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ABSTRACT

The Nenana coal basin of interior Alaska includes a structurally similar series of disconnected subbasins containing separate coal fields. The basin forms the most important economic deposits of coal along the Nenana trend and constitutes the third largest coal resource base in Alaska. The major coal fields of the Nenana basin include Western Nenana (Teklanika), Healy Creek, Lignite Creek, Rex Creek, Tatlanika Creek, Mystic Creek, Wood River, and Jarvis Creek. The Jarvis Creek field east of the Delta River occupies an isolated subbasin at the easternmost extent of the Nenana trend. Deposits at the western margin of the trend are found from 240 to 320 km southwest of the Nenana basin near Farewell at Little Tonzona River, Windy and Middle Forks of the Kuskokwim River, and at Cheeneetnuk River.

The approximately 900-m thick Tertiary coal-bearing group rests directly on a highly irregular surface of Precambrian- and Paleozoic-aged metamorphic rocks, and is overlain by Pliocene Nenana Gravels and Quaternary surficial deposits. The coal-bearing strata of the Nenana basin are products of continental fluvial environments, including stream-laid, lacustrine, and poorly drained swamp deposits. The coal-bearing group includes three formations with significant coal deposits---Healy Creek, Suntrana, and Lignite Creek Formations. Coal seams in the Nenana basin attain thicknesses to 18 m. The Suntrana Formation contains the bulk of the economically exploitable coal resources of the Nenana basin. The Usibelli Coal Mine, Inc. at Poker Flats of the western Lignite Creek field is the only significant coal mining operation in Alaska and is currently mining the Nos. 3, 4, and 6 seams of the Suntrana Formation, each of which averages about 6-m thick. The mine will produce about 1.4 million metric tons of coal in 1985.

Identified coal resources of the Nenana basin are about 7.25 billion metric tons, and additional inferred coal resources along the entire Nenana trend increase the total to about 9 billion metric tons. At least 1.25 billion metric tons are estimated to be potentially surface minable (to 150 m depth) under current economic conditions. Major coal deposits of the Nenana basin also occur to the south and west of Jumbo Dome, particularly along the Marguerite Creek drainage basin and eastern Lignite Creek field. A smaller and more isolated field with considered high future coal development potential is Wood River on the northeast side of Mystic Mountain, where at least 16 significantly thick coal seams with an aggregate thickness over 30 m are exposed.

The coals of the Nenana basin are predominantly subbituminous and comparable in overall quality to Alaska's Susitna lowland and Wyoming's Powder River Basin coals. Petrologically, the Nenana coals are similar to Susitna lowland coals and Tertiary coals of British Columbia and Australia. Huminites are consistently high, liptinites vary but appear to be more abundant in the older Healy Creek Formation, and the inertinites are typically low but increase upward in the coal-bearing group.

Coal overburden characterization studies to date and the overall success of reclamation programs at the Usibelli Coal Mine over the past 15 years suggest that few environmental problems can be expected in the future with regard to mine spoil quality and revegetation.

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INTRODUCTION

The coals of the Nenana basin were probably discovered about 1898 (Collier, 1903). Coal production has been relatively continuous in the Nenana basin since about 1918. Currently, the Usibelli Coal Mine on lower Lignite Creek near Healy is the only significant operating coal mine in Alaska. The most economic deposits of the Nenana basin occur adjacent to the Alaska Railroad and Parks Highway corridor near the Nenana River. Coal mining will always be more feasible here than in the more inaccessible areas in the interior of the basin. In addition to other operations in the Lignite Creek field, high potential for further coal development is also envisioned for the Jarvis Creek and Wood River fields.

The coal-bearing rocks of the Nenana basin are similar in age, structure, and sedimentologic character. Wahrhaftig and others (1969) informally redesignated the coal-bearing formation of this region a group and subdivided it into five formations (from oldest to youngest)---the Healy Creek, Sanctuary, Suntrana, Lignite Creek, and Grubstake Formations. Based on plant megafossils and palynological materials collected from the rocks, they found that the coal-bearing group ranges in age from late Oligocene to late Miocene. The strata have been folded and faulted into a series of smaller subbasins with coal-bearing rocks eroded away in intervening areas. The sedimentary rocks of the basin are weakly indurated terrestrial clastics interbedded with numerous subbituminous coal beds from 3 to 18 m thick. Late Tertiary Nenana Gravels and Quaternary surficial deposits undoubtedly conceal large areas of coal-bearing group strata.

The Nenana coal basin contains the third largest coal resource base in Alaska and is surpassed only by the deposits of northwest Alaska and those of the Susitna lowland. The magnitude of these deposits assures that they will play an important role in Alaska's energy future. Indeed, there are several coal deposits of economic interest within the Nenana basin that will assume increased importance in the future on a localized, regional, and international basis.

LOCATION AND ACCESS

The general location of the Nenana basin of interior Alaska is shown in Figure 1 along with other major coal fields and occurrences throughout the state. The region falls within the Fairbanks, Healy, and Mt. Hayes 1:250,000-scale topographic maps and encompasses over 6,400 km^2. Outcrops of the coal-bearing group are restricted to an area less than 2,500 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 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---NEAR HERE

The Alaska Railroad crosses the Nenana basin and generally parallels the Nenana River. Both Anchorage-to-Fairbanks highways (the Parks on the west and the Richardson on the east) transect the region. However, most of the region is unpopulated, undeveloped, and relatively isolated from existing transportation routes. Helicopters are generally required for field investigations. Healy is 180 km from Fairbanks, 390 km from Anchorage, and 590 km from coastal access at Seward.

GENERAL GEOLOGY AND GEOLOGIC SETTING

The location and configuration of the structurally similar series of disconnected, synclinally folded coal subbasins that comprise the Nenana basin are shown in Figure 2. Of these, the Lignite Creek and Healy Creek subbasins are most important. The Poker Flats and Gold Run Pass pits of the Usibelli Coal Mine are located in the Lignite Creek field. The Healy Creek field has historically been one of the most important coal-mining areas in Alaska. Other subbasins of the region from west to east are Western Nenana, Rex Creek, Tatlanika Creek, Mystic Creek, Wood River, West Delta, East Delta, and Jarvis Creek. The Western Nenana field lies at the west end of the Nenana basin proper, and almost entirely lies within the confines of Mt. McKinley National Park. The Jarvis Creek subbasin is situated at the east end of the basin. These relatively shallow coal subbasins are generally aligned east to west parallel to the structural trend of the main mountains of the northern foothills belt and of the north-central Alaska Range.

Figure 2---NEAR HERE

The generalized geology for the Nenana basin is shown in Figure 3. The map of Figure 3 includes the Fairbanks A-2, A-3, A-4, and A-5, and the Healy D-2, D-3, D-4, and D-5 quadrangles. The distribution of the formations of the coal-bearing group are depicted in relation to other Tertiary and pre-Tertiary units. Extensive deposits of Late Tertiary Nenana Gravels mantle areas on the west, east, and north sides of the Nenana basin. A belt of Quaternary deposits flanks the north side of the basin covering the southern Tanana Flats.

Figure 3---NEAR HERE

PHYSIOGRAPHY

The Nenana coal basin is located within the Alaska Range physiographic province according to Wahrhaftig (1965). More specifically, it lies within the foothills belt of the north-central Alaska Range south of the Tanana Flats. It is a region of diverse physiographic features. The rugged, generally parallel, alpine ridges of the Alaska Range trend east-west. Numerous peaks within the range attain altitudes over 3,000 m. Mt. Hayes has an altitude of 4,200 m, and Mt. McKinley, the highest mountain peak in North America, has an altitude of 6,200 m and lies southwest of the main coal fields.

The parallel ridges of the Alaska Range foothills are separated by terraced lowlands or narrow canyons with talus along stream margins and locally blocking valleys. The main drainage lines run northward transverse to the ridges. The most important drainages from west to east are the Nenana and Totatlanika Rivers, and the Wood, Little Delta, and Delta Rivers, all tributaries to the Tanana River. Healy and Lignite Creeks drain westward into the Nenana River.

The foothills belt gradually descends down to the broad Tanana Flats, a lowland of slight relief about 50 km wide. The region is occupied by the Tanana River, the second largest river in Alaska, and is locally interrupted by a few isolated hills. The northward extent of the belt of coal-bearing rocks beneath the Tanana Flats is unknown.

DISTRIBUTION OF COAL-BEARING ROCKS

The Tertiary coal-bearing rocks of the Nenana basin occupy a discontinuous belt extending for about 225 km along the north-central flank of the Alaska Range and up to 50 km wide. The deposits are centered in an area about 100 km southwest of Fairbanks and 325 km north of Anchorage.

Although the coal-bearing rocks are widely distributed along the northern foothills, they are discontinuous, having been removed by erosion in intermediate areas. Isolated patches of these rocks near the tops of certain ridges are indicative of their once more extensive distribution. In addition, their areal distribution is undoubtedly greater than their surface exposure over the region, with large areas covered by Nenana Gravel or unconsolidated outwash gravel (sandur plains) and morainal material. The belt of coal-bearing rocks probably continues into the subsurface beneath the southern Tanana Flats.

Tertiary coal deposits are also found east of the Delta River. The Jarvis Creek field, at the easternmost limit of the trend, is favorably located near the community of Big Delta on the Richardson Highway. The western margin of the Nenana trend is indefinite, but probably extends up to 240 to 320 km southwest (Player, 1976; Sloan and others, 1981; Solie and Dickey, 1982; and Dickey, 1984). Coal outcrops along the Teklanika River were previously considered to be the western boundary of the trend.

Thin lignitic and subbituminous coals occur in the Kantishna Hills (Bundtzen, personal commun., 1983). The Farewell-Little Tonzona field, over 160 km west of the Nenana field proper, contains one subbituminous coal seam over 30-m thick (Player, 1976). Coals of the Western Nenana (Teklanika) field are scattered along the northeast boundary of Mt. McKinley National Park. Coal outcrops are also found at several locations within the park itself, and at Yanert near its eastern margin about 200 km south of Fairbanks. In 1923-1924, the Mount McKinley Bituminous Coal Company operated the Yanert Mine. An improved knowledge of the true extent and character of the coals of the less known deposits of the Nenana basin (and farther west along the Nenana trend) will develop in time, and these more remote resources could assume importance in the future.

STRUCTURAL GEOLOGY AND REGIONAL TECTONISM

Tertiary coal-bearing rocks of the Nenana basin occur within a structurally similar series of disconnected subbasins isolated by faulting and folding along the north-central flank of the Alaska Range. The fold axes of these relatively shallow warped basins are generally aligned east-west (Figure 4A) parallel to the structural trend of the foothills belt of the Alaska Range. Corresponding, generalized aeromagnetic anomalies are shown in Figure 4B. The most important of the coal-bearing subbasins are the Healy Creek, Lignite Creek, Rex Creek, Tatlanika Creek, Mystic Creek, Wood River, and Jarvis Creek. In intervening areas, the coal-bearing rocks have been removed by erosion. Precambrian-Paleozoic metamorphic rocks border the coal-bearing clastics. Generalized cross sections for areas in the Nenana basin are shown on Figure 5.

Figures 4 and 5---NEAR HERE

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. These uplifts resulted in the elevation and tilting of certain structural blocks, and caused faulting and folding in the coal beds. Recurrent movements along the faults have taken place during the Quaternary (Thorson, 1978). The late Pliocene-Pleistocene upheaval of Jumbo Dome, a hornblende dacite intrusion, greatly affected the section adjacent to its flanks and caused significant structural adjustments and attitude changes within the Tertiary clastics. Typically, dips of coal-bearing beds on the south side of the dome are high. Most of the igneous rocks that outcrop in the region are older than the coal-bearing group. These include Early Tertiary (Paleocene-Oligocene) diabase and basalt dikes and sills, latite, andesite plugs, and vent breccias. However, Reidel (1984) has found Miocene lava flows that are locally intercalated with the coal-bearing group.

Hackett and Gilbert (personal commun., 1983) 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 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 cite 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 subbasins and the denser underlying Precambrian-Paleozoic 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 coal basin to the east.

Both the Healy Creek and Lignite Creek coal deposits occur in synclinal structures (Figure 5). The Usibelli Coal Mine is located on a smaller-scale anticlinal structure south of Lignite Creek and north of the major fault separating the two fields. This near-vertical fault displaces the coal-bearing strata on the north upward about 900 m to 1200 m, bringing the coal beds close enough to the surface to create favorable surface-mining situations. Birch Creek Schist is also brought in direct contact with Nenana Gravel in certain areas on the upthrown northern block (Wahrhaftig and Birman, 1954).

The Healy Creek 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 field 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 deposits is dominated by several synclines and anticlines with typically gentler dips around 20°, but in places with dips from 30° to 35°. The local geologic structure has a great bearing on coal development potential (Wahrhaftig and Birman, 1954).

The beds of the Jarvis Creek field are gently folded with dips of 5° to 10° rimming the isolated structural basin. The coal-bearing sediments were deposited in structural depressions or small valleys on an ancient metamorphic surface. Late Tertiary structural adjustments caused by uplifts in the Alaska Range to the south resulted in minor faults and folds in the coal-bearing rocks (Wahrhaftig and Hickcox, 1955).

TERTIARY LITHOSTRATIGRAPHY

The Tertiary coal-bearing group (an informal geologic unit name) of the Nenana basin was subdivided by Wahrhaftig and others (1969) based on bio- and lithostratigraphy and age dating into five formations (in ascending order): the Healy Creek Formation, Sanctuary Formation, Suntrana Formation, Lignite Creek Formation, and Grubstake Formation (Figure 6). The succession may be over 900 m thick. The strata are loosely to moderately consolidated and deeply incised by streams. Locally thick and nearly complete sections of the entire group are exposed on Lignite or Hoseanna Creek. These stratigraphic sequences consist of terrestrial (continental) cross-bedded sandstones, siltstones, soft-blue claystones (locally shaley), loosely cemented conglomerates, gravel beds, and clean whitish quartzose sandstone interbedded with numerous coal seams. Wahrhaftig (1973) constructed detailed isopach maps for the formations of the coal-bearing group and isolith maps for individual seams. The general limits of deposition for the formations of the coal-bearing group as conceived by Wahrhaftig and others (1969) are shown in Figure 2.

Figure 6---NEAR HERE

The lithologic (sedimentational) characteristics and the degree of alteration of the coal-bearing rocks are dependent on local conditions in the paleoenvironment and post-depositional diagenesis. The units are characterized by rapid lateral changes in lithologies and varying thicknesses in individual facies. Correlations of beds in continental fluvial sediments such as these are difficult at best and often are not possible. Volcanic ash (tonstein) partings, which can be utilized for correlation purposes, are observable locally throughout the Nenana basin. Coaly materials occur in sandstones as wavy stringers and lenses. Locally, fossilized tree trunks and other abundant plant remains are present. Fossils other than plants are extremely rare. Schlaikjer (1937) did report fossilized fish of probable Miocene age in beds near the old Suntrana Coal Mine on Healy Creek.

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. The Suntrana and Lignite Creek Formations are strongly crossbedded by the trough and planar cross-stratification types of McKee and Weir (1953). The cross-stratification sets, composed of parallel cross-strata units bounded by trough-like or plane erosion surfaces both above and below, generally range from less than 0.3 m to 1.5 m in thickness, and average between 0.3 m and 0.6 m thick (Wahrhaftig, 1958). Sandy shales and claystones often exhibit high chroma yellow or buff colors. Differential erosion in softer portions of sandstone beds result in mushroom-shaped remnants and castellated forms; these can also rarely occur in coal beds of the region. Differentially-cemented calcium carbonate concretions to 1.5 m in diameter occur in certain sections of the coal-bearing group; laths, lenses, and concretions of this type are also common in the Lignite Creek Formation. The larger concretions if abundant in an area, could be problematic during overburden removal.

Dickson (1981) points to two lithologic changes during the deposition of portions of the coal-bearing group that indicate a general climatic cooling from late Oligocene to middle Miocene: 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 decreases from older to younger formations of the group.

Burned coal beds and baked rocks are common in the coal-bearing group on Healy Creek, more rarely on Lignite Creek and other areas of the Nenana basin. Rocks fired and baked by the combustion of coal can be underclay, other seatrock, or a roof rock. These rocks are referred to variously as porcellanite, scoria, red dog, or clinker. Some of the baked rocks are resistant to erosion and stand in relief with coal beds, while others weather and break down to form varicolored gleys and areas prone to slumping. Leaf impressions are often well preserved in these rocks. Although typically of local extent in the Nenana basin, burned coal zones can be significantly detrimental to resources and reserves.

HEALY CREEK FORMATION

The basal unit of the coal-bearing group is the Healy Creek Formation. Its type section is on the northeast canyon wall of Healy Creek at Suntrana from the top of the Birch Creek Schist to the top of the F coal bed (Wahrhaftig, 1958). It is of late Oligocene and early Miocene age, and the thickness of the formation varies greatly within short distances. One geologic section in the Jarvis Creek field has up to 600 m of strata (Wahrhaftig, 1958).

The Healy Creek Formation is the most widely distributed unit of the coal-bearing group and has been mapped from the Sushana River of the western Nenana coal basin to the Jarvis Creek field east of the Delta River. Most of the scattered patches of coal-bearing rocks of undecided affinity north of the Alaska Range are probably correlatable with the Healy Creek Formation (Wahrhaftig and others, 1969, p. D8). The unit was deposited on an irregular surface of the schist, and its included subrounded quartz pebbles were probably derived from quartz veins in nearby metavolcanics (Wahrhaftig, 1958).

