided streams, point bars.)
Fine-grained deposits (overbank, flood plain or lake deposits)
Coal deposits

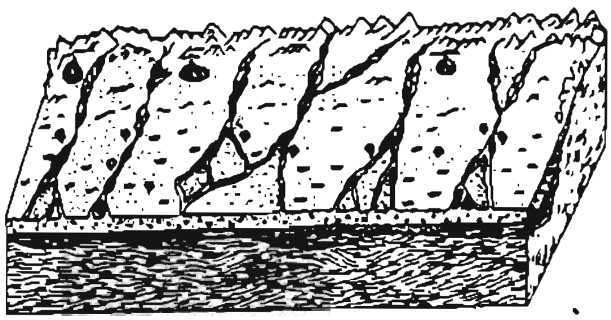
Figure 11



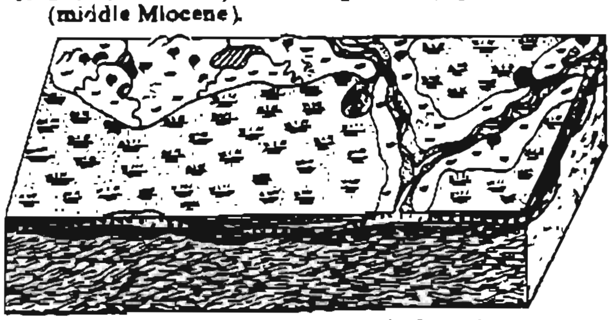
A. Healy Creek time (late Oligocene — early Miocene).



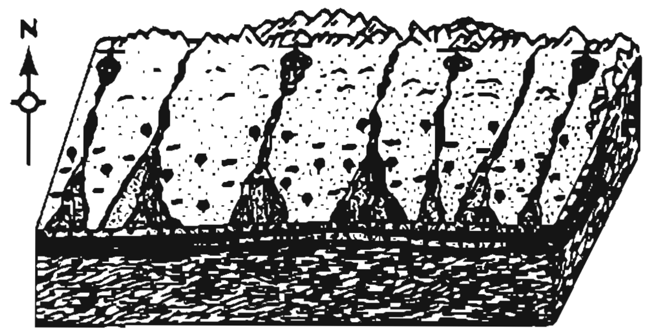
B. Sanctuary time (early to middle Miocene).



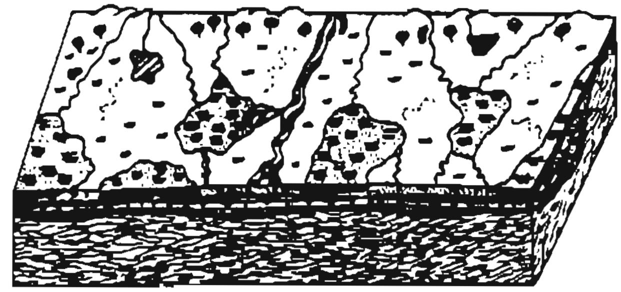
C. Suntrana time 1, alternating with D, cyclic (middle Miocene).



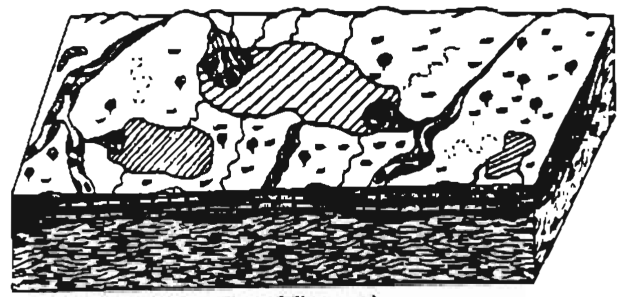
D. Suntrana time 2, alternating with C, cyclic (middle Miocene).



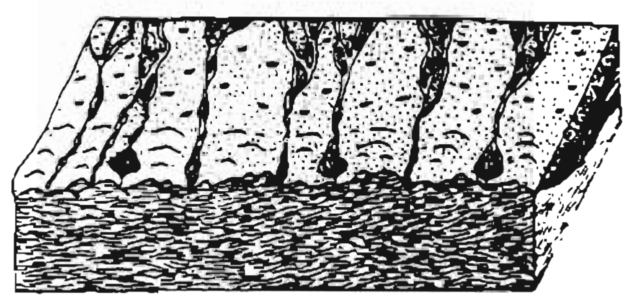
E. Lignite Creek time 1, alternating with F, quasicyclic (middle Miocene).



