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COAL ATLAS OF THE NENANA BASIN, ALASKA

By

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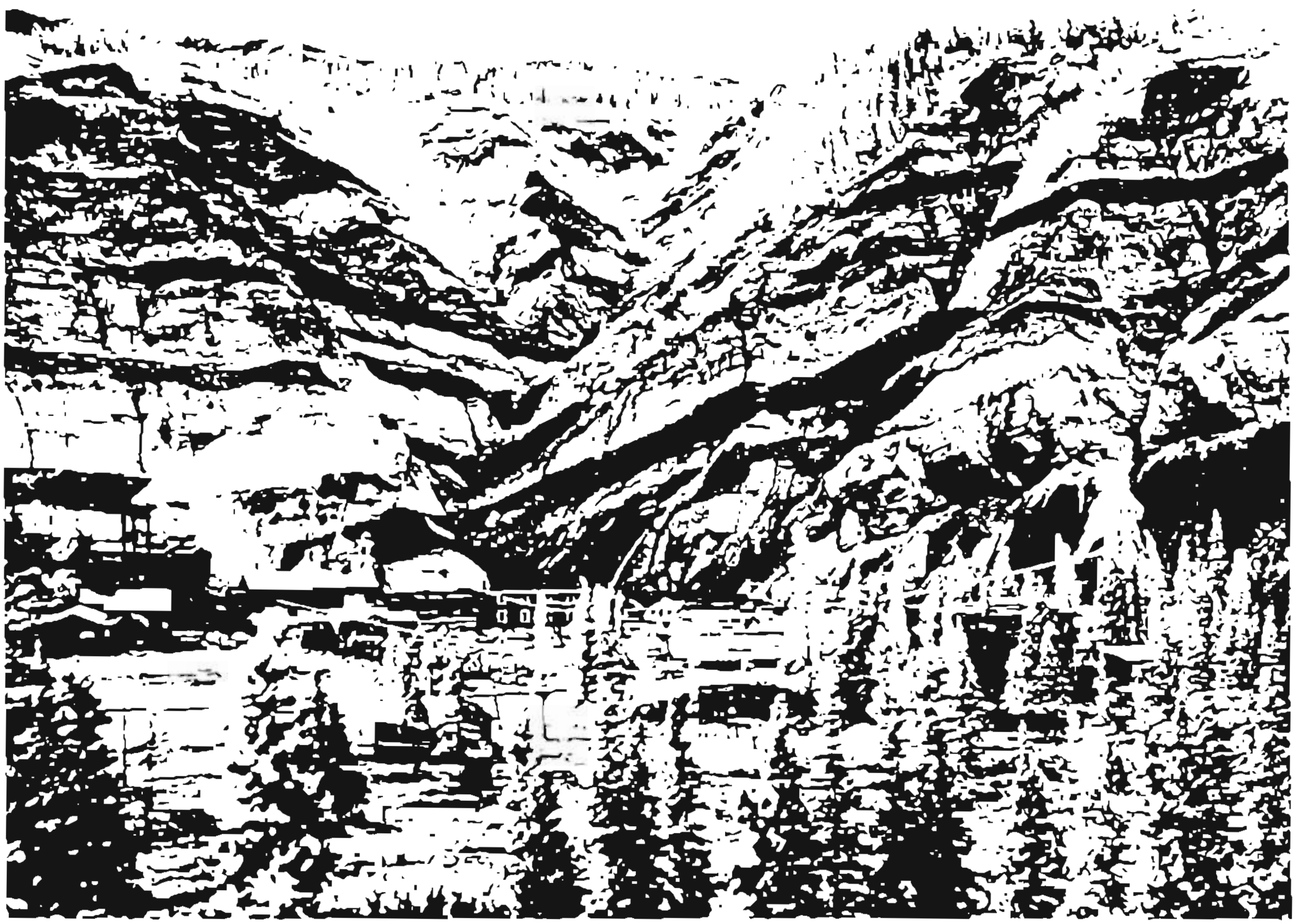

Suntrana Mine, Healy Creek, Nenana Coal field, 1922-1962 (Bunnell Collection, University of Alaska Archives, Fairbanks).

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FOREWORD

Alaska has extensive deposits of minable lignite to anthracite grade coals. The high cost of petroleum fuels and uncertainty of supply have created a strong interest by industry, government, and the public in Alaska's coal resources and the feasibility of producing them for local use, export, and the generation of synthetic fuels.

The Alaska Division of Geological and Geophysical Surveys (DGGS) has initiated a program to investigate various coal fields to assess the coal resources of the state. DGGS will compile a separate coal atlas for each important coal field. The reports will assemble all available geological and resource information pertinent to coal development. The Nenana coal basin is the second area selected for study.

The purposes of these investigations are: a) to aid land classification and management as well as in issuing coal prospecting permits and coal leases; b) to more accurately determine coal resources and reserves and the potential for coal development; c) to address the numerous inquiries of industry interested in developing the coal resources and of Pacific-rim countries seeking coal supplies; and d) to provide a single source of information on the coal deposits of an area.

The present report summarizes the results of field studies and compilation efforts during the 1982-83 fiscal year. It is hoped that this report will serve the interests and needs of a broad spectrum of individuals and agencies within and outside Alaska.

ACKNOWLEDGMENTS

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ABSTRACT

The Nenana coal basin includes a structurally similar series of disconnected subbasins or subfields, 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-bearing areas of the Nenana basin or field proper include Healy Creek, Lignite Creek, Rex Creek, Tatlanika Creek, Mystic Creek, Wood River, and Jarvis Creek. The Jarvis Creek subfield east of the Delta River occupies an isolated subbasin at the easternmost extent of the Nenana trend. Deposits of the western margin of the trend are found from 150 to 200 miles southwest of the Nenana field near Farewell at Little Tonzona River, Windy and Middle Forks of the Kuskokwim River, and at Cheeneetnuk River.

The approximately 3,000-ft 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 field attain thicknesses to 60 ft. The Suntrana Formation contains the bulk of the economically exploitable coal resources of the Nenana field. The Usibelli Coal Mine, Inc. at Poker Flats of the lower Lignite Creek subbasin is the only significant coal mining operation in Alaska and is presently mining the 3, 4, and 6 seams of the Suntrana Formation, each of which averages about 20-ft thick. The mine is currently producing over 800,000 short tons of coal per year.

Identified coal resources of the Nenana basin are about 8 billion short tons, and additional inferred coal resources along the entire Nenana trend increase the total to about 10 billion short tons. At least 1.4 billion short tons are estimated to be potentially surface-minable (to 500 ft depth) under current economic conditions. Major coal deposits of the Nenana field also occur to the south and west of Jumbo Dome, particularly along the Marguerite Creek drainage basin (Meadowlark Farms, Inc. state coal lease tracts) and upper Lignite Creek region. A smaller and more isolated subbasin 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 100 ft 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 may 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 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.

This Nenana basin analysis is mainly complimentary and supplementary to previous geologic and coal resource investigations in the Nenana coal field. The present study summarizes and builds upon the earlier excellent geologic work of Clyde Wahrhaftig and his associates in the region from 1943 to 1958, but changes few of the basic geologic concepts and maps of past researchers.

INTRODUCTION

The coals of the Nenana basin were probably discovered about 1898 (Collier, 1903). Coal production has been relatively continuous in the Nenana coal field since about 1918. Currently, the Usibelli Mine on lower Lignite Creek near Healy is the only significant operating coal mine in Alaska; the mine produced 803,000 short tons in 1983. 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 subbasin, 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 the intervening areas. The sedimentary rocks of the basin are weakly indurated terrestrial clastics interbedded with numerous subbituminous coal beds from 10 to 60 ft 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 following U.S. Geological Survey 1:250,000 scale topographic maps: Fairbanks, Healy, Big Delta, and Mt. Hayes. The approximate area (plate 1), as considered in this report, includes townships 8-14 south (Fairbanks Meridian) at its west extremity, townships 9-12 south in the central portion, and townships 13-15 south at its east extremity, and ranges 12 west to 11 east inclusively. This area encompasses over 2,500 mi^2.

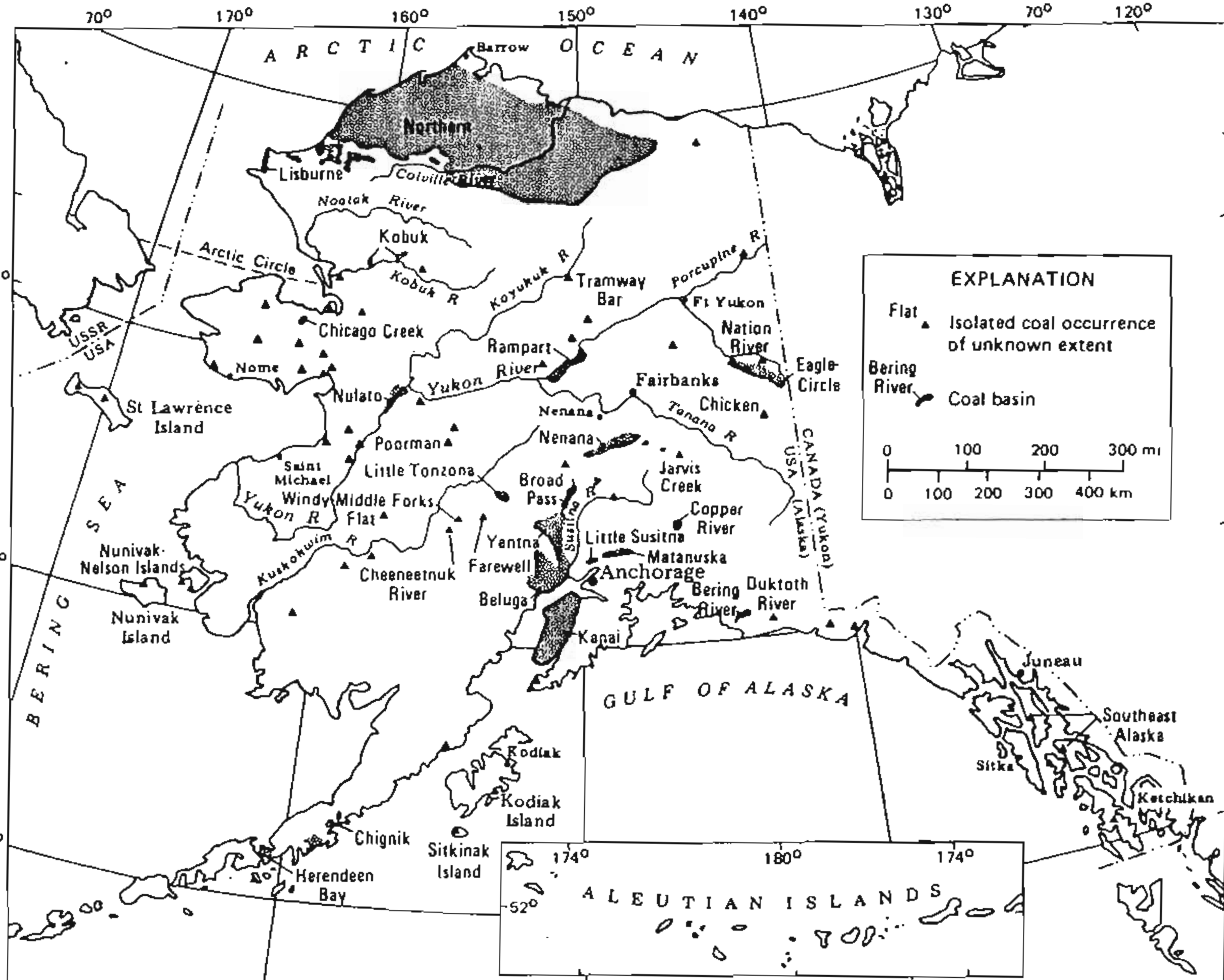


Figure 1. Coal fields, basins, and isolated occurrences in Alaska showing general location of the Nenana basin of interior Alaska.

Outcrops of the coal-bearing group are restricted to an area less than 1,000 mi^2. The belt of Tertiary coal-bearing rocks extends for about 140 miles along the north-central flank of the Alaska Range and is up to 30 miles wide. The Nenana trend continues 150 to 200 miles southwest of the Nenana basin proper and includes the coal-bearing rocks of the Farewell (Little Tonzona) field.

The Alaska Railroad crosses the Nenana field 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. Numerous haul roads and trails extend from Healy northeastward to Jumbo Dome. However, most of the region is unpopulated, undeveloped, and relatively isolated from existing transportation routes. Helicopters are generally required for field investigations. Several private landing strips are located at Healy, Suntrana, and other sites in the Nenana region. Scheduled commercial flights operate between Anchorage and Fairbanks and McKinley Park.

The historic mining and railroad town at Healy is connected to the Parks Highway by a 2.5 mile side road. Healy is 112 miles from Fairbanks, 244 miles from Anchorage, 100 miles west of Delta, and 370 miles to coastal access at Seward. Delta Junction, which has a population of about 4,000, is located at the intersection of the Alaska and Richardson Highways. Many of the workers at the Usibelli Coal Mine live in the coal-mining town of Usibelli. Coal mining and railroad communities of the past include Suntrana, Lignite, and Ferry. A 22,000-kw coal-fired power plant at the mouth of the Usibelli Coal Mine near Healy supplies electricity to Fairbanks. Fort Greely, an army arctic training center, includes portions of the eastern Nenana basin.

GENERAL GEOLOGY AND GEOLOGIC SETTING

The location and configuration of the structurally similar series of disconnected, synclinally folded coal subbasins that compromise the Nenana basin are shown in figure 2. Of these, the Lignite Creek and Healy Creek subbasins (inset of figure 2) are most important. The Pokers Flats and Gold Run Pass pits of the Usibelli 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 straddles the northern boundary of Mt. McKinley National Park, which includes most of its coal resources (plate 1), and lies at the west end of the Nenana basin proper. 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 central Alaska Range. Thus, some of the deposits are in fairly close proximity to highland areas.

The generalized geology for the Nenana basin is shown in figure 3 and in greater detail on plate 1. 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

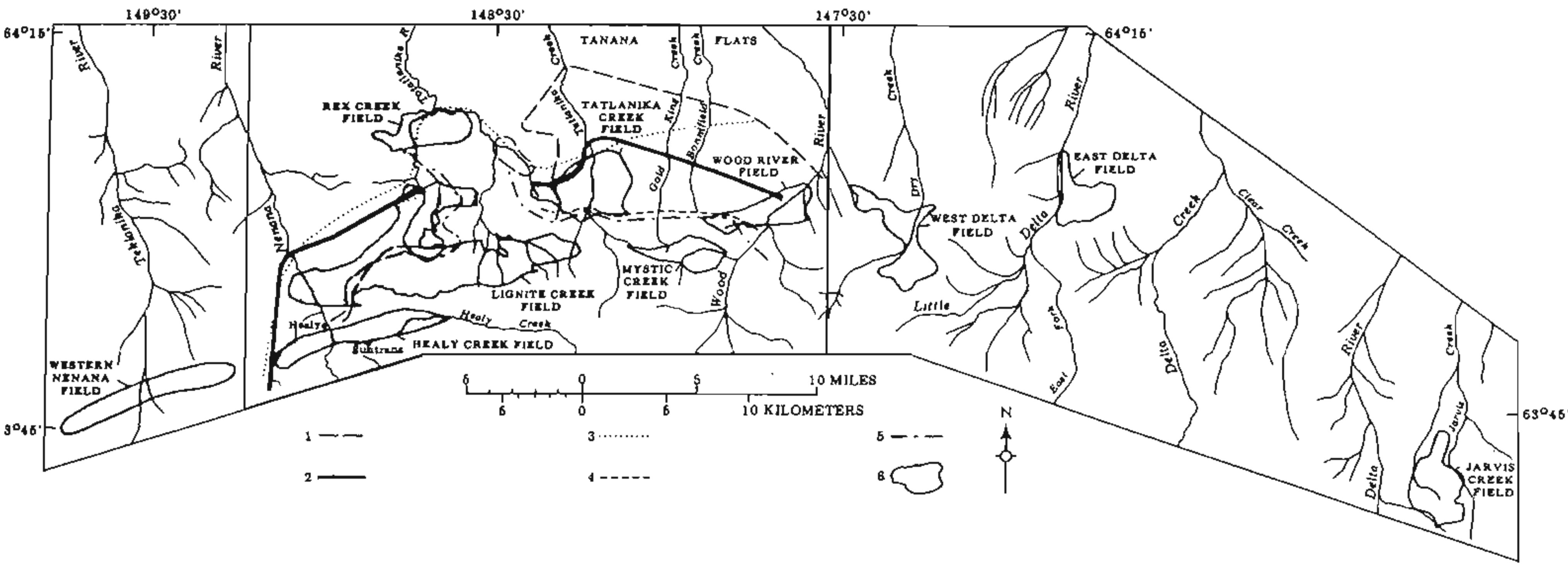


Figure 2. Subbasins or sub-fields forming the Nenana basin.

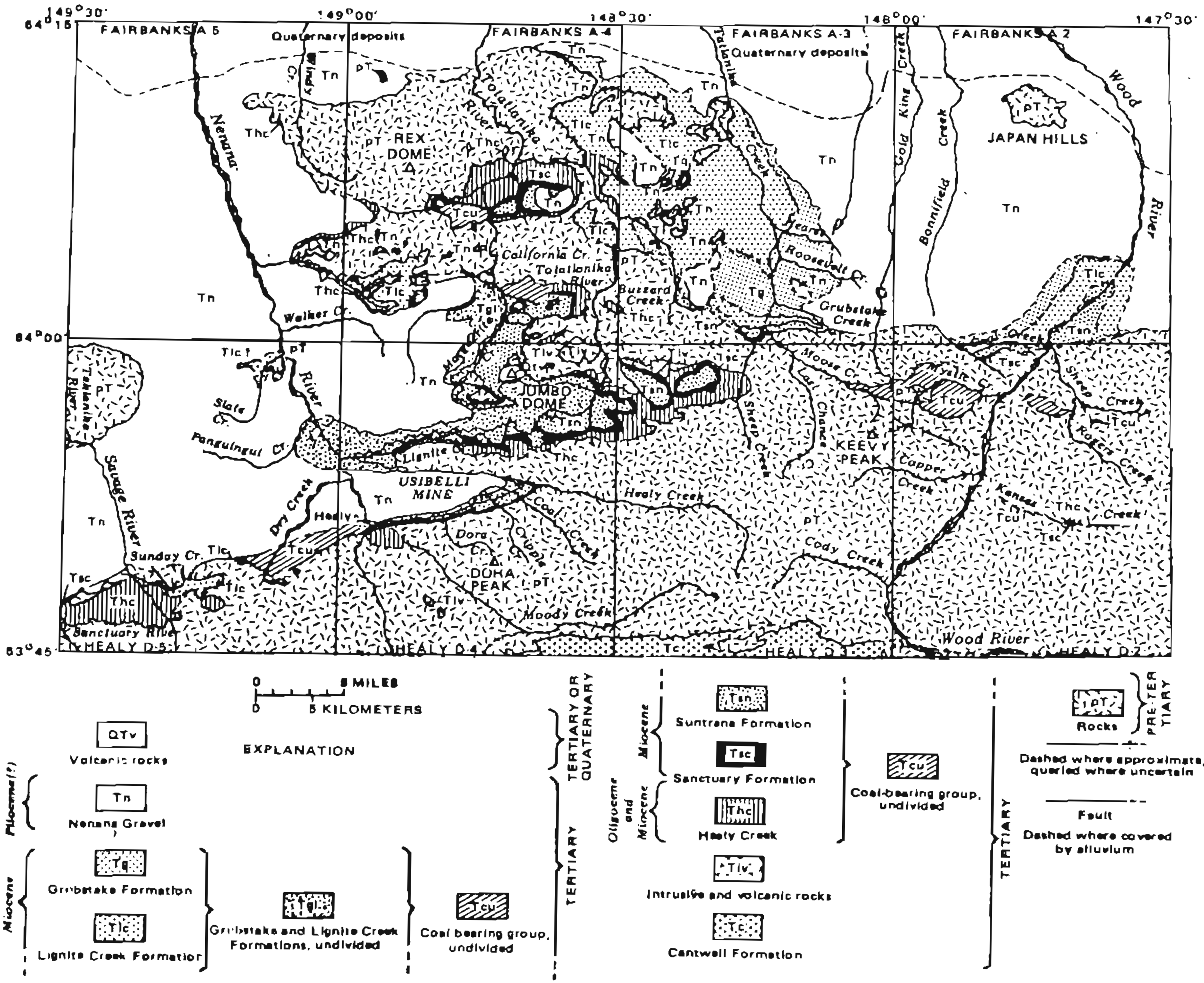


Figure 3. Generalized geologic map of the Nenana coal basin (after Wahrhaftig and others, 1969).

Tertiary Nenana Gravels mantle broad areas on the west, east, and north side of the Nenana basin. A belt of Quaternary deposits flanks the north side of the basin covering the southern Tanana Flats.

HISTORY

Coal has been known in the Nenana region since the late 1800's (Collier, 1903). Brooks and Prindle were the first geologists to visit the coal fields, and conducted geologic reconnaissance in 1902. Prindle returned in 1906 and studied the distribution of coal beds between Nenana and Wood Rivers (the Bonnifield region) in greater detail. Brooks and Prindle mistakenly correlated the coal beds with the "Kenai Formation" of south-central Alaska (Wahrhaftig and Freedman, 1945). Capps studied the coals of the Healy and Lignite (or Hoseanna) Creeks in 1910, and Martin returned in 1918 to complete a detailed study of the Lignite Creek deposits. Martin's 1919 U.S. Geological Survey report described the geology and occurrences of the numerous coal seams in the region. Capps (1912) and Martin (1919) both referred to the coal-bearing rocks as early Tertiary (possible Eocene) strata. Capps delineated the coal basins of the Nenana region nearly in their present configuration, and in 1919 referred to the group as the Tertiary coal-bearing formation. The Alaska Railroad reached the Nenana coal field by 1918, and since then coal production from the region has been continuous (Wahrhaftig and others, 1969).

The Peterson Mine of the Healy River Coal Corporation (HRCC) operated from 1920 to 1922 on the west bank of the Nenana River to supply the railroad. A "new mine," which saw only limited production, opened an inclined slope approximately 100 feet from the Peterson entry in the same year. Work began on the underground Suntrana Mine (frontispiece) in 1921 by the HRCC when a 4.5 mile spur track from the Alaska Railroad to the mine site on Healy Creek was completed (Wahrhaftig and Freedman, 1945). In 1927, this mine was the only producer in the Nenana field and in 1928 produced about half of the total coal mined in Alaska. By 1940, it was the largest coal mine in the Alaskan Territory (Naske and Triplehorn, 1980).

The U.S. Bureau of Mines worked in the region in the early 1940's trenching coal beds. Clyde Wahrhaftig and his associates of the U.S. Geological Survey began geologic work in the Healy area in the early 1940's and this work continued into the 1970's. The resulting publications of numerous geologic and coal resource studies on the Nenana field appear in the Bibliography. Wahrhaftig named the "coal-bearing group," and made essential stratigraphic subdivisions by breaking out five formations (Wahrhaftig and others, 1969).

The Diamond open-pit mine opened in 1943 about 4 miles southwest of Healy Forks and produced coal for the territorial Army Coal Procurement Section (ACPS). Emile Usibelli and T.E. Sanford opened a strip mine east of the Suntrana Mine in early 1944 under an Army coal contract; this development was the founding company of the present-day Usibelli Coal Mine (U.S. Bureau of Mines, 1944).

When a serious coal shortage developed in interior Alaska during World War II, the Army created the ACPS to alleviate the problem by obtaining adequate reserves. The ACPS studied prospects along the Alaska Railroad, including Houston, Wasilla, Willow, Broad Pass, and Donnelly in addition to the Nenana deposits (U.S. Bureau of Mines, 1944). However, most if the coal mines which opened in the Nenana field during and after the second world war were short-time operations (Sanders, 1981).

The Gold Run Pass Mine, a strip mining operation south of the Sanderson Creek tributary, on upper Lignite Creek, opened in 1955; it now operates intermittently as a secondary pit for the Usibelli Mine. Several hundred tons of coal were produced at a small operation in the Jarvis Creek field in 1958. Emile Usibelli purchased the Suntrana Mine in 1960, but the mine was subsequently closed in 1962 because of serious mine fires. A mine-mouth power plant was built at Healy in 1969; it supplies electricity to the Golden Valley Electric Association and other customers in the Fairbanks area. Although principal production to date has been from Healy Creek, stripping conditions are now less favorable on Healy Creek and much of the original surface-minable reserve has been depleted; mining ended there in the late 1970's. Usibelli has now shifted to the Lignite Creek area, specifically Poker Flats. Except for minor production at the Premier Mine of the Matanuska field to supply local citizens, the Usibelli Coal Mine, Inc. has been the only operating coal mine in the state of Alaska since 1971 (Naske and Triplehorn, 1980).

CLIMATE

The climate of the Nenana Coal field region is continental with the average annual precipitation varying locally from 12 to 20 inches. Precipitation is generally greater that at Fairbanks with moderate to heavy snowfalls occurring from November to March. Light snows may come as early as September 1. Over half of the annual precipitation falls from June through September with July and August typically the wettest months. Cloudbursts are common on late afternoons during summer and these cause rapid erosion and dissection of gullies within the relatively soft coal-bearing rocks. High winds are also frequent, and occasionally have been known to reach 70 miles per hour (U.S. Department of Commerce, 1968).

Extremes in temperature may occur in summer and winter. Summers are usually cool in the region with a mean temperature of 55°F; the mean July temperature is over 60°F. The mean temperature during the coldest winter months is between 0°-5°F. The short-term winter temperature may dip to -60°F (U.S. Department of Commerce, 1968).

Permafrost zones 100 to 200 ft thick are common in the Interior region of Alaska, and zones to 400 ft are locally present in the Nenana region. However, the permafrost zones are thinner than in the Arctic region (Gold and Lachenbruch, 1973; Ferrians and others, 1969). Northern Alaska and much of western Alaska is underlain by continuous permafrost. Southeast Alaska, the Alaska Peninsula, and portions of south-central Alaska surrounding Cook Inlet are generally free of permafrost, while interior Alaska (including the Nenana coal field) is underlain by discontinuous permafrost (Ferrians, 1965). Only minor permafrost problems have been encountered by Usibelli Coal Mine in lower Lignite Creek. Melting of ice pockets in spoil during the relative warm summer months have resulted in localized slumps.

PHYSIOGRAPHY

The Nenana coal field 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 10,000 ft. Mt. Hayes has an altitude of 13,800 ft, and Mt. McKinley, the highest mountain peak in North America, has an altitude of 20,300 ft and lies southwest of the main coal fields.

Several other isolated prominences form important landmarks within the region. Jumbo Dome (fig. 3), a hornblende andesite intrusion, has an altitude of 4,505 ft. Walker Dome, which lies about 5 miles west of Jumbo Dome, has an altitude of 3,900 ft; it is an isolated mound within a rather extensive northward-sloping erosion surface overlain by the Nenana Gravel. Rex Dome, approximately 12 miles northwest of Jumbo Dome, has an altitude of 4,155 ft and consists of Mississippian(?) schist.

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 (fig. 3 and pl. 1) 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. Sanderson Creek enters Lignite Creek from the southwest about 11 miles above its mouth.

Although some isolated peaks of the foothills belt within the Bonnifield mining district (named after John E. Bonnifield, an early explorer of this region between the Nenana and Delta Rivers, south of the Tanana Flats and north of the Alaska Range) range from 4,500 to 6,000 ft in altitude, most of the coal deposits are found in areas at elevations less than 3,000 ft lying between rather dissected valleys. The foothills belt gradually descends down to the broad Tanana Flats, a lowland of slight relief about 30 miles wide. This region is occupied by the Tanana River, the second largest river in Alaska, and is locally interrupted by a few isolated hills. Swampy, irregular creeks, lakes, and marshes are also common. 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 140 miles along the north-central flank of the Alaska Range and up to 30 miles wide. The deposits are centered in an area about 60 miles southwest of Fairbanks and 200 miles north of Anchorage. The greatest geologic development of the coal fields occurs within the Bonnifield mining district.