The Healy Creek Formation contains interbedded sandstones, conglomerates, claystones, and subbituminous coals. The conglomeratic sandstones have a clayey matrix, are commonly gray to light reddish brown, and poorly lithified. The continuity of individual beds varies greatly within a short distance. Lenticular beds and mixed lithologic components in the same bed are diagnostic features. Dickinson (1979) reported the presence of uraninite in siderite nodules from Healy Creek Formation strata along Dexter Creek; associated minerals are kaolinite, quartz, goethite, and manganite. Siderite and manganite are indicative of alkaline depositional conditions. Considered in its entirety, the Healy Creek Formation possesses characteristics of a high-energy fluvial environment. Coalified leaves and carbonized plant detritus are abundant in some portions of the unit.

Wahrhaftig (1958) found that paleocurrent directional indicators pointed to a multi-source provenance of sediments. Dickson (1981) has inferred a northerly provenance for the formation (most likely the Yukon-Tanana upland) based on the presence of abundant black chert in the unit.

The Healy Creek Formation contains the second largest resource of coal within the coal-bearing group.

SANCTUARY FORMATION

The Sanctuary Formation type section lies between the top of the F coal bed and the base of the coarse conglomerate below the No. 1 and G coal beds near Suntrana on Healy Creek. The formation is named for exposures on the Sanctuary River near the northern boundary of Mt. McKinley National Park in the Western Nenana (Teklanika) coal field. The unit is early to middle Miocene in age, and varies from a few meters to over 100 m in thickness. It is found in most of the subbasins of the Nenana basin, and generally conformably overlies the Healy Creek Formation (Wahrhaftig, 1958; Wahrhaftig and others, 1969). The unit forms a useful marker 'bed' in the coal-bearing group.

The Sanctuary Formation is a chocolate-brown to yellowish-brown weathering shale (gray on fresh exposure). Varve-like or lenticular banded silts and clays are present. It breaks down rapidly on exposure and forms brown to gray gleys when saturated. Rounded landforms, landslides, and slumps are common and particularly characteristic of the Sanctuary Formation. The fine silts and clays most likely accumulated in a large shallow lake. The unit also contains coalified woody fragments, and its clay mineralogy (high silica, chlorite, and illite and low kaolinite) possibly suggests a basic igneous rock source, different from clays in the Healy Creek Formation. Thin coal and bone layers are found in some sections of the Sanctuary Formation, but they are unminable and the unit holds no economic value (Wahrhaftig, 1958).

SUNTRANA FORMATION

The Suntrana Formation type section includes strata in the walls of Suntrana Creek, tributary to Healy Creek, between the top of the Sanctuary Formation and the top of the No. 6 coal bed (Wahrhaftig, 1958). The unit is of middle Miocene age. Maximum thicknesses measured are nearly 400 m on the Coal Creek tributary of Healy Creek and over 300 m on Coal Creek northeast of Mystic

Mountain. The formation is widely exposed in the Healy Creek and Lignite Creek fields, and also crops out in the Rex Creek, Tatlanika Creek, and Wood River fields. It appears to be conformable with the overlying Lignite Creek Formation, but locally unconformably overlies the Sanctuary Formation (Wahrhaftig, 1958).

The composition of the Suntrana Formation averages 70 percent sandstone and 15 percent each of coal and claystone. It is lithologically similar to the Healy Creek Formation, but its sands are cleaner overall. The sandstones of the Suntrana Formation are whitish to light buff, weakly consolidated, typically well-sorted, and cross-bedded. A petrologic analysis shows the following average composition: quartz 70-75 percent, orthoclase 5-10 percent, plagioclase 1-5 percent, chert and rock fragments 5-10 percent, and heavy minerals (predominantly a low-grade metamorphic suite) 6.5 percent. Pebbles of conglomerates are typically less than 2.5 cm in diameter and consist predominantly of the following rock types: 1) resistant rock types, 65 percent---quartz, quartzite, chert, argillite, and jasper; and 2) nonresistant rock types, 35 percent---granitic rocks, gabbro, greenstone, graywacke, and volcanic rocks. Orange and red iron oxide staining is common for a meter or more above the coal beds of the formation (Wahrhaftig, 1958).

The Suntrana Formation exhibits cyclic sedimentation. The maximum number of repetitive cycles described by Wahrhaftig (1958) was 10 to 12, whereas Buffler and Triplehorn (1976) recognized 23 cycles in the entire coal-bearing group section on Healy Creek. Individual cycles may include the following units grading upward from conglomerate and coarse-grained sandstone to claystone and coal at the top: coal; bone; carbonaceous claystone; claystone, gray to greenish, silty, micaceous, with numerous scattered carbonized rootlets; siltstone; fine sandstone, cross-bedded; sandstone, coarse-grained, pebbly, cross-bedded; and conglomerate.

Coalified stumps, roots, leaves, and twigs are found throughout the Suntrana Formation. Schlaikjer (1937) found fossil fish of Miocene age in coal-bearing rocks of this unit near the old Suntrana Coal Mine on Healy Creek.

The Suntrana Formation accumulated in a subsiding basin, but conditions were apparently more uniform in this depositional basin at this time than during the deposition of the Healy Creek Formation earlier. Paleocurrent measurements from crossbeds show predominantly southward directions in the Healy and Lignite Creek fields, and westward in the Tatlanika Creek and Wood River fields. Clastic components (particularly black chert and garnet) are thought to have been derived from the southern Yukon-Tanana upland (Wahrhaftig, 1958).

The Suntrana Formation contains the bulk of the coal resources and reserves of the Nenana basin, including most of the thicker (commonly 3 m to 18 m thick) and laterally more continuous coal beds. These beds can be correlated better than those in other parts of the coal-bearing group, and can be traced up to 13 km in some cases. The numbered coal beds (3, 4, and 6 seams) currently being mined at Poker Flats (Usibelli Coal Mine) occur within the Suntrana Formation.

LIGNITE CREEK FORMATION

The Lignite Creek Formation type section is found at Suntrana Creek (Healy Creek field) from the top of the No. 6 coal bed to the base of the distinctive greenish-gray shale near the top of the coal-bearing group. The unit is named for the extensive badland exposures in the hills on the north side of Lignite Creek (Wahrhaftig, 1958). The formation is of middle Miocene age, and is 190 m thick at the type section. It consists of a coal-bearing facies and a non-coal-bearing facies described by Wahrhaftig (1958). The coal-bearing facies is exposed in the Healy Creek and Lignite Creek fields and southern part of the Tatlanika and Wood River fields, and the non-coal-bearing facies crops out along the northern and western parts of the Nenana basin. The coal-bearing facies varies in thickness from 150 m in the northwest part of the Lignite Creek field to 300 m at its east end, to over 180 m in the Tatlanika Creek field, and 240 m in the Wood River field. The non-coal-bearing facies averages about 75 m but locally is over 300 m in an upland area between the lower canyon of Tatlanika Creek and the valleys of the Totatlanika River and Buzzard Creek (Wahrhaftig, 1958). The Lignite Creek Formation is usually conformable with the underlying Suntrana Formation but local unconformities do exist (Wahrhaftig, 1958; Wahrhaftig and others, 1969).

The unit consists of interbedded, buff sandstones, greenish-gray claystones, arkosic conglomerates, and relatively thinner and more discontinuous coal beds than in the Suntrana Formation. Repetitive sequences are also present as in the Suntrana Formation. In contrast to the blocky-fracturing coals of the Suntrana Formation upon weathering, the coals of the Lignite Creek Formation break into long, narrow chips and flakes. Woody materials from the original coal-forming forest are preserved throughout the formation (Wahrhaftig, 1958).

The Lignite Creek Formation was deposited in the same basin(s) in which the Suntrana Formation accumulated, but the basin continued to subside at a faster rate. Most paleocurrent features in cross-bedded sandstones are for a southern source with a secondary northern source for the larger clastic components (Wahrhaftig, 1958).

The Lignite Creek Formation contains the smallest coal resource of the three significant coal-bearing units of the coal-bearing group in the Nenana basin.

GRUBSTAKE FORMATION

The Grubstake Formation type section is on Grubstake Creek of the Lignite Creek field. The unit is of late Miocene to early Pliocene age and is the youngest formation of the coal-bearing group. It is nearly 300 m thick at its type locality, but is of local extent. Exposures are found in the Healy Creek, Lignite Creek, Tatlanika Creek, and Wood River fields. The formation conformably overlies the lighter (buff) sandstone beds of the Lignite Creek Formation, and underlies the Nenana Gravel. The relationship between the coal-bearing group and Nenana Gravel apparently is generally unconformable but locally conformable (Wahrhaftig, 1958).

The Grubstake Formation consists of greenish-gray, thin-bedded shale and claystone in the Healy Creek and Lignite Creek fields. Elsewhere, interbedded dark claystones and sandstones, grus (fine conglomerate), and local reworked ash beds are present. Lithologically, the unit is more similar to the Nenana Gravel than to the coal-bearing group. Two thick beds of fine white vitric ash are found in the lower part of the Grubstake Formation on the east bank of Tatlanika Creek and the mouths of Roosevelt and Hearst Creeks. The Tatlanika Creek ash consists of more than 99 percent glass in lunelike shards and with the remainder made up of chlorite, muscovite, quartz, plagioclase, and sanidine crystals. The lower ash bed is over 7 m thick and the upper ash bed is about 4 m thick. The lower ash buried a forest and it has rooted, erect coalified tree trunks rising to 6 m in the ash (Wahrhaftig, 1958; Wahrhaftig and others, 1969).

The Grubstake Formation probably accumulated in a lacustrine environment. Certain clastic components as well as crosscurrent directions indicate a southerly provenance. Only thin beds of bone coal are found in the Grubstake Formation; thus, the unit contains no significant coal resources.

NENANA GRAVEL

The name 'Nenana Gravel' was first used by Capps (1912) to refer to gravel overlying the coal-bearing 'formation.' The Pliocene-aged unit is the youngest of the Tertiary deposits of the Nenana basin. Thick exposures of Nenana Gravel as much as 1,200 m thick occur between Healy and Lignite Creeks (Wahrhaftig and Freedman, 1945). They are extensively exposed along the lower slopes of the mountains on the north side of the Alaska Range and west of the Delta River in the Nenana basin. Localized discontinuous areas are reported in drainage basins east of the Delta River including small deposits at Jarvis Creek. In most areas where present, the Nenana Gravel unconformably overlies the coal-bearing group. Wahrhaftig (1958) found it to be conformable along Healy Creek, where it is locally folded along with the underlying coal-bearing group strata.

The Nenana Gravel contains loose to poorly consolidated, well-rounded and relatively uniform, medium to coarse gravel with large cobbles and boulders of nonglacial origin included locally. Pebbles in the gravel are predominantly graywacke and conglomerate, but also include schist, quartzite, granite, dacite, and green ophitic diorite. A few interstratified lenses of cross-bedded sandstone and thin beds of purplish clay and silt are also locally present. The unit is predominantly unconsolidated but locally is slightly cemented. They are yellow- to brownish-weathering, generally oxidized deposits. The formation was originally deposited as a continuous sheet that was later subjected to erosion.

Wahrhaftig and others (1951) state that the pebbles of this formation were derived from a rejuvenated orogeny in the Alaska Range and deposited by north-flowing streams that formed coalescing gravel deposits.

Quaternary and Holocene terraces have formed locally above the Pliocene Nenana Gravel and also serve to conceal coal-bearing group strata.

PALYNOLOGY

The palynology of Nenana basin coal-bearing units was analyzed by Wahrhaftig and others (1969). From this study, it was determined that the continental coal-bearing group ranges in age from late Oligocene to late Miocene (Figure 7) based on pollen and plant megafossil leaves. Table 1 summarizes the palynological assemblage characteristics for the coal-bearing formations of the Nenana basin based on this work.

Figure 7, Table 1---NEAR HERE

Fossil leaves are ubiquitous and best preserved in baked beds adjacent to coal seams which have burned. Among the genera which commonly occur as floral elements in these baked rocks are *Populus*, *Alnus*, and *Metasequoia*.

Pollen from a fern (Polypodiaceae) and two woody plants (*Alnus* or black alder and *Betula* or birch), which are commonly involved in peat formation, are shown in Figure 8. These were extracted from relatively pollen-poor samples from Red Mountain Creek and cored coal samples near Dry Creek, West Delta field. These samples are from undifferentiated Tertiary coal-bearing sections. Most of the scattered areas of coal deposits which have not been assigned to one of the coal-bearing formations are probably correlative with the Healy Creek Formation (Wahrhaftig and others, 1969).

Figure 8---NEAR HERE

Other than the work of Wahrhaftig and others (1969), little additional paleobotanical or palynological work has been completed on the Tertiary sediments of the north-central Alaska Range. Further research will be required in the future to determine the true stratigraphic affinity of several of the scattered, presently undifferentiated, Tertiary coal-bearing deposits along the north-central foothills belt of the Alaska Range in the Nenana basin.

DEPOSITIONAL ENVIRONMENTS

The Tertiary coals of the Nenana basin formed in late Oligocene and Miocene epochs about 10 to 30 million years ago (Wolfe and Tanai, 1980). These coal deposits are each similar in age, structure, and sedimentologic character. They are products of terrestrial (continental) 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 Paleozoic schist) 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 sequences or 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 9 summarizes the basic lithologic components and depositional types for the common fining-upward cycles. Figure 10 is a generalized Healy Creek section illustrating the cycles and respective interpretations of their depositional environment.

Figures 9 and 10---NEAR HERE

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

The Healy Creek Formation is a fluvial sequence of conglomeratic sandstones interbedded with claystones and subbituminous coal. It was deposited in late Oligocene and early Miocene epochs (Figure 11A). The weathered schist basement on which it was deposited was a very irregular surface with up to 100 m or more of relief, resulting in a major unconformity. Densely vegetated coal swamps developed locally in nearly isotopographic lows on this irregular surface. Poorly drained swamps, ponds, sandy stream channels, levees and crevasse splays (overwash flood deposits) 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 (depocenters) formed in a region about 160 km long and 50 km wide.

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.

Figure 11---NEAR HERE

The Sanctuary Formation is a locally thick claystone of probable lacustrine origin. It was deposited during the early to middle Miocene (Figure 11B). The silt and clay that washed into this large shallow lake were derived apparently from sources different than the Healy Creek Formation, 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 the period, the lake was sufficiently deep to prevent the rooting of aquatic vegetation, but parts of the lake became restricted late in the depositional cycle 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 middle Miocene (Figures 11C and 11D). Periods in which streams carried sheets of sand and gravel from northern source areas, that is, uplift and subsidence (Figure 11C) alternated with periods in which most of the plain was a coal-forming swamp (Figure 11D). Important subenvironments include channels, levees, crevasse splays, forested plains, 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. Depositional conditions were much more uniform in the coal-forming periods than during the deposition of the Healy Creek Formation earlier and resulted in 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 in middle Miocene (Figures 11E and 11F). The pattern of deposition was similar to that of the Suntrana Formation, 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 (Figure 11E). Since the pebble lithologies are less resistant than those of the Suntrana Formation, they may have been derived from a less distant source 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 highland source areas. The coal swamps that developed during this time were often inundated by flood waters depositing silts, sands, and gravels (Figure 11F). Hence, coal seams of the Lignite Creek Formation are very lenticular and laterally discontinuous. The former highlands to the north were lowered depleting the supply of clastic materials. Shallow lakes formed locally and silts and clay were deposited.

The Grubstake Formation consists mainly of claystone and was deposited during the transition period in late Miocene to early Pliocene that separates the derivation of clastic materials from northerly source areas and later on from southerly source areas (Figure 11G). An unconformity separates the Lignite Creek and Grubstake Formations. This period was relatively unstable and depositional conditions shifted between large shallow lakes and broad alluvial plains. 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 (Wahrhaftig, 1958).

The Nenana Gravel was derived from southerly source areas in the Pliocene and covers the coal-bearing sediments in a thick layer of coarse gravel with some included cobbles and boulders (Figure 11H).

COAL PETROLOGY

The coals of the Nenana basin are similar petrologically to Tertiary coals of British Columbia and Australia. They are all predominantly huminitic with minor inertinite and variable liptinite contents. However, the main liptinites in Nenana coals are resinite and suberinite, whereas in the aforementioned coals, it is mainly sporinite. Sclerotinite, fusinite, and inertodetrinite are commonly the main inertinites in all the coals, and micrinite is not present. However, Nenana coals do usually contain macrinite whereas the Tertiary coals of British Columbia and Australia usually do not (Stach and others, 1982).

Table 2 summarizes the maceral compositions for Nenana basin coal samples. Photomicrographs of coal macerals from samples of the region are shown in Figure 12. The huminite group of macerals is the most abundant in the coals of the Nenana basin. The huminite group content ranges from over 68 percent to about 91 percent, and the mean content is about 83 percent in the 70 samples analyzed. Ulminite is the main huminite (mean content over 74 percent) and often occurs partially gelified (texto-ulminite) or more rarely completely gelified (eu-ulminite). Corpohuminites are present as primary cell infillings (phlobaphinite) and secondary cell infillings (pseudophlobaphinites), but they usually compose less than 1 percent by volume. Porigelinite is also very low (mean less 0.5 percent). Rare pseudovitrinites were observed in a few coal samples. Whether these resulted from primary (fossil) oxidation or secondary oxidation (weathering) is uncertain, but since the samples were collected from outcropping seams, the latter may be more probable. Following ulminite, humodetrinite (usually as attrinite but sometimes as densinite) is consistently the most abundant huminite. It tends to be more abundant in high ash coals and typically increases in the upper portions of thick seams and in the relatively thin coals toward the top of coal-bearing sections. The mean humodetrinite content is over 7 percent.