F. Lignite Creek time 2, alternating with E, quasicyclic (middle Miocene).

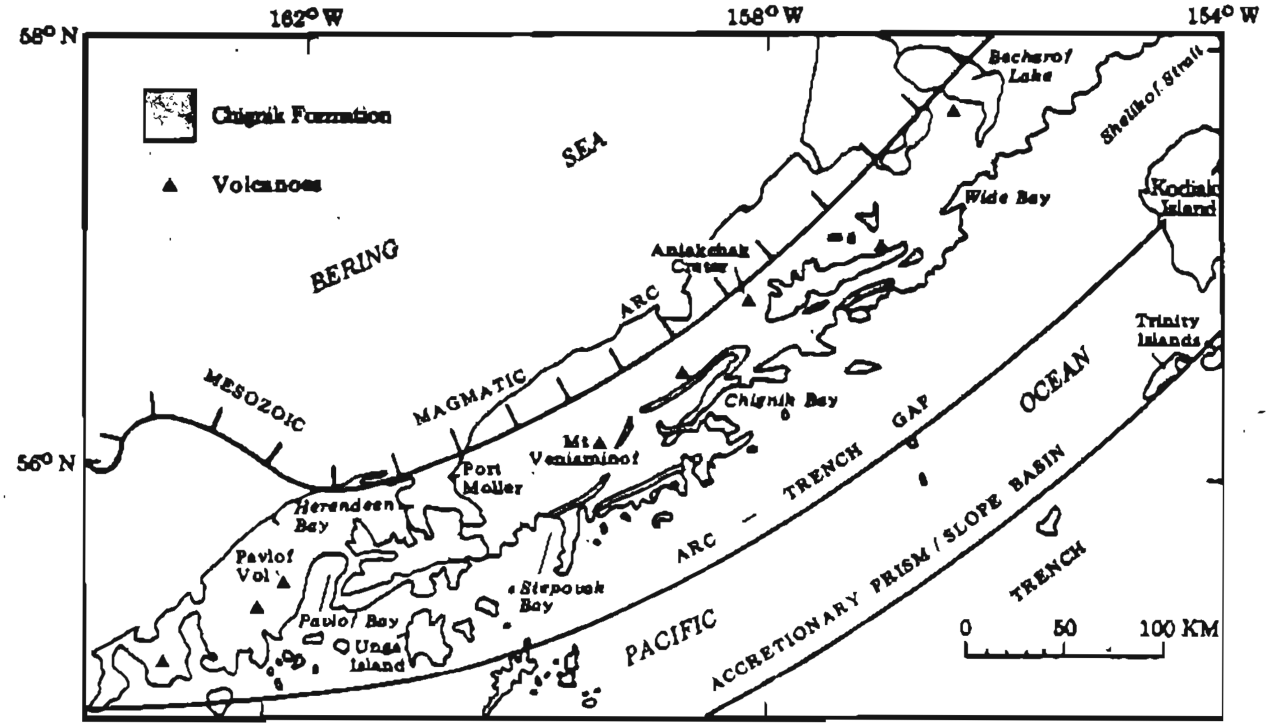


G. Grubstake time (late Miocene).



H. Nenana Gravel time (Pliocene).

Figure 13



162° W
158° W
154° W
58° N
56° N
Chignik Formation
Volcanoes
SEA
BERING
Becharof Lake
Shelikof Strait
Wide Bay
Kodiak Island
Aniakchak Crater
ARC