Although the coal-bearing rocks are widely distributed along the northern foothills, they are discontinuous, having been removed by erosion in the 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 150 to 200 miles southwest (Player, 1976; Sloan and others, 1981; Solie and Dickey, 1982; 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 communication, 1983). The Farewell-Little Tonzona field, over 100 miles west of the Nenana field proper, contains one subbituminous coal seam over 100 feet thick (Player, 1976). Coals of the western Nenana 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 130 miles south of Fairbanks. In 1923-24, 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 field (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 coal field 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 (fig. 4A) parallel to the structural trend of the foothills belt of the Alaska Range. 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 (figure 2). In the intervening areas, the coal-bearing sequence has been removed by erosion. Precambrian-Paleozoic metamorphic rocks border the coal-bearing clastics. Both the structure and stratigraphy of the sedimentary rocks of the region have been strongly influenced by the fringing metamorphics (fig. 5). Generalized cross sections and lithologic sections for areas in the Nenana coal field are shown on plates 4 and 5.

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

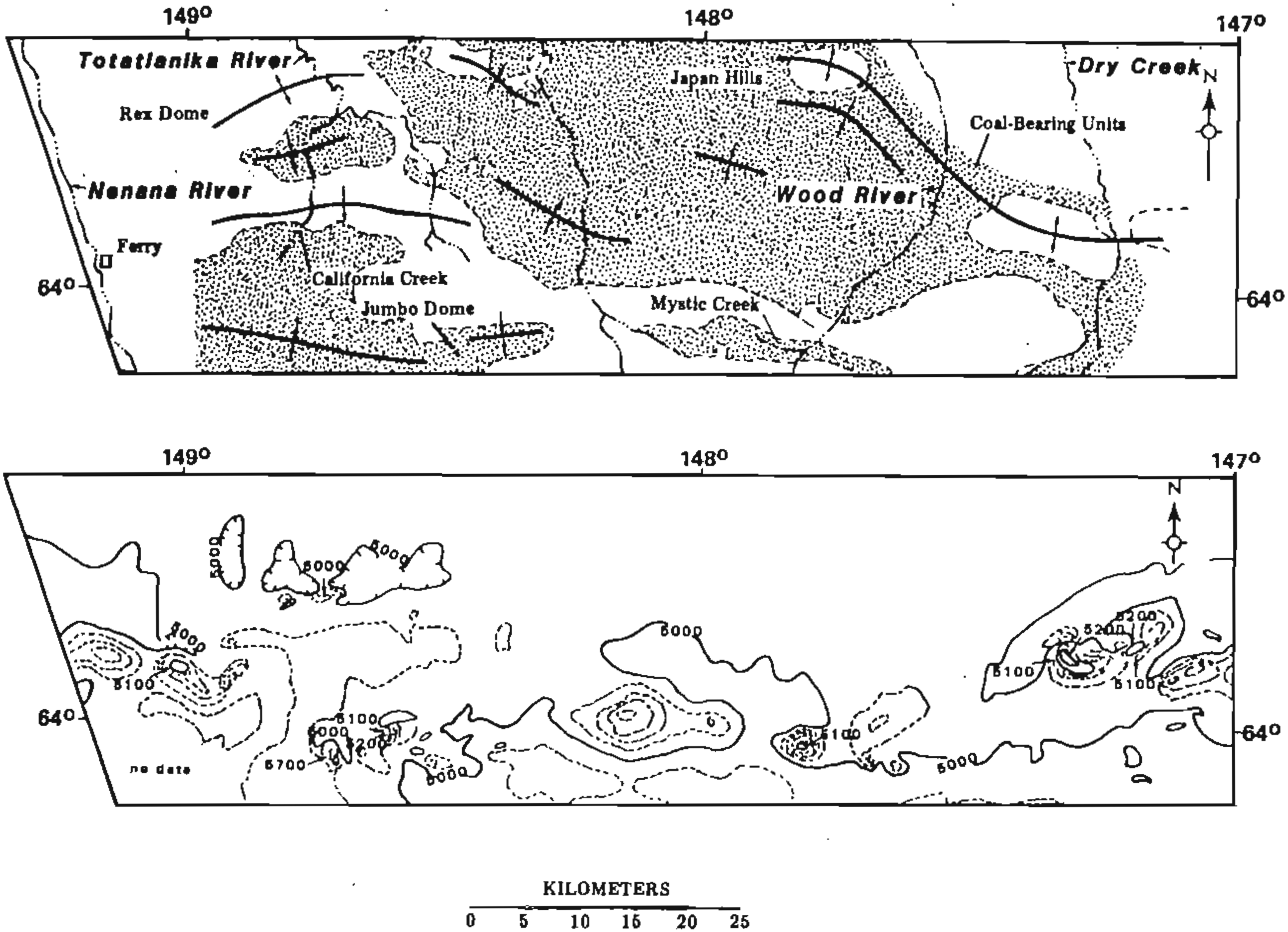
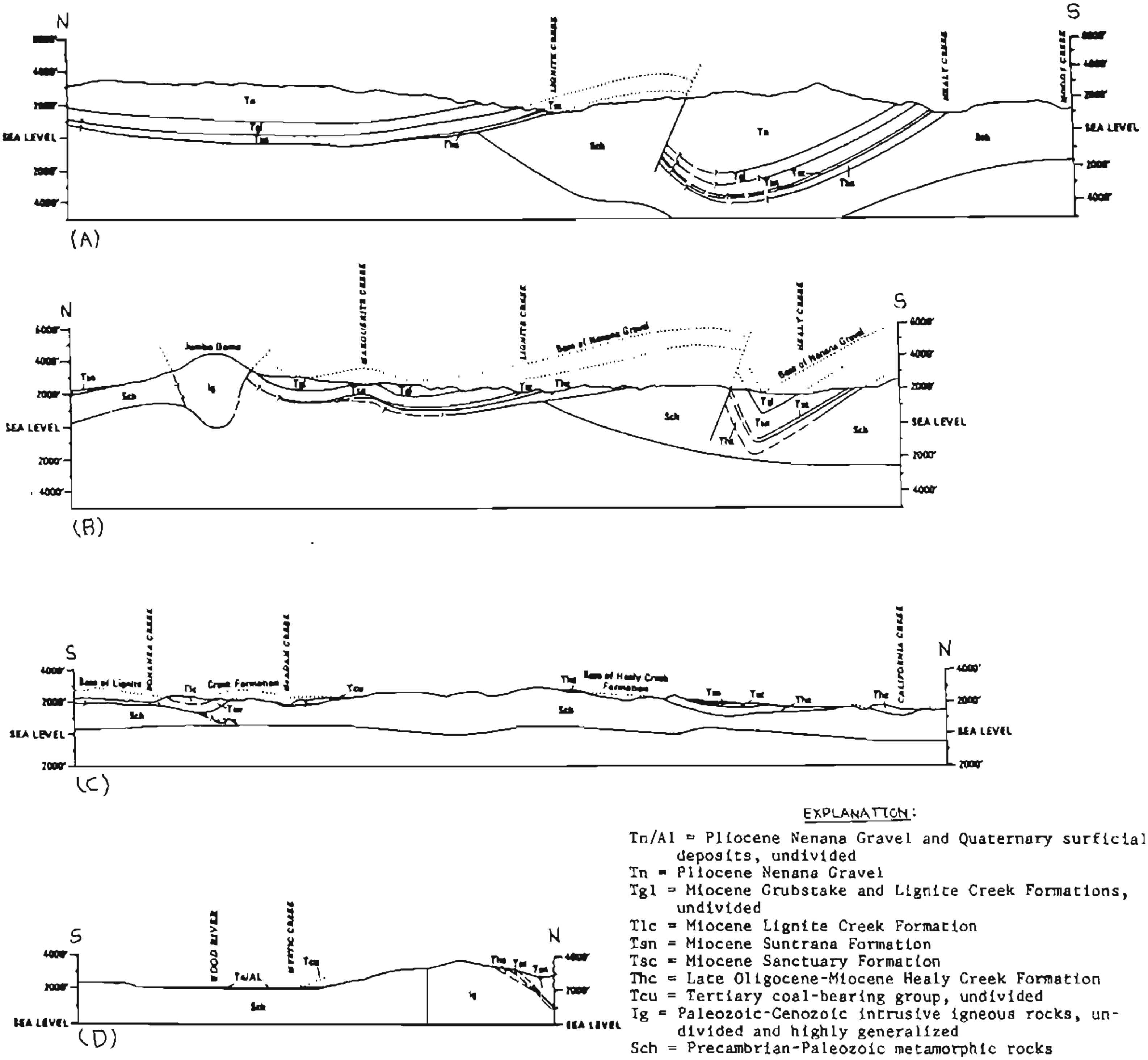


Figure 4 (A & B). Major east-west trending fold axes of coal basins of the Nenana region (A) and generalized aeromagnetic map for the same area (B, after Reidel, 1984). Stipple pattern indicates coal-bearing units.



EXPLANATION:

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. Geologic cross sections of the Nenana Basin coal fields: (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 (after Wahrhaftig, 1970 a-h).

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 (fig. 6). 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 Bouger gravity low greater than 12 milligals near Healy and for large density contrasts between the Tertiary coal-bearing sediments of the Healy Creek and Lignite Creek basins and the denser underlying Precambrian-Paleozoic 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 field to the east.

Both the Healy Creek and Lignite Creek coal deposits occur in synclinal structures. A near-vertical fault separates the two fields displacing the coal-bearing strata of the north side upward about 5,000 ft, bringing the coal beds close enough to the surface locally to create favorable surface-mining situations. Birch Creek Schist is also brought in direct contact with the 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 basin 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 to 30°-35°. The local geologic structure has a great

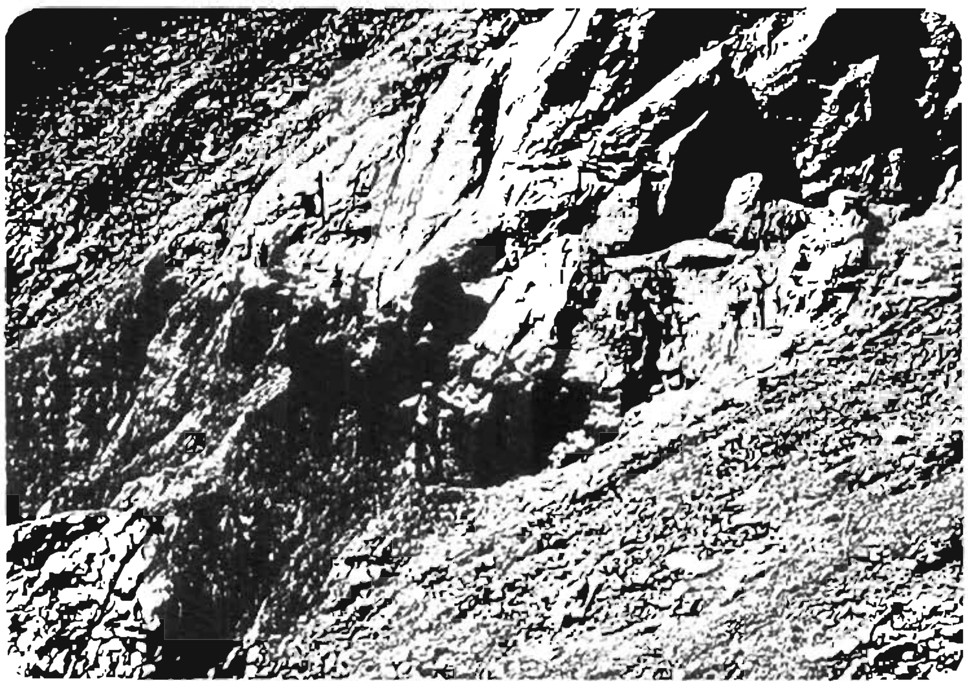


Figure 6. Moderately dipping coal bed on the south side of Jumbo Dome, a hornblende dacite intrusive. Structural adjustments left the Tertiary sedimentary rocks at various attitudes.

bearing on coal development potential (Wahrhaftig and Birman, 1954).

The beds of the Jarvis Creek coal field are gently folded with dips of 5°-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).

Figure 7 shows a faulted coal-bearing section exposed on a tributary to Lignite Creek south of Jumbo Dome. Moderately dipping coal beds of the Suntrana Formation at another upper Lignite Creek locale is shown in figure 8, and two views of sections in the Healy Creek Formation are depicted in figures 9 and 10. The former shows an open flexure at an exposure near the head of Shovel Creek, and the latter highly contorted coal beds in a ravine south of Coal Creek on the northeast side of Mystic Mountain.

TERTIARY LITHOSTRATIGRAPHY AND ASSOCIATED ROCKS

Precambrian and Paleozoic Schist Belt Rocks

Schist belt rocks are exposed over broad areas on the north-central flank and foothills region of the Alaska Range (pl. 1; fig. 11). The coal-bearing group unconformably overlies these metasediments and metavolcanics which are assigned to the Birch Creek Schist, Keevy Peak Schist, and Totatlanika Schist. The general nonconformable relationship of the Precambrian and Paleozoic schist belt rocks with the overlying Tertiary sedimentary rocks of the coal-bearing group can be observed in the cross sections of figure 5.

The Birch Creek Schist is a Precambrian to early Paleozoic black to gray (locally also greenish) quartz-sericite, quartz-mica, or quartz-chlorite schist with veins of white quartz. Lesser amounts of black graphitic schists can be mistaken for coal when observed from a distance. The Birch Creek Schist is the oldest exposed formation in the region and possibly the oldest in the state. The exposed surface of the schist on which the coal-bearing units were deposited underwent considerable chemical and physical erosion resulting in a deeply weathered, irregular surface of unconformity (Wahrhaftig, 1970a-h; Gilbert and Bundtzen, 1979).

The early- to mid-Paleozoic aged Keevy Peak Schist is chiefly a dark gray to black carbonaceous phyllite, but also contains black quartzite and muscovite-quartz schist. The unit is locally chloritic with abundant marble and sometimes stretched pebble conglomerates (Wahrhaftig, 1970a-h; Gilbert and Bundtzen, 1979).

The Totatlanika Schist (Mississippian-Permian) is the youngest unit of basement rock in the north-central Alaska Range flank and foothills region, and is composed of several important members. The oldest Moose Creek Member lies conformably on the Keevy Peak Formation and is composed of interbedded rhyolitic flows, crystal tuff, and basaltic to andesitic flows. The California Creek Member conformably overlies the Moose Creek Member and consists primarily of metafelsite (porphyrite metarhyolite and felsic

Figure 7. Faulted coal-bearing section outcropping south of Jumbo Dome along a tributary to upper Lignite Creek with two thick coal beds of the Suntrana Formation on the west block (footwall) and thinner beds of the Lignite Creek Formation on the east block (hanging wall). View is to the north.

Figure 8. Moderately dipping coal beds of the Suntrana Formation at an upper Lignite Creek location (LCT site, plate 1).

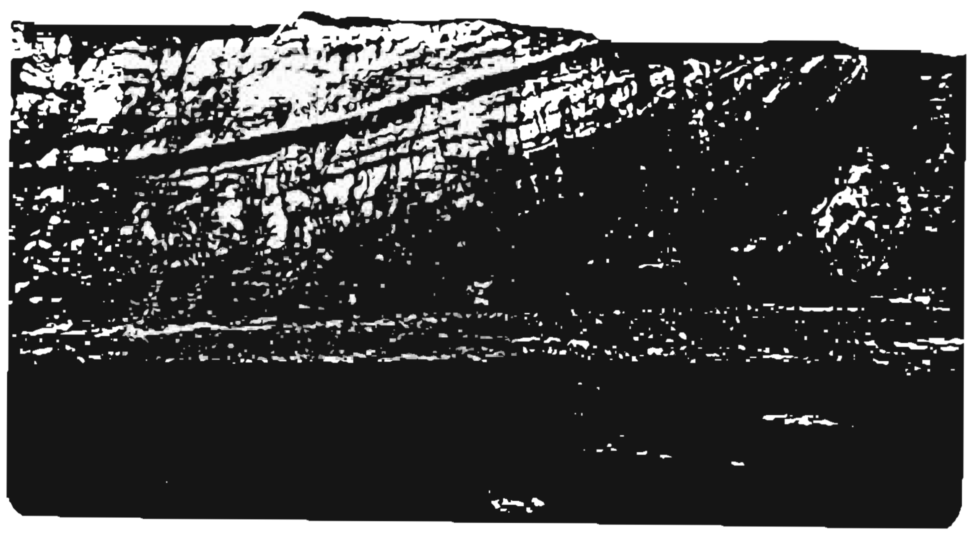


Figure 9. Folded coal beds of the Healy Creek Formation at an exposure near the head of Shovel Creek.

Figure 10. Highly contorted coal beds of the Healy Creek Formation in a ravine along Coal Creek, northeast side of Mystic Mountain.

Figure 11. Southward perspective along Shovel Creek showing Birch Creek Schist along the mountain rim, schists of the Keevy Peak Formation in the foreground, and coal-bearing strata of the Healy Creek Formation in between.

metatuff) with relict phenocrysts of quartz and K-feldspar. The Chute Creek Member is chiefly a metabasalt, and is conformably overlain by the Mystic Creek Member. The latter unit is a rhyolitic to rhyodacitic tuff and agglomerate with thin lenses of shale, graywacke, calcarenite and quartzite. The Sheep Creek Member consists of volcaniclastic metasandstone, metasiltstone, and metatuff that are locally calcareous, marble-bearing, and exhibit relict detrital textures (Wahrhaftig, 1970a-h; Gilbert and Bundtzen, 1979; Freeman, 1983).

General Stratigraphy and Lithology of the Coal-bearing Group

The Tertiary coal-bearing group (an informal geologic unit name) of the Nenana Coal Field 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 (fig. 12). The series may be as much as 3,000 ft thick. The folded and locally faulted strata are loosely to moderately consolidated and deeply incised by streams. Locally thick sections are exposed (particularly on Lignite or Hoseanna Creek), which are nearly complete sections of the entire group. 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 13.

Plate 3 summarizes the chief characteristics of the formations of the coal-bearing group of the Nenana Basin based on work of Wahrhaftig (1958); it emphasizes particularly the lithologic features of the different units. The lithologic (sedimentational) characteristics and the degree of alteration 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 coal field. A tonstein from a Mystic Creek coal bed is shown in figure 14. Coaly materials occur in sandstones as wavy stringers and lenses (fig. 15). Locally, fossilized tree trunks (fig. 16) 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.

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; figures 17 through 19 show views of this bedding at an outcrop on Emma Creek. The Suntrana and Lignite Creek formations are strongly crossbedded by the trough cross-stratifica-

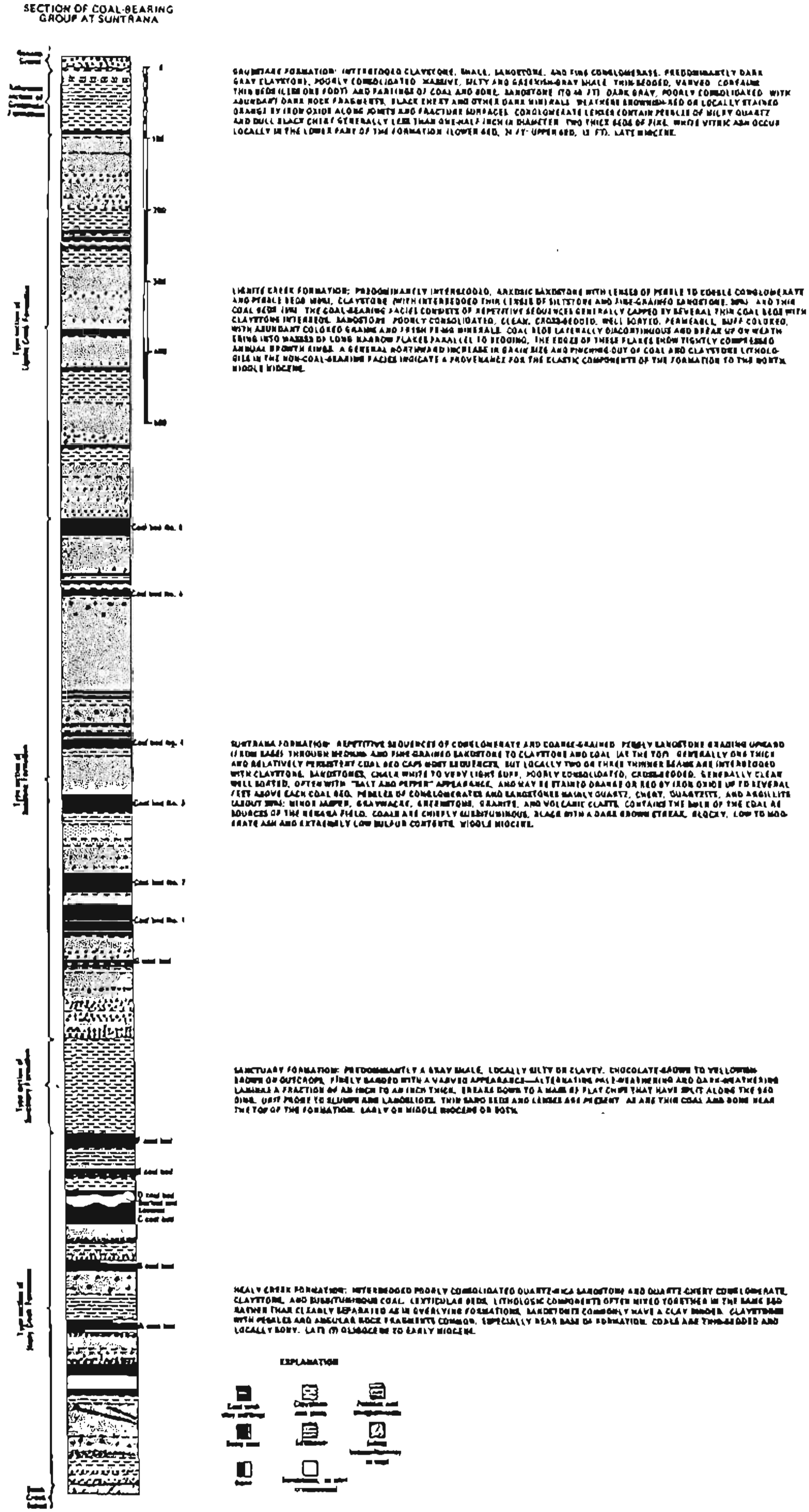


Figure 12. Generalized section of the coal-bearing group at Suntrana (Healy Creek field) with the chief lithologic characteristics of the different formations and seam identifications (after Wahrhaftig and others, 1969).

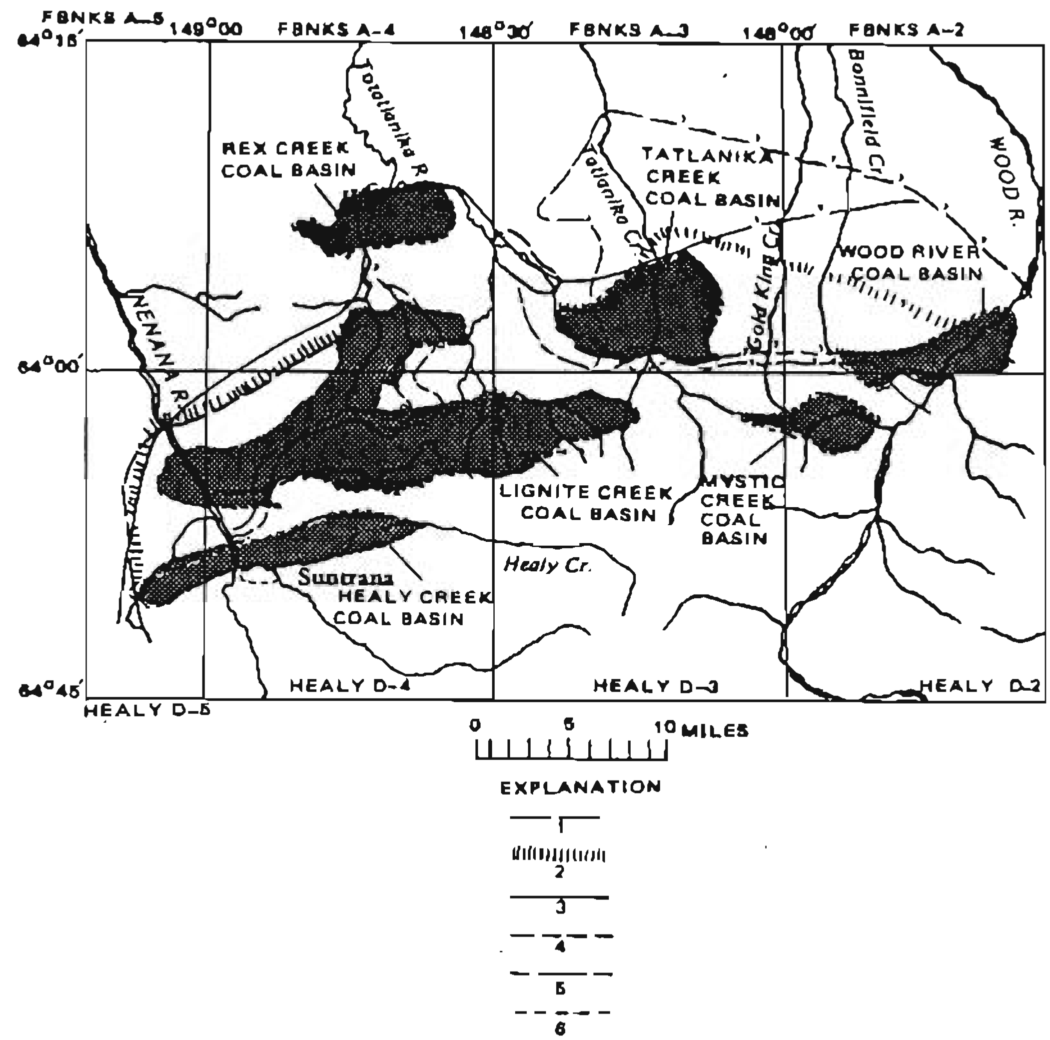


Figure 13. Major coal fields of the Nenana basin and northern limits of deposition of formations (after Wahrhaftig and others, 1969). Key: 1-northern limit of deposition of Grubstake Formation; 2-approximate zone of interfingering of the coal-bearing and non-coal-bearing facies of the Lignite Creek Formation; 3-northern limit of deposition of the Suntrana Formation; 4-northern limit of deposition of the Sanctuary Formation; 5-northern limit of deposition of the Healy Creek Formation; and 6-coal field.

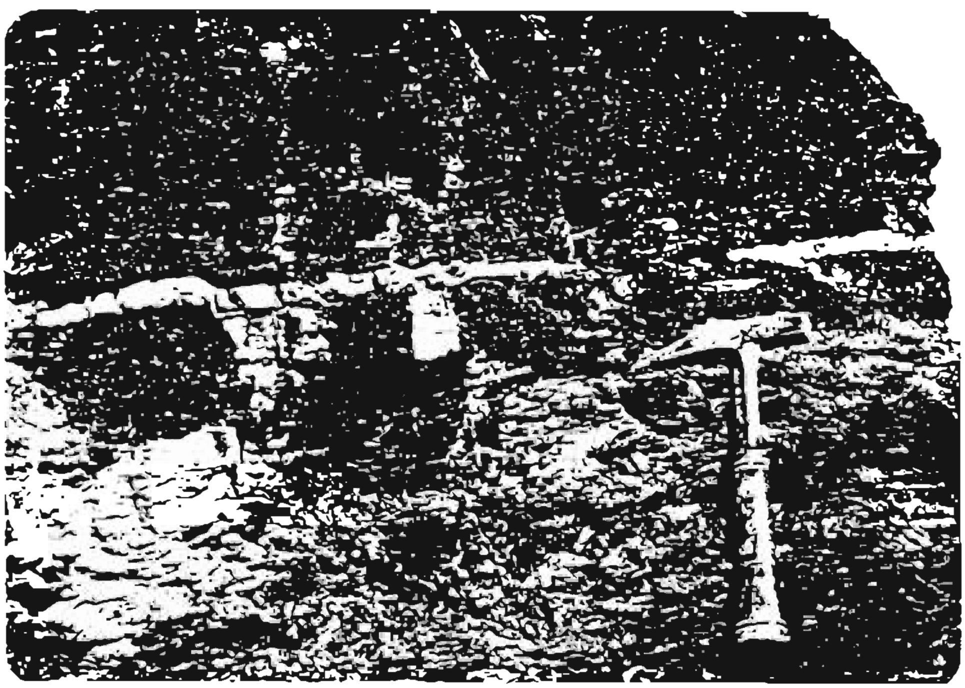


Figure 14. Volcanic ash or tonstein parting within coal bed at an exposure of the undifferentiated Tertiary coal-bearing unit (as mapped by Wahrhaftig, 1970) within the Mystic Creek coal basin.