Table 2, Figure 12---NEAR HERE

Inertinites occur as minor constituents in most of the Nenana coal samples analyzed with a mean content of 2.7 percent, but they range up to over 20 percent (volume, mineral-matter-free basis). The coals with a relatively high inertinite content point to a terrestrial or 'dry' paleoenvironment where the precursor peat was

was highly oxidized (Stach and others, 1982). The most common of the high-carbon inertinites are inertodetrinite, macrinite, and semifusinite. Sclerotinite and fusinite are fairly consistently present, but relatively lower in abundance. Inertodetrinite and macrinite result in the peat stage through the biochemical disintegration of plant remains, particularly by the activity of fungi and bacteria under somewhat oxidizing conditions (Stach and others, 1982). Sclerotinite is diagnostic of Tertiary coals, and is believed to be indicative of intense fungal activity at the time they were formed. They occur as celled or lumenated chitinous fungal spores, and often too as plectenchyma from the stroma of tubular fungi (Stach and others, 1982). They are especially resistant to alteration and destruction. Sclerotites multicellulatus, other Sclerotites species, and plectenchyma occur in Alaska Tertiary coals. Semifusinite is commonly more abundant than fusinite; these macerals were produced by forest fires and compose the microlithotype fusite and the lithotype fusain. Fusinization has produced both the perforated screen ('screen structure') and bogen- or star-structured varieties. Micrinites were not identified in the coals of this region.

The liptinites (or exinites) occur as significant components in the coals of the Nenana basin. In fact, they are relatively high in some samples. The mean liptinite content is about 14 percent on a volume, mineral-matter-free basis. Resinite, suberinite, and exsudatinite form by far the most abundant liptinites, with rare sporinite, cutinite, liptodetrinite, and alginite.

Resinite predominates in abundance over suberinite and exsudatinite. Resinite occurs as cell fillings, secretions, and isolated elongate or spherical bodies. Resinite fluoresces bright orange, while exsudatinite fluoresces dark orange. Exsudatinite fills cracks in vitrinite, cell lumina of fusinite or semifusinite, and the chambers in sclerotinite (Spackman, Davis, and Mitchell, 1976). Resinite can be transformed into gray or whitish, 'grapestone,' inertinitic or vitrinitic bodies by oxidation (Stach and others, 1982), and these forms are rarely observed in the Nenana coals. Suberinite is diagnostic of Tertiary coals and may compose up to 5 percent of the volume (mineral-matter-free basis).

Sporinite is generally less than 1 percent, and occurs as squashed elongate bodies with slitted centers. Cutinite occurs as crenulated or toothed yellow stringers in both the thin-walled (tenuicutinite) and thick-walled (crassicutinite) varieties. One thick-walled variety found in Alaska Tertiary coals is referred to informally as 'algicutinite' (Rao, personal commun., 1983). Preserved algal remains (alginite) is extremely rare in the Nenana coals analyzed. Although some Tertiary brown coals (particularly the bright lithotypes) are reported to contain abundant liptodetrinite (Stach and others, 1982), it is found to compose no more than 0.5 percent of the volume in the samples analyzed during this study.

Figure 13 shows ternary diagrams for maceral compositions of Nenana coal samples analyzed. The end members of the inner (larger) triangle are the three major maceral groups---huminite, inertinite, and liptinite. The patterned area of this triangle shows that the huminite group is by far the most abundant. Each of the major groups has been subdivided in the smaller triangles into its chief components. The contents of the individual or combined macerals and maceral types for most of the Nenana samples fall within the patterned areas of the smaller triangles. The huminite triangle shows the high proportion of ulminite, the liptinite triangle the abundance of resinite and suberinite, and the inertinite triangle the predominance of the combined macrinite, inertodetrinite, and sclerotinite end member. In addition, the huminite triangle shows that the humodetrinite end member is of secondary importance to ulminite and is more abundant than the corpohuminite and porigelinite end member; in the liptinite triangle that sporinite is typically more abundant than the combined cutinite, alginite, and liptodetrinite end member; and in the inertinite triangle the usual predominance of semifusinite over fusinite.

Figure 13---NEAR HERE

Mean maximum reflectance values ($\overline{R}om$) for selected Nenana coal samples are summarized in Figure 14. Reflectance values measured in the Nenana coal samples range from 0.21 to 0.53 percent, and generally support the rank grades assigned by proximate and ultimate analyses.

Figure 14---NEAR HERE

Table 3 shows that certain general trends can be expected in the maceral compositions of coals sampled from the different coal-bearing formations in the Nenana field. Huminite contents are high in coals from all of the formations. Exinite or liptinite contents tend to be somewhat more abundant in the older formation (Healy Creek Formation and probable equivalent undifferentiated Tertiary coal-bearing unit) and is typically less abundant in the Lignite Creek Formation and more variable in the Suntrana Formation. Inertinite shows a trend toward increasing abundance upward in the coal-bearing formations.

Table 3---NEAR HERE

The petrology of Nenana coals is consistent with their interpreted origin (as presented in the section dealing with depositional environments), that is, Tertiary continental-fluvial systems and associated subenvironments. It suggests that most of the coal seams formed from tree-vegetation peats with abundant preservation of woody materials as huminites. The woody peats accumulated in poorly drained forest-moor swamps filling nearly isotopographic lows. The thicker and more continuous peats originated during relatively quiescent periods that alternated with periods of uplift and the influx of clastics that ended each peat-forming cycle. A forest-terrestrial moor environment is envisioned for certain coals of the Lignite Creek Formation as indicated by their higher content of inertinite. They would have formed under drier conditions than the coals of the forest-moor in the telmatic (or groundwater level) zone, as did most coals of the Suntrana and Healy Creek Formations.

COAL QUALITY

Coals of the Healy Creek Formation and lower Suntrana Formation are typically of better quality than coals higher in the coal-bearing group. This is reflected in measured values for most rank parameters---particularly calorific value, vitrinite reflectance, fixed carbon and carbon content. Coals of the Lignite Creek Formation tend generally to have higher ash and moisture contents, sometimes higher sulfur, and to be thinner and more discontinuous laterally.

Figure 15 shows the classification for the lower stages of coalification. Shaded areas represent the general range of values for different rank parameters as measured in Nenana basin coal samples. These include mean-maximum reflectance values from 0.21 to 0.53 percent, volatile matter contents from about 8 to 30 percent, and calorific values from 6650 to 11650 British thermal units per pound (moist, ash-free basis). Table 4 gives a brief summary of proximate and ultimate analysis data for Nenana basin coal samples.

Figure 15, Table 4---NEAR HERE

Total sulfur values for Nenana basin coal samples are shown in Figure 16. The mean pyritic sulfur content is less than 0.02 percent and the mean total sulfur content is about 0.30 percent. Typically in most Alaskan coals, the organic sulfur content occurs in the highest proportion.

Figure 16---NEAR HERE

Figure 17 summarizes the range of trace element contents commonly found in all coals with the range in Nenana basin coal samples. The latter values were averaged from the results of Rao and Wolff (1981), Conwell (1976), and Affolter, Simon, and Stricker (1981). For most elements, Nenana basin samples fall toward the lower end of the range observed in other coals.

Figure 17---NEAR HERE

Certain elements are known to be generally enriched in coal ash over their average content in the Earth's crust. Table 5 summarizes the average contents and factors of enrichment for these elements in coal ash in general and coal ash of Nenana samples compared to the same values for that element in the Earth's crust. In general, the factor of enrichment in Nenana samples is quite similar to the usual factor of enrichment for a particular element.

Table 5---NEAR HERE

COAL RESOURCES AND RESERVES

The formations of the coal-bearing group that contain the greatest reserves of minable coal (in decreasing order) are the Suntrana, Healy Creek, and Lignite Creek Formations. Thus, significant coal deposits occur in three of the five formations composing the Tertiary sequence. The Suntrana and Healy Creek Formations, making up the lower half of the coal-bearing group, contain the majority of the economic deposits with the most numerous and thickest beds. Thinner and more discontinuous seams characterize the Lignite Creek Formation. The subbituminous coal beds of the Nenana basin range from 3- to 18-m thick.

The Nenana basin contains the third largest coal-resource base in Alaska and is surpassed only by the deposits of northwest Alaska and Cook Inlet-Susitna lowland provinces. Measured reserves are about 4 billion short tons, identified resources are 8 billion short tons, and hypothetical resources are estimated at 20 billion short tons. Relative conservative estimates of potentially minable coal resources of the ten fields of the Nenana basin are listed in Table 6. Three different scenarios are shown based on different levels of assurance---high, moderate, and low. Considering the Nenana basin proper, there is relative high assurance of at least 1.4 billion short tons of surface-minable coal resources to a depth of 150 m in beds over 0.75-m thick.

Table 6---NEAR HERE

WESTERN NENANA FIELD

The coal-bearing rocks of the Western Nenana (Teklanika) field occupy a belt about 25-km long and 5-km wide that stretches from 5 km west of the Nenana River on the east to the Sanctuary River on the west. The outcrop belt is aligned east to west north of Primrose Ridge, which is composed of Birch Creek Schist. The region is located within the foothills belt and is traversed by four northward flowing major streams---the Sushana, Teklanika, Sanctuary, and Savage Rivers. The strata probably include only the lower part of the coal-bearing group as present on Healy and Lignite Creeks.

Wahrhaftig and others (1951) made a separate investigation of the coals of the Western Nenana field, and estimated the coal resources of this region at 250 million tons. These deposits mostly fall within the confines of the recently expanded Mt. McKinley National Park. Potentially minable coal resources of the the Western Nenana field to a projected depth of 150 m are estimated to be at least 80 million short tons (Table 6).

HEALY CREEK FIELD

The Healy Creek field covers an area less than 65 km^2 stretching from the middle reaches of the Healy Creek drainage westward to the Nenana River. It lies south of the large fault that separates it from the Lignite Creek field and north of the central Alaska Range mountain front.

Nearly complete sections of the coal-bearing group crop out along Healy Creek. At the east end of the field, 32 different coal beds were once exposed ranging to 17 m in thickness, together totaling 115 m of coal in 450 m of strata (Wahrhaftig and Freedman, 1945). The Healy Creek syncline is essentially depleted of economically attractive strip-minable coal, and the stripping ratio of that remaining is relatively high (COACMAR, 1980; Naske and Triplehorn, 1980). However, undoubtedly substantial amounts of additional coal can be exploited in the future by underground methods. Denton (1981) estimates remaining coal resources of the Healy Creek field at 250 million short tons to depths over 1000 m. Potentially minable coal resources of the Healy Creek field to a projected depth of 150 m are estimated here to be at least 250 million short tons (Table 6). Usibelli Coal Company, Inc. and its predecessors operated mines on Healy Creek from about 1944 to 1972.

LIGNITE CREEK FIELD

The Lignite Creek field extends from the upper reaches of Sheep Creek in the east to the Nenana River on the west to Eva, Elsie, and California Creeks confluence in the north. The western end of the field lies about 6.5 km north of Healy. Healy and Lignite Creeks are about 8 km apart and are separated by a schist ridge. Outcrops of the Lignite Creek field are scattered over an area of about 250 km^2.

The field includes nearly complete sections of coal-bearing group strata from the Healy Creek Formation upward to the Grubstake Formation. Over 300 m of coal-bearing strata are exposed in steep-sided cuts along typical Lignite Creek valley outcrops. At one location on Lignite Creek, a coal-bearing section exposes an aggregate 80 m of coal, while sections commonly expose up to 60 m aggregate thickness. The number 1 bed is the thickest of the coal-bearing group extending up to over 18 m locally within the region, and the number 2 and number 3 beds can be over 12-m thick. The number 6 seam has been found to be continuous along strike for up to 15 km (Wahrhaftig, 1958, 1973; Wahrhaftig and others, 1969).

The coal deposits of the Lignite Creek field are the most important of the region. Renshaw (1977) estimated the reserves of strippable coal (at an overburden:coal ratio less 4.25:1) for the Lignite Creek syncline at 150 million tons. Sanders (1981) estimated reserves of the Usibelli Coal Mine leases alone at over 250 million tons, and Denton (1981) estimated mining reserves at Poker Flats at 28 million tons at a stripping ratio of 4.5:1. Potentially minable coal resources of the Lignite Creek field to a projected depth of 150 m are estimated at 850 million short tons (Table 6).

Currently, at Usibelli Coal Mine's Poker Flats pit on the south side of Lignite Creek, numbers 3,4, and 6 seams of the Suntrana Formation are being mined and contain most of the reserves of the area (Denton, 1981). The three beds are all over 6-m thick totaling over 18 m of coal in a 70-m section. A modified box-cut strip-mining (open pit) method utilizing a 25-cubic meter bucket capacity dragline called 'Ace-in-the-Hole' resulted in a 1984 production of about 850,000 short tons. Nearly 1.5 million short tons are expected to be produced in 1985.

REX CREEK FIELD

The Rex Creek field occupies one of the smaller subbasins of the Nenana basin. The outcrop extent of the field is less than 65 km^2. It is situated east of Rex Dome and west of Iron Creek, and is crossed by Rex and California Creeks. The Healy Creek, Sanctuary, and Suntrana Formations, and an area of yet undifferentiated coal-bearing group strata crop out in the field. It is estimated with relative high assurance that the Rex Creek field contains at least 15 million short tons of potentially minable coal resources to a projected depth of 150 m (Table 6).

TATLANIKA CREEK FIELD

The Tatlanika Creek field occupies one of the larger subbasins of the Nenana basin with outcrops of coal-bearing group strata covering an area about 300 km^2. The coal field extends from Grubstake, Roosevelt, and Hearst Creeks in the east to Buzzard Creek on the west side of the subbasin. A nearly complete section of the coal-bearing group from the Healy Creek Formation upward through the Grubstake Formation crop out on the south side of the field in an east-west trending belt near the confluence of Sheep and Moose Creeks. The Lignite Creek and Grubstake Formations together crop out over 80 percent of the field. It is estimated with relative high assurance that the Tatlanika Creek field contains at least 70 million short tons of potentially minable coal resources to a projected depth of 150 m (Table 6).

MYSTIC CREEK FIELD

The Mystic Creek field is located southwest of Mystic Mountain about 3 km west of Wood River, and is centered about 6.5 km northeast of Keevy Peak. Outcrops of undifferentiated Tertiary coal-bearing group strata occur in an area less than 50 km^2. The Tertiary section is probably relatively thin ($\pm$ 100 m), rests unconformably on Paleozoic metamorphic basement rocks, and in part at least may be correlative with the Healy Creek Formation.

As many as ten coal beds to 5-m in thickness crop out locally on Mystic Creek. Potentially minable coal resources of the Mystic Creek field are estimated to be 10 million short tons or a deposit about twice the size of the West Delta field (Table 6). The field is judged to be of considerable less importance than the Wood River field lying about 1.5 km northeast.

WOOD RIVER FIELD

The Wood River field occupies an area less than 100 km^2 that stretches northeastward from Mystic Mountain and is generally restricted to the north and west side of the Wood River. The field includes a nearly complete stratigraphic section of the Tertiary coal-bearing group from the Healy Creek Formation upward to the Grubstake Formation. The series is exposed dipping from the schist ridge of Mystic Mountain beneath the gravels north of Coal Creek. At least 16 significantly thick coal seams with an aggregate thickness over 30 m are exposed here. Due to uplift and crumpling of the beds, the seams along Coal Creek may have been given a greater thickness locally than they have farther north (Wahrhaftig, 1958). Potentially minable coal resources of the Wood River field to a projected depth of 150 m are estimated to be at least 65 million short tons (Table 6).

WEST DELTA FIELD

The West Delta field contains outcrops scattered over an area less than 100 km^2 north of the West Fork of the Little Delta River, including exposures on Red Mountain, Newman, Dry, Slate, and Slide Creeks. Six coal beds to 1.5-m thick crop out on Red Mountain Creek. A core drilled by Resource Associates of Alaska near Dry Creek in 1982 revealed a relatively thin Tertiary section of about 40 m with several thin coal beds. The undifferentiated Tertiary coal-bearing unit here rests unconformably on Mississippian quartzite and schist basement. The sequence may be correlative at least in part with the Healy Creek Formation. The field is about the same magnitude in size as the East Delta, but may have a slightly higher coal development potential. It is estimated with relative high assurance that the West Delta field contains

5 million short tons of potentially minable coal resources (Table 6).

EAST DELTA FIELD

The East Delta field occupies a subbasin of about 35 km^2 between the Little Delta River and Delta Creek, and lies entirely within Fort Greely Army Reservation. The thin coals resemble those of the Jarvis Creek field to the east and occur in a currently undifferentiated Tertiary coal-bearing unit that is probably correlative with the lower part of the coal-bearing group, and possibly belongs to the Healy Creek formation. The sedimentary sequence here is believed to be relatively thin ($\pm$ 100 m). It is estimated with relative high assurance that the East Delta field contains 5 million short tons of potentially minable coal resources (Table 6).

JARVIS CREEK FIELD

The Jarvis Creek field is located at the easternmost extent of the Nenana trend. Geologically, the field is an eastern extension of the Nenana basin, of which it is considered a part here. It is about 55 km south of the community of Big Delta and east of the Richardson Highway, and lies on a gentle ridge between the Delta River and Jarvis Creek. The field encompasses an area less than 100 km^2, with the economically important deposits occupying a 40-km^2 area.