MAGMATIC
MESOZOIC
Trinity Islands
Chignik Bay
Mt Veniaminof
Port Moller
Herendeen Bay
Pavlof Vol
Pavlof Bay
Unga Island
Stepovak Bay
ARC - TRENCH GAP
OCEAN
PACIFIC
ACCRETIONARY PRISM / SLOPE BASIN
TRENCH
0
50
100 KM

Figure 14

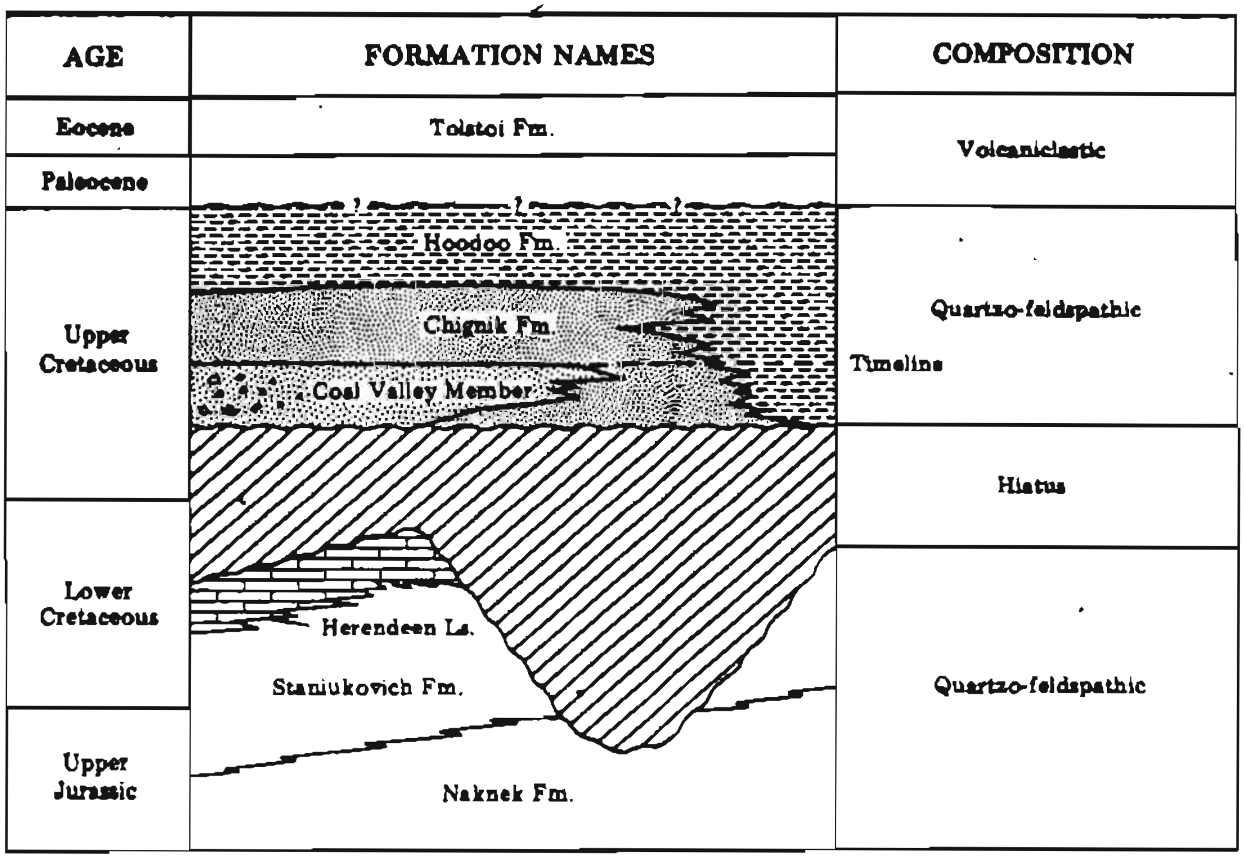
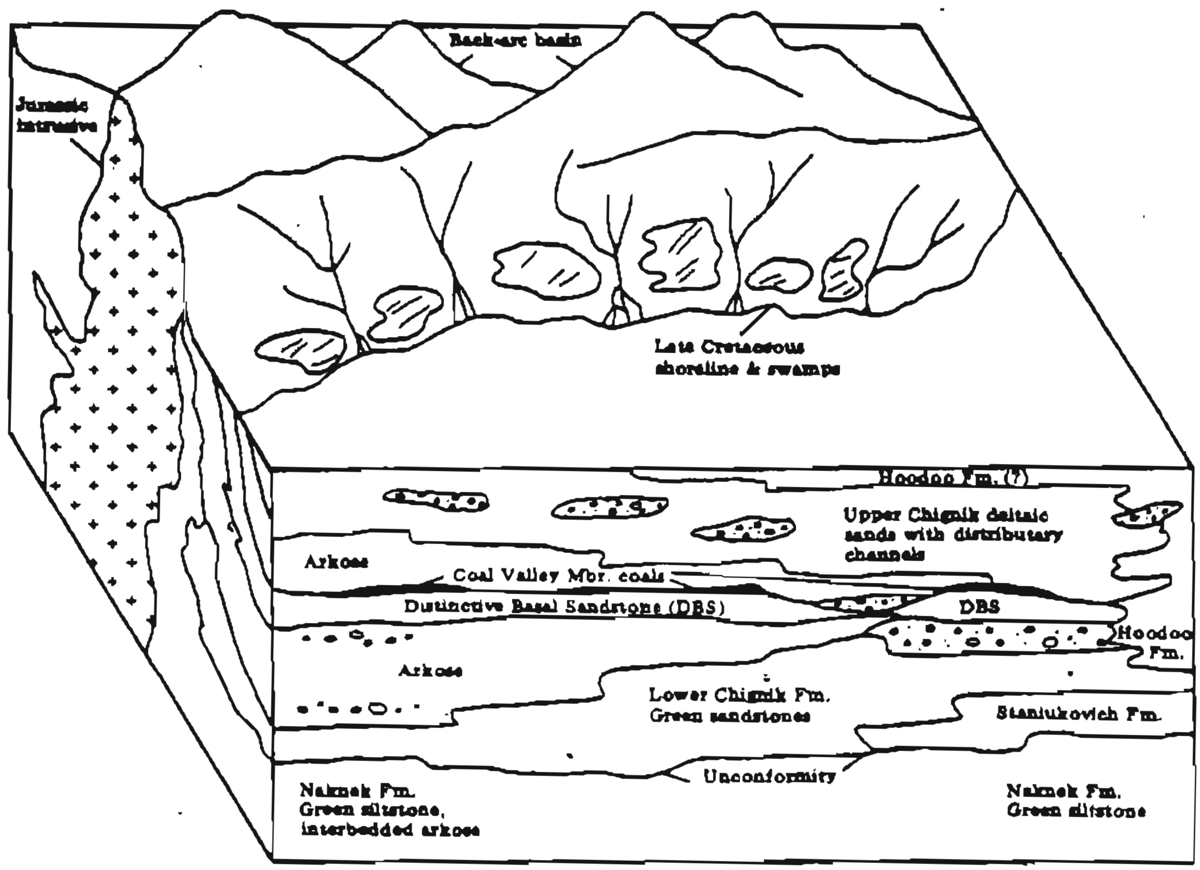
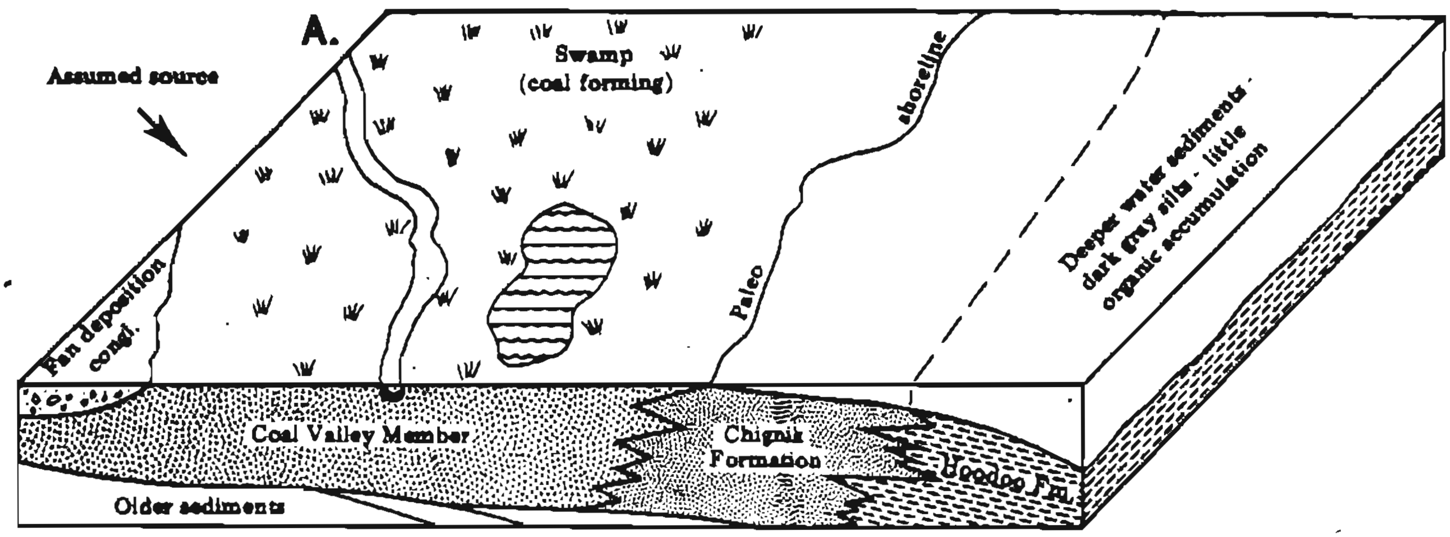