Figure 15. Lenticular coal pods within the sandstones and conglomerates of the Lignite Creek Formation along the Emma Creek exposure. These pods are common in active sandstone fill of fluvial channel deposits.

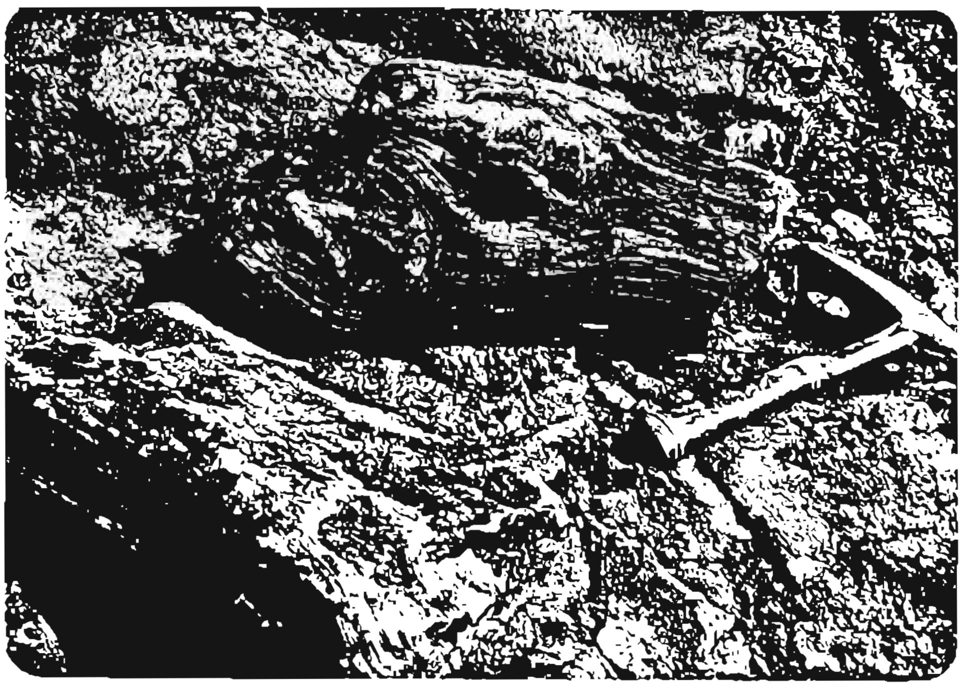


Figure 16. Petrified hematitic logs formed by the replacement of the organic matter in buried logs by iron oxides in solution, ultimately preserving the original woody structure. These logs are from the Lignite Creek Formation on upper Lignite Creek.

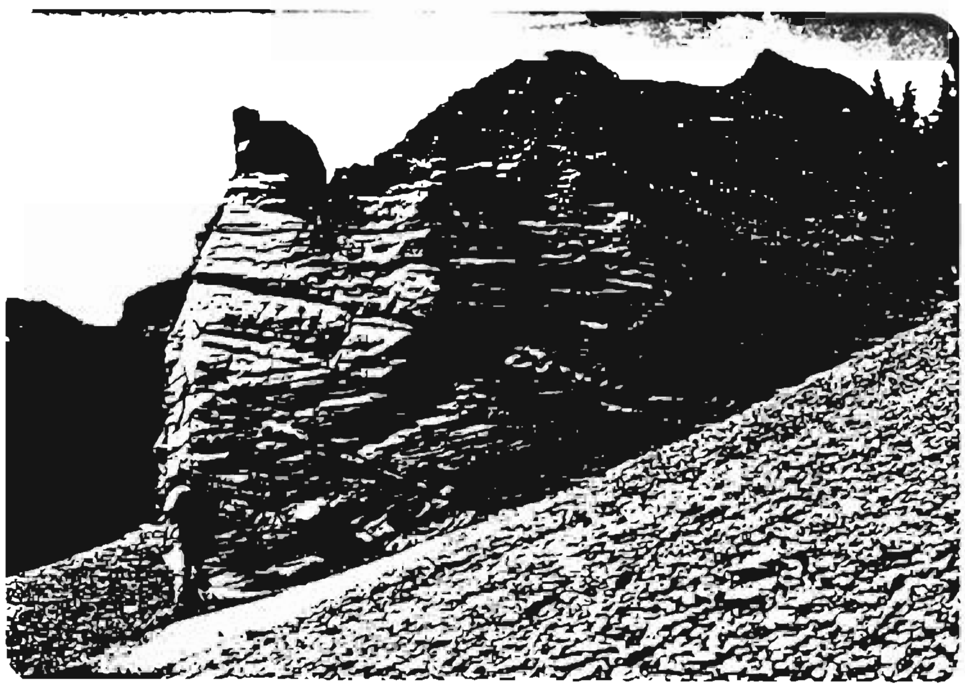


Figure 17. Outcrop of cross stratified medium- to coarse-grained pebbly sandstone and conglomerate within the Lignite Creek Formation on Emma Creek.

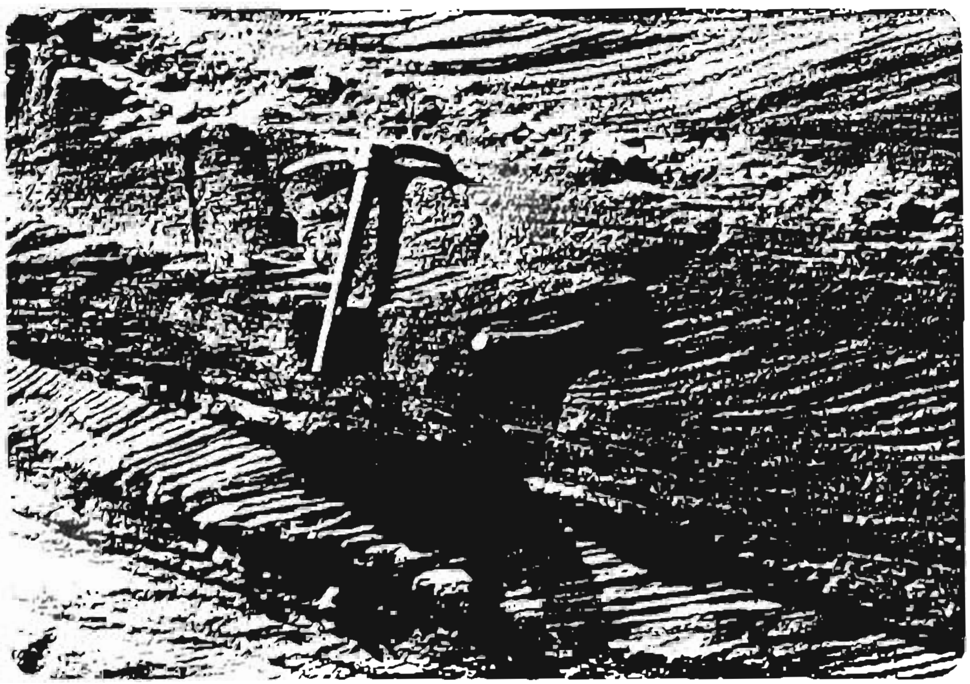


Figure 18. Close view of cross stratification and pebble to cobble lenses and trains of the Lignite Creek Formation at Emma Creek.

Figure 19. Convolute or contorted bedding beneath crossbeds at Emma Creek site probably resulting from overloading by the overlying sand and flow of hydroplastic or differentially liquefied sediment layers.

tion type of McKee and Weir (1953; fig. 20) with poorer development of the planar cross-stratification type. 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 a foot to 5 ft in thickness, and average between 1 and 2 ft thick (Wahrhaftig, 1958). Sandy shales and claystones often exhibit high chroma yellow or buff colors. Abundant mica occurs in sediments and was derived from underlying schists. Differential erosion in softer portions of sandstone beds result in mushroom-shaped remnants and castellated forms (figs. 21-22); these can also rarely occur in coal beds (fig. 23). Differentially-cemented calcium carbonate concretions to five feet in diameter occur in certain sections of the coal-bearing group (fig. 24); laths, lenses, and concretions of this type are also common in the Lignite Creek Formation (fig. 25). The larger concretions if abundant in an area, could be problematic during overburden removal. Metamorphic rocks, volcanic deposits, andesitic lavas, and other igneous rocks are found in close proximity to the sediments.

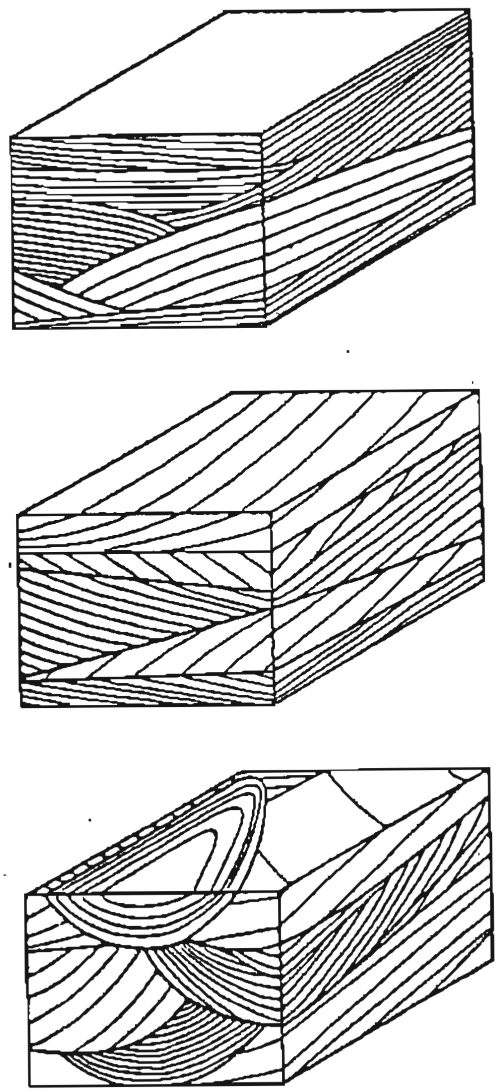
Dickson (1981) points to two lithologic changes during the deposition of portions of the coal-bearing group which indicate a general climatic cooling from late Oligocene to middle Miocene: (1) transition from dominantly kaolinitic clays of the Healy Creek Formation to montmorillonitic clays in the Suntrana Formation and above (cf. Triplehorn, 1976), 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 preserved in the 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 2,000 ft (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 field to the Jarvis Creek field east if 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



SIMPLE CROSS-STRATIFICATION

The lower bounding surfaces of sets are nonerosional surfaces

PLANAR CROSS-STRATIFICATION

The lower bounding surfaces of sets are planar surfaces of erosion

TROUGH CROSS-STRATIFICATION

The lower bounding surfaces of sets are curved surfaces of erosion

Figure 20. Basic classes of cross-stratification (from McKee and Weir, 1953). All three types can locally be observed within the formations of the coal-bearing group. Cross-strata are best developed in the Lignite Creek and underlying Suntrana Formations.

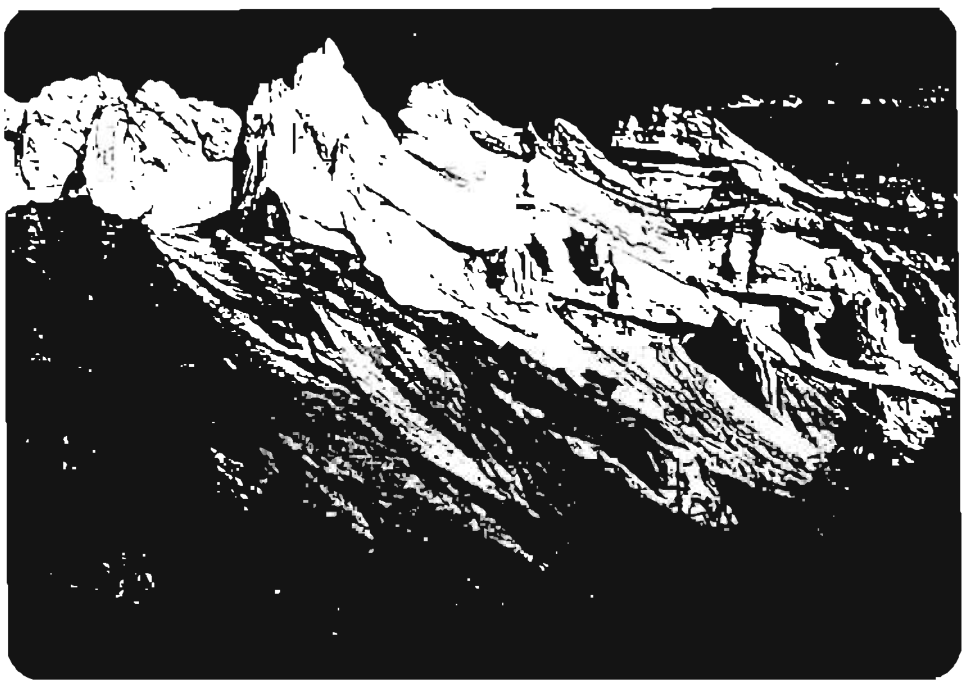


Figure 21. Castellated whitish to buff Suntrana Formation sandstones of the Mystic Mountain-Coal Creek deposit.

Figure 22. Northeasterly view of coal-bearing section along Emma Creek with the overlying, castellated, differentially-weathered sandstones of the Lignite Creek Formation.

Figure 23. Differentially weathered pillar of coal (toadstool or hoodoo rock) near the confluence of Bonanza-Marguerite Creeks, western Lignite Creek field.

Figure 24. Large (about 5 ft. diameter), dense, and nearly spherical calcium carbonate-cemented concretion at a coal-bearing outcrop on Red Mountain Creek, West Delta field. These concretions form by localized, differential precipitation and cementation by carbonate early postdepositionally in the pores of a sandstone around a nucleus or center.

Figure 25. Differentially calcium carbonate-cemented laths, lenses, and concretions are common within sandstones of the Lignite Creek Formation at Emma Creek.

(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) reports 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 throughout the unit.

Wahrhaftig (1958) found that the paleocurrent directional indicators pointed to a multi-source provenance of sediments. Dickson (1981) has 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 coal field. The unit is early to middle Miocene in age, and varies from a few feet to 350 ft in thickness. It is found in most of the subbasins of the Nenana coal field, 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 (fig. 26). 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).

Figure 26. Characteristic slumps and landslides occurring in the plastic brown and gray clays of the Sanctuary Formation along Marguerite Creek.

Suntrana Formation

The Suntrana Formation type section includes the 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 1,290 ft on the Coal Creek tributary of Healy Creek and 1,000 ft on Coal Creek northeast of Mystic Mountain. The formation is widely exposed in the Healy Creek and Lignite Creek subbasins, and also crops out in the Rex Creek, Tatlanika Creek, and Wood River subbasins. 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 one inch 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 several feet 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, while 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 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 coal basins, and westward in the Tatlanika Creek and Wood River coal basins. 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 coal resources and reserves of the Nenana coal field, including most of the thicker (commonly 10 to 60 feet) 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 8 miles in some cases. The numbered coal beds (3,4, and 6 seams) presently being mined at Poker Flats (Usibelli Mine) occur within the Suntrana Formation.

Lignite Creek Formation

The Lignite Creek Formation type section is found at Suntrana Creek (Healy Creek subbasin) 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 630 ft 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 and Lignite coal basins and southern part of the Tatlanika and Wood River coal basins, and the non-coal-bearing facies crops out along the northern and western parts of the Nenana coal field. The coal-bearing facies varies in thickness from 500 ft in the northwest part of the Lignite Creek basin to 1,000 ft at its east end, to over 600 ft in the Tatlanika Creek basin, and 800 ft in the Wood River basin. The non-coal-bearing facies averages about 250 ft but locally is over 1000 ft 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 of interbedded, buff sandstones, greenish-gray claystones, arkosic conglomerates, and relatively thinner 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 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 subbasin. The unit is of late Miocene to early Pliocene age and is the youngest formation of the coal-bearing group. It is nearly 1,000 ft 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 the 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 basins. 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 with the remainder made up of chlorite, muscovite, quartz, plagioclase, and sanidine crystals. The lower ash bed is 24 ft thick and the upper ash bed is 13 ft thick. The lower ash buried a forest and it has rooted, erect coalified tree trunks rising to 20 ft in the ash (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 coal field. Thick exposures of Nenana Gravel as much as 4,000 ft thick occur between Healy and Lignite Creeks (Wahrhaftig and Freeman, 1945). The unit is 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 areas 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 inclusions locally of large cobbles and boulders of nonglacial origin. 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 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 Terrace Deposits

Quaternary and Holocene terraces have formed locally above the Pliocene Nenana Gravel, and serve to conceal coal-bearing group strata. Major drainages and glacial erosion have removed gravels from many areas. Wind-blown loess deposits are also locally present capping the graveled terraces. Both terrace deposits and Nenana Gravels overlie the Suntrana Formation strata at the Poker Flats pit near the west end of the Lignite Creek field. The terrace deposits are of two general types---alluvial and glacial (Wahrhaftig, 1958; Péwé, 1975).

A series of alluvial terraces have developed adjacent to the Nenana River and its tributaries due to continued aggradation and erosion along the Nenana River valley. These terraces are formed by a layer of relatively coarse, unconsolidated, poorly sorted gravel mainly derived from the Nenana Gravel. These mantles of material often cut across the tilted coal-bearing strata. The lithologies of gravels and cobbles in the sediments include granite, diabase, chert, and quartzite conglomerate (Wahrhaftig, 1958; Péwé, 1975).

Wahrhaftig (1958) recognized four major Pleistocene glaciations of the Nenana River valley, two of which he found evidence for in the Healy area. The older moraine and outwash deposits are of the Healy Glaciation and are thought to be of early Wisconsin age (30,000-70,000 yr B.P.). Glacial erratics are found scattered intermittently over the region. Areally extensive and thick terrace deposits flank the Nenana River, indicating the different episodes of glaciation. These deposits are particularly prominent near the western side of the Nenana coal field. A complete and well-preserved series of glacial terraces are found along the south side of Healy Creek from near Moody Creek west to the Nenana River (Wahrhaftig, 1958; Péwé, 1975).

PALYNOLOGY

The palynology of the Nenana Coal field seams 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 27) based on pollen and plant megafossil leaves. Table 1 summarizes the palynological assemblage characteristics for the coal-bearing formations of the Nenana Coal field based on this work.

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 (and also ironstone concretions) 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 28. These were extracted from relatively pollen-poor

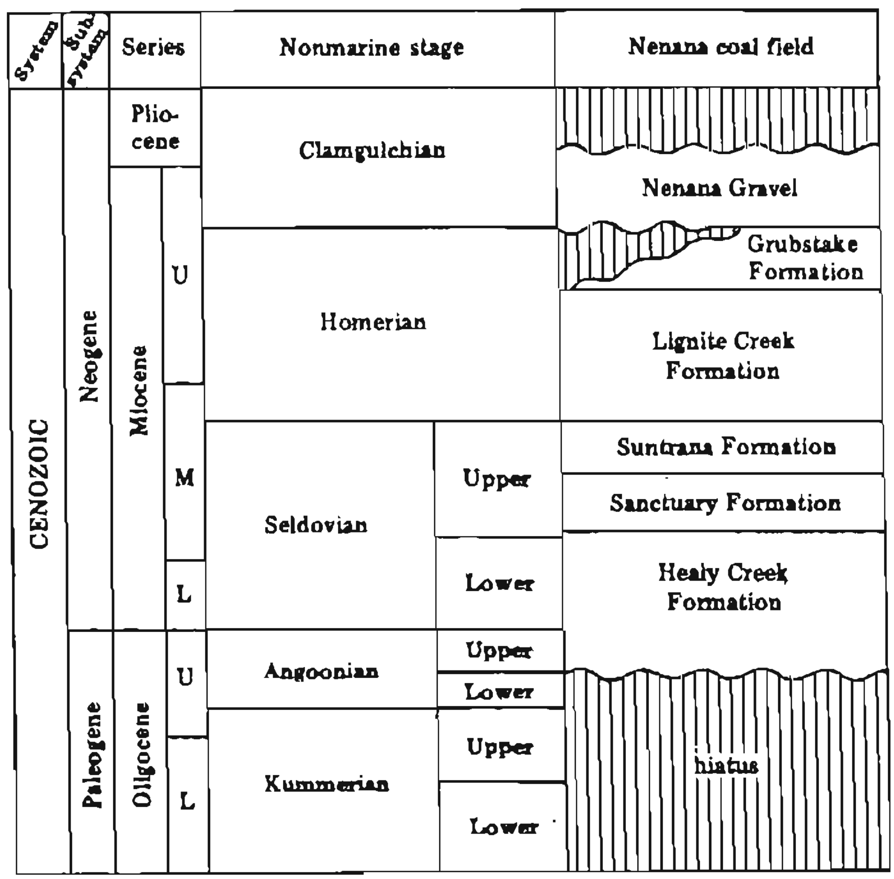


Figure 27. Stratigraphic nomenclature, stage and age of coal-bearing formations of Nenana coal field (modified from Magoon, Adkison, and Egbert, 1976; Wolfe and Tanai, 1980; and Affolter, Simon, and Stricker, 1981).

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

Formation	Pollen forms	Dominants	Percent exotic genera	Stage/ series	Comments
Grubstake	Problematic due to possibility of re-deposition 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 indidicate 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.	Od 40 vascular genera identified, 60% now exotic to Alaska.	Angoonian; Late(?) Oligocene	Eight pollen and spore assemblages show diverse pollen flora.

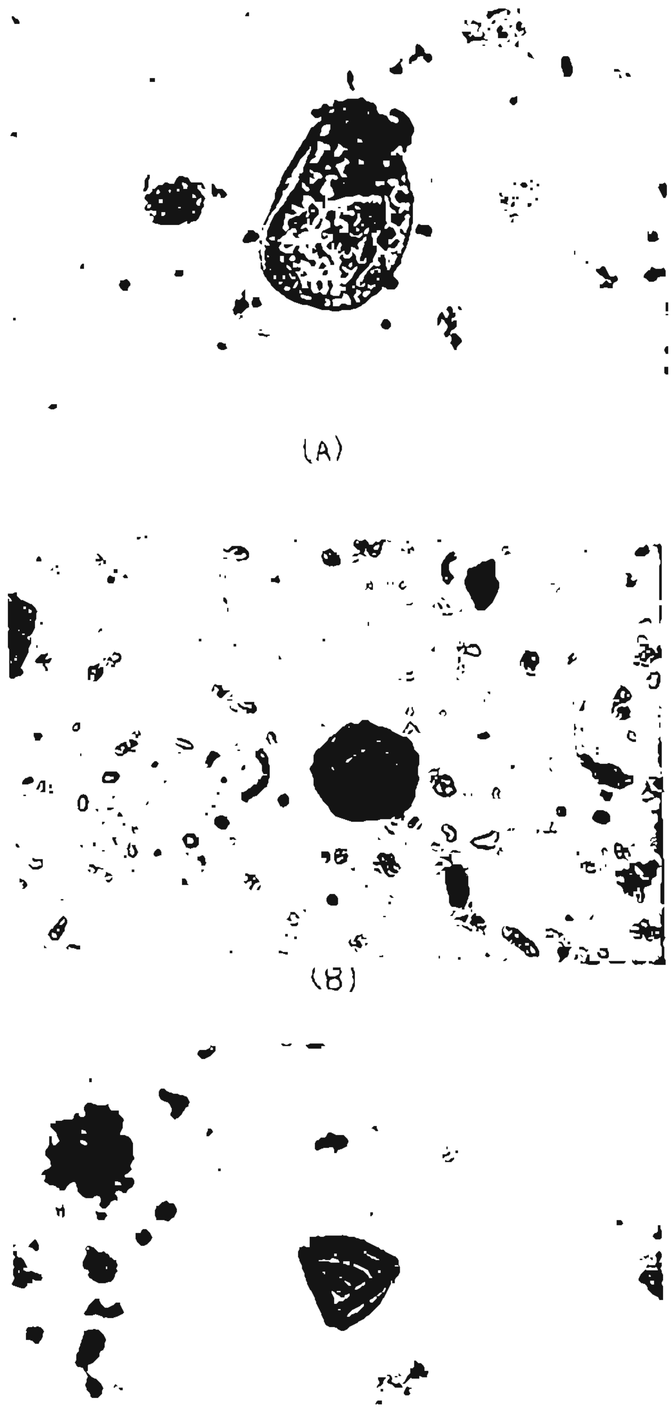


Figure 28. Pollens extracted from Red Mountain Creek and Dry Creek (West Delta field) coal samples: (A) Polypodiaceae, fern, RMC1-1, 160X; (B) Alnus, black alder, RAA4, 160X; (C) Betula, birch, RAA4, 160X. See appendix B for sample locations.

samples from Red Mountain Creek (a, sample RMC1-1) and cored coal samples near Dry Creek (b and c, sample RAA4), Bonnifield district (see appendix B). 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).

Other than the work of Wahrhaftig and others (1969) and that of McFarlane (1981) on the palynology of seams 4, 5, and 6 of the Suntrana Formation sampled at the Usibelli Coal Mine, 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 true 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 coal field.

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 29 summarizes the basic lithologic components and depositional types for the common fining-upward cycles. Figure 30 is a generalized Healy Creek section illustrating the cycles and respective interpretations of their depositional environment.

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 during Healy Creek time (fig. 31A) in late Oligocene and early Miocene epochs. The weathered schist basement on which it was deposited was a very irregular surface with several hundred feet of relief, resulting in a

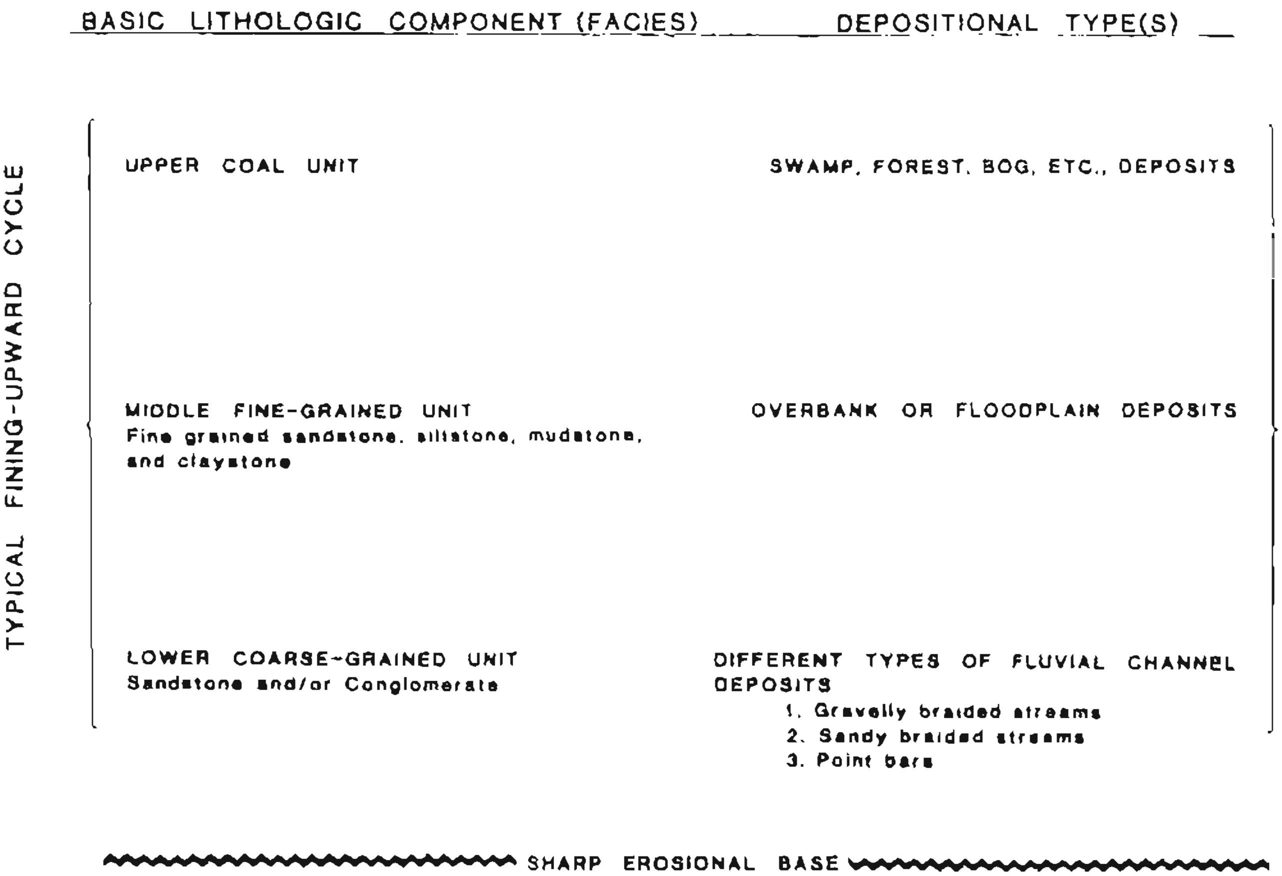


Figure 29. Basic lithologic components and depositional types for the common fining-upward cycles in the coal-bearing group (after Buffler and Triplehorn, 1976).