The coal-bearing section of the Jarvis Creek field, which has been tentatively correlated in part with the Healy Creek Formation, is about 600-m thick and has at least 30 beds exposed over 0.6-m thick. The gently folded strata has one 3-m bed that is locally exposed along Ober Creek. Wahrhaftig and Hickcox (1955) estimate coal resources of the Jarvis Creek field at over 75 million tons, and Metz (1981) infers an additional 100 million tons based on recent drilling data. Potentially minable coal resources of the Jarvis Creek field to a projected depth of 150-m are estimated to be at least 30 million short tons (Table 6).

FAREWELL (LITTLE TONZONA) FIELD, WESTERN NENANA TREND

Coal deposits of the Farewell (Little Tonzona) field are situated near the westernmost extent of the Nenana trend and the southeastern margin of the Minchumina basin in southwest Alaska. Outcrops of the field are scattered over an area of about 500 km^2 from Little Tonzona River to the Middle Fork of the Kuskokwim River. The coal deposits are not a part of the Nenana basin proper, but they are an extension of the same belt of Tertiary rocks that are similar stratigraphically and sedimentologically. The belt is located over 160 km west of the Nenana basin.

The coals are predominantly of subbituminous rank, and occur in low-angle block faults with minor folds. One subbituminous coal bed at Little Tonzona River is about 35 m thick, and at least seven other beds over 0.75 m crop out (Sanders, 1981). Seams at Deepbank Creek range from 1.5- to 6-m thick (Friedmann, 1981).

The coal resources of the Farewell (Little Tonzona) field are estimated to exceed 1.5 billion short tons (Sanders, 1983). Canadian Superior (McIntyre Mines) carried out an extensive exploration drilling program there for Doyon (a Fairbanks-based regional native corporation) during the summer of 1980. Probable future development will be by surface mining.

OVERBURDEN CHARACTER

Coal seams of the Nenana basin are interbedded with sandstone, siltstone, claystone, and conglomerate beds. Overburden samples of mainly roof rocks and seatrocks were collected for analysis. The rocks are characterized predictably by low pyrite and generally low trace element contents. The samples revealed no significant potential for the development of high levels of salt or sodium accumulation. Sodium adsorption ratios were below the range commonly associated with poor soil structure and its resultant negative effects on plant growth.

A summary of the results of overburden characterization analyses conducted during this study is given in Table 7. The samples also show excesses of inherent neutralizers (expressed in tons $CaCO_3$ equivalent / 1000 tons of material), neutral to slightly acid pH levels, low sulfur contents, relatively high organic matter and lime contents. In general, the levels of trace elements do not suggest the development of a toxicity or deficiency condition in mine soils formed from these overburden materials. Certain amendments, particularly nitrogen and phosphorous, may need to be added to promote mine spoil revegetation.

Table 7---NEAR HERE

CONCLUSIONS

The Tertiary coal-bearing group of the Nenana basin of interior Alaska contains with relative high assurance at least 1.4 billion tons of potentially surface-minable coal resources. The resources occupy a series of isolated subbasins within a 225 km by 50 km belt along the north-central flank of the Alaska Range. The coals are predominantly subbituminous with low sulfur, variable ash, and relatively high moisture contents. They are comparable in quality to Susitna lowland (Alaska) and Powder River Basin coals. The most economic deposits are those near the west side of the basin, close to the Parks Highway and Alaska Railroad, and adjacent to the Nenana River (particularly those of the Lignite Creek field); the deposits of the Jarvis Creek field on the east side near the Richardson Highway are also strategically located.

The coals of the Nenana basin are products of continental fluvial depositional environments. Coal petrologic studies indicate that the coals probably originated within poorly-drained forest-moor swamps filling nearly isotopographic lows. The coals are predominantly huminitic with minor inertinite and variable liptinite contents. Liptinites tend to be somewhat more abundant in the older Healy Creek Formation, and the inertinites generally increase upward within the coal-bearing group.

The coals of the Healy Creek and lower Suntrana Formations are typically of better quality than coals higher in the coal-bearing group. The coals of the Lignite Creek Formation generally exhibit higher ash and moisture contents, sometimes higher sulfur, and are thinner and more discontinuous laterally.

Coal overburden characterization research to date and the overall success of reclamation programs at the Usibelli Coal Mine over the years suggest that few environmental problems can be expected in the future with regard to mine spoil quality and revegetation.

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FIGURE CAPTIONS

Figure 1...Coal basins and isolated coal occurrences in Alaska showing the general location of the Nenana basin of interior Alaska.

2...Major coal fields of the Nenana basin and northern limits of deposition of formations (center section of map only; after Wahrhaftig and others, 1969). Key: 1=northern limit of deposition of Grubstake Formation; 2=approximate zone of interfingering of coal-bearing and non-coal-bearing facies of the Lignite Creek Formation; 3=northern limit of deposition of the Suntrana Formation; 4=northern limit of deposition of Sanctuary Formation; 5=northern limit of deposition of the Healy Creek Formation; and 6=coal field.

3...Generalized geologic map of the Nenana basin west of the Wood River (after Wahrhaftig and others, 1969).

4...(A and B) Major east-west trending axes of Nenana basin (A) and generalized aeromagnetic map for the same area (B; after Reidel, 1984).

5...Geologic cross sections of the Nenana basin: (A) section through western Lignite Creek and Healy Creek fields; (B) section through Lignite Creek field south of Jumbo Dome; (C) section through northern portion of Lignite Creek field (north Jumbo Dome) and Rex Creek field; and (D) section through the Wood River coal field (modified from Wahrhaftig, 1970a-d).

6...Generalized section of the coal-bearing group at Suntrana, Healy Creek field, with the chief lithologic characteristics of the different formations and seam identifications (modified from Wahrhaftig and others, 1969).

7...Stratigraphic nomenclature, stage, and series of coal-bearing formations of the Nenana basin (modified from Wolfe and Tanai, 1980).

Figure 8...Pollens extracted from Red Mountain Creek and Dry Creek (West Delta field) coal samples: A) Polypodiaceae, fern; B) Alnus, black alder; and C) Betula, birch; all 160X.

9...Basic lithologic components and depositional types for the common fining-upward cycles in the coal-bearing group (modified from Buffler and Triplehorn, 1976).

10...Geologic section of coal-bearing group showing individual cycles of deposition and their respective depositional type (modified from Buffler and Triplehorn, 1976).

11...Generalized and simplistic depositional models representing paleoenvironmental conditions during the formation of the Tertiary coal-bearing group of rocks of the Nenana basin. Refer to text for discussion. No particular scale or specific area is implied. The ancestral mountains of C and E represent potential source areas of clastics near the western end of the Yukon-Tanana upland. The ancestral mountains to the south on H represent uplifts in the Alaska Range.

12...Photomicrographs of various macerals and maceral types from Nenana basin coal samples (reflected light; oil immersion).

A. Texto-ulminite, 500X.

B. Ulminite, phlobaphinite, and porigelinite, 500X.

C. Sporinite, resinite, humodetrinite, inertodetrinite, and disseminated mineral matter, 300X.

D. Ulminite, sporinite, semifusinite, and humodetrinite, 300X.

E. Semifusinite, 500X.

F. Fusinized microspore, ulminite, and humodetrinite, 300X.

G. Sclerotinite (Sclerotites sp.), semifusinite, ulminite, and humodetrinite, 500X.

H. Framboidal pyrite in ulminite, 450X.

Figure 13...Ternary diagrams for maceral composition of Nenana basin coal samples. Refer to text for explanation.

14...Vitrinite reflectance frequency histogram for Nenana basin coal samples. Number in brackets indicates total number of vitrinites counted at the given reflectance interval.

15...General range of values for different rank parameters in Nenana basin coal samples. Classification of coalification stages from Stach and others, 1982, table 4, p. 45.

16...Bar graph showing the maximum and arithmetic mean values for the percent pyritic and total sulfur of analyzed coal samples from the Nenana basin (as received basis).

17...Range of trace element contents commonly found in coal ash compared with the range found in Nenana basin coals (range reported in literature from Mason, 1966, fig. 9.5, p. 242).

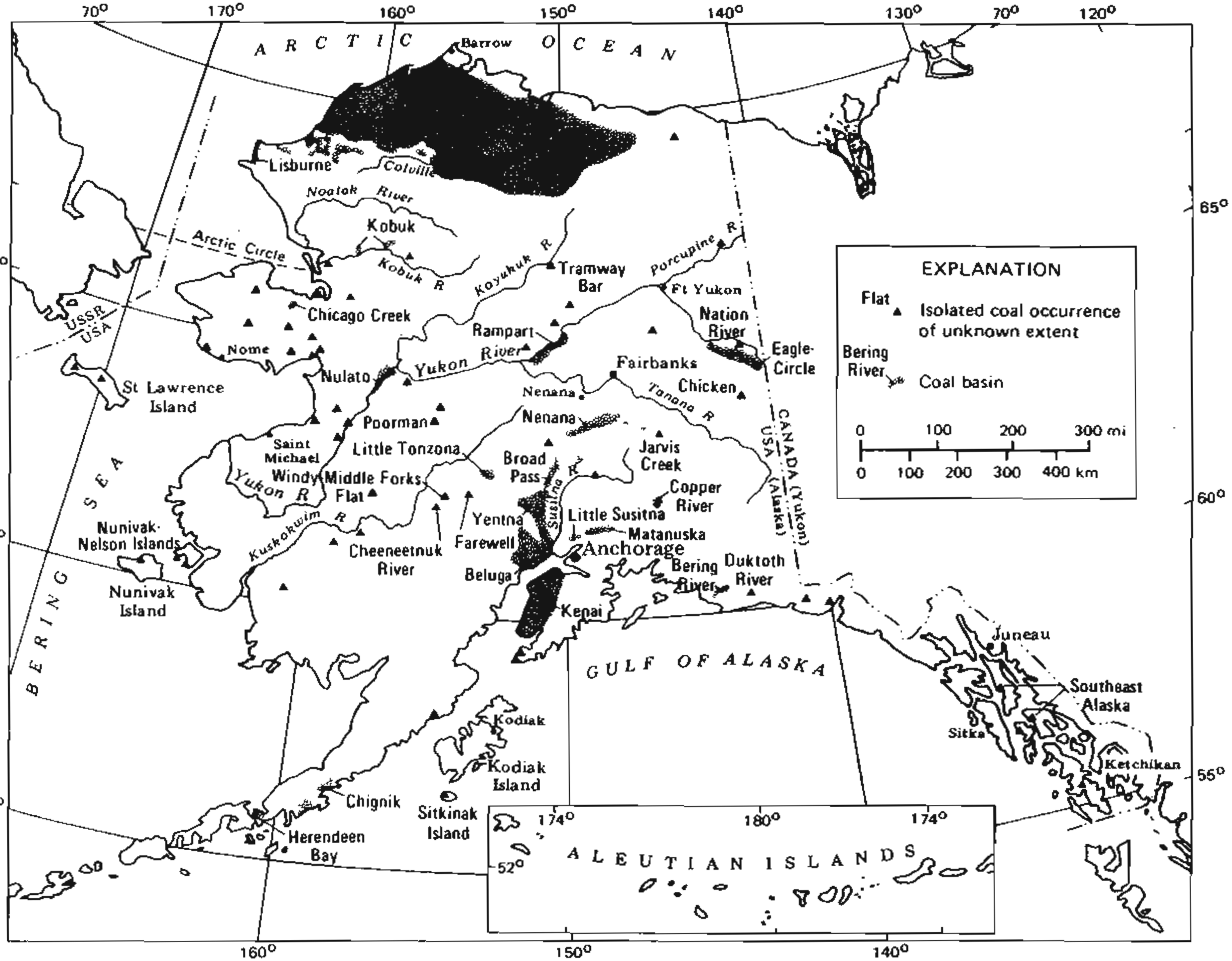

ARCTIC OCEAN
Barrow
Lisburne
Colville
Noatak River
Kobuk
Kobuk R
Koyukuk R
Arctic Circle
Tramway Bar
Porcupine R
Ft Yukon
Nation River
Eagle-Circle
Chicago Creek
Rampart
Yukon River
Nome
USSR
USA
St Lawrence Island
Nulato
Fairbanks
Nenana
Chicken
Tanana R
Poorman
Saint Michael
Little Tonzona
Broad Pass
Jarvis Creek
Windy Flat
Middle Forks
Yukon R
Copper River
Susitna R
Little Susitna
Yentna
Farewell
Matanuska
Kuskokwim R
Cheeneetnuk River
Anchorage
Nunivak-Nelson Islands
Nunivak Island
Beluga
Bering River
Duktoth River
Kenai
CANADA (Yukon)
USA (Alaska)
BERING SEA
GULF OF ALASKA
Juneau
Southeast Alaska
Sitka
Ketchikan
Kodiak
Kodiak Island
Chignik
Sitkinak Island
Herendeen Bay
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

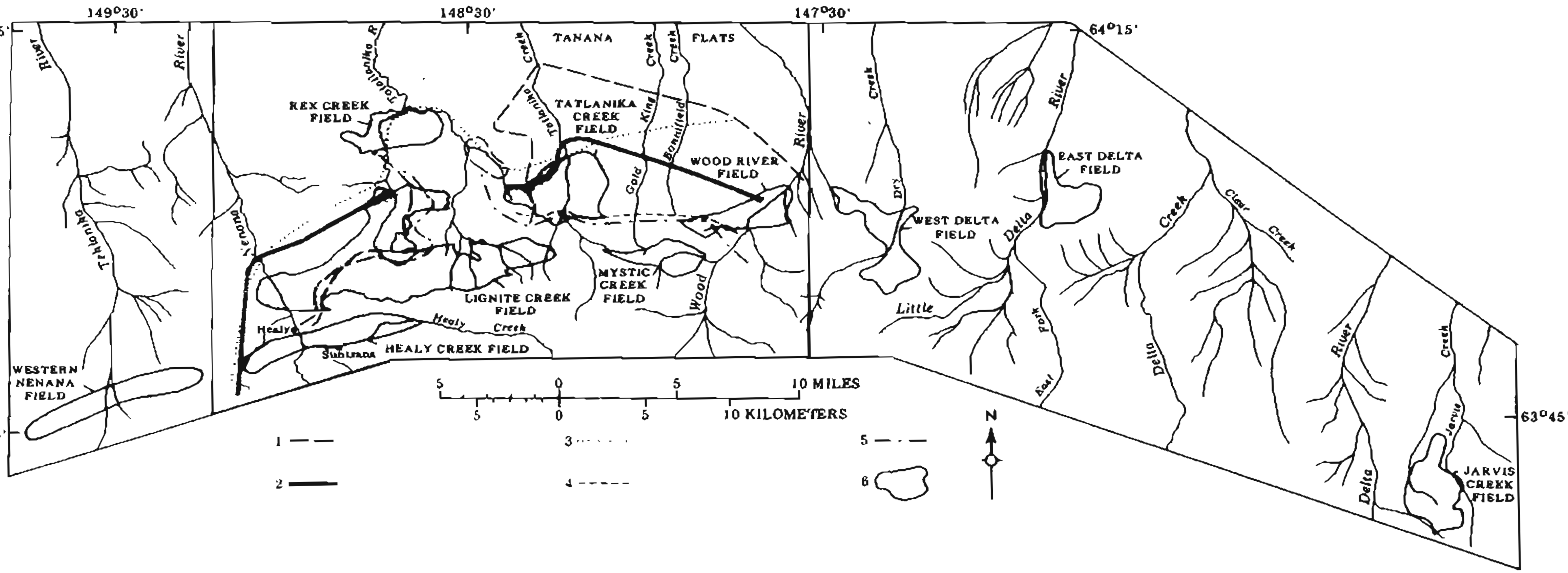
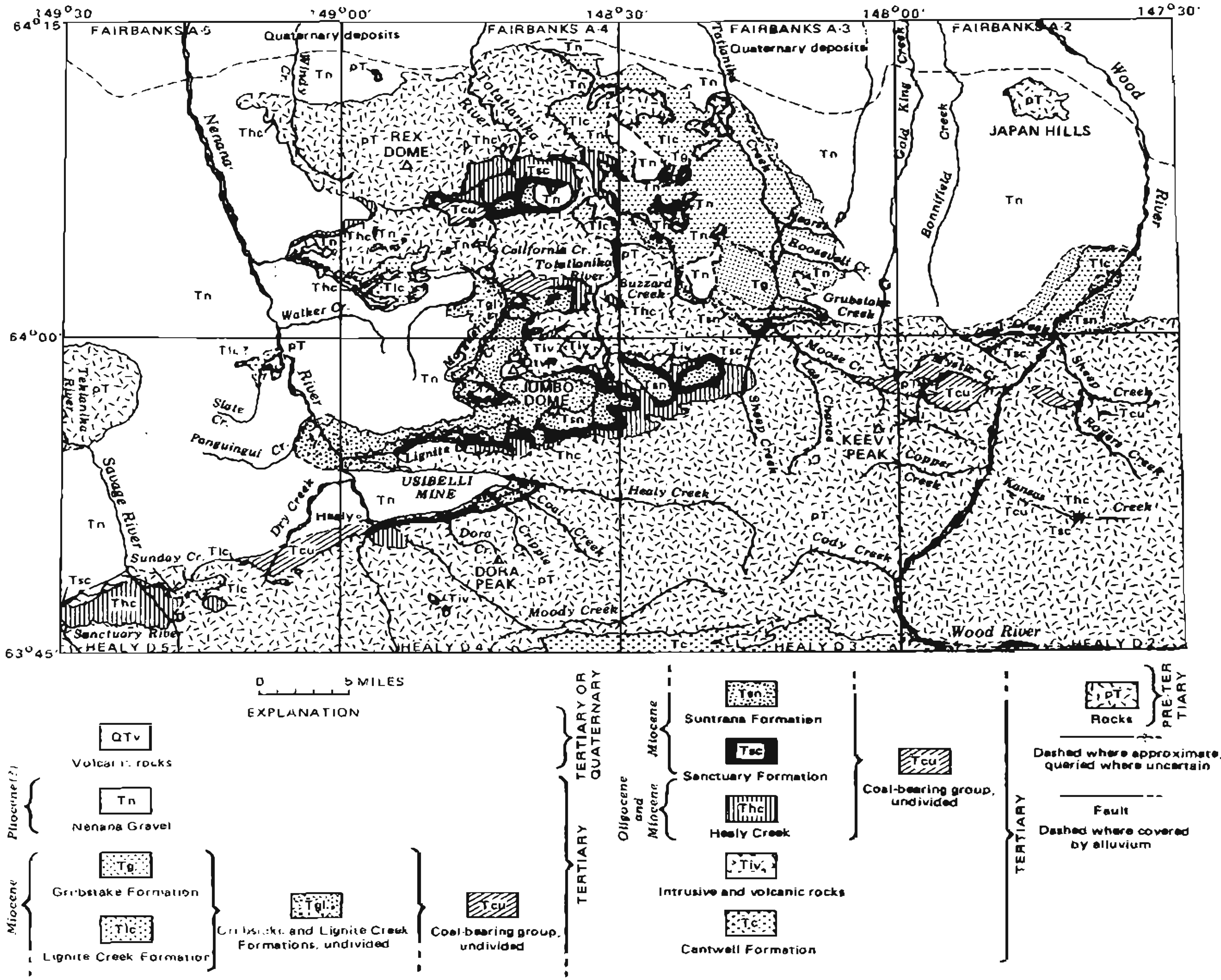