AGE
FORMATION NAMES
COMPOSITION
Eocene
Tolstoi Fm.
Paleocene
Volcaniclastic
Hoodoo Fm.
Upper Cretaceous
Chignik Fm.
Quartzo-feldspathic
Timeline
Coal Valley Member
Hiatus
Lower Cretaceous
Herendeen Ls.
Staniukovich Fm.
Quartzo-feldspathic
Upper Jurassic
Naknek Fm.

Figure 1[illegible]



Back-arc basin
Jurassic intrusive
Late Cretaceous shoreline & swamps
Hoodoo Fm. (?)
Upper Chignik deltaic sands with distributary channels
Arkose
Coal Valley Mbr. coals
Distinctive Basal Sandstone (DBS)
DBS
Hoodoo Fm.
Arkose
Lower Chignik Fm. Green sandstones
Staniukovich Fm.
Unconformity
Naknek Fm. Green siltstone, interbedded arkose
Naknek Fm. Green siltstone

Figure 16


A.
Assumed source
Swamp
(coal forming)
Paleo
shoreline
Deeper water sediments - dark gray silts - little organic accumulation
Fan deposition congl.
Coal Valley Member
Chignik
Formation
Hoodoo Fm.
Older sediments

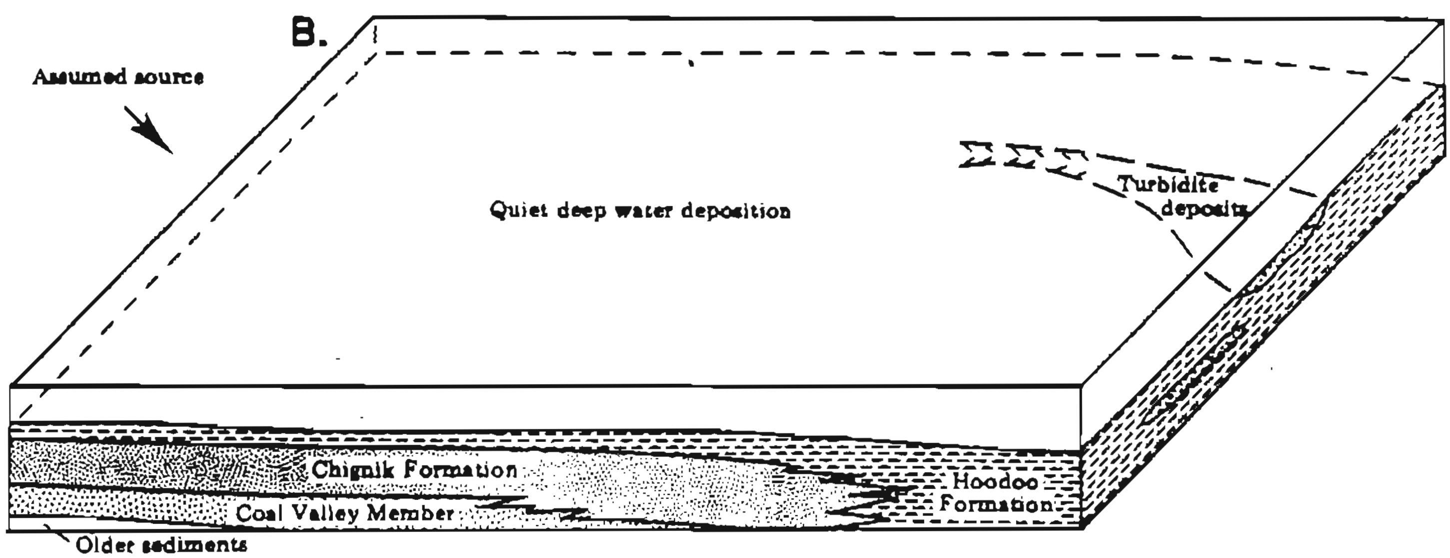
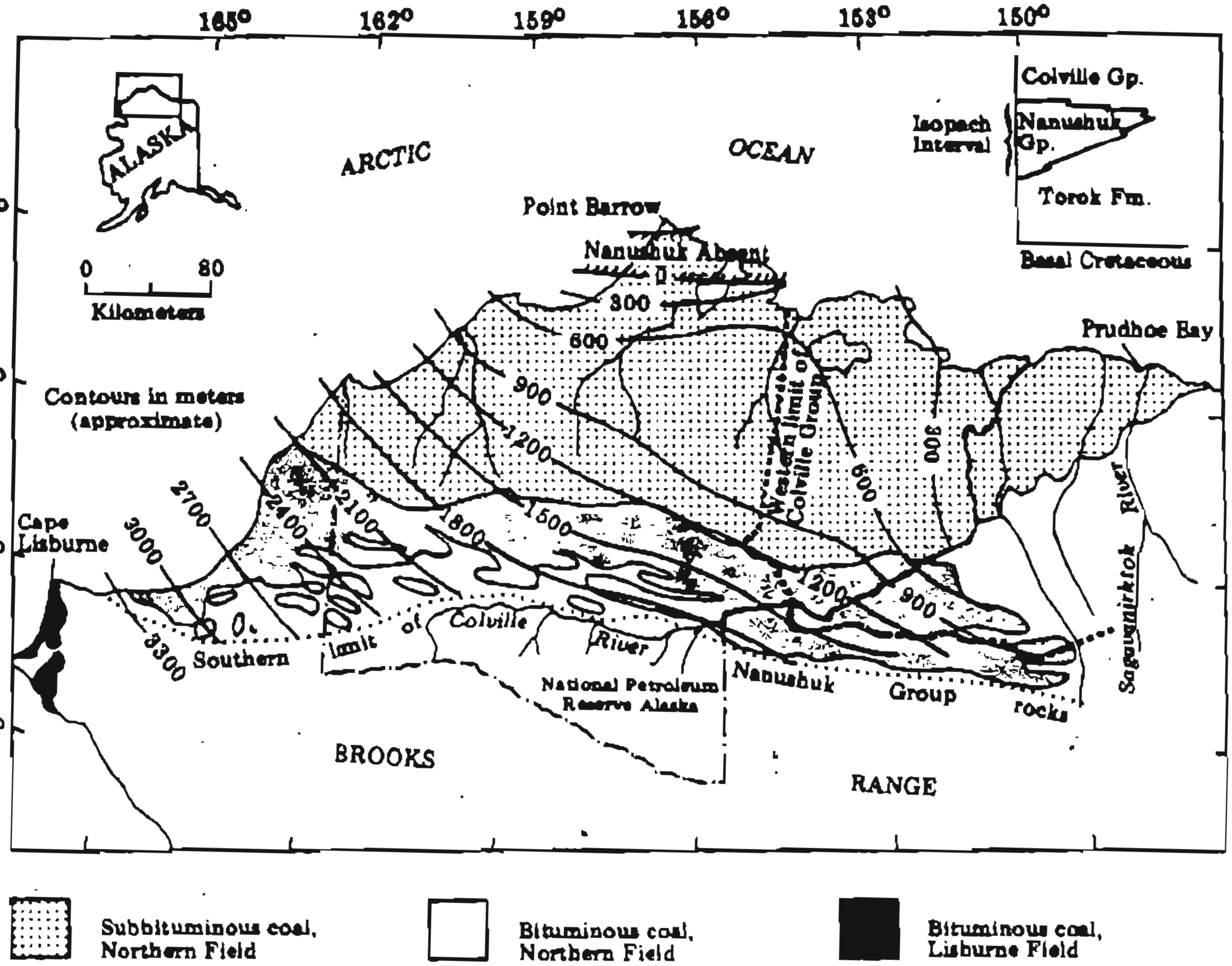

B.
Assumed source
Quiet deep water deposition
Turbidite
deposits
Chignik Formation
Coal Valley Member
Hoodoo
Formation
Older sediments

Figure 17



165°
162°
159°
156°
153°
150°
71°
70°
69°
68°
ALASKA
0
80
Kilometers
ARCTIC
OCEAN
Colville Gp.
Isopach Interval
Nanushuk Gp.
Torok Fm.
Basal Cretaceous
Point Barrow
Nanushuk Absent
300
600
900
1200
1500
1800
2100
2400
2700
3000
3300
Prudhoe Bay
Contours in meters (approximate)
Western limit of Colville Group
Cape Lisburne
Southern limit of Colville River
National Petroleum Reserve Alaska
Nanushuk Group rocks
Sagavanirktok River
BROOKS
RANGE
Subbituminous coal, Northern Field
Bituminous coal, Northern Field
Bituminous coal, Lisburne Field