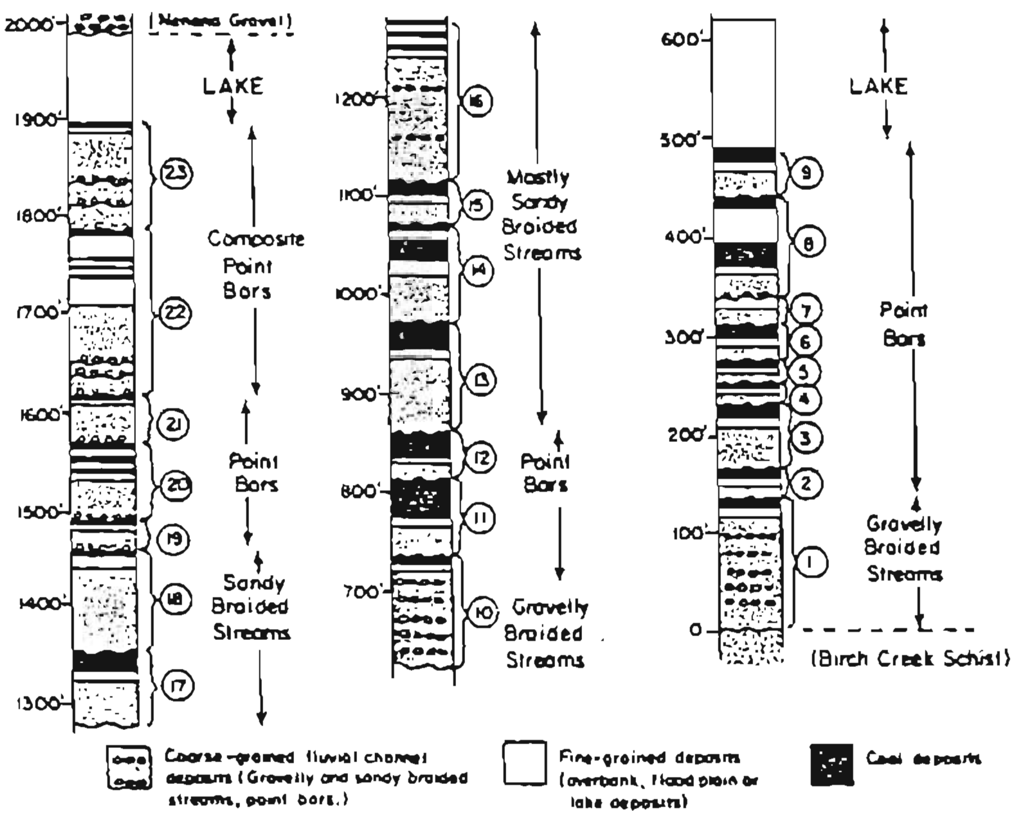


Figure 30. Generalized coal-bearing section from Healy Creek field showing individual cycles and their respective depositional type (from Buffler and Triplehorn, 1976).

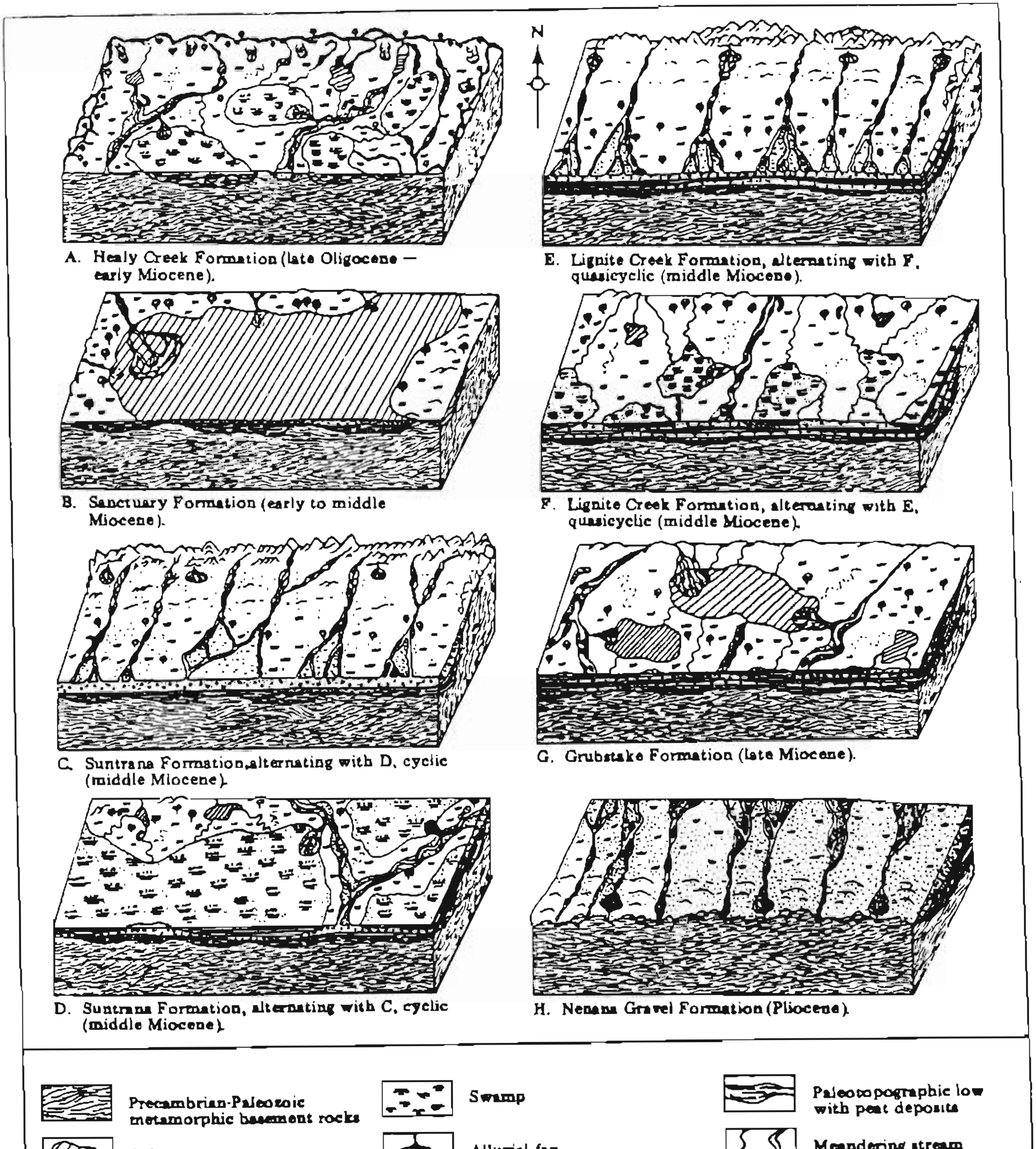


Figure 31. Generalized and simplistic depositional models representing paleo-environmental conditions at certain times during the formation of the Tertiary coal-bearing group of the Nenana coal field. No particular relative scale or defined area is implied. Refer to text for discussion. The ancestral mountains of C and E represent potential source areas of clastics near the northern part of the Tanana Flats or western end of the Yukon-Tanana upland.

major unconformity. Densely vegetated coal swamps developed in nearly isotopographic lows on this irregular surface. Poorly drained swamps, ponds, sandy stream channels, levees and crevasse splays (overwash flood deposits) occurred over this lowland plain surrounded by forested uplands of moderate relief. Sediments carried by meandering streams across 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 100 miles long and 30 miles 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. Wahrhaftig (1958) believed that firm reserve figures could not be calculated due to the thin coal beds and their marked lenticularity.

The Sanctuary Formation is a locally thick claystone of probable lacustrine origin. It was deposited during Sanctuary time (fig. 31B) in early to middle Miocene. The silt and clay that washed into this large shallow lake were derived apparently from sources different than the Healy Creek, possibly from basic igneous rocks in a fairly distant region. Prominent lacustrine deltas formed locally. The formation thickens somewhat to the south and southeast. During most of Sanctuary time, the lake was sufficiently deep to prevent the rooting of aquatic vegetation, but parts of the lake became restricted by late Sanctuary time and coal swamps began to form. However, very little coaly material has been preserved, and it is near the top of the formation.

The Suntrana Formation formed on a subsiding plain with scattered, fairly extensive, coal swamp development during Suntrana time in the middle Miocene (figs. 31C and D). Periods in which streams carried sheets of sand and gravel from northern source areas, i.e., uplift and subsidence (Suntrana time 1, fig. 31C) altered with periods in which most of the plain was a coal-forming swamp (Suntrana time 2, fig. 31D). Important subenvironments include channels, levees, crevasse splays, forested plains (evidenced by coalified logs), and alluvial fans. Subsidence was greatest to the south, and the formation gradually thickens in this direction. Chert pebbles indicate a source near the western margin of the Yukon-Tanana upland, perhaps from the Livengood Chert (Wahrhaftig, 1958).

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

Sediments of the Lignite Creek Formation were deposited in the same basin(s) as the Suntrana Formation during Lignite Creek time (figs. 31 E and F) in middle Miocene. The pattern of deposition was similar to that of the Suntrana, and was to some degree also cyclic. Little or no significant break in deposition occurred, and sediments derived from the north poured into the subsiding basin at an increased rate (Lignite Creek time 1, fig. 31E). Since the pebble lithologies are less resistant than those of the Suntrana, they may have been derived from a less distant source area or different source unit, and/or after considerable rejuvenation of the source area (Wahrhaftig, 1958). Large alluvial fans developed on the sloping terrain between the subsiding basin and the highland source areas. The coal swamps that developed during Lignite Creek time 2 (fig. 31F) were often inundated by flood waters depositing silts, sands, and gravel. Hence, coal seams of the Lignite Creek Formation are very lenticular and laterally discontinuous. The highlands to the north were eventually lowered by erosion depleting the supply of clastic materials. Shallow lakes formed locally and silts and clay were deposited.

The Grubstake Formation consists mainly of claystone and was deposited during the transition period (Grubstake time, fig. 31G) in late Miocene which separates the derivation of clastic materials from northerly source areas (Suntrana and Lignite Creek times) and later on from southerly source areas (Nenana Gravel time). An unconformity separates the Lignite Creek and Grubstake formations. Grubstake time was relatively unstable and depositional conditions shifted between large shallow lakes and broad alluvial plains. The old highlands to the north were lowered and new ones to the south began to rise. Local uplifts closed off rivers and the drainage was "ponded" in the lowland. Lacustrine deltas locally splayed into the lakes. The unstable depositional conditions are reflected in the absence of coal and in the interbedded finer grained sediments with relatively dark-colored sandstones and conglomerates (Wahrhaftig, 1958).

The Nenana Gravel (fig. 31H) was derived from southerly source areas in the Pliocene and covers the coal-bearing sediments in a thick layer of coarse gravel with inclusions of cobbles and boulders.

COAL PETROLOGY

Methods of Analysis

Procedures of the International Committee on Coal Petrology and the brown coal terminology of Stach's Textbook of Coal Petrology were adopted and followed for the petrologic analysis of coal samples from the Nenana coal field.

Coal samples (about 50 grams) were crushed to -20 mesh, kneaded with epoxy resin, and briquetted in two 1-inch (i.d.) diameter molds using a hydraulic press at 4,000 to 5,000 PSI. The pellets were ground using a

Buehler automet and consecutively a 120u diamond lap and a 30u metal-bonded diamond lap, and then polished in 1u and 0.05u aluminum oxide suspensions.

A Swift point counter was used for quantitative maceral determinations. All pellets were randomly counted to avoid bias; 500 counts were made of the different macerals encountered along grid traverses. Maceral contents were recorded on a volume percent, mineral-matter-free basis, and later averaged for the two pellets of each sample.

Reflectance measurements were made on a Leitz Ortholux triocular body microscope equipped with an MPV-3 system and a motorized-drive stage. A square-leaf diaphragm with a 5u square measuring area on the specimen was used, and an interference filter was inserted to give a peak transmittance at 546 nm wavelength. Bausch and Lomb Company optical glasses were used as reflectance standards. The mean maximum reflectance of ulminite (or vitrinite) particles was measured in oil along equally spaced traverses; 100 measurements were made on each sample. The polished pellets were dried in a desiccator prior to taking reflectance measurements (Rao and Wolff, 1981).

Discussion of Results

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, while 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 while the Tertiary coals of British Columbia and Australia usually do not (Stach and others, 1982).

Table 2 lists the main characteristics of the three maceral groups---huminite, liptinite, and inertinite---in brown coals and lignites. Table 3 summarizes the maceral compositions for Nenana coal field samples, and quantitative data on individual samples are enumerated in table D7 of appendix D. Photomicrographs of coal macerals from samples of the region are shown in figures 32 and 33 and show the general types, morphology, and common associations.

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 taken from outcropping seams, the latter may be more probable. Following ulminite, humodetrinite (usually as attrinite but sometimes as densinite) is

Table 2. Nomenclature and characteristics for major brown coal-lignite macerals.*

Maceral group	Characteristics: Origin	Abundance	Chemistry	Reflectance	Fluorescence	Maceral subgroup	Maceral	Maceral type	Comments
Huminite	Derived from woody or vascular tissues of plants---cell wall material, stems, roots, or bark	Generally makes up 50-90% of most coals	Carbon and hydrogen contents are intermediate between liptinites and inertinites	Intermediate between liptinites and inertinites	Some macerals exhibit a weak brownish fluorescence when excited by ultraviolet light	Humotelinite	Ulminite	Texto-ulminite	Alteration product from textinite, partially gelified
								Eu-ulminite	Alteration product from textinite, completely gelified
							Textinite		Humified tissues which are ungelified and still resemble the original cell walls, being characterized by open cell lumens
							Attrinite		Humic detrital particles and finely divided and mainly porous gel which are loosely packed and well differentiated from one another
						Humodetrinite	Densinite		Individual humic detrital particles and finely divided humic gel which are cemented tightly together

Table 2. (con.)

Maceral group	Characteristics: Origin	Abundance	Chemistry	Reflectance	Fluorescence	Maceral subgroup	Maceral	Maceral type	Comments
								Pori-gelinite	Finely porous to granular gels originating from colloidal humic solutions
							Gelinite	Levi-gelinite	Three forms--- eugelinite (dense and massive), telogelinite (completely gelified tissues), and detrogelinite (humic detritus occurring as cavity fillings---shrinkage cracks, cleats, root ducts)
						Homo-collinite		Phlobaphinite	Primary cell infillings liberated as excretions from living plant cell walls
							Corpo-huminite	Pseudo-phlobaphinite	Produced as secondary cell infillings from humic gels
Liptinite (exinite)	Derived from the waxy and resinous parts of plants such as spores, cuticles, and wound resins	Usually makes up 5-15% of most coals	Lowest carbon and highest hydrogen contents of all macerals	Lowest reflectances of all macerals	All fluoresce when excited by ultraviolet light		Sporinite		Spore and pollen perines and exines; takes the form of a flattened spheroid, upper and lower hemispheres compressed until they come together

Table 2. (con.)

Maceral group	Characteristics: Origin	Abundance	Chemistry	Reflectance	Fluorescence	Maceral subgroup	Maceral	Maceral type	Comments
							Alginite		Algal remains; rare; fluoresces with a brilliant yellow color in ultraviolet light
							Cutinite		Cuticles of leaves and stems; occurs as long stringers which have one surface that is fairly flat and another surface that is crenulated
							Resinite		Resins, plant secretions, and exudates; occurs as ovoid bodies or fissure-filling material
							Suberinite		Cork cell walls which occur mainly in barks
Inertinite	Derived from plant material that has been strongly altered and degraded in the peat stage of coal formation; e.g., fossil charcoal	Composes from less than 5% up to 40% of some coals	Highest carbon and lowest hydrogen contents of all macerals	Highest reflectances of all macerals	Do not fluoresce		Macrinite		Minor component; occurs as structureless ovoid bodies with the same reflectance as fusinite; may have globular appearance

Table 2. (con.)

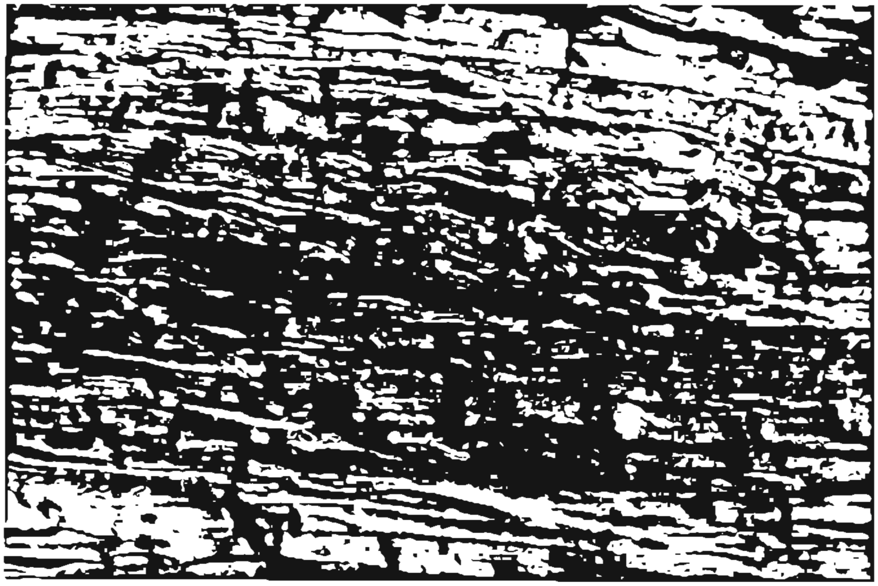
Maceral group	Characteristics: Origin	Abundance	Chemistry	Reflectance	Fluorescence	Maceral subgroup	Maceral	Maceral type	Comments
							Fusinite		Charcoal-like structure with a cell texture; commonly broken in small shards and fragments (bogen)
							Semifusinite		Same cell texture as fusinite but of lower reflectance
							Sclerotinite		Formed from hard fungal remains; occurs as ovoid bodies with cell structure
							Inertodetrinite		Clastic form of inertinite; fragments of different inertinite macerals occurring as dispersed particles

*Adapted from Crelling, J.C., and Dutcher, R.R., 1980, Principles and applications of coal petrology: SEPM Short Course Notes No. 8, 127 p.
Stach, E., and others, 1975, Stach's textbook of coal petrology: translated and English revision by Murchison, D.G., Taylor, G.H., and Zierke, F.; Gebruder Borntraeger, Berlin, 428 p.

Table 3. Summary of coal petrologic data for 70 coal samples from the Nenana field.

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

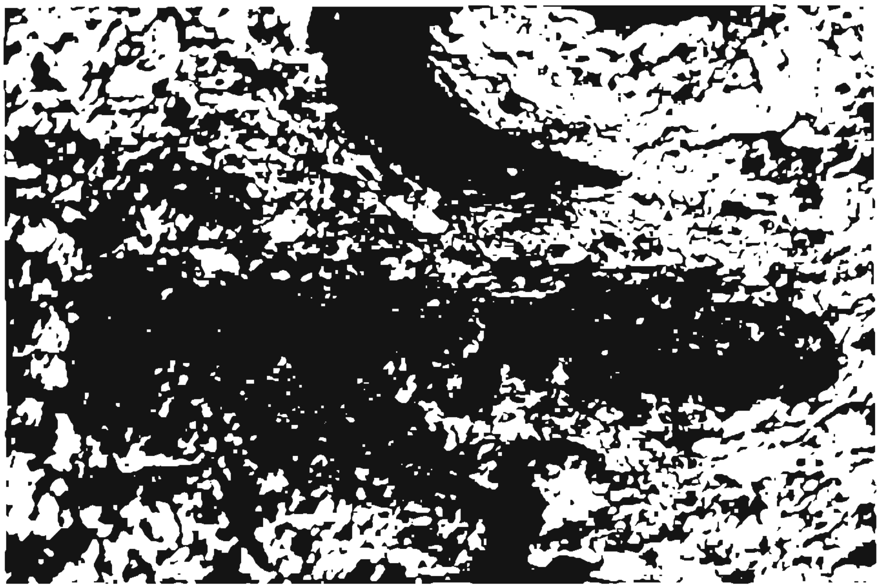
*Almost exclusively ulminite.
**Predominantly resinite.



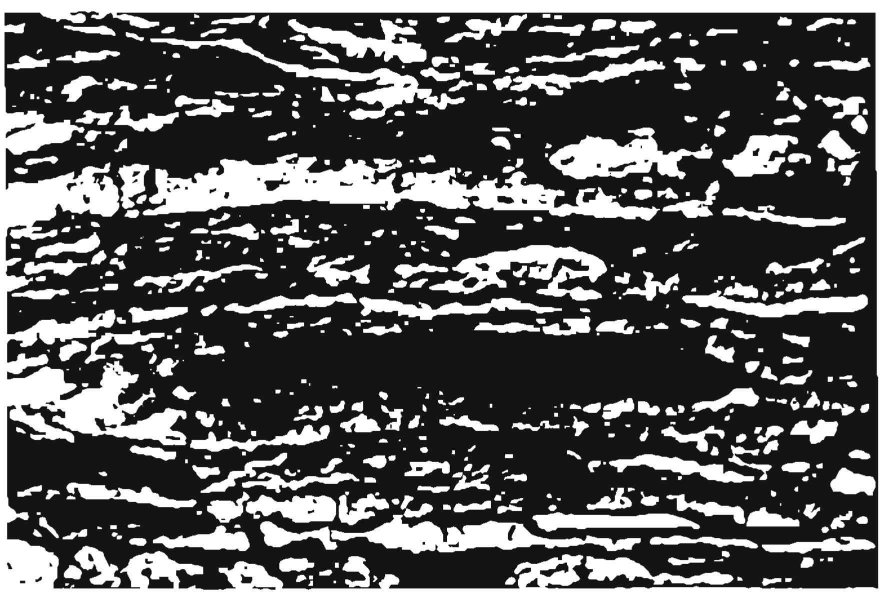
A. Texto-ulminite (RAA2-1; 500X).

B. Ulminite, phlobaphinite, and porigelinite (RAA2-1; 500X).

Figure 32. Photomicrographs of various macerals and maceral types from the Nenana coal field samples indicated (reflected light; oil immersion).

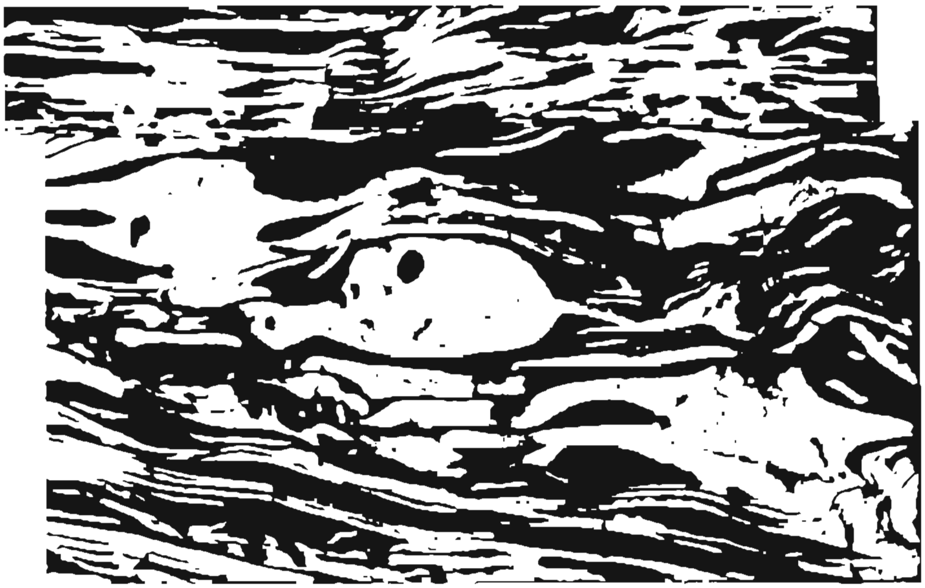


C. Sporinite, resinite, humodetrinite, inertodetrinite, and disseminated mineral matter (SC4-1; 300X).



D. Ulminite, sporinite, semifusinite, and humodetrinite (RMC1-1; 400X).

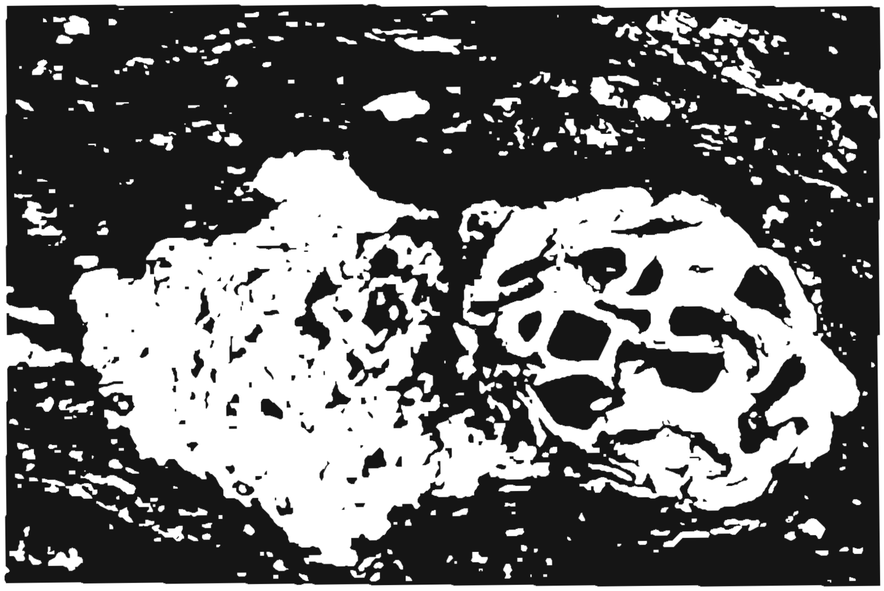
Figure 32. (con.)



E. Semifusinite (LCT5-2; 500X).

F. Fusinized microspore, ulminite, and humodetrinite (NC1-1; 300X).

Figure 32. (con.)



G. Sclerotinite (Sclerotites sp.), semifusinite, ulminite, and humodetrinite (NC1-1; 500X).

H. Framboidal pyrite in ulminite (MS1-1; 450X).

Figure 32. (con.)