149°30'
148°30'
147°30'
64°15'
63°45'
TANANA
FLATS
REX CREEK FIELD
TATLANIKA CREEK FIELD
WOOD RIVER FIELD
LIGNITE CREEK FIELD
MYSTIC CREEK FIELD
HEALY CREEK FIELD
WESTERN NENANA FIELD
WEST DELTA FIELD
EAST DELTA FIELD
JARVIS CREEK FIELD
Tatlanika
River
Nenana
Totatlanika R
Creek
King
Gold
Bonnifield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

Figure 2



FAIRBANKS A-5
FAIRBANKS A-4
FAIRBANKS A-3
FAIRBANKS A-2
HEALY D-5
HEALY D-4
HEALY D-3
HEALY D-2
Quaternary deposits
REX DOME
JUMBO DOME
KEEVY PEAK
DORA PEAK
JAPAN HILLS
USIBELLI MINE
Healy
Nenana River
Wood River
Savage River
Sanctuary River
Teklanika River
Totatlanika River
Walker Cr.
Windy Cr.
Slate Cr.
Panguingui Cr.
Dry Creek
Sunday Cr.
Lignite Cr.
California Cr.
Buzzard Creek
Roosevelt Cr.
Grubstake Creek
Moose Cr.
Sheep Creek
Healy Creek
Coal Creek
Cripple Cr.
Dora Cr.
Moody Creek
Cody Creek
Copper Creek
Kansas Creek
Rogers Creek
Gold King Creek
Bonnifield Creek
0 5 MILES
EXPLANATION
QTv Volcanic rocks
Tn Nenana Gravel
Tg Grubstake Formation
Tlc Lignite Creek Formation
Tgl Grubstake and Lignite Creek Formations, undivided
Tcu Coal-bearing group, undivided
Tsn Suntrana Formation
Tsc Sanctuary Formation
Thc Healy Creek
Tiv Intrusive and volcanic rocks
Tc Cantwell Formation
pT Rocks
Dashed where approximate, queried where uncertain
Fault
Dashed where covered by alluvium
Pliocene(?)
Miocene
Oligocene and Miocene
TERTIARY OR QUATERNARY
TERTIARY
PRE-TERTIARY

Figure 3

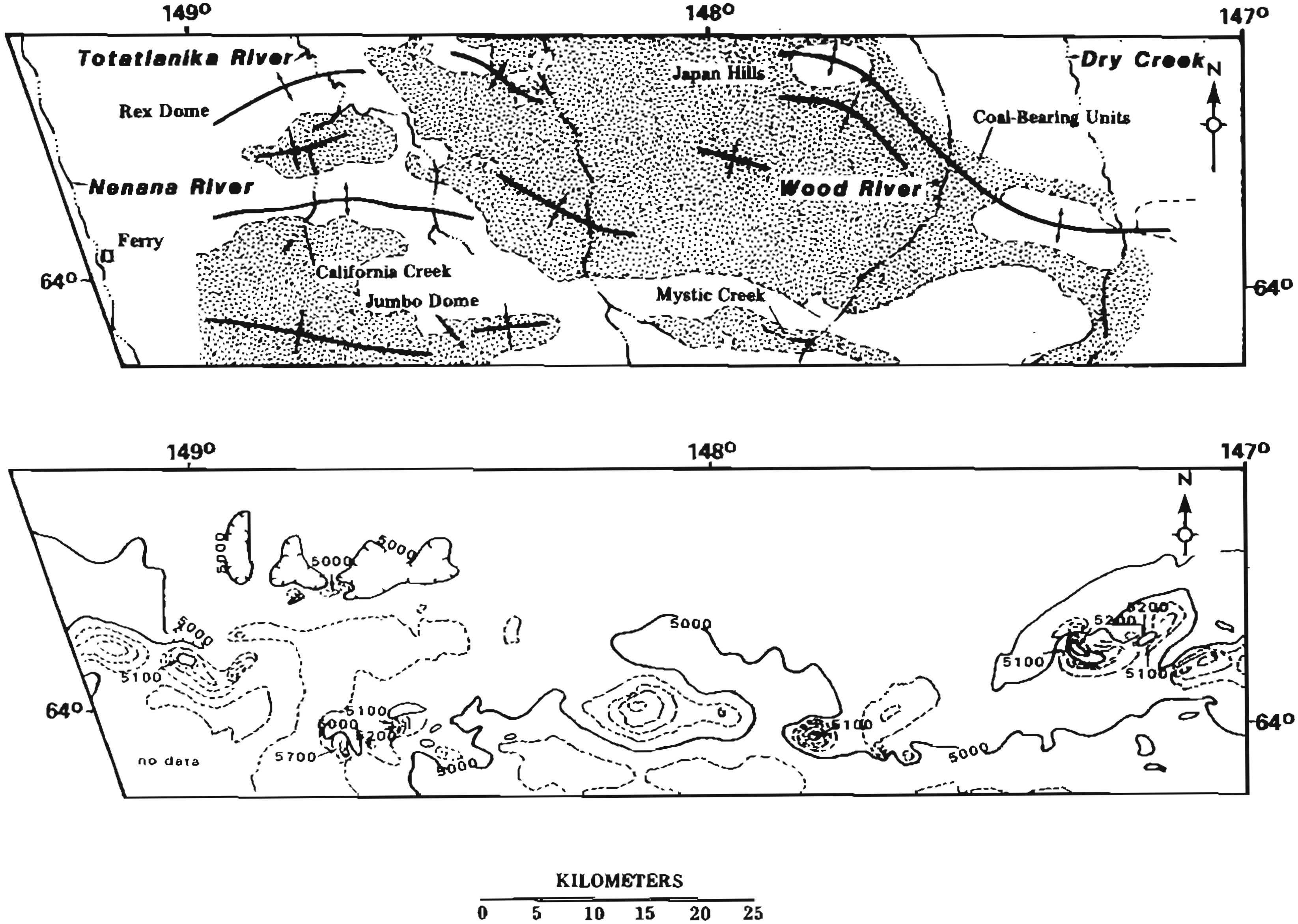
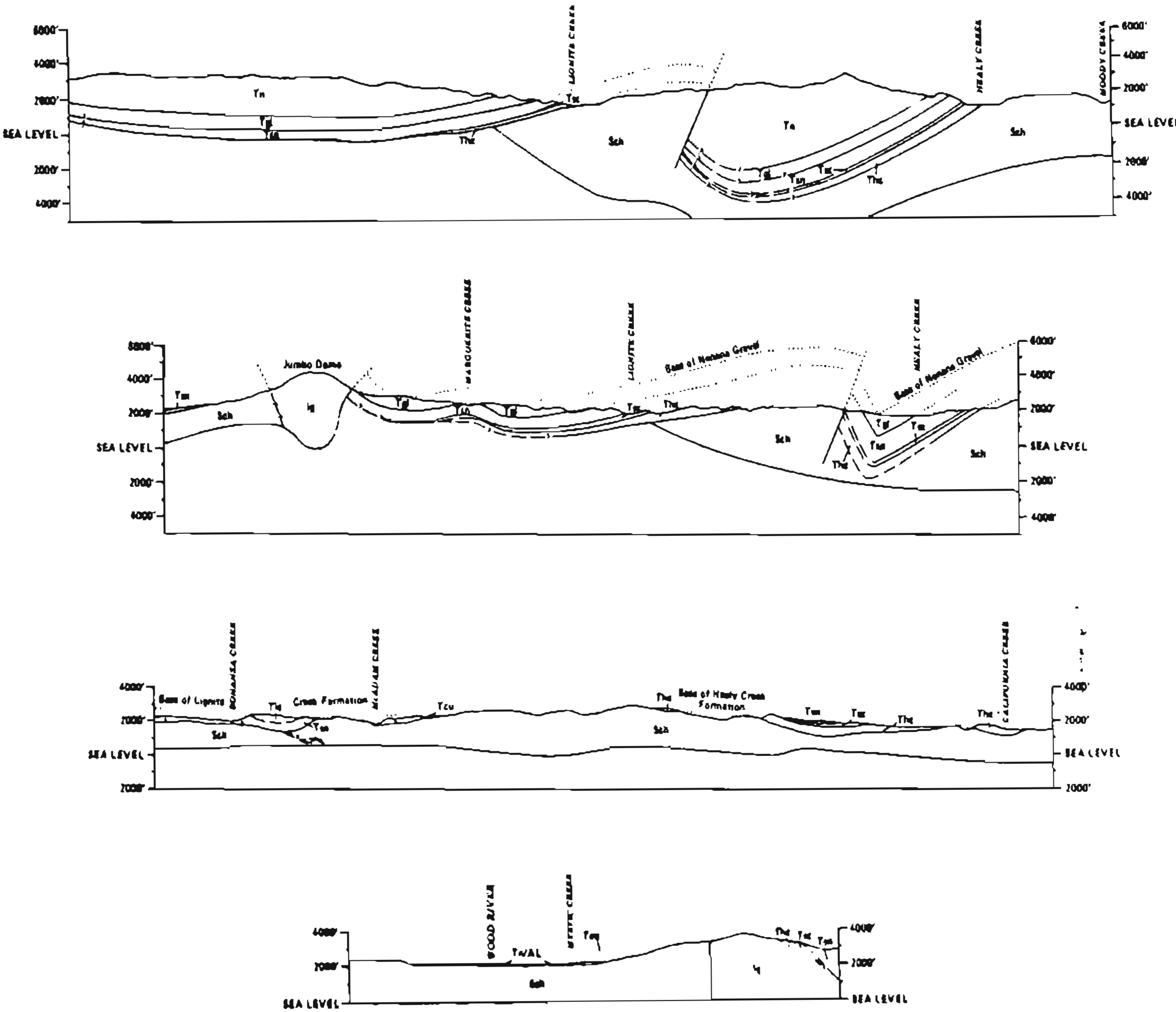

149°
148°
147°
64°
Totatlanika River
Rex Dome
Nenana River
Ferry
California Creek
Jumbo Dome
Japan Hills
Wood River
Mystic Creek
Dry Creek
Coal-Bearing Units
N
no data
5000
5100
5200
5700
KILOMETERS
0 5 10 15 20 25

Figure 4



Tn/Al = Pliocene Nenana Gravel and Quaternary surficial deposits, undivided
Tn = Pliocene Nenana Gravel
Tgl = Miocene Grubstake and Lignite Creek Formations, undivided
Tlc = Miocene Lignite Creek Formation
Tsn = Miocene Suntrana Formation
Tsc = Miocene Sanctuary Formation
Thc = Late Oligocene-Miocene Healy Creek Formation
Tcu = Tertiary coal-bearing group, undivided
Ig = Paleozoic-Cenozoic intrusive igneous rocks, undivided and highly generalized
Sch = Precambrian-Paleozoic metamorphic rocks