Figure 13

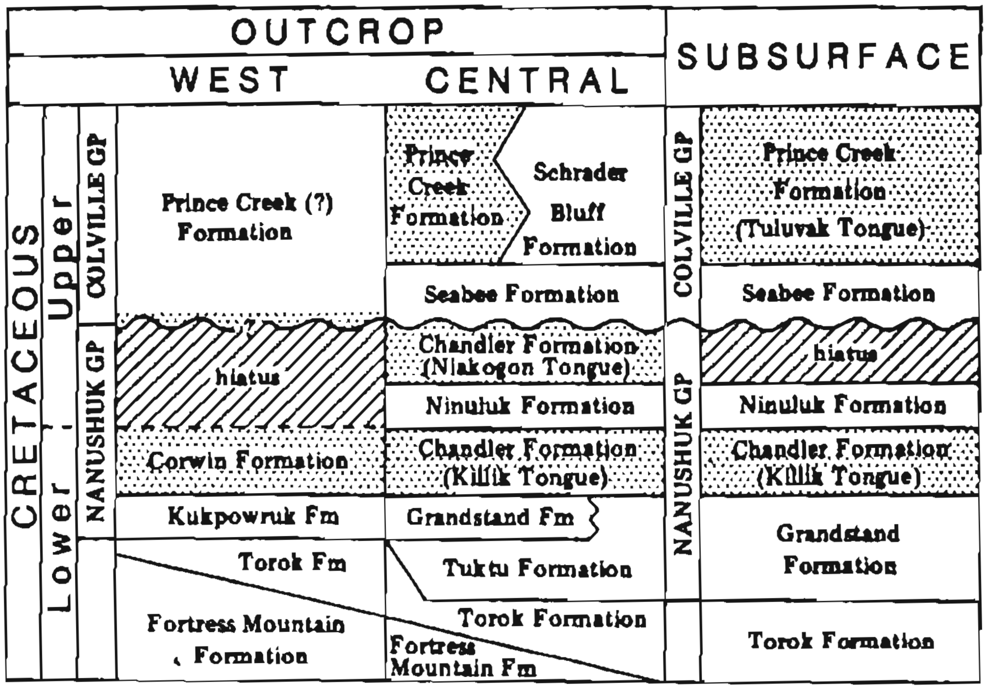

OUTCROP
WEST
CENTRAL
SUBSURFACE
CRETACEOUS
Upper
Lower
COLVILLE GP
NANUSHUK GP
Prince Creek (?) Formation
Prince Creek Formation
Schrader Bluff Formation
Prince Creek Formation (Tuluvak Tongue)
Seabee Formation
hiatus
Chandler Formation (Niakogon Tongue)
Ninuluk Formation
Corwin Formation
Chandler Formation (Killik Tongue)
Kukpowruk Fm
Grandstand Fm
Grandstand Formation
Torok Fm
Tuktu Formation
Torok Formation
Fortress Mountain Formation
Fortress Mountain Fm

Figure 19

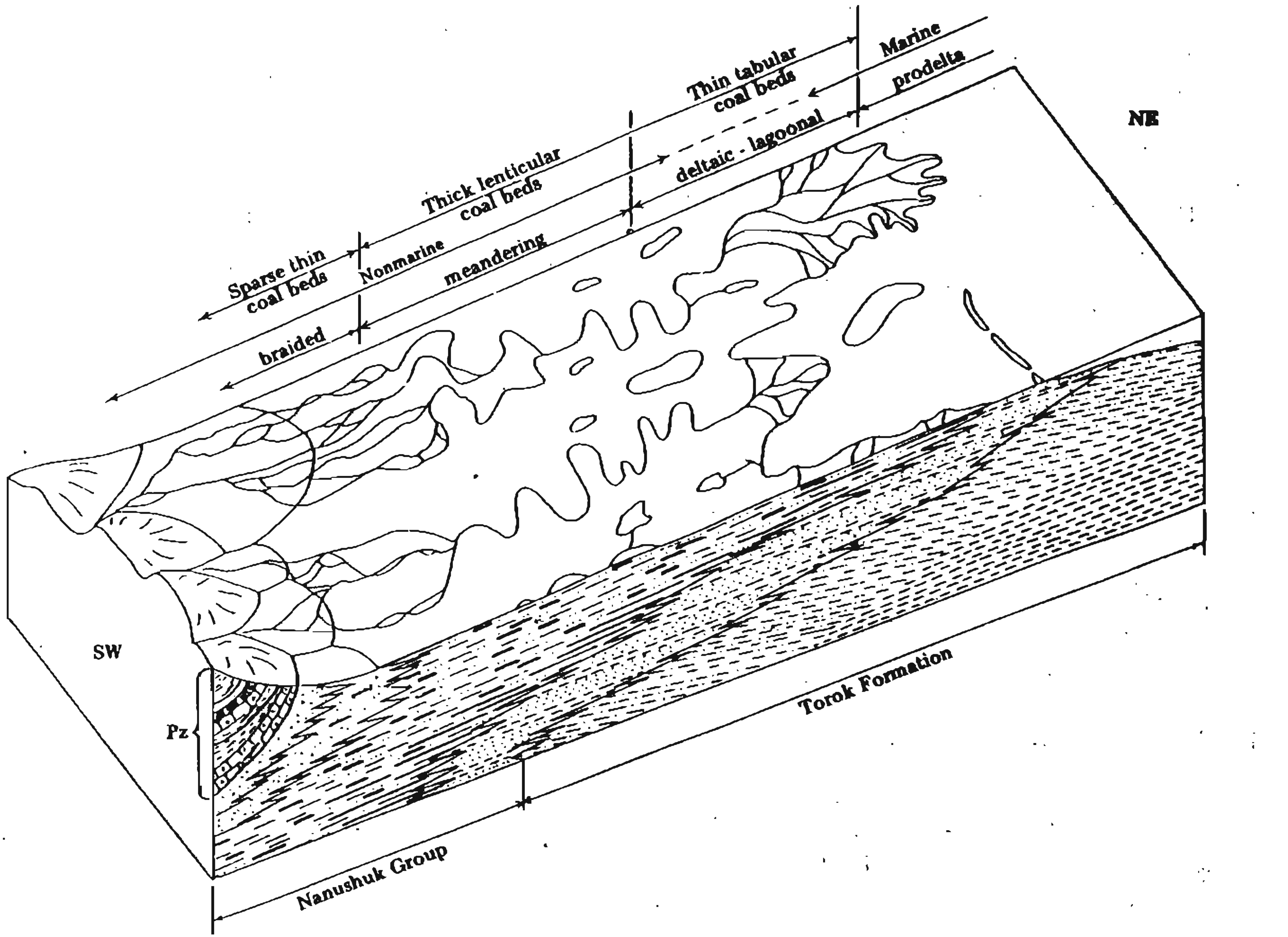

Marine
prodelta
Thin tabular
coal beds
deltaic - lagoonal
Thick lenticular
coal beds
Nonmarine
meandering
Sparse thin
coal beds
braided
NE
SW
Pz
Nanushuk Group
Torok Formation

Figure 20

Table 1. Summary of the coal resources of major coal basins in Alaska (in millions of short tons; modified from McGee and Emmel, 1979, and McConkey and others, 1979).