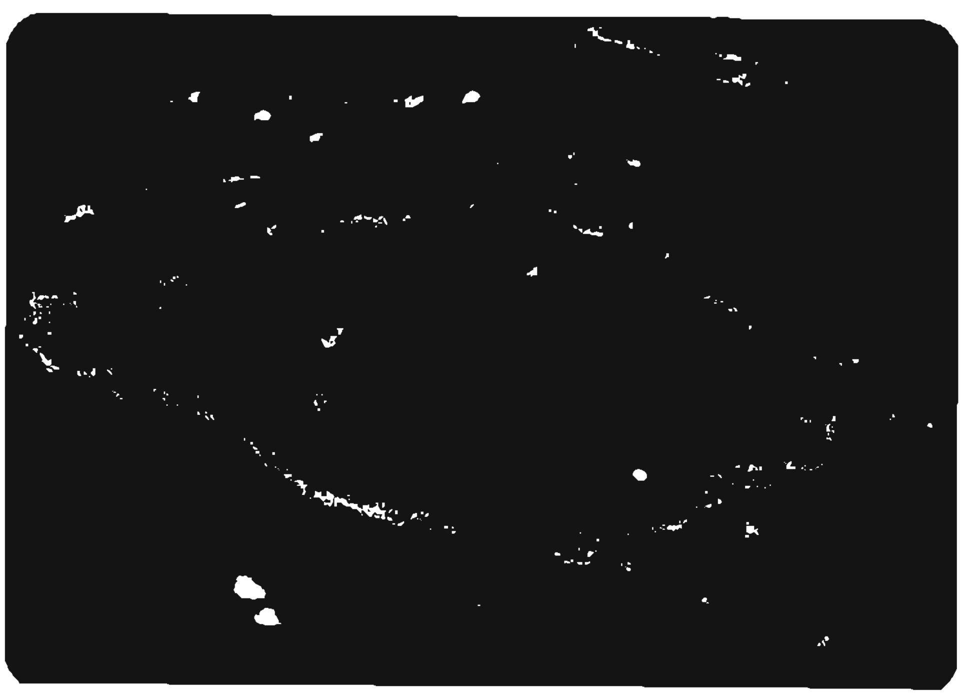
consistently the most abundant huminite. It tends to be more abundant in high ash coals and typically increases in the upper portions of thick seams and in the relatively thin coals toward the top of coal-bearing sections. The mean humodetrinite content is over 7 percent.

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' paleo-environment where the precursor peat 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 diagonstic 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. Various fluorescent liptinite macerals from the Nenana samples analyzed are shown in figure 33.

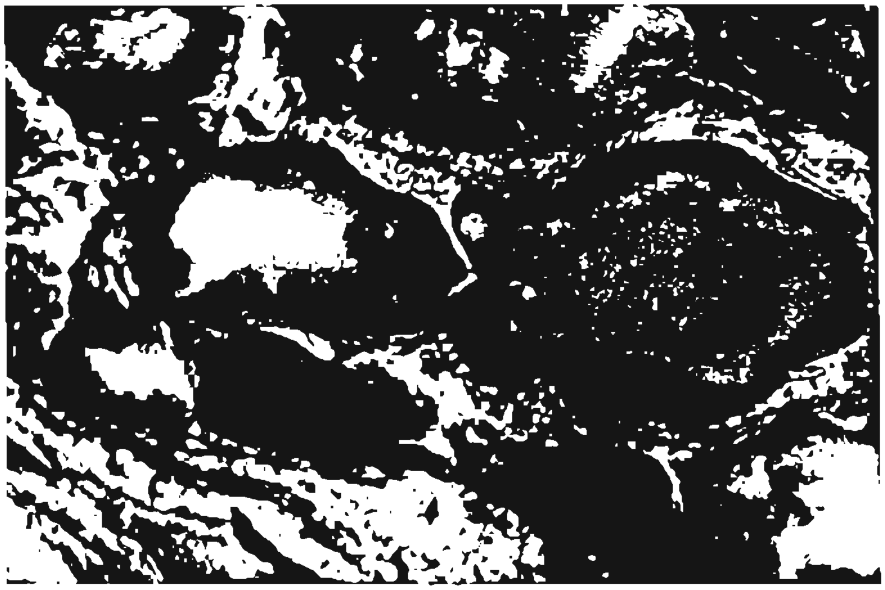
Resinite predominates in abundance over suberinite and exsudatinite. Resinite occurs as cell fillings, secretions, and isolated elongate or spherical bodies. Resinite fluoresces bright orange, while exsudatinite fluoresces dark orange. Exsudatinite fills cracks in vitrinite, cell lumina of fusinite or 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 communication, 1983). Preserved algal remains (alginite) is extremely rare in the Nenana coals analyzed. Although some

A. Sporangium with resinite cell fillings, porigelinite, humodetrinite, and dispersed mineral matter. Outside the sporangium are ulminite, humodetrinite, and exinite (MM2-3; 300X; normal reflected light).



B. Same as A but under blue-light irradiation.

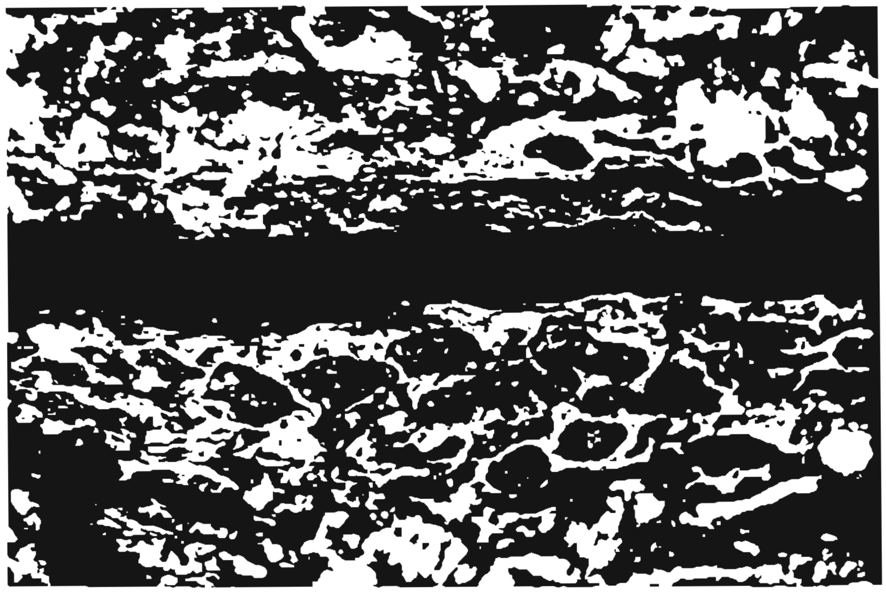
Figure 33. Photomicrographs of fluorescing liptinites and other associated macerals and maceral types from the Nenana coal field samples analyzed (oil immersion).



C. Resinite, ulminite, and porigelinite (BC1-4; 400X; normal reflected light).

D. Same as C but under blue-light irradiation.

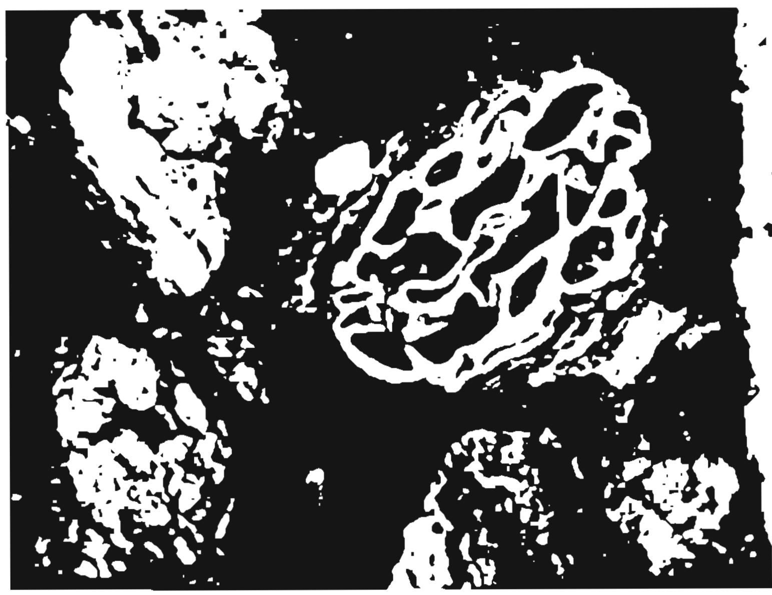
Figure 33. (con.)



E. Resinite, ulminite, and inertodetrinite (BC1-4; 400X; normal reflected light).

F. Same as E but under blue-light irradiation.

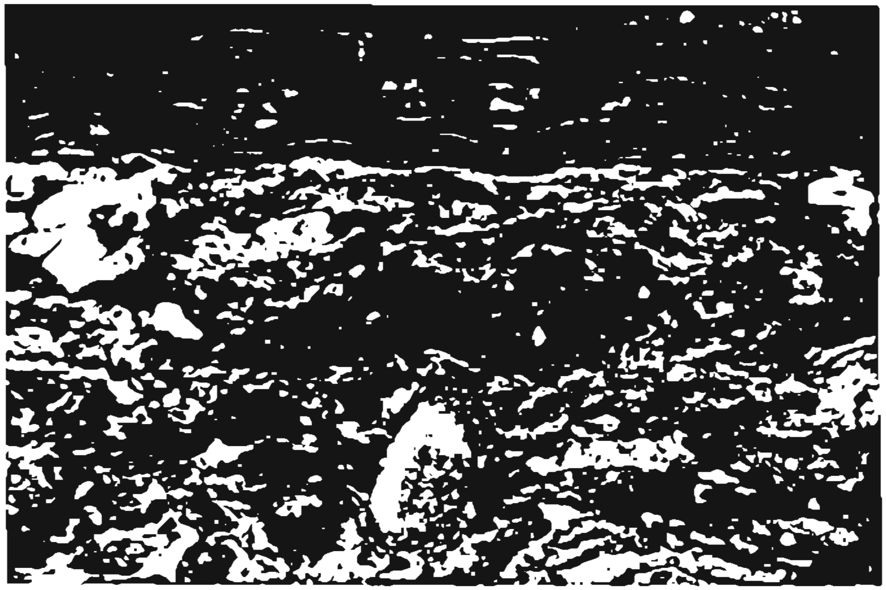
Figure 33. (con.)



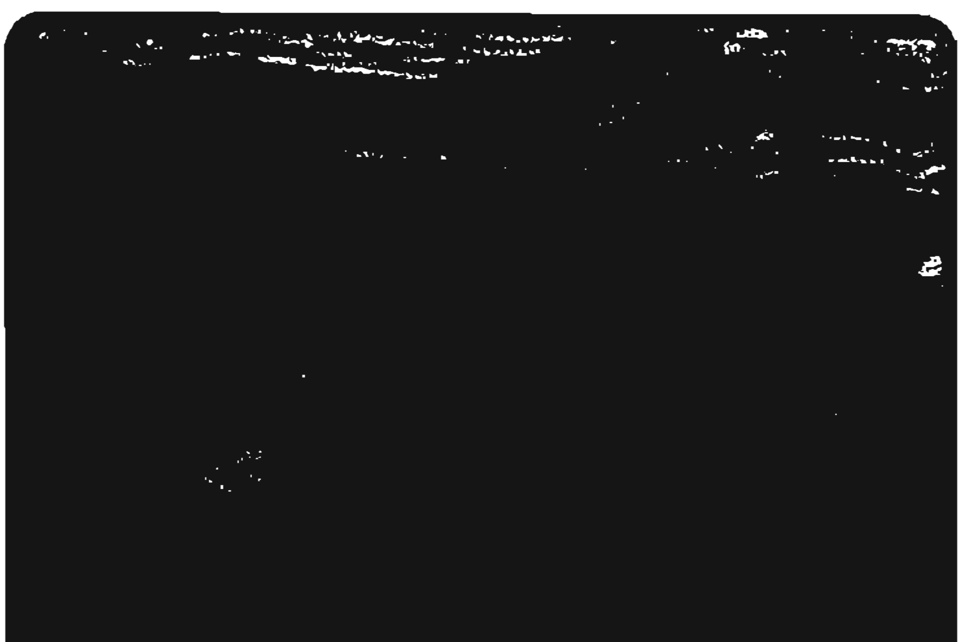
G. Resinite filling lumen and surrounding sclerotinite with ulminite and humodetrinite (RMC1-1; 400X; normal reflected light).

H. Same as G but under blue-light irradiation.

Figure 33. (con.)

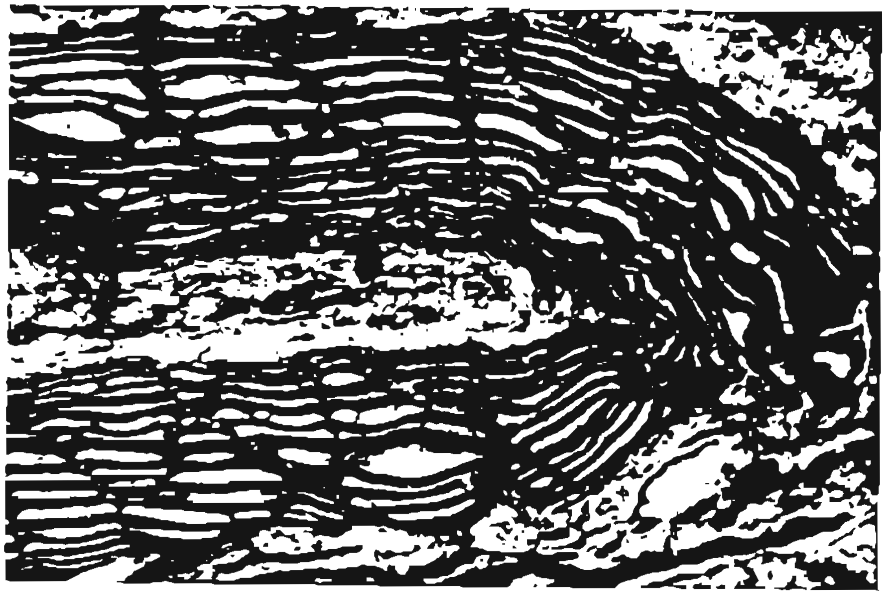


I. Suberinite, resinite, ulminite, cutinite, humodetrinite, and dispersed mineral matter (LCT5-2; 400X; normal reflected light).



J. Same as I but under blue-light irradiation.

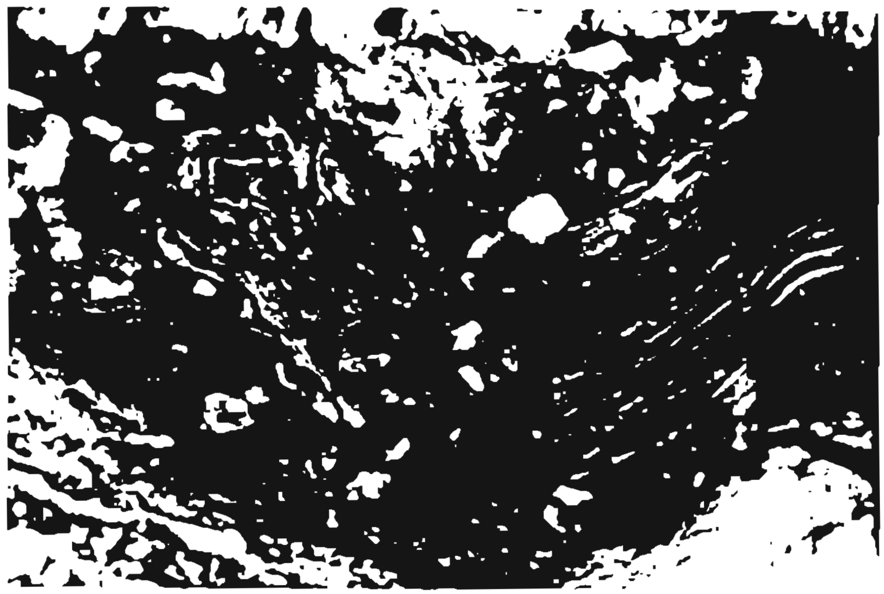
Figure 33. (con.)



K. Suberinite, phlobaphinite, and ulminite (MS1-1; 500X; normal reflected light).

L. Same as K but under blue-light irradiation.

Figure 33. (con.)



M. Suberinite, sporinite, humodetrinite, inertodetrinite, dispersed mineral matter, and resinite (LCT5-2; 400X; normal reflected light).

N. Same as M but under blue-light irradiation.

Figure 33. (con.)

O. Thick-walled cutinite (crassicutinite) or "algicutinite" with humodetrinite, exinite(?), inertodetrinite, and dispersed mineral matter (MM2-3; 400X; normal reflected light).

P. Same as O but under blue-light irradiation.

Figure 33. (con.)

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 34 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 huminoid 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.

Mean maximum reflectance values (Rom) for selected Nenana coal samples are summarized in figure 35, and listed individually in table D5 of appendix D. Table D6 (appendix D) compares the reflectance values with their respective ASTM rank. (Note: Analyses of samples from outcrops and weathered or oxidized coal cannot be used for classification by rank according to 6.1.3 of ASTM D388-77). Reflectance increases with the rank of a coal. 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.

Additional coal petrologic data has been summarized from Rao and Wolff (1981) and is included in appendix D. Table D8-B lists reflectance values for several seams in the Nenana field, compared to one seam at Ober Creek (Jarvis Creek sub-field) and the main seam at Little Tonzona River. Table D8-C lists maceral composition data for the same seams. The petrology of these coals appears to be very similar to the results obtained during this study; the mean maximum reflectance values fall within the same range, and the proportions of macerals in the different groups are comparable.

Table 4 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 and probable equivalent undifferentiated Tertiary coal-bearing unit) and is typically less abundant in the Lignite Creek and more variable in the Suntrana. Inertinite shows a trend toward increasing abundance upward in the coal-bearing formations.

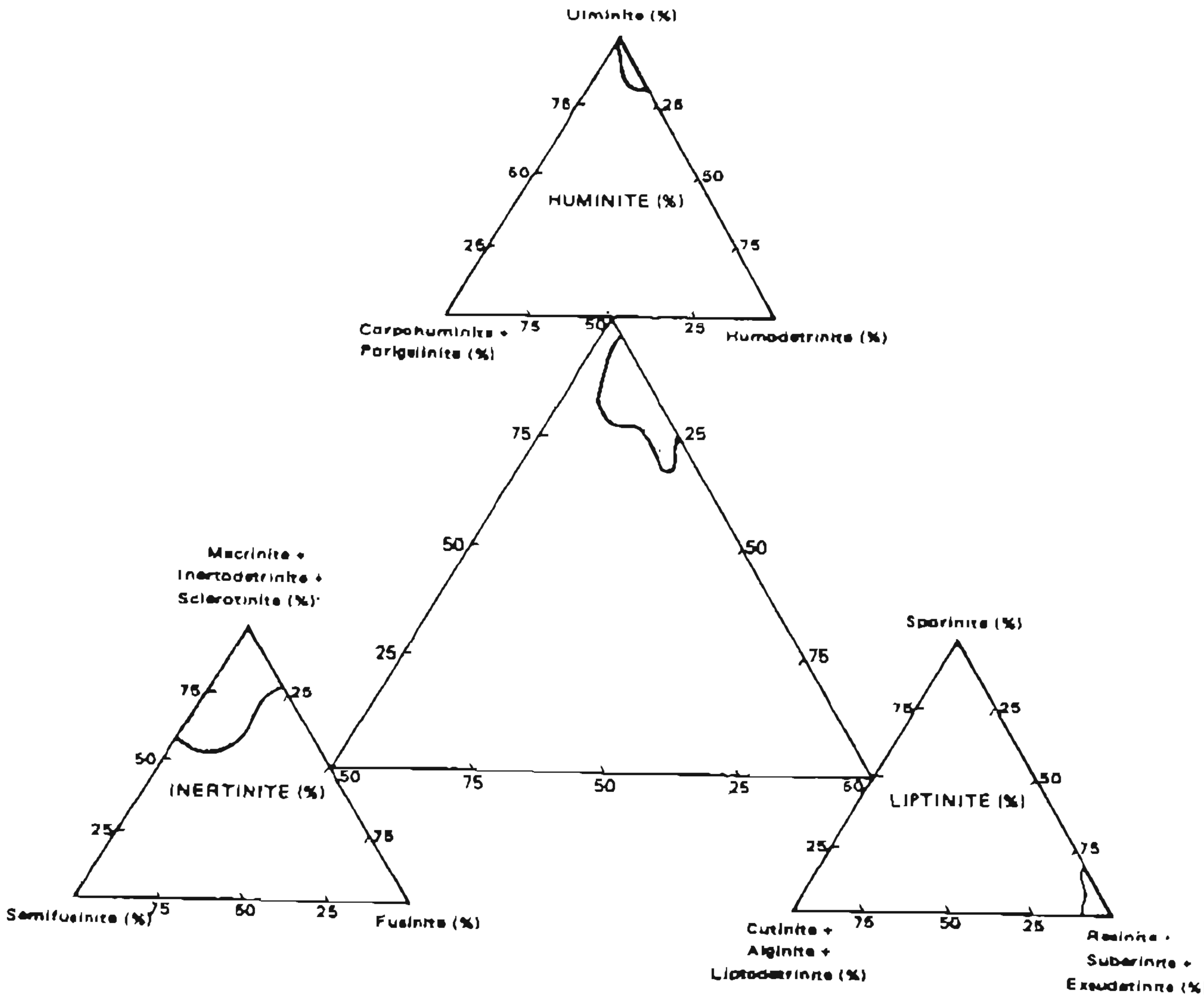


Figure 34. Ternary diagrams for maceral composition of Nenana coal samples. Refer to text for explanation.

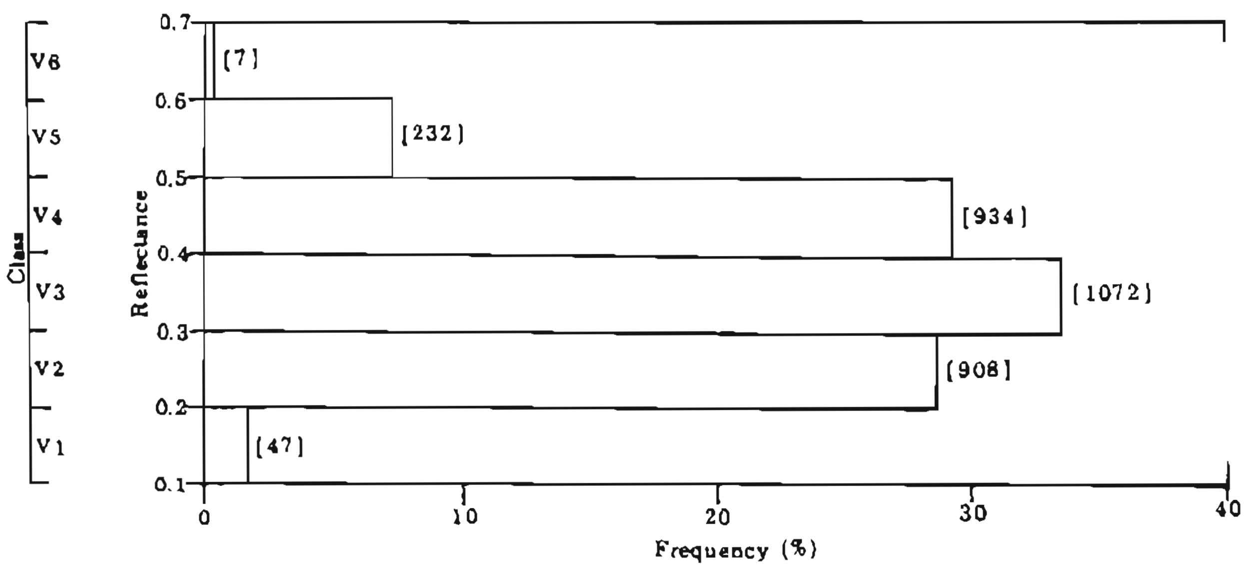


Figure 35. Vitrinite reflectance frequency histogram for coal samples from the Nenana field. Number in brackets indicates total number of grains counted at the given reflectance interval.

Table 4. Proportions of the three maceral groups in coal samples of the coal-bearing formations of the Nenana coal field.

Formation	Maceral group: 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.

The petrology of the 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 quiscent periods that alternated with periods of uplift and the influx of clastics that ended each peat-forming cycle. A forest-terrestrial moor environment is envisaged for certain coals in 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

Based on previous coal-quality studies (e.g., Conwell, 1976; Rao and Wolff, 1981; and Affolter, Simon, and Stricker, 1981), we know that the coals of the Nenana Basin are predominantly of subbituminous rank (B and C). Physically, the coals appear dull black but are locally bright-banded (particularly adjacent to structural flexures) with a dark brown streak, and for the most part discontinuous laterally. Ash contents generally range from 5 to 15 percent, but some are less than 5 percent, and average 10 percent. Sulfur is very low, typically ranging from 0.1 to 0.4 percent, and averaging 0.2 percent. Coals of the Jarvis Creek field show a higher sulfur content (generally ranging from 1.0 to 1.3 percent) than other Nenana coals; they also show a relatively high ash content. Coals of the Farewell-Little Tonzona field (extreme southwest extension of Nenana trend) also show higher sulfur (generally 0.7 to 1.7 percent) than Nenana coals, and much of this sulfur is in the pyritic form (in contrast to the high organic fraction of most Nenana coals), and is often framboidal. The common range for heating values is 8000 to 9500 BTU per pound, averaging 8200 BTU per pound. Some of the coal in the present strip pit at Poker Flats has BTUs upward to 9000 on an as-received basis (Steve Denton, personal commun., 1982). Moisture values are usually around 25 percent.

Coals in the lower part of the coal-bearing group tend to be of better quality, being hard and dense, while coals of the upper part of the section are usually woody and fibrous with shaley interbeds. Typical interbeds or partings are gray to brown carbonaceous claystones, which are often massive, nonfissile, plastic, and grade to bone coal. This bone coal has a high ash content due to the inclusion of fine silts and clays, and it generally weathers to gray or grayish-brown colors on outcrop. Other coals of the region are lignites containing compressed twigs, branches, and other woody components, and are brownish to reddish-brown on freshly broken surfaces. All of the coals have ferric oxide stains (limonite and geothite) on surfaces, cleats, and fractures.

Locally, coal beds have burned baking adjacent rocks. These reddish baked beds are typically harder than enclosing rocks and often bear the imprints of fossil leaves. Both the coals and baked rocks are more competent than enclosing strata, and stand out dramatically in relief along streams and ridges.

It is known that igneous intrusions can cause substantial secondary alterations in coal rank. In the zone of contact between dikes or sills and a coal seam, high ash 'burnt coal' is sometimes found, while cinder coal or natural coke occurs in others. Because of the intense alteration, the character of the coal prior to the intrusive event cannot be determined (Stach and others, 1982). Whether some of the coals of the Nenana field that exhibit apparent slightly elevated ranks (i.e., above that normally expected) have been thermally affected is not known. Sanders (1981) believes that some coals of the Lignite Creek field containing Tertiary diorite intrusions may show evidence of carbonization and pyrolitic effects. Reidel (1984) reports the occurrence of an iron-rich lava flow intercalated with sediments of the coal-bearing group at three locations in the Nenana Basin---in the Rex Creek field, in the Mystic Creek field, and on the east side of Dry Creek (West Delta field). Sanders (1981) states that coals of the Farewell-Little Tonzona area appear to have been thermally altered by contact metamorphism resulting from localized pyrolitic and diastrophic carbonization effects. The late Tertiary-Quaternary intrusion of Jumbo Dome does not appear to have altered the ranks of the coals adjacent to its flanks, even though rather dramatic structural adjustments in the coal-bearing strata occurred. Additionally, the coals of the Nenana field generally show no systematic variance in rank along strike.

Most coal quality data to date have been drawn from analyses of weathered outcrop samples; needless to say, conclusions from such data should be drawn with caution. However, BTU differences for weathered subbituminous and lignite coals are thought to differ only slightly from unweathered core samples. In addition, much petrologic data have been gathered from weathered samples. Chandra (1962) measured reflectances of naturally weathered outcrop samples and fresh, unoxidized samples obtained at greater depths, and found no significant differences in rank ash shown by reflectance measurements of the two sample groups.