Figure 5

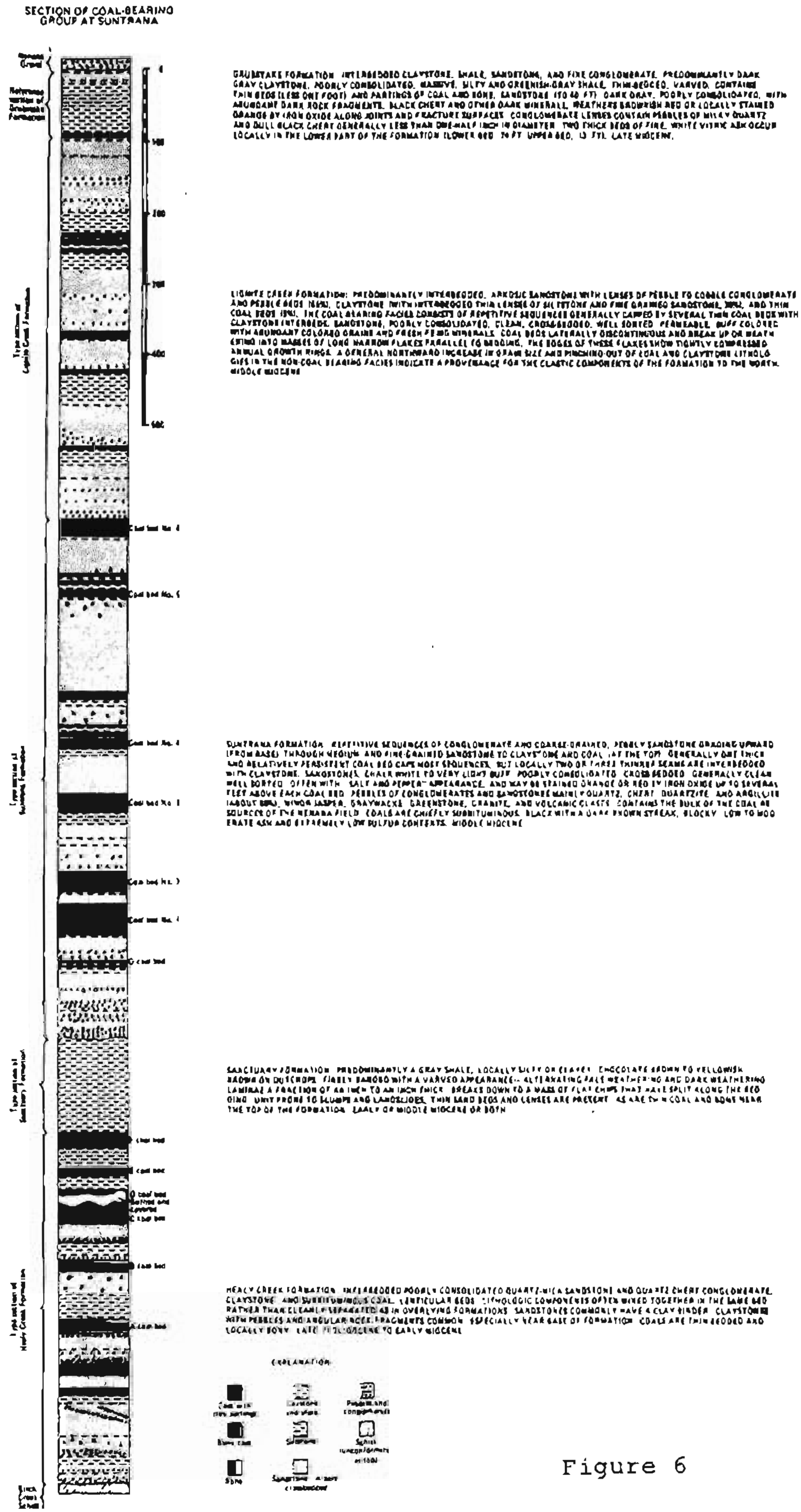

SECTION OF COAL-BEARING GROUP AT SUNTRANA
GRUBSTAKE FORMATION. INTERBEDDED CLAYSTONE, SHALE, SANDSTONE, AND FINE CONGLOMERATE. PREDOMINANTLY DARK GRAY CLAYSTONE, POORLY CONSOLIDATED, MASSIVE. SILTY AND GREENISH-GRAY SHALE, THIN-BEDDED, VARVED. CONTAINS THIN BEDS (LESS ONE FOOT) AND PARTINGS OF COAL AND BONE. SANDSTONE (10 TO 40 FT) DARK GRAY, POORLY CONSOLIDATED, WITH ABUNDANT DARK ROCK FRAGMENTS, BLACK CHERT AND OTHER DARK MINERALS. WEATHERS BROWNISH RED OR LOCALLY STAINED ORANGE BY IRON OXIDE ALONG JOINTS AND FRACTURE SURFACES. CONGLOMERATE LENSES CONTAIN PEBBLES OF MILKY QUARTZ AND DULL BLACK CHERT GENERALLY LESS THAN ONE-HALF INCH IN DIAMETER. TWO THICK BEDS OF FINE, WHITE VITRIC ASH OCCUR LOCALLY IN THE LOWER PART OF THE FORMATION (LOWER BED 20 FT, UPPER BED, 13 FT). LATE MIOCENE.
LIGNITE CREEK FORMATION: PREDOMINANTLY INTERBEDDED, ARKOSIC SANDSTONE WITH LENSES OF PEBBLE TO COBBLE CONGLOMERATE AND PEBBLE BEDS, CLAYSTONE WITH INTERBEDDED THIN LENSES OF SILTSTONE AND FINE GRAINED SANDSTONE, AND THIN COAL BEDS. THE COAL BEARING FACIES CONSISTS OF REPETITIVE SEQUENCES GENERALLY CAPPED BY SEVERAL THIN COAL BEDS WITH CLAYSTONE INTERBEDS. SANDSTONE, POORLY CONSOLIDATED, CLEAN, CROSSBEDDED, WELL SORTED, PERMEABLE, BUFF COLORED WITH ABUNDANT COLORED GRAINS AND FRESH FELDSPAR MINERALS. COAL BEDS LATERALLY DISCONTINUOUS AND BREAK UP ON WEATHERING INTO MASSES OF LONG NARROW FLAKES PARALLEL TO BEDDING. THE EDGES OF THESE FLAKES SHOW TIGHTLY COMPRESSED ANNUAL GROWTH RINGS. A GENERAL NORTHWARD INCREASE IN GRAIN SIZE AND PINCHING-OUT OF COAL AND CLAYSTONE LITHOLOGIES IN THE NON-COAL BEARING FACIES INDICATE A PROVENANCE FOR THE CLASTIC COMPONENTS OF THE FORMATION TO THE NORTH. MIDDLE MIOCENE
SUNTRANA FORMATION. REPETITIVE SEQUENCES OF CONGLOMERATE AND COARSE-GRAINED, PEBBLY SANDSTONE GRADING UPWARD (FROM BASE) THROUGH MEDIUM AND FINE-GRAINED SANDSTONE TO CLAYSTONE AND COAL (AT THE TOP). GENERALLY ONE THICK AND RELATIVELY PERSISTENT COAL BED CAPS MOST SEQUENCES, BUT LOCALLY TWO OR THREE THINNER SEAMS ARE INTERBEDDED WITH CLAYSTONE. SANDSTONES, CHALK WHITE TO VERY LIGHT BUFF, POORLY CONSOLIDATED, CROSSBEDDED, GENERALLY CLEAN, WELL SORTED, OFTEN WITH "SALT AND PEPPER" APPEARANCE, AND MAY BE STAINED ORANGE OR RED BY IRON OXIDE UP TO SEVERAL FEET ABOVE EACH COAL BED. PEBBLES OF CONGLOMERATES AND SANDSTONES MAINLY QUARTZ, CHERT, QUARTZITE, AND ARGILLITE. MINOR JASPER, GRAYWACKE, GREENSTONE, GRANITE, AND VOLCANIC CLASTS. CONTAINS THE BULK OF THE COAL RESOURCES OF THE NENANA FIELD. COALS ARE CHIEFLY SUBBITUMINOUS, BLACK WITH A DARK BROWN STREAK, BLOCKY. LOW TO MODERATE ASH AND EXTREMELY LOW SULFUR CONTENTS. MIDDLE MIOCENE
SANCTUARY FORMATION. PREDOMINANTLY A GRAY SHALE, LOCALLY SILTY OR CLAYEY. CHOCOLATE BROWN TO YELLOWISH BROWN ON OUTCROPS. FINELY BANDED WITH A VARVED APPEARANCE-- ALTERNATING PALE WEATHERING AND DARK WEATHERING LAMINAE A FRACTION OF AN INCH TO AN INCH THICK. BREAKS DOWN TO A MASS OF FLAT CHIPS THAT HAVE SPLIT ALONG THE BEDDING. UNIT PRONE TO SLUMPS AND LANDSLIDES. THIN SAND BEDS AND LENSES ARE PRESENT, AS ARE THIN COAL AND BONE NEAR THE TOP OF THE FORMATION. EARLY OR MIDDLE MIOCENE OR BOTH
HEALY CREEK FORMATION. INTERBEDDED POORLY CONSOLIDATED QUARTZ-MICA SANDSTONE AND QUARTZ CHERT CONGLOMERATE, CLAYSTONE, AND SUBBITUMINOUS COAL. LENTICULAR BEDS. LITHOLOGIC COMPONENTS OFTEN MIXED TOGETHER IN THE SAME BED RATHER THAN CLEANLY SEPARATED AS IN OVERLYING FORMATIONS. SANDSTONES COMMONLY HAVE A CLAY BINDER. CLAYSTONE WITH PEBBLES AND ANGULAR ROCK FRAGMENTS COMMON, ESPECIALLY NEAR BASE OF FORMATION. COALS ARE THIN BEDDED AND LOCALLY BONY. LATE OLIGOCENE TO EARLY MIOCENE
EXPLANATION

Figure 6

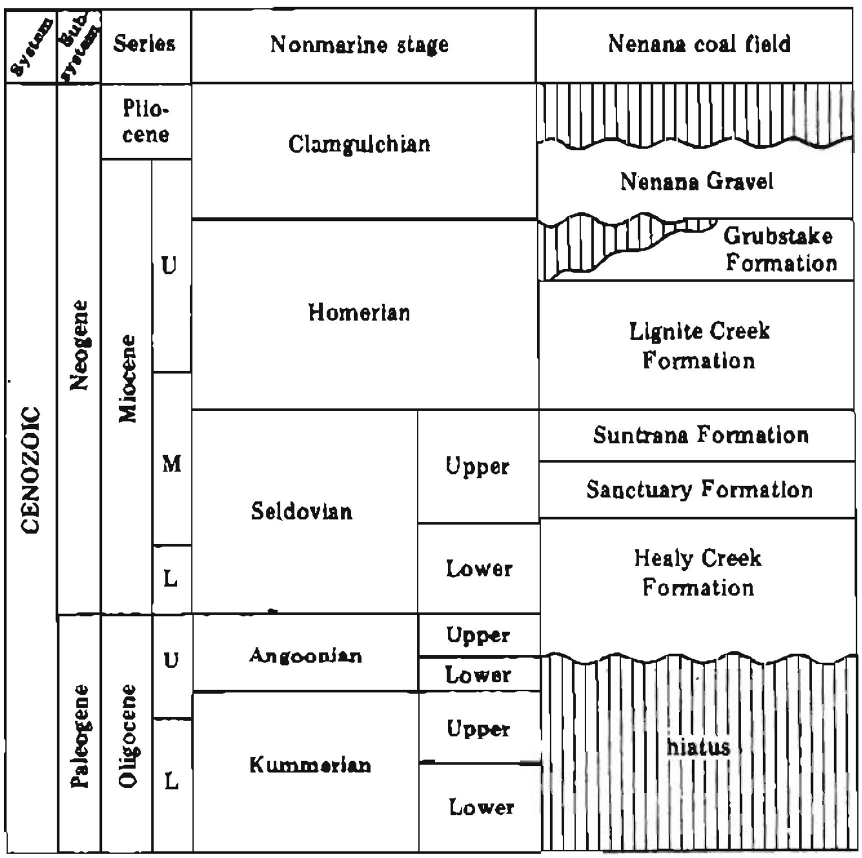

System
Sub system
Series
Nonmarine stage
Nenana coal field
CENOZOIC
Neogene
Paleogene
Plio-cene
Miocene
Oligocene
U
M
L
U
L
Clamgulchian
Homerian
Seldovian
Angoonian
Kummerian
Upper
Lower
Upper
Lower
Upper
Lower
Nenana Gravel
Grubstake Formation
Lignite Creek Formation
Suntrana Formation
Sanctuary Formation
Healy Creek Formation
hiatus

Figure 7

A

B

C

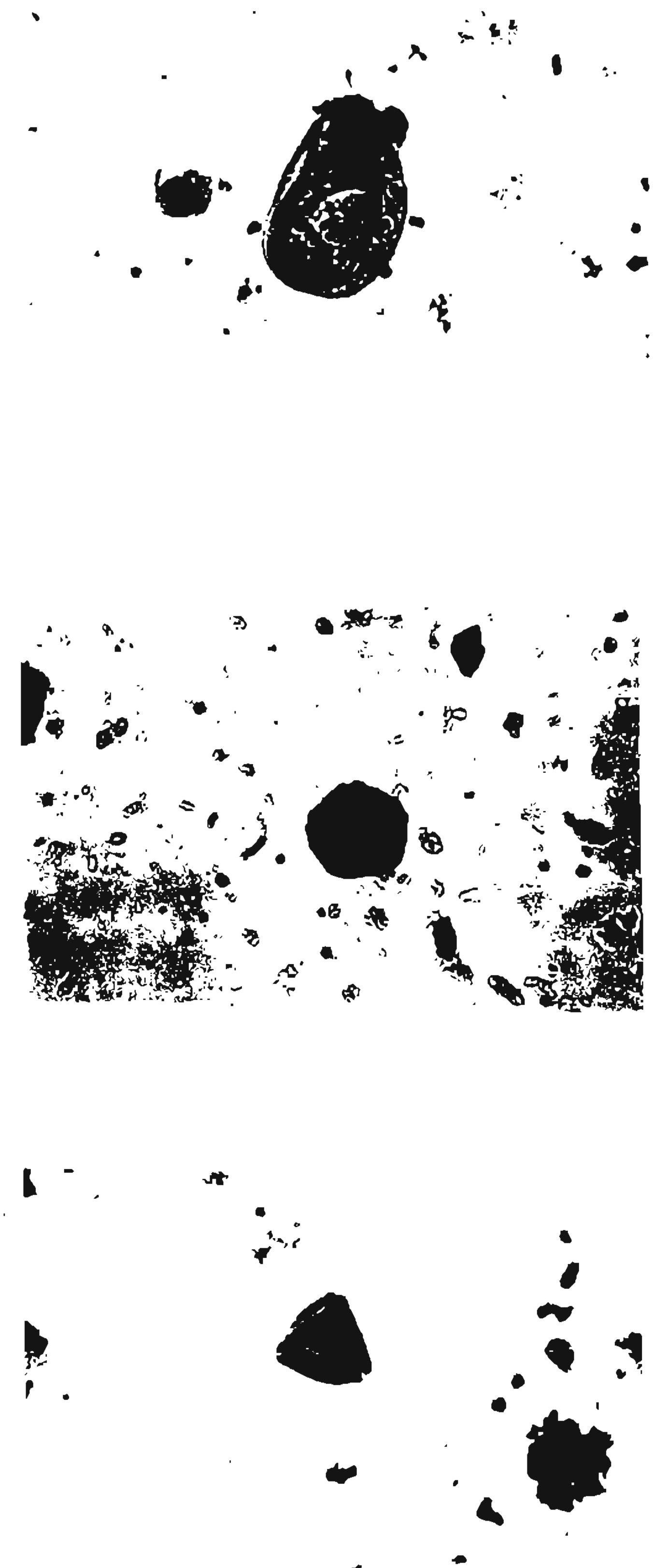


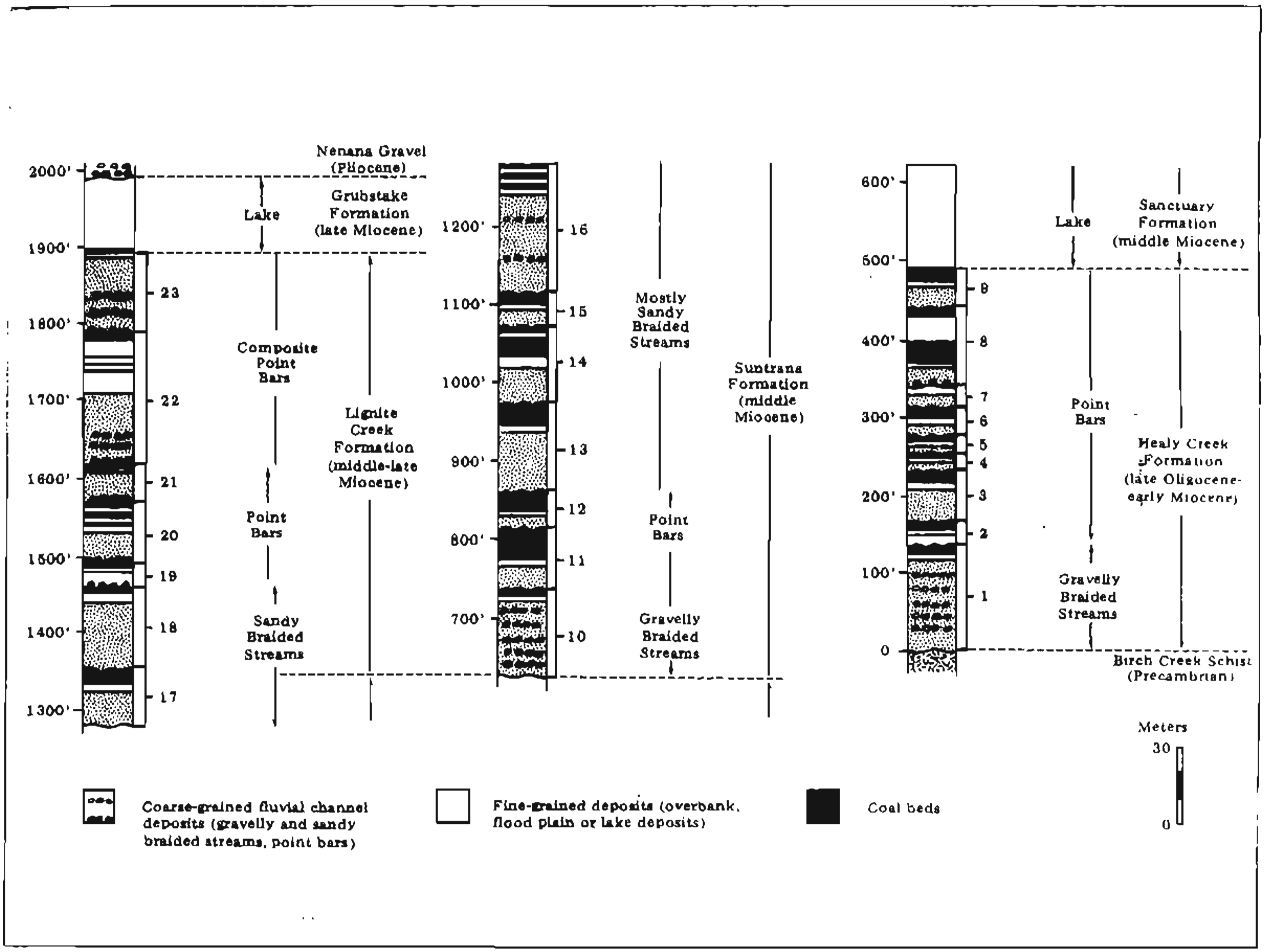
Figure 8

TYPICAL FINING-UPWARD CYCLE

BASIC LITHOLOGIC COMPONENT (FACIES)	DEPOSITIONAL TYPE(S)
UPPER COAL UNIT	SWAMP, FOREST, BOG, ETC., DEPOSITS
MIDDLE FINE-GRAINED UNIT Fine grained sandstone, siltstone, mudstone, and claystone	OVERBANK OR FLOODPLAIN DEPOSITS
LOWER COARSE-GRAINED UNIT Sandstone and/or Conglomerate	DIFFERENT TYPES OF FLUVIAL CHANNEL DEPOSITS 1 Gravelly braided streams 2. Sandy braided streams 3 Point bars