Major coal basin	Measured Reserves	Identified Resources	Hypothetical Resources
Susitna lowland (Beluga and Yentna fields)	2,500	10,000	30,000
Matanuska Valley	50	120	500
Bering River basin	60	100	3,500
Nenana basin	4,000	8,000	20,000
Chignik Bay-Herendeen Bay basins	20	200	3,000
Northern field	250	150,000	4,000,000

Table 2. Representative analyses of coals from major Alaska coal basins on an as-received basis (compiled from various sources).

Major coal basin	Moisture	Volatile Matter	Fixed Carbon	Ash	Sulfur	Heating Value	Rank*
Susitna lowland	10-30	28-40	25-45	3-30	0.1-0.7	6200-9500	subC
Matanuska Val.							
Wishbone Hill	3-9	32-45	38-51	4-22	0.2-1.0	10400-13200	hvBb
Chickaloon	1-5	14-24	60-72	5-20	0.4-0.7	11960-14400	lvb
Anthracite Ridge	3-9	7-11	65-81	7-20	0.2-0.7	10720-14000	sa
Bering River basin	1-8	13-17	65-91	2-18	0.1-1.0	11000-15000	lvb
Nenana basin	10-31	21-43	24-25	3-30	0.2-1.2	6200-9800	subC
Chignik Bay-Herendeen Bay	7-9	32-45	45-51	7-12	0.2-0.4	11300-11800	hvBb
Northern field							
Foothills	2-10	31-36	53-58	4-15	0.1-0.3	10000-13500	hvCb
Coastal Plain	8-20	30-36	38-50	3-20	0.2-0.8	7700-10700	subB

* sa=semianthracite, lvb=low-volatile bituminous, hvBb=high-volatile B bituminous, hvCb=high-volatile C bituminous, subB=subbituminous B, subC=subbituminous C.

Table 3. Depositional regime of Alaska's major coal-bearing formations.

FORMATION	AREA	COAL PROVINCE REGION	AGE	LITHOLOGY	DEPOSITIONAL REGIME
Koyukuk Group (upper member)	Kobuk field	Northern	Late Cretaceous	Sandstone, conglomerate, subbituminous to bituminous coal	Continental
Koyukuk Group (upper member)	Tramway Bar—middle fork of Koyukuk River	Northern	Late Cretaceous	Sandstone, conglomerate, and bituminous coal	Continental
Kapaluk Formation of Lisburne Group	Lisburne field	Northern	Mississippian	Mudstone, sandstone, limestone, minor conglomerate, and coal	Transitional—marine and non-marine
Nanushuk Group	Northern field	Northern	Cretaceous	Sandstone, claystone, silty claystone, siltstone, carbonaceous shale and coal beds	Prograding deltaic depositional system in swampy coastal lowland
Coal-bearing	Chicago Creek-Kugruk River field	Western	Late Cretaceous-Early Tertiary	Poor- to well-consolidated gravel, sand, silt, carbonaceous debris, and lignitic coal beds	Continental
Kaltag Formation	Nulato and Katmai Rivers area, Koyukuk basin, Yukon River—Blackburn to Nulato	Western	Late Cretaceous	Siltstone, dark gray and olive gray shale, lesser sandstone, and bituminous and subbituminous coal beds	Continental
Coal-bearing	Palisades—Yukon River	Western	Miocene	Grayish white granule conglomerate and sandstone, reddish-brown claystone, and lignitic coal	Continental
Kaltag and Nulato Formations	Koyuk, Unalakleet	Western	Late Cretaceous-Tertiary	Graywacke, mudstone, sandstone, conglomerate, and coal	Terrigenous—shallow marine
Coal-bearing	St. Lawrence Island	Western	Oligocene	Poorly consolidated sandstone, grit, conglomerate, carbonaceous mudstone, ashy tuff, volcanic breccia, and pods of lignitic coal to 0.6 m	Continental
Coal-bearing	Selawik Basin and southeastern Baird Mountains	Western, Northern	Late Cretaceous	Conglomerate, sandstone, mudstone, and bituminous coal	Continental
Coal-bearing	Costello Creek	Eastern Interior	Tertiary	Sandstone, siltstone, mudstone, conglomerate, and subbituminous coal	Continental
Coal-bearing	Eagle field	Eastern Interior	Late Cretaceous-Tertiary	Sandstone, mudstone, shale, conglomerate, and subbituminous to lignitic coal	Continental
Coal-bearing	Rampart	Eastern Interior	Early Tertiary	Claystone, sandstone, conglomerate, and subbituminous to lignite coal	Continental
Coal-bearing	Tanacross (upper Tanana basin)	Eastern Interior	Cretaceous	Conglomerate, sandstone, shale, siltstone, tuff, tuffaceous sandstone and shale, lignite, and chert	Continental
Coal-bearing group: Healy Creek, Suntrana, and Lignite Creek Formations	Nenana coal field	Eastern Interior	Tertiary	Sandstone, conglomerate, claystone, and subbituminous coal	Continental
Healy Creek Formation	Jarvis Creek field	Eastern Interior	Tertiary	Sandstone, claystone, siltstone, and coal	Continental
Nation River	Nation River	Eastern Interior	Paleozoic Pennsylvanian(?)	Sandstone, conglomerate, shale, and bituminous coal	Continental
Coal-bearing	Farewell field—Little Tonzona, Deepbank Creek, Windy Fork of Kuskokwim River	Southwestern	Tertiary	Sandstone, siltstone, coal, tuff, and bentonite	Continental
Coal-bearing	Yukon-Kuskokwim delta region—Nunivak-Nelson Islands	Southwestern	Late Cretaceous	Graywacke, siltstone, pebble conglomerate, and coal	Littoral marine
Kuskokwim Group	Eek River	Southwestern	Cretaceous	Black carbonaceous shale, graywacke, conglomerate, siltstone, and coal	Shallow marine, nonmarine
Chickaloon	Matanuska Valley	Southcentral	Paleocene-Eocene	Claystones, siltstones, sandstones, conglomerate, and coal	Fluvial braided-meandering (lower part) and fluvial meandering-deltaic (upper part)
Coal-bearing	Broad Pass	Southcentral	Late Tertiary	Lignite, conglomerate, sandstone, claystone, carbonaceous claystone	Continental
Frederika	McCarthy area, Copper River basin	Southcentral	Miocene	Conglomerate, sandstone, siltstone, shale, impure limestone and lignite	Continental
Kenai Group: Beluga, Tyonek, and Sterling Formations	Susitna lowland-Kenai lowland	Southcentral	Tertiary	Sandstone, conglomerate, claystone, siltstone, and subbituminous, lignite, and bituminous coal beds	Continental
Kulthieth	Malaspina district; Robinson Mountains, Yakutaga district	Southcentral	Paleocene(?)-Eocene	Sandstone, siltstone, and numerous thin beds of high-rank coal	Transitional—continental and marine
Kushtaka	Bering River field	Southcentral	Tertiary	Graywacke, feldspathic sandstone, siltstone, shale, and bituminous to anthracite coal beds	Continental
Coal-bearing	Kootznahoo Inlet, Admiralty Island	Southeastern	Tertiary	Coarse sandstone, conglomerate, shale, and bituminous coal beds	Continental
Chignik	Chignik Bay and Herendeen Bay fields	Alaska Peninsula and Kodiak	Late Cretaceous	Sandstone, pebble-cobble conglomerate, siltstone, shale, and bituminous coal beds	Cyclic nearshore marine and nonmarine
Bear Lake: Unga Conglomerate Mbr.	South and east of Herendeen Bay	Alaska Peninsula and Kodiak	Tertiary	Sandstone, conglomerate, claystone, and subbituminous coal	Transitional—marine and nonmarine
Bear Lake: Unga Conglomerate Mbr.	Unga Island	Alaska Peninsula and Kodiak	Tertiary	Sandstone, conglomerate, claystone, and lignite	Transitional—marine and nonmarine
Coal-bearing	Sitkinak Island Tugidak Island	Alaska Peninsula and Kodiak	Tertiary	Sandstone, shale, conglomerate, and subbituminous coal	Continental