Table 5 shows the ASTM classification for the lower stages of coalification (i.e., low rank coals); the shaded areas represent the general range of values for the different rank parameters as measured in Nenana coal field samples. These include mean maximum reflectance values from 0.21 to 0.53 percent, volatile matter contents from about 47 to 69 percent (dry, ash-free basis), bed moisture contents from about 8 to 30 percent, and calorific values from 6650 to 11650 BTUs per pound (moist, ash-free basis). Table D4 of appendix D lists the criteria for the ASTM classification of coals by rank. Table 6 gives a brief summary of proximate and ultimate analysis data for the Nenana coal samples analyzed during this study. A detailed tabulation of individual sample results are presented in tables D1 and D2 of appendix D, and the general locations of sampled coal-bearing sections of the Nenana Basin are shown on plate 1.

Total sulfur values are shown in figure D1 of appendix D for all the coal samples analyzed during this study. Samples in which framboidal pyrite was identified is indicated by an asterisk after each bar. The figure

Table 5. ASTM classification for the lower stages of coalification (adapted from Stach and others, 1982, table 4, p. 45). Shaded areas show the general range of values for different rank parameters in Nenana coal field samples. (Note: Based on ASTM, 1981, D388-77-6.1.2, analyses of outcrop samples and weathered or oxidized coals cannot be used for classification by rank.)

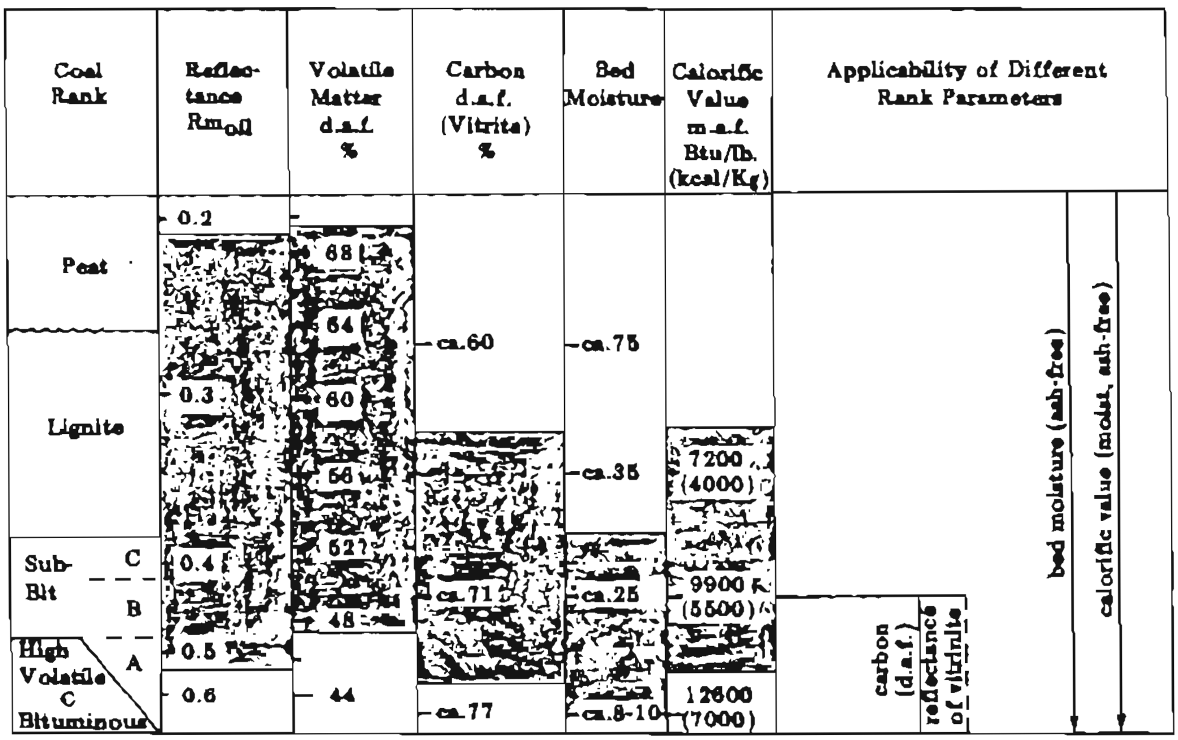


Table 6. Summary of proximate analysis data (71 coal samples) and ultimate analysis data (27 coal samples) for the Nenana coal field.

		Proximate					Ultimate				
Statistic	Basis*	Moisture	Volatile matter	Fixed carbon	Ash	Heating value	Hydrogen	Carbon	Nitrogen	Oxygen	Sulfur
Range	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
	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
Mean	1	23	34	30	12	7900	6.2	47	0.6	36	0.3
	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.

confirms the general range and average sulfur contents reported earlier in this section. However, a few of the samples have sulfur contents over 0.5 percent, and one sample over 1.2 percent. This sample is from Newman Creek of the West Delta field. The pyritic sulfur content of these samples is very low (figure 36). The mean pyritic sulfur content for the Nenana coal samples analyzed is less than 0.02 percent and the mean total sulfur content is about 0.30 percent. Typically, in an unweathered sample of most Alaskan coals, the organic sulfur content occurs in the highest proportion.

Figures 37 through 42 show various scatter plots of paired proximate, proximate versus ultimate, and rank-indicative variables. The plots are presented in order to delimit the range and distribution in the coal quality factors for Nenana coal samples, and so that general trends can be easily recognized. The relationships illustrated are expected for a group of samples exhibiting a narrow range in rank variance, for example, most coals of the Nenana field being of subbituminous rank. Fixed carbon and volatile matter contents, heating value, carbon content, and vitrinite reflectance values increase with rank and thus are all directly related. In coals of a given rank, the ash content has an inverse relationship with the fixed carbon and volatile matter contents.

Table D3 of appendix D lists various coal quality calculations for the Nenana coal samples based on proximate, ultimate, and heating value data. For a given coal sample, it includes the fuel ratio; carbon ratio; Perch and Russell ratio; the H value of Lord; the mineral matter content; the approximate heating value calculated from the ultimate analysis data; moist, mineral-matter-free BTU; and its apparent rank. Only the Perch and Russell ratio arranges the coals in the same general order as the ASTM method. This ratio is thought to be closely related to the coking properties of coals used in coke-oven practice (Considine, 1977).

Table D5 of appendix D lists the reflectance data for individual Nenana coal field samples. The mean maximum reflectance values ($\bar{R}om$) range from 0.21 to 0.53 percent. Table D6 of appendix D compares the ASTM rank of coal with its vitrinite reflectance value. According to this criteria, the Nenana coals range from lignite, through subbituminous, to high-volatile C bituminous ranks. The maceral composition of Nenana coals analyzed during this study is listed for individual samples in table D7 of appendix D. The results of the quantitative maceral analysis are discussed in the coal petrology section of this report.

Rao and Wolff (1981) reported detailed results from coal quality and petrologic studies on several coal samples from the Nenana coal field. Most of the samples were taken at the Poker Flats pit. Certain of these analyses are summarized in table D8 (A-E) of appendix D. Results are also given for a coal from Ober Creek (Jarvis Creek field) and a seam from Little Tonzona River, western Nenana trend (the latter is from comparison only). Table D8-A lists proximate and ultimate data on the raw coals and confirms earlier conclusions relating to coal quality. Table D8-B lists vitrinite reflectance data ranging from 0.27 for the main seam at Little Tonzona River to 0.42 for the Caribou seam, and table D8-C lists coal petrologic data for the same samples. They show that huminite contents range from 80 to nearly 95 percent,

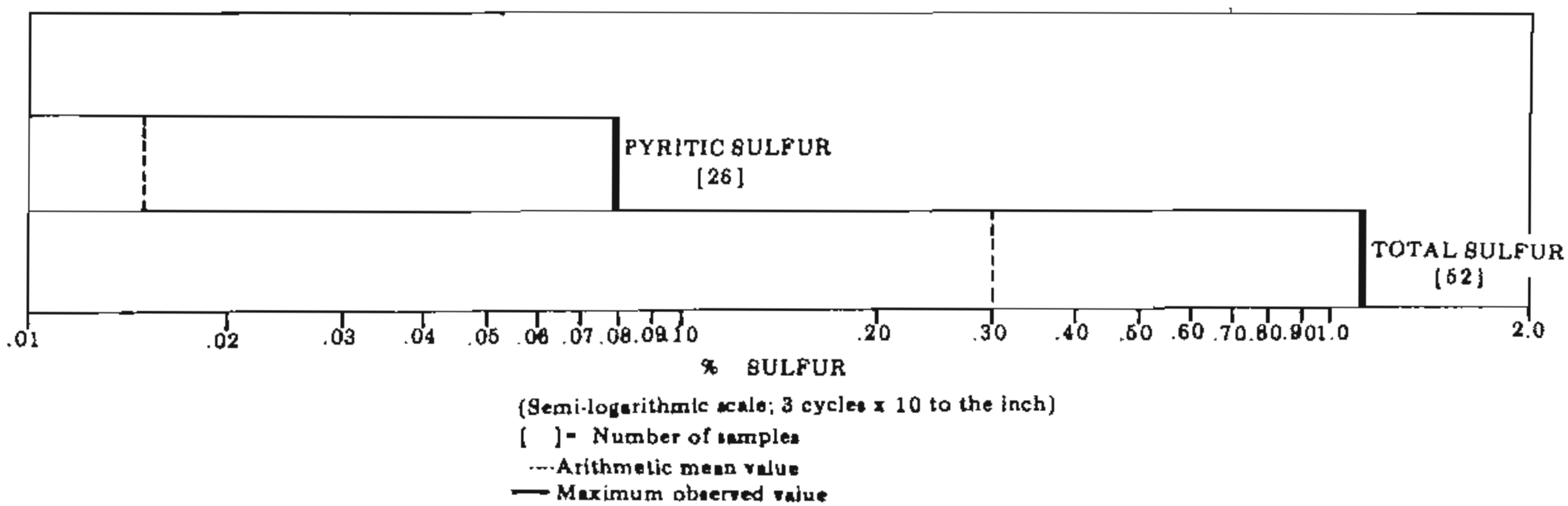


Figure 36. Bar graph showing the maximum and arithmetic mean values for the percent pyritic and total sulfur of analyzed coal samples from the Nenana coal field (as received basis).

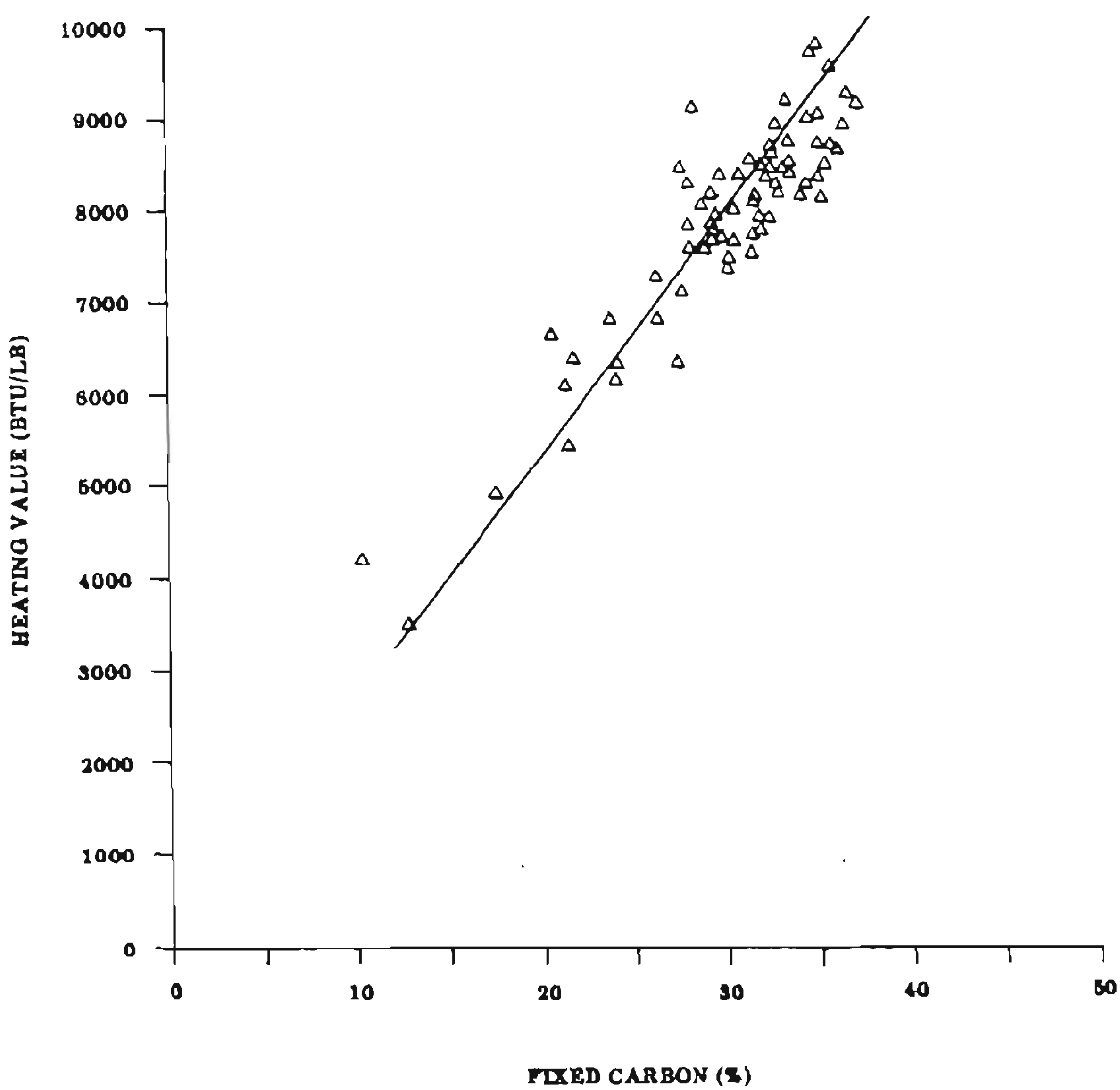


Figure 37. Scatter plot showing the direct relationship of the heating value (in Btu/lb) with the fixed carbon content for coal samples analyzed from the Nenana field (proximate data, equilibrium moisture basis).

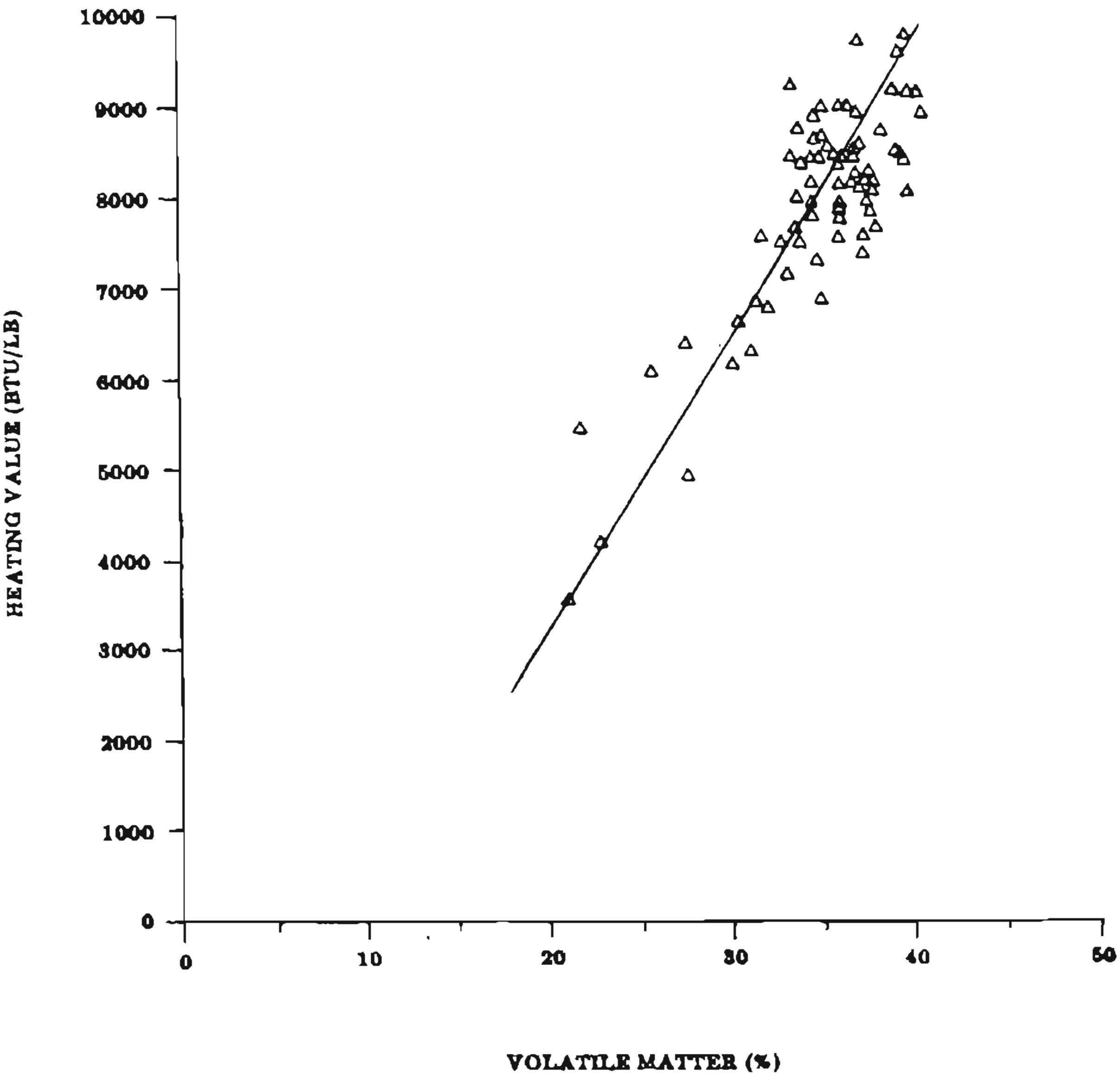


Figure 38. Scatter plot showing the direct relationship of the heating value (in Btu/lb) with the volatile matter content (in percent) for coal samples analyzed from the Nenana field (proximate data, equilibrium moisture basis).

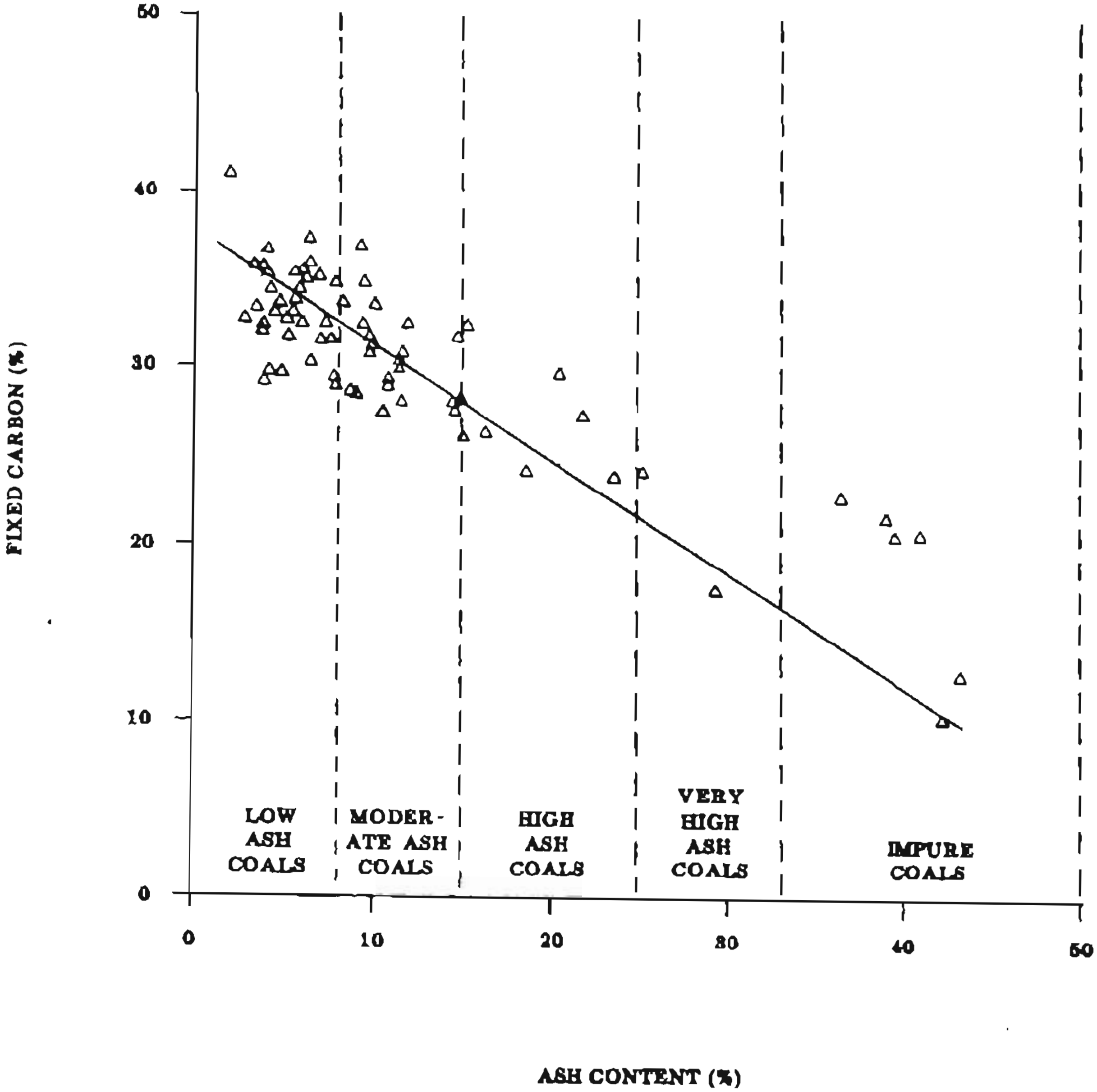


Figure 39. Scatter plot showing the inverse relationship of the fixed carbon content and ash content for coal samples analyzed from the Nenana field. The high ash coals tend to have lower fixed carbon contents (proximate data, equilibrium moisture basis).

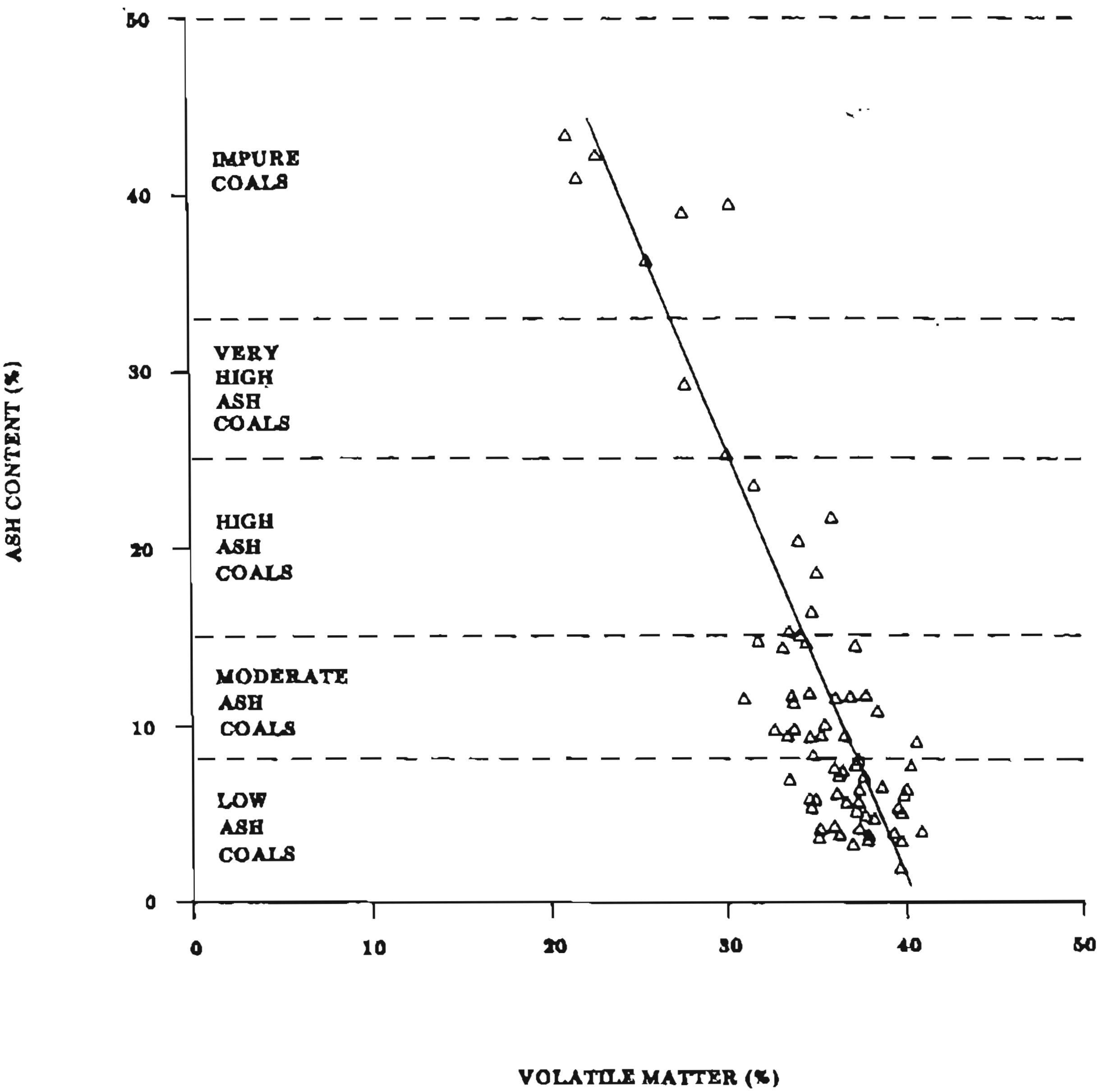
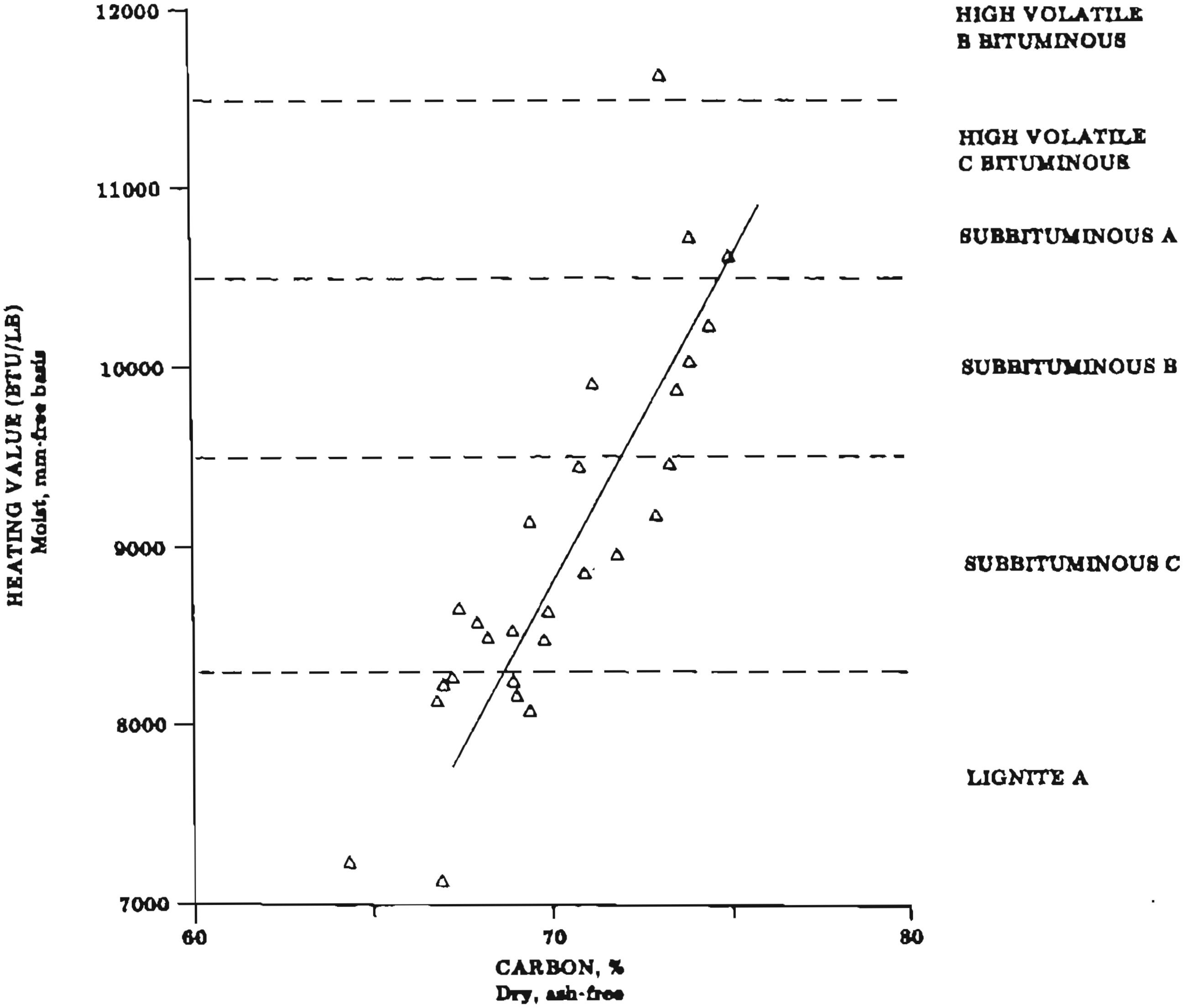
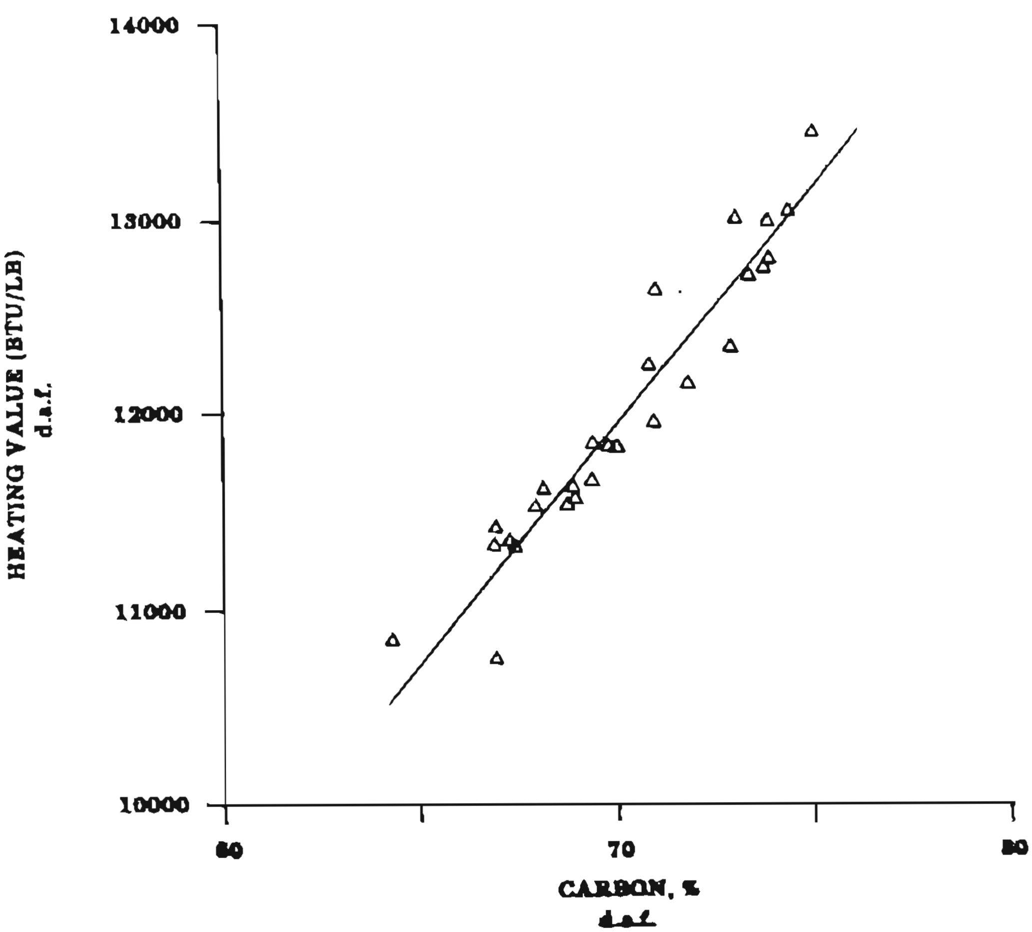