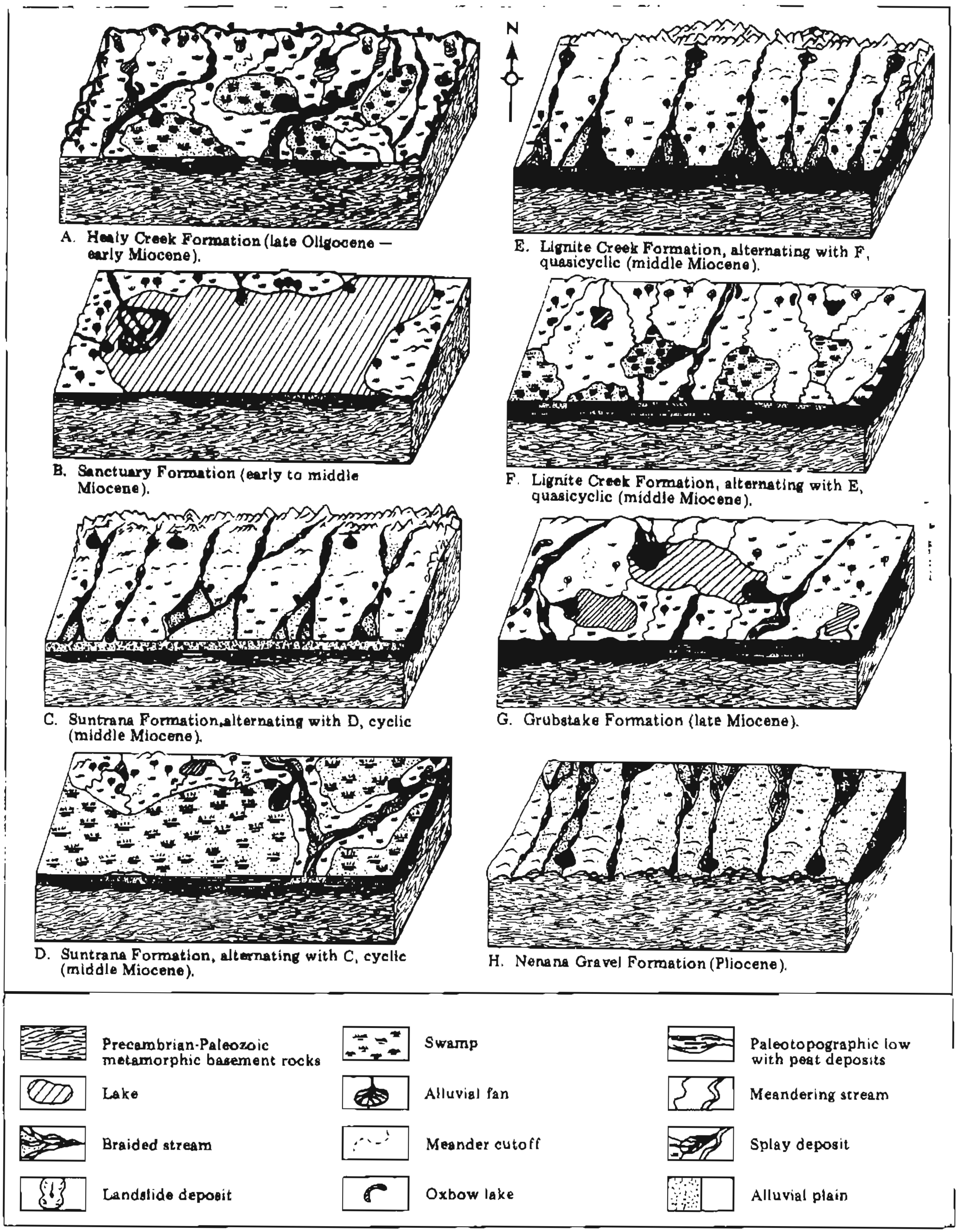
SHARP EROSIONAL BASE

Figure 9



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

Figure 10



N
A. Healy Creek Formation (late Oligocene — early Miocene).
B. Sanctuary Formation (early to middle Miocene).
C. Suntrana Formation, alternating with D, cyclic (middle Miocene).
D. Suntrana Formation, alternating with C, cyclic (middle Miocene).
E. Lignite Creek Formation, alternating with F, quasicyclic (middle Miocene).
F. Lignite Creek Formation, alternating with E, quasicyclic (middle Miocene).
G. Grubstake Formation (late Miocene).
H. Nenana Gravel Formation (Pliocene).
Precambrian-Paleozoic metamorphic basement rocks
Lake
Braided stream
Landslide deposit
Swamp
Alluvial fan
Meander cutoff
Oxbow lake
Paleotopographic low with peat deposits
Meandering stream
Splay deposit
Alluvial plain

Figure 11

A

B

Figure 12

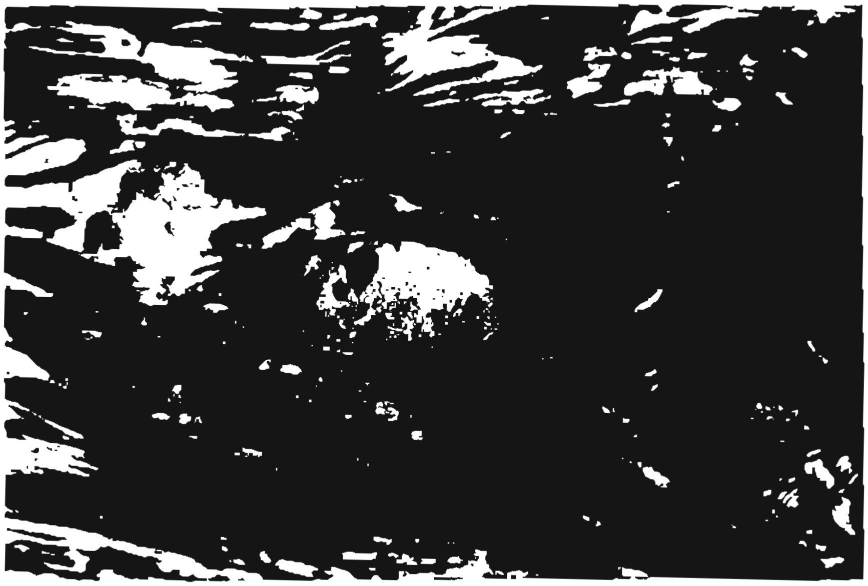
C

D

Figure 12

(Con.)

E

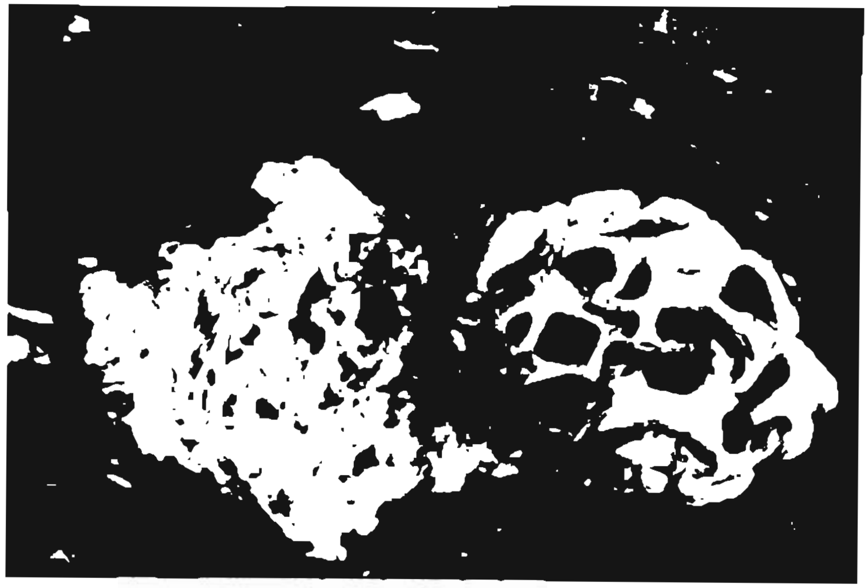


F

Figure 12

(Con.)

G



H

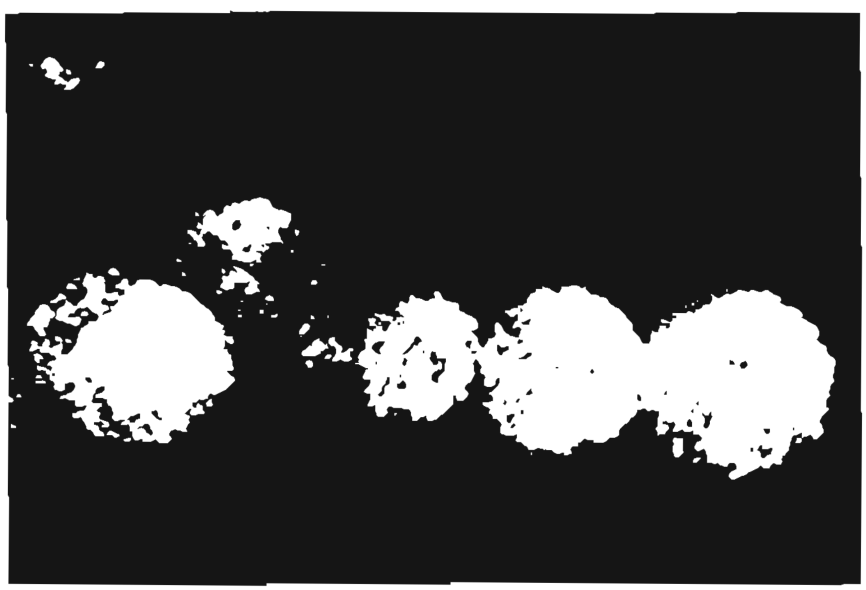
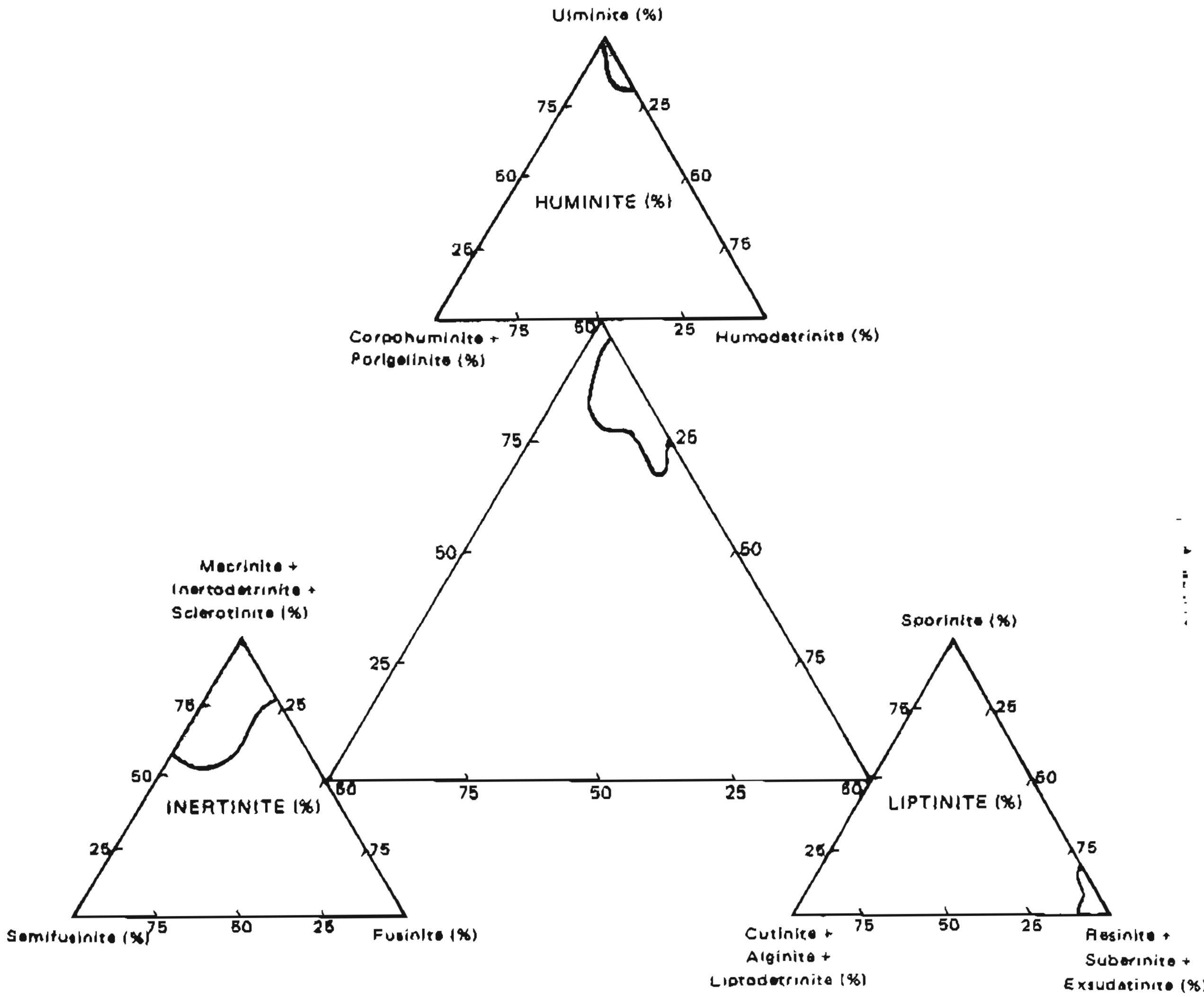


Figure 12

(Con.)



Uiminite (%)
HUMINITE (%)
Corpohuminite +
Porigelinite (%)
Humodetrinite (%)
Macrinite +
Inertodetrinite +
Sclerotinite (%)
INERTINITE (%)
Semifusinite (%)
Fusinite (%)
Sporinite (%)
LIPTINITE (%)
Cutinite +
Alginite +
Liptodetrinite (%)
Resinite +
Suberinite +
Exsudatinite (%)
75
50
25

Figure 13

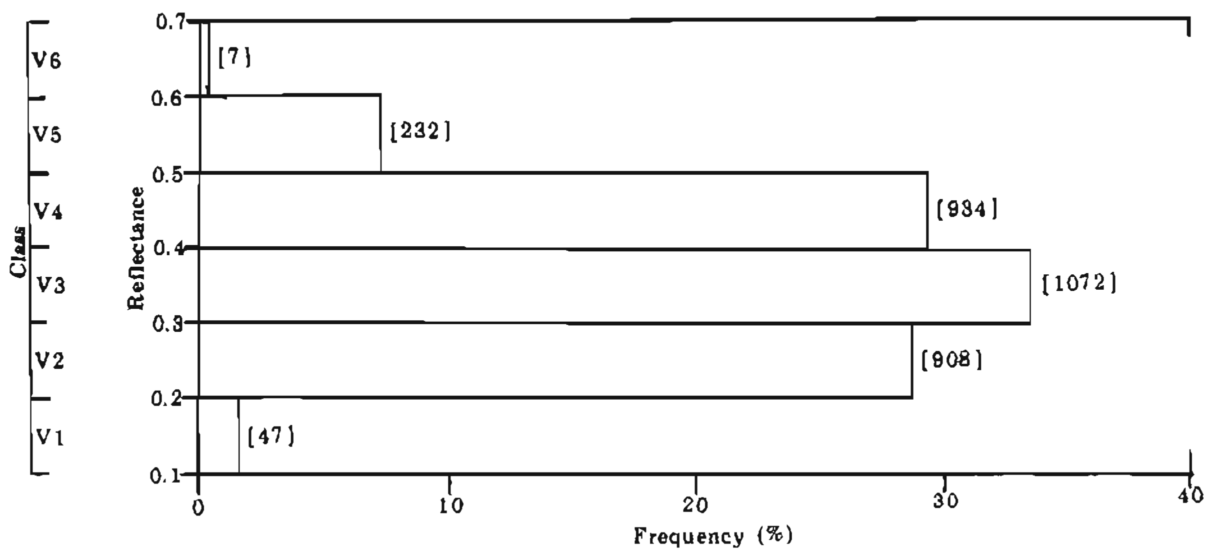

Class
V6
V5
V4
V3
V2
V1
Reflectance
0.7
0.6
0.5
0.4
0.3
0.2
0.1
[7]
[232]
[934]
[1072]
[908]
[47]
0
10
20
30
40
Frequency (%)

Figure 14

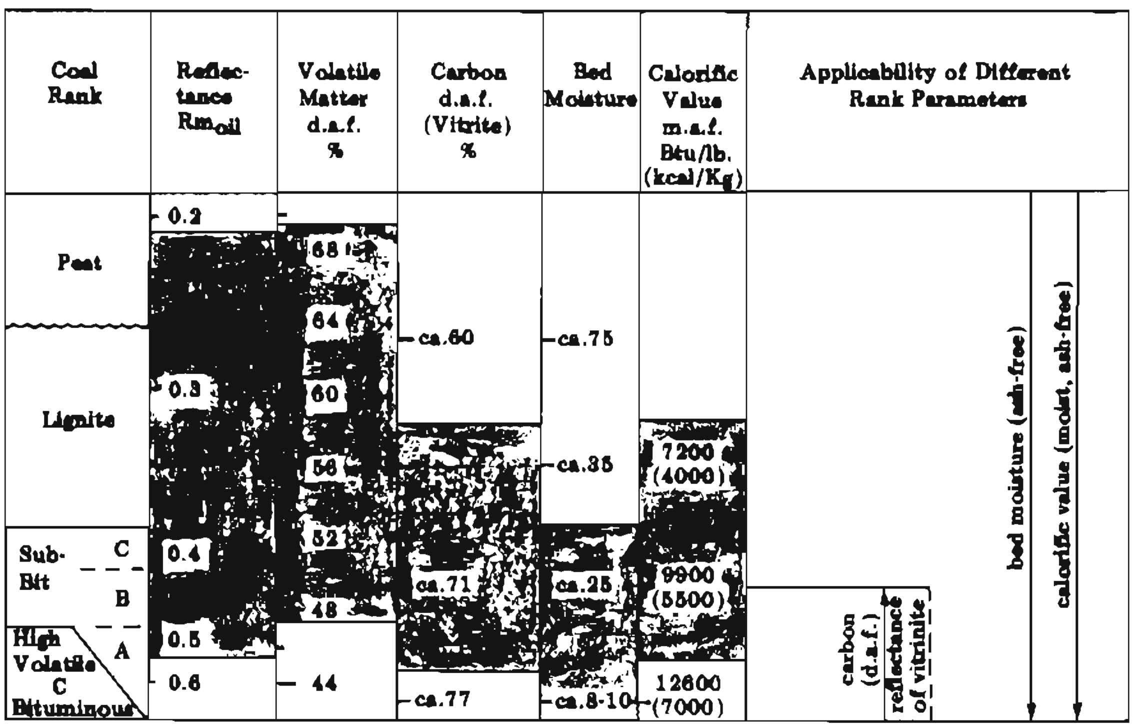

Coal Rank
Reflec-tance Rm_{oil}
Volatile Matter d.a.f. %
Carbon d.a.f. (Vitrite) %
Bed Moisture
Calorific Value m.a.f. Btu/lb. (kcal/Kg)
Applicability of Different Rank Parameters
Peat
Lignite
Sub-Bit
C
B
A
High Volatile C Bituminous
0.2
0.3
0.4
0.5
0.6
68
64
60
56
52
48
44
ca.60
ca.71
ca.77
ca.75
ca.35
ca.25
ca.8-10
7200
(4000)
9900
(5500)
12600
(7000)
carbon (d.a.f.)
reflectance of vitrinite
bed moisture (ash-free)
calorific value (moist, ash-free)