Table 4. Summary of chief characteristics of Tertiary and Cretaceous sedimentary rock formations of the Matanuska Valley (compiled from Clardy, 1978).

FORMATION	AGE	THICKNESS	LITHOLOGY	STRATIGRAPHIC RELATIONSHIP	DEPOSITIONAL ENVIRONMENT
Tsadaka	Oligocene; time equivalent of lowest beds of Kenai Gp.	Over 150 m in Tsadaka Canyon	Crudely stratified, massive conglomerate; marginal conglomeratic facies of Kenai Group	Overlies Wishbone and Chickaloon Formations with a distinct angular unconformity in lower Matanuska Valley	Sheet-flood debris deposited on alluvial fan
Wishbone	Eocene	550-600 m	Well-lithified conglomerates, sandstones and siltstones	Overlies Chickaloon Formation unconformably in Matanuska Valley	Fluvial environment; alluvial fans and associated braided streams, perhaps meandering stream deposits in part
Chickaloon	Paleocene	At least 1,500 m	Well-indurated claystones, siltstones, sandstones, conglomerates, coal	Conformable with overlying Wishbone Formation south of Willow Creek in southwestern Talkeetna Mountains	Fluvial braided to meandering stream environment in lower part, and fluvial meandering to paludal environment in upper part
Arkose Ridge	Paleocene	Unknown	Coarse-grained clastics—arkosic conglomerates, minor shales	Nonconformably overlies plutonic rocks along south flank of Talkeetna Mountains and overlies Talkeetna Formation to northeast	Local source, fanglomerate deposit
Matanuska	Early to late Cretaceous (Albian to Maestrichtian)	Over 1,200 m thick at type section	Siltstones, sandstones, and cobble conglomerates	Underlies Tertiary rocks with local disconformity	Marine; sublittoral to outer bathyal or abyssal deposition by density currents or submarine slumps

Table 1. Depositional regime of Alaska's major coal-bearing formations.