Figure 40. Scatter plot showing the inverse relationship of the ash and volatile matter contents for coal samples analyzed from the Nenana field. Low ash coals tend to have higher volatile matter contents (proximate data, equilibrium moisture basis).

Figure 41 (A and B). Scatter plots showing the direct relationship of the heating value (in Btu/lb) with the carbon content (in percent) of coal samples analyzed from the Nenana field. Both the heating value and carbon content increase with the rank of a given coal. Proximate and ultimate data. A, Moist, mineral matter-free vs. dry, ash-free percent carbon; B, Both variables, dry, ash-free basis.

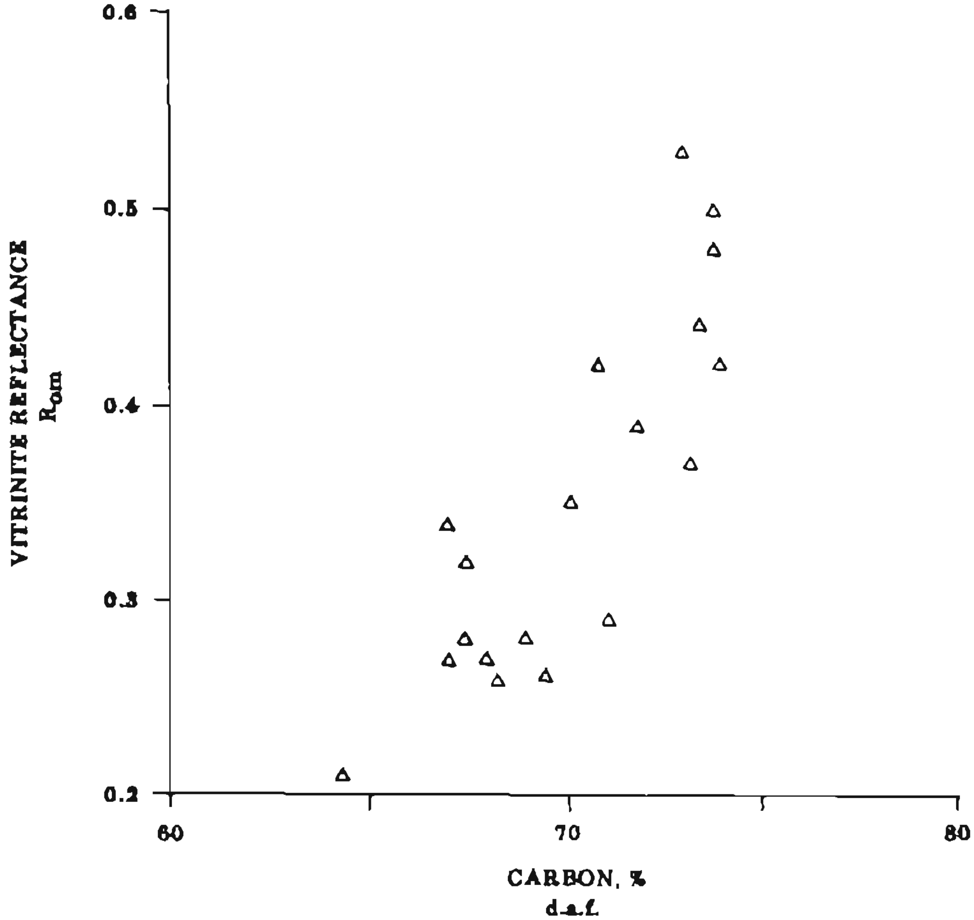


(A) Figure 41

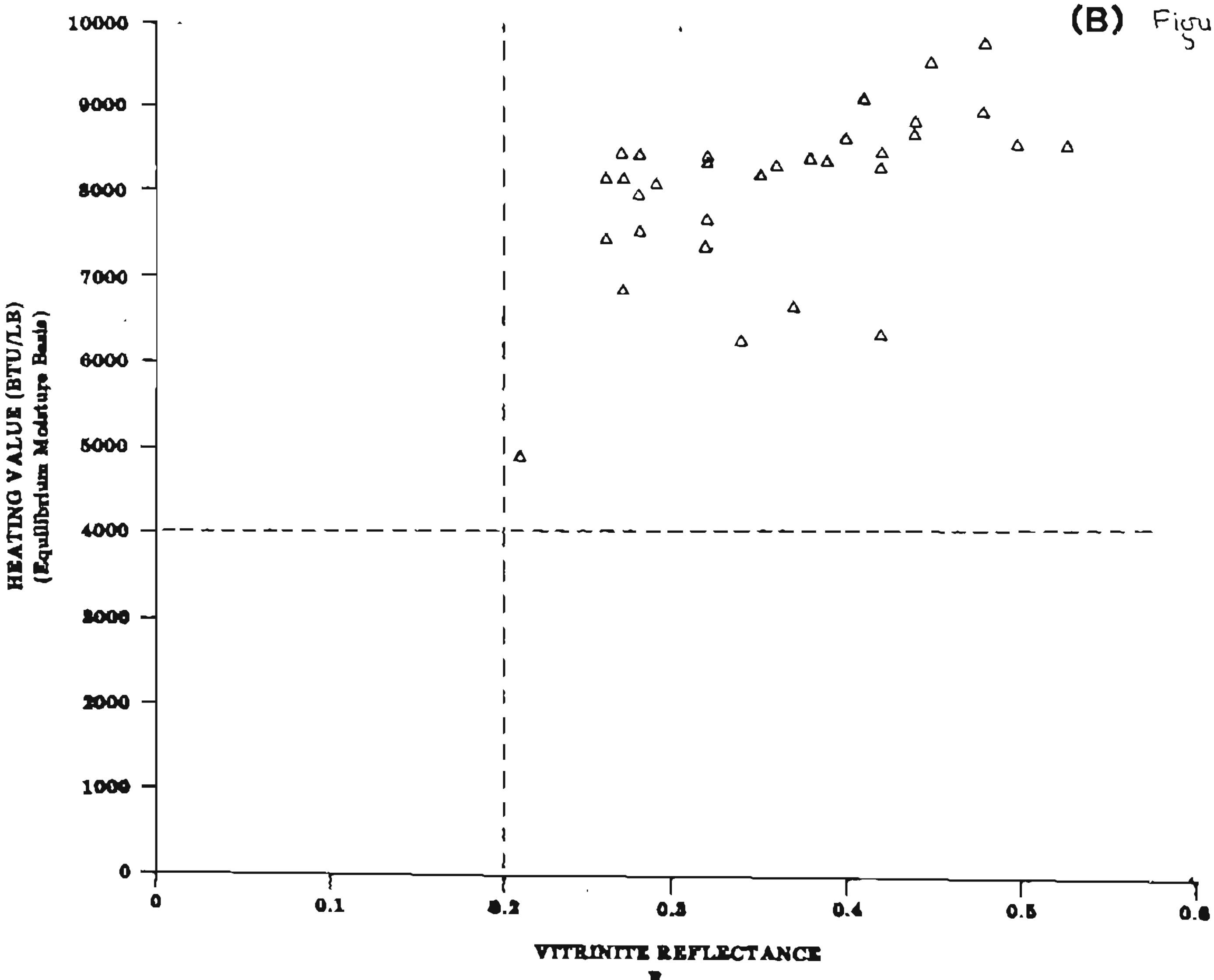


(B) Figure 41

Figure 42 (A and B). Scatter plots showing the general direct relationship of the mean maximum vitrinite (ulminite) reflectance values (Rom) with two other rank indicators in coal samples analyzed from the Nenana field: A, Rom versus percent carbon (dry, ash-free basis) and B, Rom versus heating value (in Btu/lb, equilibrium moisture basis). The three variables---Rom, carbon content, and heating value---increase with the rank of a given coal.



(A) Figure 42



(B) Figure 4

liptinites from about 4 to 9 percent, and inertinites from less than 1 percent to 16 percent.

Concentrations of major and certain trace elements in the raw coals and ashes are given in table D8-D and D8-E of appendix E. Silica, aluminum, calcium, iron, and magnesium account for most of the inorganic matter in these coal samples. Low-rank Alaska coals (lignites and subbituminous C) are commonly enriched in CaO and MgO. SO_3 values range from about 3 percent to nearly 22 percent. As expected, the concentrations of major oxides calculated as volume percent of the raw coal composition are low compared to their content in raw coal ash. The Caribou Seam from upper Lignite Creek shows anomalously high concentrations of boron. Rao and Wolff (1981) found that the concentrations of all trace elements increased in the ash of lower density fractions, and that beneficiation of the coals would result in partial elimination of trace elements from the raw coals.

Figure 43 shows a coal-bearing section and sample intervals for the Gold Run Pass pit area on Sanderson Creek. The result of analyses of coal samples of the Caribou, Parting, and Moose seams were reported by Conwell (1976). The detailed analytical data resulting from this study are summarized in table D9 (A-C) of appendix D. Table D9-A lists proximate and ultimate data, heating values, and forms of sulfur for the samples, all comparable to the results of Rao and Wolff (1981). Table D9-B enumerates the major oxide and elemental analysis results on the samples (both raw coal and raw coal ash). Table D9-C compares elemental contents of these Nenana coal samples with average values for the same elements in shale and the Earth's crust. Conwell (1976) concluded that the contents of undesirable volatile elements (As, F, Hg, Sb, and Se) in the coals were very low. The Parting Seam did show a somewhat higher U and Th content than the other two beds and than the average for the shale and the Earth's crust.

Affolter, Simon, and Stricker (1981) reported rather detailed analyses on 20 coal samples from the Healy Quadrangle. Summary data on these samples are listed in table D10 (A-D) of appendix D. Table D10-A gives general sample information. Table D10-B compares values for proximate and ultimate analyses, heats of combustion, forms of sulfur, and ash-fusion temperatures of the Nenana samples with similar values reported for Powder River region samples. Table D10-C compares major oxide analysis values on the Nenana coal ashes with values reported for Powder River region samples. Sample D10-D summarizes the results of elemental analyses on the Nenana samples and compares them to a mean value for the same element in Powder River region samples.

Several of the conclusions reached by Affolter, Simon, and Stricker (1981) based on comparison of the various coal quality and geochemical parameters for the Healy Quadrangle coal samples versus Powder River region and general United States coal samples are:

- Coal from the Healy Quadrangle is significantly higher in volatile matter and oxygen, significantly lower in fixed carbon, carbon, nitrogen, total sulfur, sulfate, pyritic and organic sulfur contents, and has a significantly lower heat of combustion. The moisture, ash and hydrogen contents are not significantly different. When compared

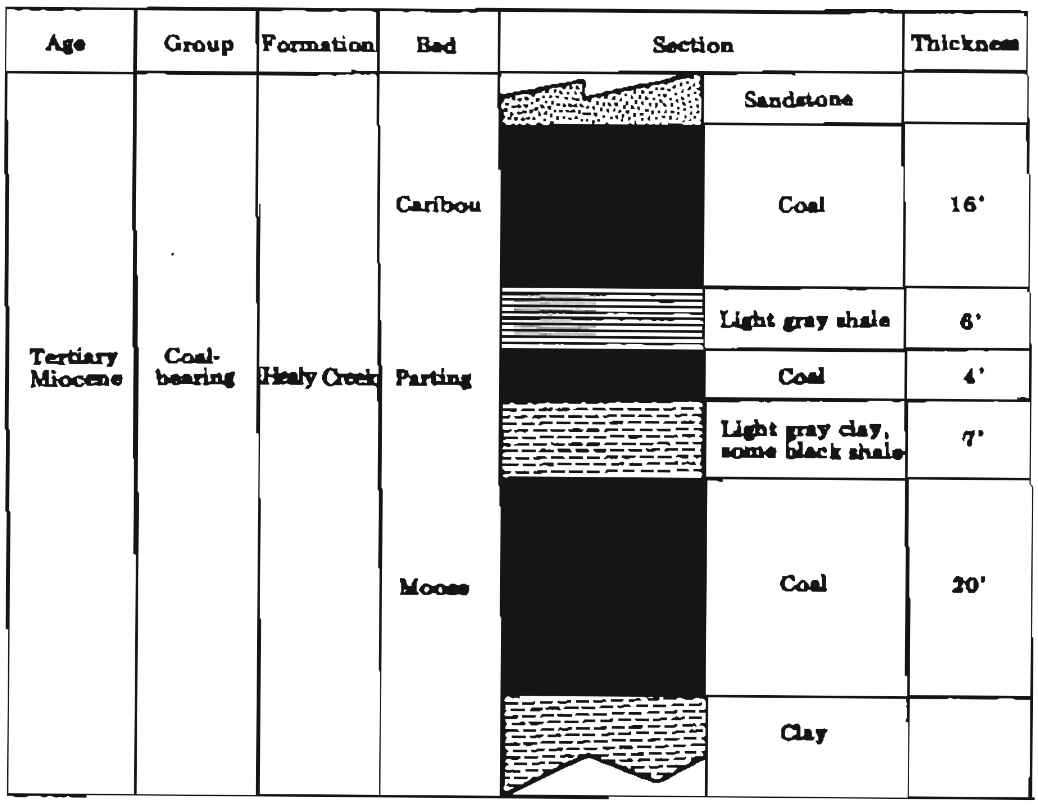


Figure 43. Coal section and sample intervals for locality on Sanderson Creek, Nenana coal field (Healy D-4 Quadrangle, NE¼ of SE¼ of sec. 34, T. 11 S., R. 6 W., lat. 63.9158° N., long. 148.6878° W; from Conwell, 1976). See appendix D, tables D9-A - D9-C for coal analyses of these samples.

at the 99 percent confidence level the carbon and oxygen contents are not significantly different. [Statistical comparison of geometric mean contents of the U.S. Department of Energy's data for 12 coal samples from the Healy Quadrangle with 33 coal samples from the Powder River region (Swanson and others, 1976).]

- Coal from the Healy Quadrangle contains significantly higher ash, and this ash is significantly higher in K_2O and TiO_2 contents and significantly lower in Na_2O, Fe_2O_3 and SO_3 contents. Contents of SiO_2, Al_2O_3, CaO and MgO are not significantly different. When compared at the 99 percent confidence level, the contents of Fe_2O_3 are not significantly different. [Statistical comparison of geometric mean contents of coal ash and of nine major and minor oxides of the ash for 20 Healy Quadrangle coal samples and 410 Powder River region coal samples (Hatch and Swanson, 1977).]

- Coal from the Healy Quadrangle is significantly higher in contents of Si, Al, Ca, K, Ti, Ba, Co, Cr, Cu, F, Ga, Ni, Sb, Sc, U, V, Y, and Yb, and is significantly lower in contents of Na, B, Be, and Sr. The contents of Mg, Fe, As, Hg, Li, Mn, Mo, Nb, Pb, Se, Th, Zn, and Zr are not significantly different. When compared at the 99 percent confidence level, the contents of Si, Ca, and Sr are not significantly different. [Statistical comparison of geometric mean contents of 35 elements in the 20 coal samples from the Healy Quadrangle with 410 Powder River region coal samples (Hatch and Swanson, 1977).]

- Compared with other U.S. coals in general, coals from the Healy Quadrangle are characterized by relatively lower sulfur and heats of combustion. The contents of elements of environmental concern such as As, Be, Hg, Mo, Sb, and Se are lower.

Figure 44 summarizes the range of trace element contents commonly found in all coals with the range found in Nenana coal fields samples. The latter values were averaged from the results of Rao and Wolff (1981), Conwell (1976), and Affolter, Simon, and Stricker (1981).

Certain elements are known to be generally enriched in coal ash over their average content in the Earth's crust. Table 7 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 general factor of enrichment for a particular element.

In summary, the 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 the 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.

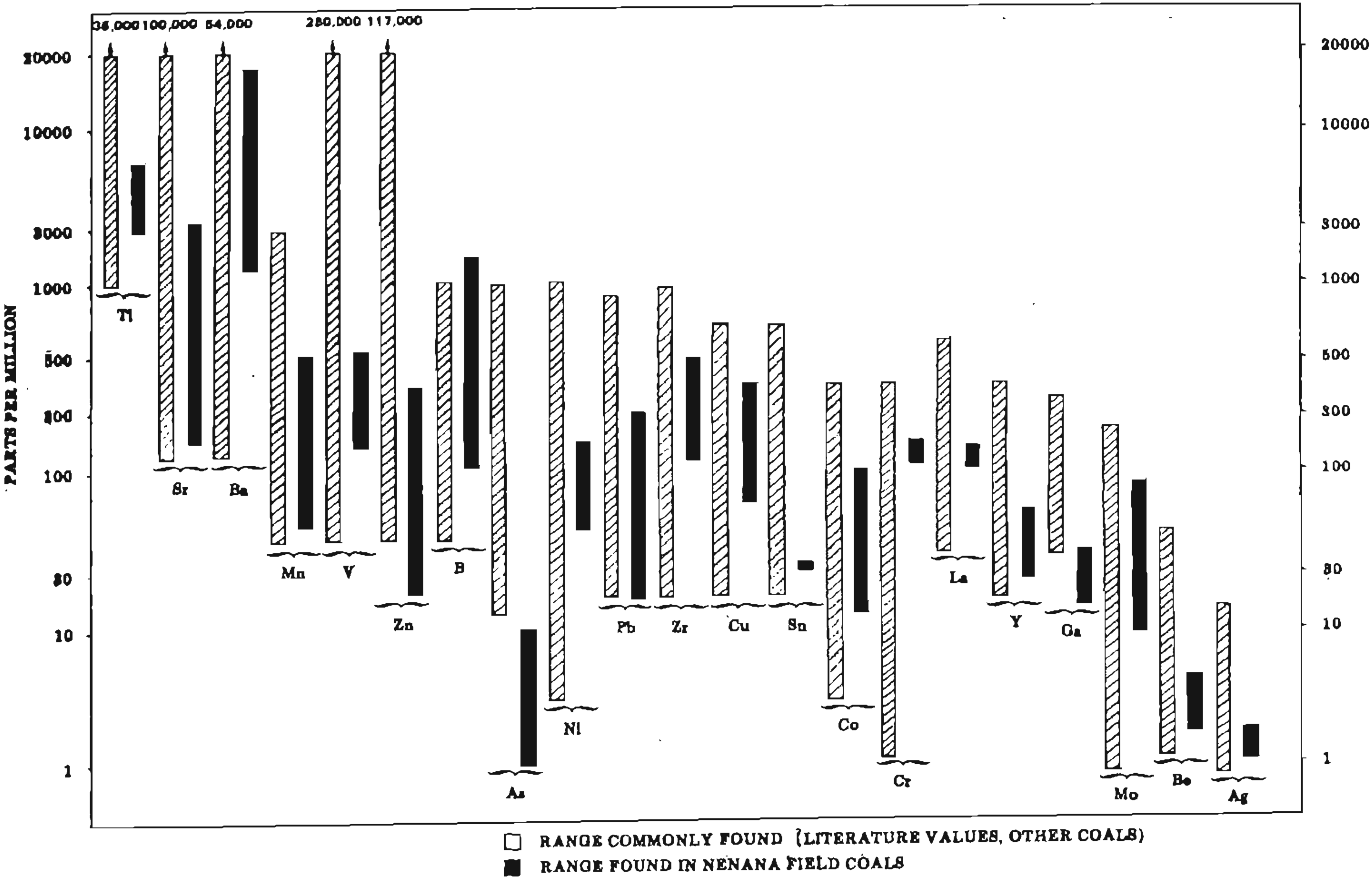


Figure 44. Range of trace element contents commonly found in coal ash compared with the range found in Nenana field coals (range reported in literature from Mason, 1966, fig. 9.5, p. 242).

Table 7. Factors of enrichment for certain rare elements in coal ash (including some Nenana samples)** 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.

**Number of Nenana samples used in compilation for each element: B = 36, Mo = 30, Cd = 35, Ag = 29, Be = 27, Co = 33, Ni = 37, Pb = 34, Ga = 37, Sc = 28.

COAL RESOURCES, RESERVES, AND PRODUCTION

Overview

Tertiary coal-bearing rocks of the Nenana basin are exposed over at least 1,000 mi^2, but they are of less extent than they were originally since large areas have been removed by erosion. These deposits occupy several subfields within the Nenana region.

The formations of the coal-bearing group that contain the greatest resources of minable coal (in decreasing order) are the Suntrana, Healy Creek, and Lignite Creek. Thus, significant coal deposits occur within three of the five formations composing the Tertiary clastic 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. In general, formation thicknesses are variable over the region. The coal-bearing group is about 2,000 ft thick at Suntrana but may be up to nearly 3,000 ft thick locally in the Nenana basin. The subbituminous coal beds of the Nenana basin range from 10 to 60 ft thick, and moderately-dipping fault blocks and gentle folds are the predominant geologic structures.

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. The U.S. Department of Energy (1977) cited 3.5 billion tons of proven reserves, an equal amount inferred from geological considerations and up to 8.7 billion tons of additional coal resources, totaling over 15 billion tons. Sanders (1981) estimated the total coal resources of the Nenana coal field at 17 billion tons with 7 billion tons of this identified and 10 billion tons hypothetical. New estimates of potentially minable coal resources of ten distinct subfields of the Nenana basin are presented in table 8. Three different scenarios are shown based on different levels of assurance---high, moderate, and low. Considering the Nenana coal basin proper, there is relative high assurance of at least 1.4 billion tons of minable coal resources to a depth of 500 ft in beds of over 2.5 ft thick.

Figure 45 shows the general locations of the existing state of Alaska coal lease areas in the Nenana basin. Table C1 of appendix C summarizes the land use information related to these particular tracts. Plate 2 rates the general coal development potential of different areas of the Nenana basin. The potential ranks include high, moderate, low to very low, none, and unknown.

The Lignite Creek, Wood River, and Jarvis Creek subbasins are rated as having the highest potential for near-term new coal development. In general, mining will always be economically more feasible in areas adjacent to the transportation corridors near the Nenana River on the west side of the basin and the Richardson Highway on the east side.