Figure 15

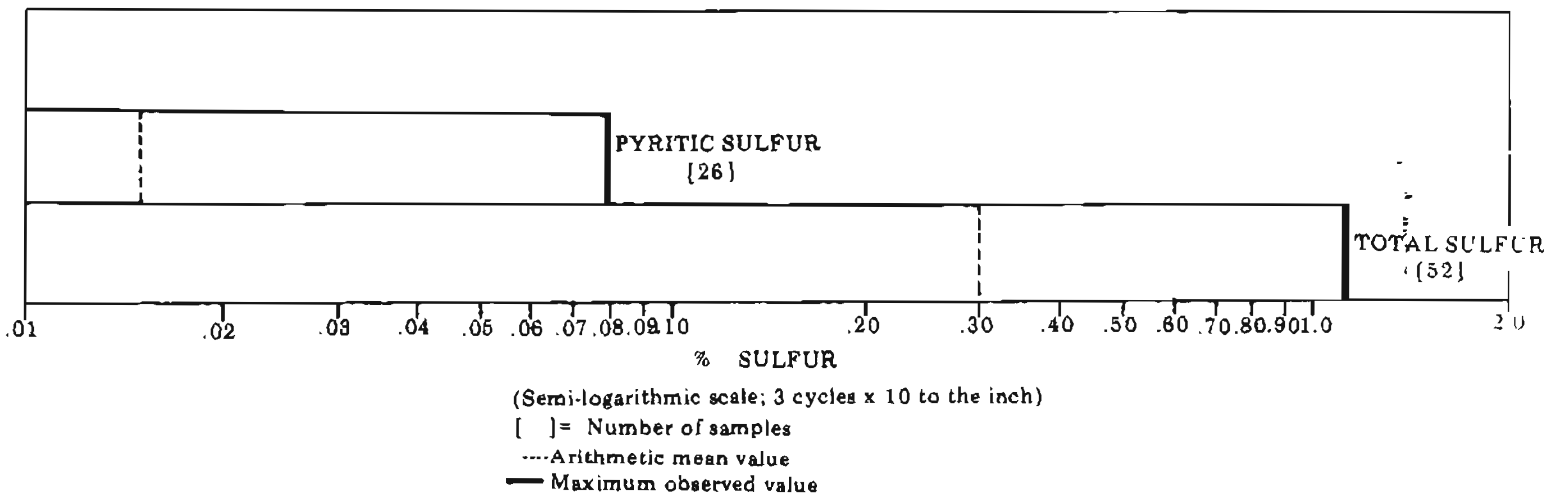

PYRITIC SULFUR
[26]
TOTAL SULFUR
[52]
.01
.02
.03
.04
.05
.06
.07
.08
.09
.10
.20
.30
.40
.50
.60
.70
.80
.90
1.0
2.0
% SULFUR
(Semi-logarithmic scale; 3 cycles x 10 to the inch)
[ ]= Number of samples
----Arithmetic mean value
Maximum observed value

Figure 16

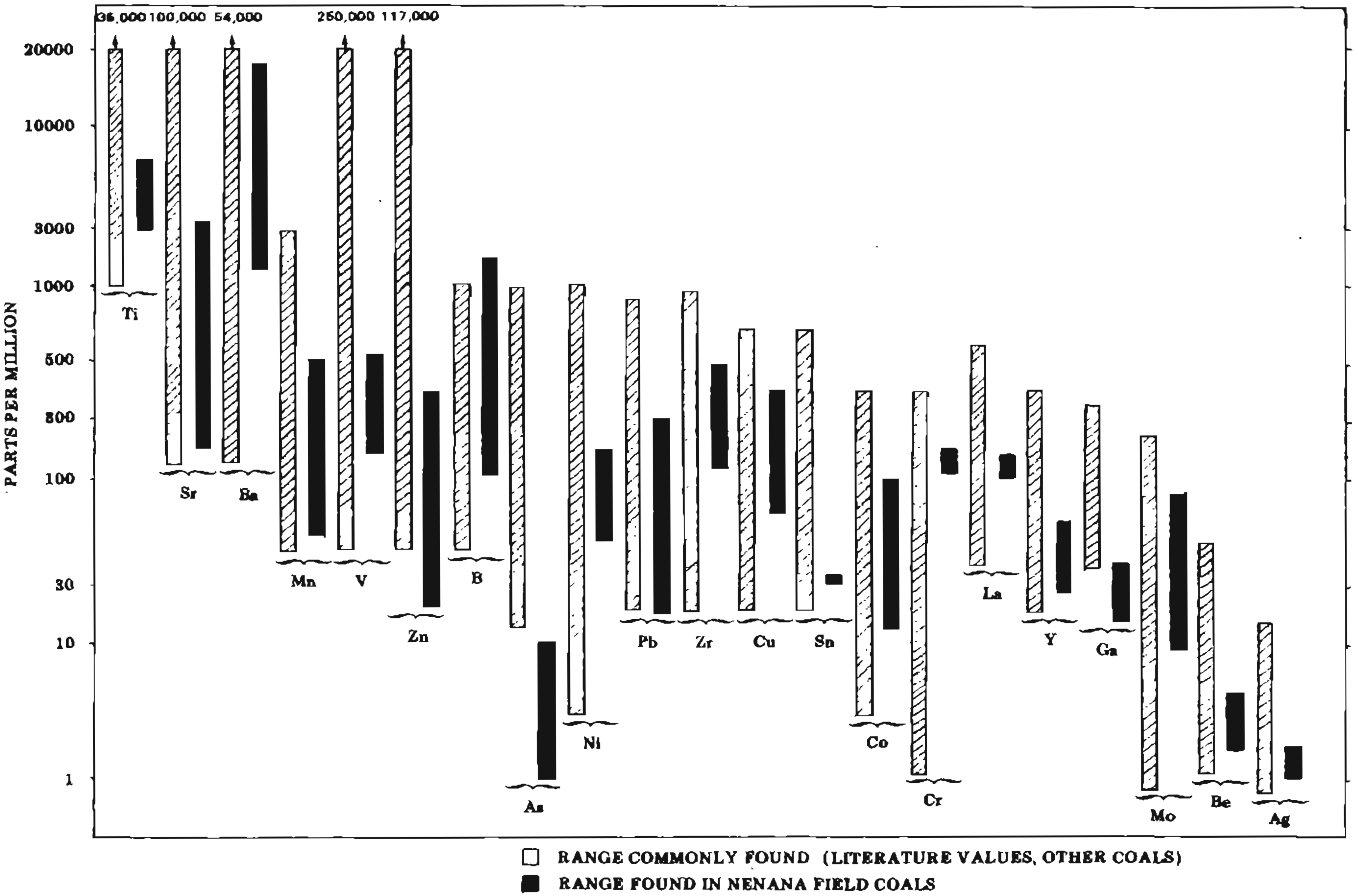

36,000 100,000 54,000 250,000 117,000
20000
10000
3000
1000
500
300
100
30
10
1
PARTS PER MILLION
Ti
Sr
Ba
Mn
V
Zn
B
As
Ni
Pb
Zr
Cu
Sn
Co
Cr
La
Y
Ga
Mo
Be
Ag
RANGE COMMONLY FOUND (LITERATURE VALUES, OTHER COALS)
RANGE FOUND IN NENANA FIELD COALS

Figure 17

Table 1. Summary of palynological assemblage characteristics for the coal-bearing formations of the Nenana basin (compiled from Wahrhaftig and others, 1969).

Formation	Pollen Forms	Dominants	Percent Exotic Genera	Stage/ Age	Comments
Grubstake	Problematic due to possibility of redeposition of pollens from older formations of the coal-bearing group.	Pinaceae and Betulaceae	Frequency of genera of broad-leaved exotics low.	Homerian; Middle to Upper Miocene	Microfossil floras from 11 samples.
Lignite Creek	Deciduous broad-leaved tree element considerably reduced both in abundance (less 2% of tallied pollen) and diversity of types. Highest occurrence of *Nyssa*.	*Pinus*, *Alnus*, or *Betula*	44%, considerably less than in underlying formations.	Late Seldovian; Middle Miocene	Flora known only from six microfossil samples.
Suntrana	Deciduous broad-leaved tree element considerably reduced in consistency of occurrence, representing 3% of pollen tallied. *Fagus* and *Acer* have highest local occurrence.	Abundance of tetraporate *Alnus* and *Betula* grains; in one sample, made up 75% of pollen tallied.	52%	Seldovian; Middle Miocene	Pollen floras determined from 26 samples.
Sanctuary	In most samples, Taxodiaceae pollen more common. One sample with pollen of *Pinus* dominant.	Pollen of broad-leaved trees consistently represented and typically more common than in upper part of Healy Creek Formation.	Of 33 identified vascular genera, 52% now exotic to Alaska.	Seldovian; Early or Middle Miocene or both	Exotic genera and broad-leaved tree element indicate stage assignment.
Healy Creek (upper part)	*Ephedra*, *Quercus*, *Nyssa*, Compositae (one grain of short-spined type of latter)	Diversity of broad-leaved tree forms.	58% of genera present now exotic to Alaska.	Seldovian; Late (?) Oligocene to Early Miocene	Eight pollen assemblages show several forms not found in lower part (at left).
Healy Creek (lower part)	*Aquilapollenites* n. spp. (heteropolar and isopolar), *Orbiculapollis*, *Saxifraga*, *Itea*, *Pachysandra*/*Sarcococca*, *Cuphea*-type, *Melia*/*Cedrela*, *Engelhardia*/*Alfaroa*, *Proteacidites globisporus* Samoil.	Deciduous broad-leaved tree forms.	Of 40 vascular genera identified, 60% now exotic to Alaska.	Angoonian; Late (?) Oligocene	Eight pollen and spore assemblages show diverse pollen flora.

Table 2. Summary of coal petrologic data for 70 coal samples from the Nenana basin.

Maceral/Maceral Type	Range	Mean
Ulminite*/Vitrinite	35.8 - 90.9	74.3
Pseudovitrinite	0.0 - 1.1	0.0
Porigelinite	0.0 - 1.9	0.4
Phlobaphinite	0.0 - 2.3	0.5
Pseudophlobaphinite	0.0 - 2.5	0.5
Humodetrinite	0.6 - 34.3	7.1
Total Huminite	68.5 - 93.9	82.9
Fusinite	0.0 - 1.8	0.2
Semifusinite	0.0 - 4.7	0.4
Sclerotinite	0.0 - 1.4	0.3
Macrinite	0.0 - 7.9	0.6
Inertodetrinite	0.0 - 6.4	1.2
Total Inertinite	0.2 - 20.1	2.7
Cutinite	0.0 - 0.7	0.0
Sporinite	0.0 - 1.1	0.2
Resinite**/Suberinite/Exsudatinite	2.5 - 27.6	14.1
Alginite	0.0 - 0.1	0.0
Liptodetrinite	0.0 - 0.4	0.0
Total Liptinite	2.6 - 27.6	14.4

* Almost exclusively ulminite

** Predominantly resinite

Table 3. Proportions of the three maceral groups in coal samples of the coal-bearing formations of the Nenana basin.

	Maceral Group		
Formation	Huminite	Liptinite	Inertinite
Lignite Creek	H	L-M	M-H
Suntrana	H	L-H	L-M
Healy Creek	H	M-H	L
Undifferentiated Tertiary coal-bearing unit*	H	M-H	L

Criteria as used here:

	Low(L)	Moderate(M)	High(H)
Huminite	<50%	50-75%	>75%
Liptinite	<5%	5-15%	>15%
Inertinite	<5%	5-15%	>15%

* Most of these samples were taken from stratigraphic sections that probably correlate with the Healy Creek Formation.

Table 4. Summary of proximate analysis data (71 coal samples) and ultimate analysis data (27 coal samples) for the Nenana basin.

		Proximate					Ultimate				
Statistic	Basis*	Moisture	Volatile matter	Fixed carbon	Ash	Heating value	Hydrogen	Carbon	Nitrogen	Oxygen	Sulfur
	1	7-36	20-42	9-42	2-45	3400-10800	4.6-7.0	28-60	0.1-0.9	18-47	0.2-0.7
Range	2	9-31	21-41	10-41	2-43	3500-9800	4.5-6.9	29-54	0.1-0.8	18-43	0.2-0.7
	3	- -	26-53	14-50	2-56	4600-12200	3.4-5.5	39-68	0.1-1.1	14-30	0.2-0.9
	4	- -	48-69	31-52	- -	10500-13500	4.6-6.8	64-75	0.2-1.2	17-29	0.2-1.0
	1	23	34	30	12	7900	6.2	47	0.6	36	0.3
Mean	2	23	35	30	12	7900	6.2	46	0.6	36	0.3
	3	- -	46	39	15	10200	4.7	61	0.8	24	0.4
	4	- -	54	46	- -	12100	54	70	0.9	23	0.4

*1 - As received; 2 - equilibrium moisture; 3 - moisture-free; and 4 - moisture- and ash-free.

Table 5. Factors of enrichment for certain rare elements in coal ash (including Nenana basin coals) compared to the average contents of the same elements in the Earth's crust.

Element	Average Content in Earth's Crust* (gms/ton)	Average Content in Coal Ash* (gms/ton)	Average Content in Coal Ash, Nenana Field** (gms/ton)	General Factor of Enrichment*	Factor of Enrichment Based on Nenana Coal Field Samples**
Ge	1.5	500	---	330	---
As	2	500	---	250	---
U	2.7	400	---	150	---
Bi	0.2	20	---	100	---
B	10	600	550	60	55
Mo	1.5	50	26	30	17
Cd	0.2	5	1.1	25	5.5
Ag	0.1	2	1.3	20	13
Be	2.8	45	4	16	1.4
Co	25	300	52	12	2.1
Ni	75	700	121	9	1.6
Pb	13	100	81	8	6.2
Ga	15	100	27	7	1.8
Sc	22	60	27	3	1.2

*From Mason, 1966, table 9.5, p. 241.

**Limited number of samples.

Table 6. Estimates of potentially minable coal resources in fields of the Nenana basin (millions of short tons), projected to an overburden limit of 150 m and including all beds greater than or equal to 0.75-m thick.

Field	High Assurance	Moderate Assurance	Low Assurance
1) Lignite Creek	850	1600	2400
2) Healy Creek	250	400	600
3) Western Nenana	80	260	300
4) Tatlanika Creek	70	145	225
5) Wood River	65	90	200
6) Jarvis Creek	30	85	175
7) Rex Creek	15	30	65
8) Mystic Creek	10	25	50
9) West Delta	5	20	40
10) East Delta	5	15	35
TOTAL	1380	2670	4090

Table 7. Summary geochemical and physical characteristics of 43 coal overburden samples from six general areas of the Nenana basin.

Overburden Parameter	Range	Mean**	Units
paste pH	5.2-7.3	6.2	pH
Electrical conductivity	0.2-1.6	0.5	mmhos/cm
Saturation percentage	20.7-101.6	50.3	%
Water soluble cations			
Calcium	0.1-42.2	3.8	meq/liter
Magnesium	0.1-11.4	2.2	meq/liter
Sodium	0.4-4.9	1.8	meq/liter
Sodium adsorption ratio	0.3-5.4	1.6	ratio
Exchangeable sodium percentage	0.4-8.7	3.2	%
Particle size			
Sand	6-83	38	%
Silt	4-68	39	%
Clay	7-42	22	%
Texture	LS, L, SL, SCL, SiL, SiCL, CL, C, SiC*	---	---
Bulk density	0.81-1.39	1.10	gms/cm^3
Organic matter	0.14-11.67	4.58	%
Total organic carbon	2.9-50.5	16.2	%
Extractable nutrients			
Nitrate nitrogen (NO_3-N)	1.1-31.5	5.9	ppm
Phosphorous	0.4-18.9	6.0	ppm
Potassium	13-273	158	ppm
Ammonium acetate extractable cations			
Calcium	0.2-161.2	17.5	meq/100 gms
Magnesium	0.8-16.1	6.0	meq/100 gms
Sodium	0.0-1.5	0.4	meq/100 gms
Potassium	0.1-0.9	0.4	meq/100 gms
Cation exchange capacity	2.7-79.7	19.1	meq/100 gms
Base saturation	34-100	89	%
Total sulfur	0.01-0.34	0.08	%
Lime	4.6-25.1	7.4	%
Acid potential	0.01-21.25	4.79	meq H^+/100 gms
Neutralization potential	13.8-60.6	21.6	tons $CaCO_3$ equivalent per 1000 tons
Potential acidity	11.9-50.6	19.2	tons $CaCO_3$ equivalent per 1000 tons
Trace elements			
Boron	0.45-6.85	2.17	ppm
Copper	0.31-32.14	10.34	ppm
Molybdenum	0.12-0.76	0.44	ppm
Lead	0.07-68.18	11.50	ppm
Selenium	<0.01	<0.01	ppm

* LS=loamy sand; L=loam; SL=sand loam; SCL=sandy clay loam; SiL=silt loam; SiCL=silty clay loam; CL=clay loam; C=clay; and SiC=silty clay.
** 43 samples from six general areas.