FORMATION	AREA	COAL RESOURCE REGION	AGE	LITHOLOGY	DEPOSITIONAL REGIME
[illegible] Group (upper member)	[illegible] field	Northern	Late Cretaceous	Sandstone, conglomerate, subbituminous to bituminous coal	Continental
[illegible] Group (upper member)	[illegible]—middle fork of [illegible] River	Northern	Late Cretaceous	Sandstone, conglomerate, and bituminous coal	Continental
Kapaloak Formation of Lisburne Group	Lisburne field	Northern	Mississippian	Mudstone, sandstone, limestone, minor conglomerate, and coal	Transitional—marine and nonmarine
Nanushuk Group	Northern field	Northern	Cretaceous	Sandstone, claystone, silty claystone, siltstone, carbonaceous shale and coal beds	Prograding deltaic depositional system in swampy coastal lowland
Coal-bearing	Chicago Creek–Kugruk River field	Western	Late Cretaceous–Early Tertiary	Poor- to well-consolidated gravel, sand, silt, carbonaceous debris, and lignitic coal beds	Continental
Kaltag Formation	Nulato and Kateel Rivers area, Koyukuk basin, Yukon River—Blackburn to Nulato	Western	Late Cretaceous	Siltstone, dark gray and olive gray shale, lesser sandstone, and bituminous and subbituminous coal beds	Continental
Coal-bearing	Palisades—Yukon River	Western	Miocene	Grayish white granule conglomerate and sandstone, reddish-brown claystone, and lignitic coal	Continental
Kaltag and Nulato Formations	Koyuk, Unalakleet	Western	Late Cretaceous–Tertiary	Graywacke, mudstone, sandstone, conglomerate, and coal	Terrigenous—shallow marine
Coal-bearing	St. Lawrence Island	Western	Oligocene	Poorly consolidated sandstone, grit, conglomerate, carbonaceous mudstone, ashy tuff, volcanic breccia, and pods of lignitic coal to 0.6 m	Continental
Coal-bearing	Selawik Basin and southeastern Baird Mountains	Western, Northern	Late Cretaceous	Conglomerate, sandstone, mudstone, and bituminous coal	Continental
Coal-bearing	Costello Creek	Eastern Interior	Tertiary	Sandstone, siltstone, mudstone, conglomerate, and subbituminous coal	Continental
Coal-bearing	Eagle field	Eastern Interior	Late Cretaceous–Tertiary	Sandstone, mudstone, shale, conglomerate, and subbituminous to lignitic coal	Continental
Coal-bearing	Rampart	Eastern Interior	Early Tertiary	Claystone, sandstone, conglomerate, and subbituminous to lignite coal	Continental
Coal-bearing	Tanacross (upper Tanana basin)	Eastern Interior	Cretaceous	Conglomerate, sandstone, shale, siltstone, tuff, tuffaceous sandstone and shale, lignite, and chert	Continental
Coal-bearing group: Healy Creek, Suntrana, and Lignite Creek Formations	Nenana coal field	Eastern Interior	Tertiary	Sandstone, conglomerate, claystone, and subbituminous coal	Continental
Healy Creek Formation	Jarvis Creek field	Eastern Interior	Tertiary	Sandstone, claystone, siltstone, and coal	Continental
Nation River	Nation River	Eastern Interior	Paleozoic Pennsylvanian(?)	Sandstone, conglomerate, shale, and bituminous coal	Continental
Coal-bearing	Farewell field—Little Tonzona, Deepbank Creek, Windy Fork of Kuskokwim River	Southwestern	Tertiary	Sandstone, siltstone, coal, burn, and bentonite	Continental
Coal-bearing	Yukon-Kuskokwim delta region—Nunivak-Nelson Islands	Southwestern	Late Cretaceous	Graywacke, siltstone, pebble conglomerate, and coal	Littoral marine
Kuskokwim Group	Eek River	Southwestern	Cretaceous	Black carbonaceous shale, graywacke, conglomerate, siltstone, and coal	Shallow marine, nonmarine
Chickaloon	Matanuska Valley	Southcentral	Paleocene–Eocene	Claystones, siltstones, sandstones, conglomerate, and coal	Fluvial braided-meandering (lower part) and fluvial meandering-paludal (upper part)
Coal-bearing	Broad Pass	Southcentral	Late Tertiary	Lignite, conglomerate, sandstone, claystone, carbonaceous claystone	Continental
Frederika	McCarthy area, Copper River basin	Southcentral	Miocene	Conglomerate, sandstone, siltstone, shale, impure limestone and lignite	Continental
Kenai Group: Beluga, Tyonek, and Sterling formations	Susitna lowland–Kenai lowland	Southcentral	Tertiary	Sandstone, conglomerate, claystone, siltstone, and subbituminous, lignite, and bituminous coal beds	Continental
Kulthieth	Malaspina district; Robinson Mountains, Yakataga district	Southcentral	Paleocene(?)–Eocene	Sandstone, siltstone, and numerous thin beds of high-rank coal	Transitional—continental and marine
Kushtaka	Bering River field	Southcentral	Tertiary	Graywacke, feldspathic sandstone, siltstone, shale, and bituminous to anthracite coal beds	Continental
Coal-bearing	Kootznahoo Inlet, Admiralty Island	Southeastern	Tertiary	Coarse sandstone, conglomerate, shale, and bituminous coal beds	Continental
Chignik	Chignik Bay and Herendeen Bay fields	Alaska Peninsula and Kodiak	Late Cretaceous	Sandstone, pebble-cobble conglomerate, siltstone, shale, and bituminous coal beds	Cyclic nearshore marine and nonmarine
Bear Lake; Unga Conglomerate Mbr.	South and east of Herendeen Bay	Alaska Peninsula and Kodiak	Tertiary	Sandstone, conglomerate, claystone, and subbituminous coal	Transitional—marine and nonmarine
Bear Lake; Unga Conglomerate Mbr.	Unga Island	Alaska Peninsula and Kodiak	Tertiary	Sandstone, conglomerate, claystone, and lignite	Transitional—marine and nonmarine
Coal-bearing	Sitkinak Island, Tugidak Island	Alaska Peninsula and Kodiak	Tertiary	Sandstone, shale, conglomerate, and subbituminous coal	Continental

Table 4. Summary of chief characteristics of Tertiary and Cretaceous sedimentary rock formations of the Matanuska Valley (compiled from Clardy, 1978).

FORMATION	AGE	THICKNESS	LITHOLOGY	STRATIGRAPHIC RELATIONSHIP	DEPOSITIONAL ENVIRONMENT
Tsadaka	Oligocene; time equivalent of lowest beds of Kenai Gp.	Over 150 m in Tsadaka Canyon	Crudely stratified, massive conglomerate; marginal conglomeratic facies of Kenai Group	Overlies Wishbone and Chickaloon Formations with a distinct angular unconformity in lower Matanuska Valley	Sheet-flood debris deposited on alluvial fan
Wishbone	Eocene	550-600 m	Well-lithified conglomerates, sandstones and siltstones	Overlies Chickaloon Formation unconformably in Matanuska Valley	Fluvial environment; alluvial fans and associated braided streams, perhaps meandering stream deposits in part
Chickaloon	Paleocene	At least 1,500 m	Well-indurated claystones, siltstones, sandstones, conglomerates, coal	Conformable with overlying Wishbone Formation south of Willow Creek in southwestern Talkeetna Mountains	Fluvial braided to meandering stream environment in lower part, and fluvial meandering to paludal environment in upper part
Arkose Ridge	Paleocene	Unknown	Coarse-grained clastics---arkosic conglomerates, minor shales	Nonconformably overlies plutonic rocks along south flank of Talkeetna Mountains and overlies Talkeetna Formation to northeast	Local source, fanglomerate deposit
Matanuska	Early to late Cretaceous (Albian to Maestrichtian)	Over 1,200 m thick at type section	Siltstones, sandstones, and cobble conglomerates	Underlies Tertiary rocks with local disconformity	Marine; sublittoral to outer bathyal or abyssal deposition by density currents or submarine slumps

Table 5. General section of rocks in the Bering River coal field (modified from Barnes, 1951).

Age	Formation	Character of rocks	Thickness (meters)
Quaternary		Stream deposits, lake sediments, morainal deposits, marine silt and clay	
Tertiary or later		Diabase and basalt dikes	
Tertiary	Katalla	Conglomerates, sandstones, and shales Sandstone Shale, concretionary Sandstone Shale	6100+
	Tokun	Sandstone Shale	
	Kushtaka	Arkose with many coal beds	1000±
	Stillwater	Shale and sandstone	
Pre-Tertiary		Graywacke, slates, and igneous rocks	