Table 8. New estimates of potentially minable coal resources in fields of the Nenana region (millions of short tons), projected to a depth of 500 ft and including all beds greater than or equal to 2.5 ft 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

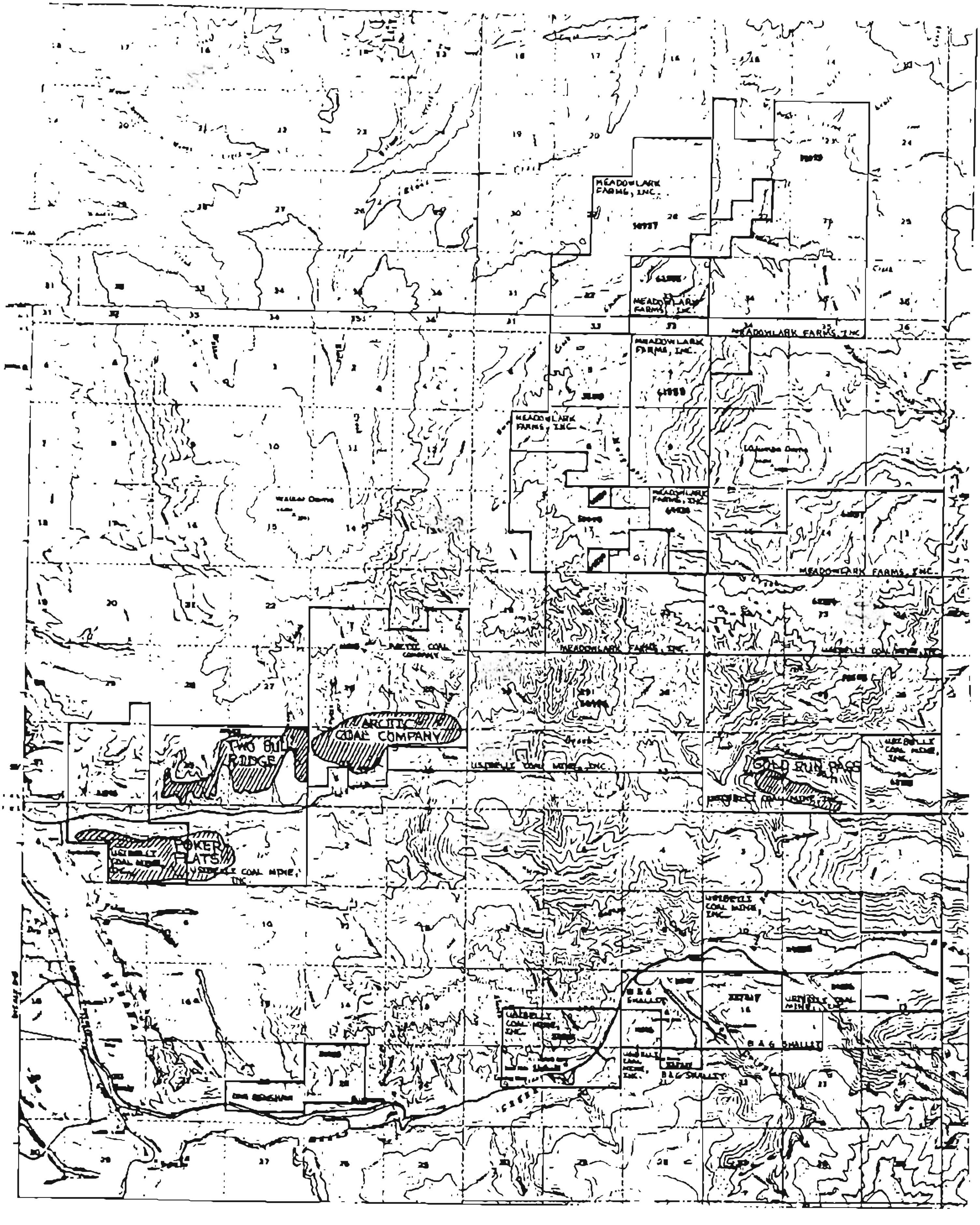


Figure 45. State of Alaska coal lease areas in the Nenana coal field. Information relating to each area is summarized in appendix C. Poker Flats and Two Bull Ridge reserve blocks of the Usibelli Coal Mine are also shown.

All of Alaska's post-1970 coal production and much of the state's production prior to 1970 is accounted for by that of the Usibelli Mine or other operations in the Nenana field (fig. 46). Early mining in the Nenana region was by underground methods mainly (Suntrana Mine). Mining in the future will probably be by both open-pit surface mining and underground methods. Most mining to date has occurred in the F bed of the Healy Creek Formation and numbers 1, 2, 3, and 6 beds of the Suntrana Formation (Conwell, 1976).

Numerous fires have occurred in coal beds of the Nenana field over the years and a few are still active. Loss of reserves may be significant locally in time if the fires are not controlled. A burned-out coal bed on upper Lignite Creek is shown in figure 47.

Western Nenana Subbasin

The coal-bearing rocks of the western Nenana subbasin occupy a belt about 15 miles long and three miles wide that stretches from 3 miles 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. One outcrop section near the Teklanika River was described by the author (site TR1, appendixes A and B).

Wahrhaftig and others (1951) made a separate investigation of the coals of the western Nenana coal field, and estimated 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 western Nenana subbasin to a projected depth of 500 ft are estimated to be at least 80 million short tons (table 8).

Healy Creek Subbasin

The Healy Creek subbasin covers an area less than 25 mi^2 stretching from 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 subbasin 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 subbasin, 32 different coal beds were once exposed ranging to 55 ft in thickness, together totaling 375 ft of coal in 1500 ft of strata (Wahrhaftig and Freeman, 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. Potentially minable coal resources of the Healy Creek subbasin to a projected depth of 500 ft are estimated herein to be at least 250 million short tons (table 8).

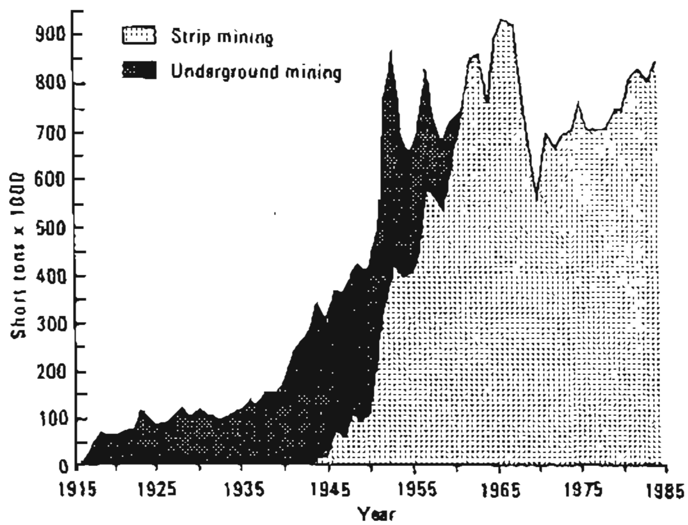


Figure 46. Coal production in Alaska, 1915-1984 (after Bundtzen and others, 1982). Coal has been mined in the Nenana field since about 1918. Essentially all the coal produced after 1967 has been from the Usibelli Mine.

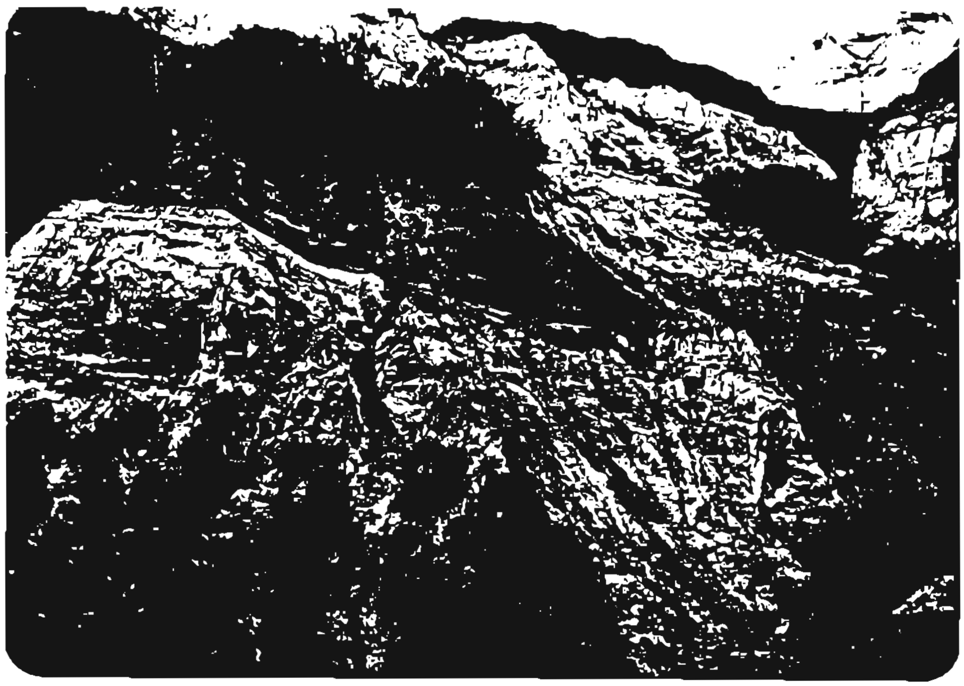


Figure 47. Burned-out coal seam at an upper Lignite Creek location.

Usibelli Coal Company, Inc. and its predecessors operated mines on Healy Creek from about 1944 to 1972. Figure 48 shows a mining section of the old Vitro west pit on Healy Creek.

Lignite Creek Subbasin

The Lignite Creek subbasin 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 Lignite Creek subbasin lies about four miles north of Healy. Healy and Lignite Creeks are about five miles apart and are separated by a schist ridge. Outcrops of the Lignite Creek subbasin are scattered over an area of about 100 mi^2.

The field includes nearly complete sections of coal-bearing group strata from the Healy Creek Formation upward to the Grubstake Formation. Over 1,000 ft 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 260 ft of coal, while sections commonly expose up to 200 ft aggregate thickness. The number 1 bed is the thickest of the coal-bearing group extending up to 60 ft locally within the region, and the number 2 and number 3 beds can be over 40 ft thick. The number 6 seam has been found to be continuous along strike for up to ten miles (Wahrhaftig, 1958, 1973; Wahrhaftig and others, 1969).

The coal deposits of the Lignite Creek subbasin 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 concentrated in four areas: 1) Poker Flats (or lower Lignite Creek); 2) Two Bull Ridge; 3) Arctic Coal Company (or middle Lignite Creek); and 4) Gold Run Pass (figure 45). Sanders (1981) estimated mining reserves of the Usibelli 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. Meadowlark Farms (AMAX Coal Company, Inc., based in Indianapolis, Indiana) holds leases with significant coal resources to the north and east of the Usibelli tracts. These deposits occur mainly in the Marguerite Creek drainage basin of the Jumbo Dome region. A coal-bearing section from this region, near the confluence of Bonanza and Marguerite Creeks, is shown in figure 49. Potentially minable coal resources of the Lignite Creek subbasin to a projected depth of 500 ft are estimated at 850 million short tons (table 8).

Currently at Usibelli'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; fig. 50). The three beds are all over 20 ft thick totaling over 60 ft of coal in a 235 ft section. A modified box-cut strip-mining (open pit) method utilizing a 33-cubic yard bucket capacity dragline called "Ace-in-the-Hole" (figure 51) resulted in a 1983 production of 803,000 short tons; the 1984 production was nearly 850,000 short tons. The overburden: coal ratio is less than 5:1, and the poorly indurated overlying sandstones of the coal beds, produce favorable stripping conditions. Figure 52 illustrates the general sequence of operation at the Usibelli Mine. The mine has practiced a successful program of coal mine land reclamation since about 1970.

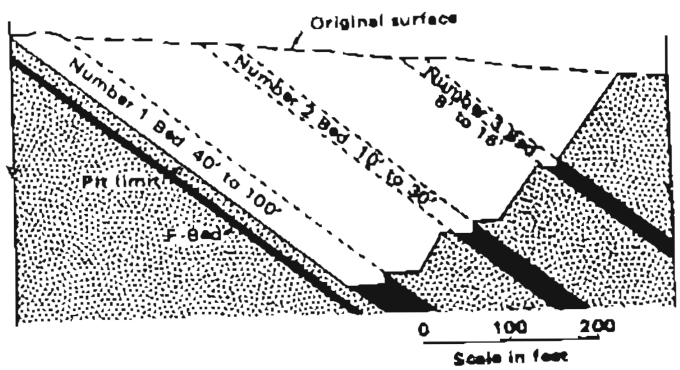


Figure 48. Typical section of coal beds on Healy Creek (Vitro west pit), Alaska (after Conwell, 1976).

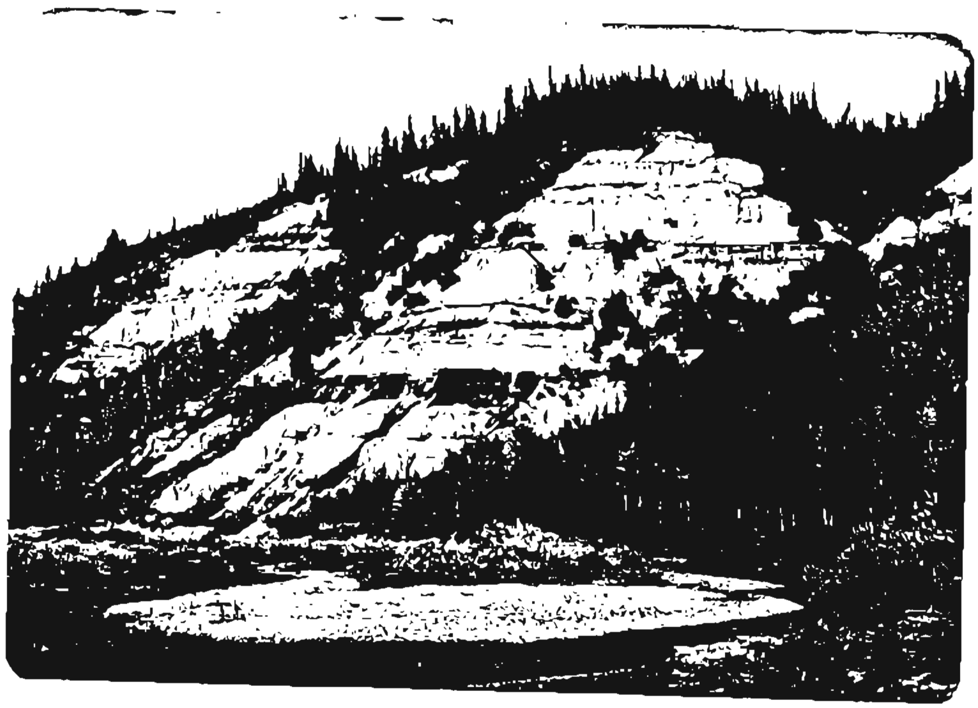


Figure 49. Coal-bearing outcrop near confluence of Bonanza and Marguerite Creeks. The thick seam may correlate with the No. 6 coal near the top of the Suntrana Formation.

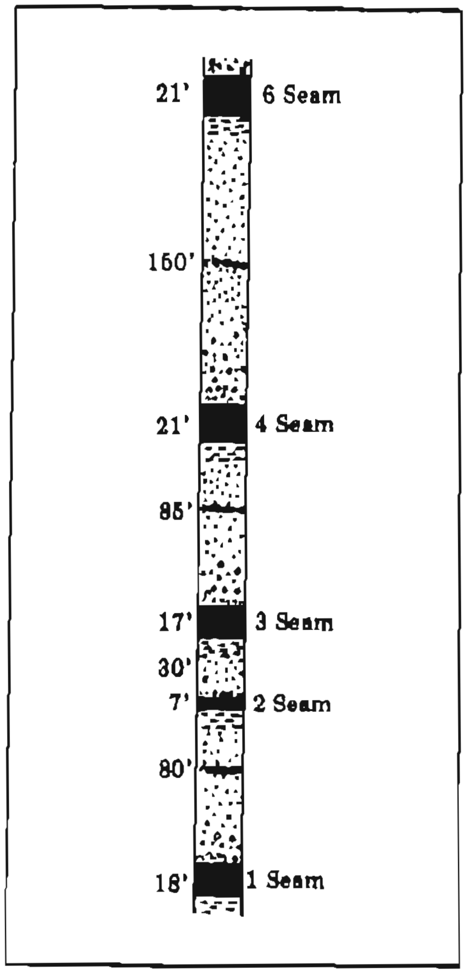


Figure 50. Typical coal-bearing section of the Suntrana Formation at Poker Flats. Seams 3, 4, and 6 are presently being mined (from Denton, 1981).

Figure 51. The Usibelli Coal Mine at Poker Flats showing the "Ace-in-the-Hole" dragline. Currently, this is the only significant operating coal mine in the state of Alaska. View is toward east.

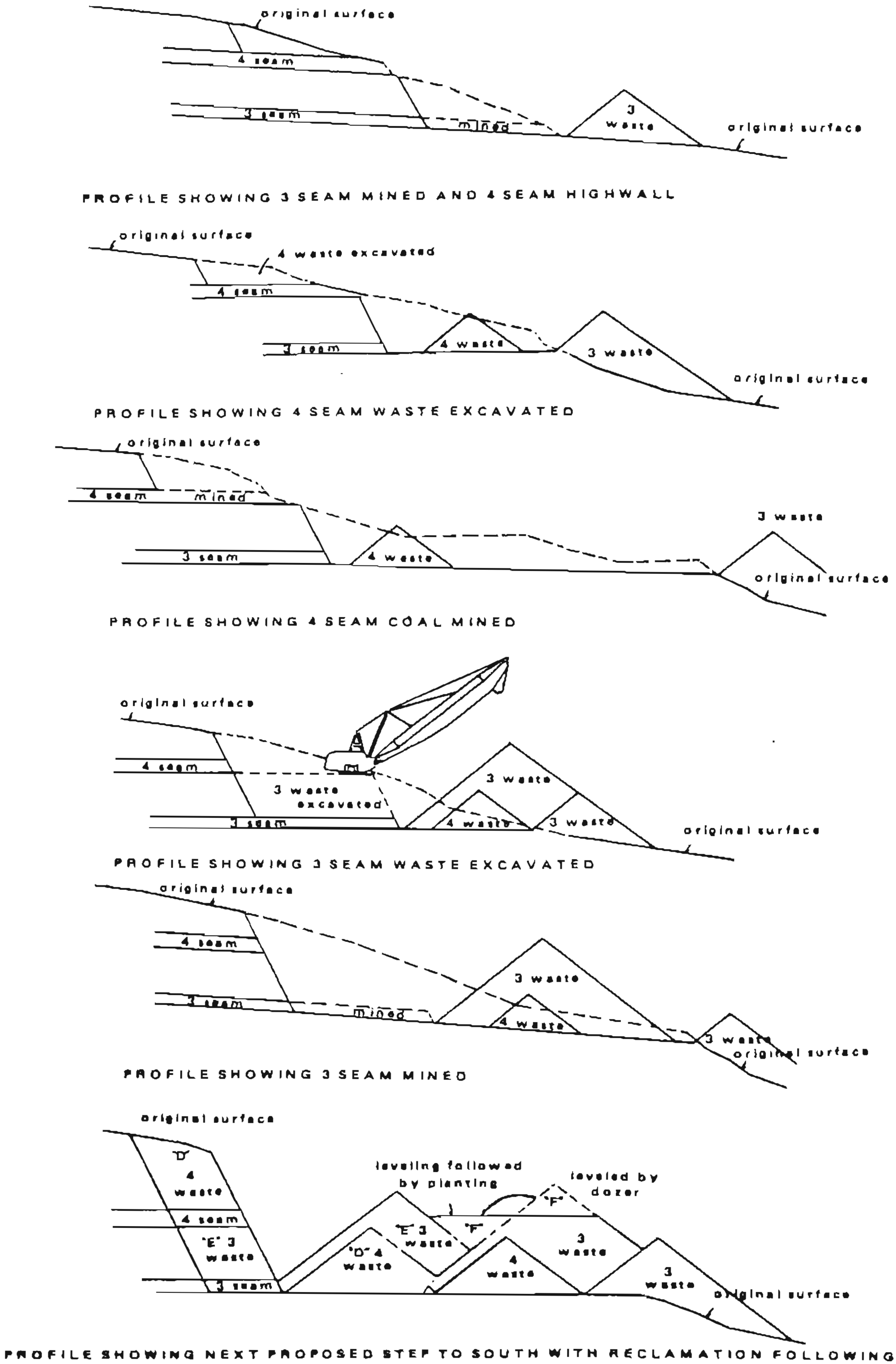


Figure 52. Sequence of operation at the Usibelli Mine (from Usibelli, 1981). Sections are oriented south to north.

The mine's production is utilized mainly by four power plants in Fairbanks and the Golden Valley Electric Association (GVEA) power plant at Healy. The 25-megawatt coal-fired electric power plant of the GVEA at Healy uses 140,000 tons of Usibelli coal to produce 200 million kwh of electricity or about 60 percent of the utilities power requirement in 1980 (Land, 1981). Production at the Usibelli Mine over the next two years will approximately double to meet contractual requirements of coal for export to Korea. The contract calls for the eventual transport of 880,000 short tons of coal per year to a Korea Electric Corporation power plant. Coal export shipments from the mine to Korea have been delayed until harbor facilities are completed at Seward which is now expected by late 1984.

After completing the mine cycle at Poker Flats, Usibelli Coal Mine will move into the Two Bull Ridge area (fig. 45), which is about 1.5 miles northeast and has proven reserves of 38 million tons at a stripping ratio of 3.6:1 (Denton, 1981). Lower Lignite Creek holds large resources of coal and will be an area of increasing future development. Mining will progress up Lignite Creek to the Arctic Coal Company tract and to the Gold Run Pass pit area of upper Lignite Creek, where mining has taken place intermittently in the past. A typical mine section at Gold Run Pass is shown in figure 53.

Rex Creek Subbasin

The Rex Creek coal field occupies one of the smaller subbasins of the Nenana region. The outcrop extent of the field is less than 25 mi^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 within the subbasin. It is estimated with relative high assurance that the Rex Creek subbasin contains at least 15 million short tons of potentially minable coal resources to a projected depth of 500 ft (table 8).

Tatlanika Creek Subbasin

Tha Tatlanika Creek subbasin is one of the larger subbasins of the Nenana region with outcrops of coal-bearing group strata covering an area about 120 mi^2. The coal field extends from Grubstake, Roosevelt and Hearst Creeks in the east to Buzzard Creek on the western 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 basin 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 subbasin (pl. 1). It is estimated with relative high assurance that the Tatlanika Creek coal field contains at least 70 million short tons of potentially minable coal resources to a projected depth of 500 ft (table 8).

Mystic Creek Subbasin

The Mystic Creek coal field is located southwest of Mystic Mountain about two miles west of Wood River, and is centered about four miles northeast of Keevy Peak. Outcrops of undifferentiated Tertiary coal-bearing

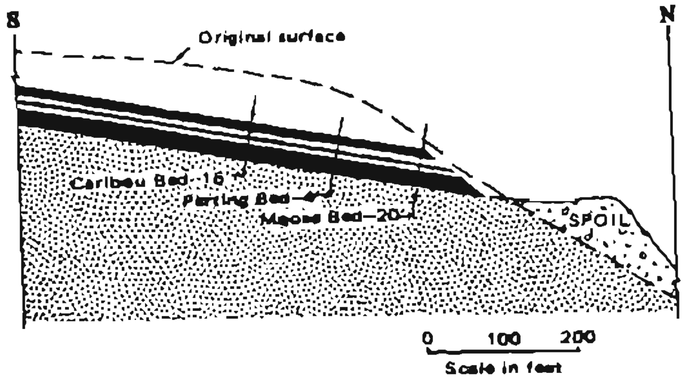


Figure 53. Typical section at Gold Run Pass on upper Lignite Creek, Alaska (after Conwell, 1976).

group strata occur in an area less than 20 mi^2. The Tertiary section is probably relatively thin (hundreds of feet?), 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 15 ft in thickness crop out locally on Mystic Creek. Figure 54 shows a perspective view (to south) of several outcropping coal seams and interbeds in a Mystic Creek section near the Wood River. [The numbers along the weathered slope refer to sample locations for the MC2 series; see appendixes D and E for related data.] Potentially minable coal resources of the Mystic Creek subbasin are estimated to be 10 million short tons or a deposit about twice the size of the West Delta field (table 8). The subbasin is judged to be of considerable less importance than the Wood River field lying about a mile northeast.

Wood River Subbasin

The Wood River coal field occupies and area of less than 40 mi^2 that stretches northeastward from Mystic Mountain and is generally restricted to the north and west side of the Wood River. The belt 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 (figure 55). At least 16 significantly thick coal seams with an aggregate thickness over 100 ft 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 subbasin to a projected depth of 500 ft are estimated to be at least 65 million short tons (table 8).

West Delta Subbasin

The West Delta coal field contains outcrops scattered over an area less than 40 mi^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 five ft thick crop out on Red Mountain Creek. A core hole drilled by Resource Associates of Alaska near Dry Creek (see log, appendix B) revealed a relatively thin Tertiary section of about 130 ft 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 subbasin is about the same magnitude in size as the East Delta, but may have slightly higher coal development potential. It is estimated with relative high assurance that the West Delta field contains five million tons of potentially minable coal resources (table 8).

East Delta Subbasin

The East Delta coal field occupies a subbasin of about 15 mi^2 between the Little Delta River and Delta Creek, and lies entirely within the Fort Greely army reservation. The thin coals resemble those of the Jarvis Creek subbasin and occur within a currently undifferentiated Tertiary coal-bearing unit that is probably correlative with the lower part of the coal-bearing

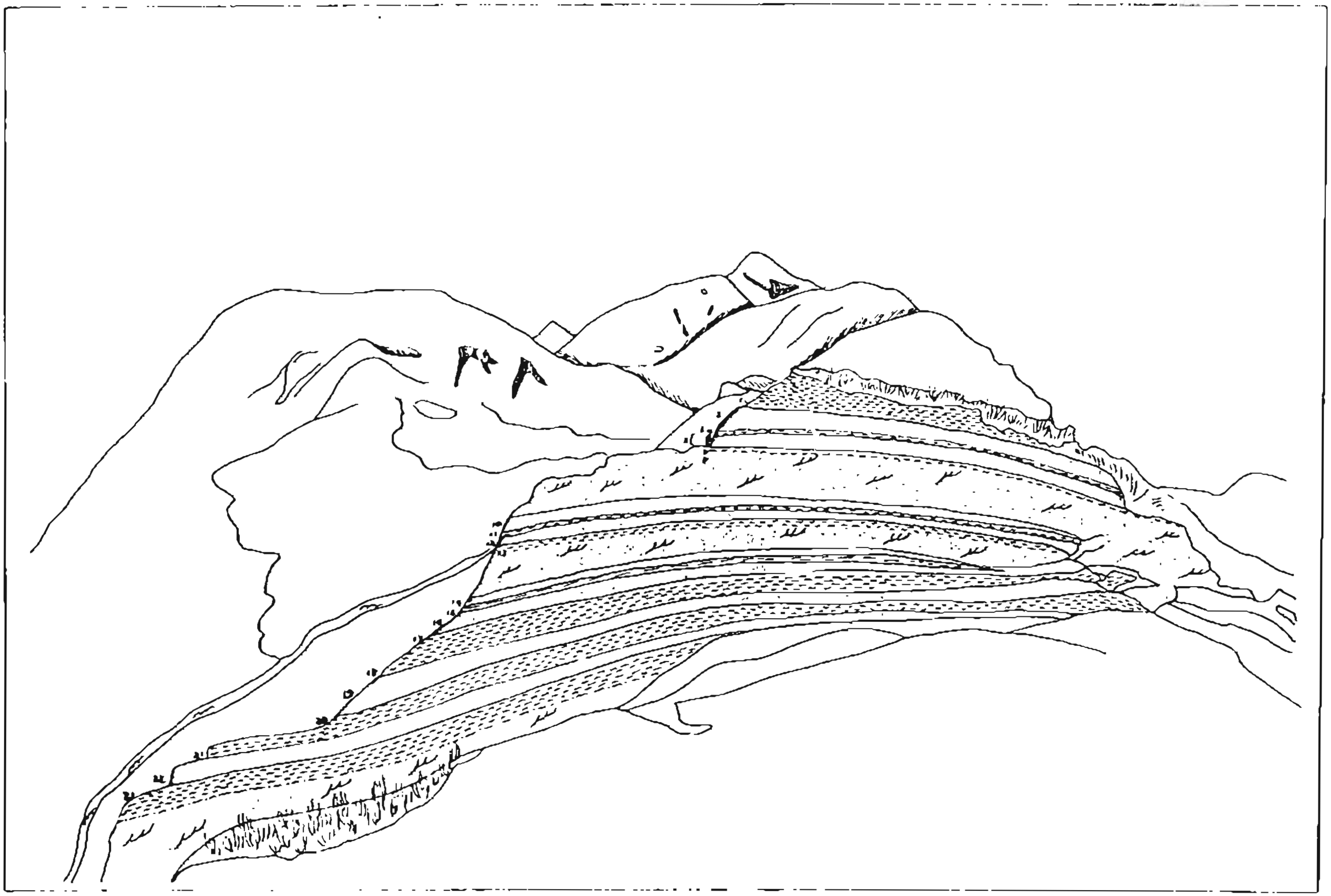


Figure 54. Coal-bearing section on Mystic Creek, Mystic Creek coal field, about 2 miles from the Wood River looking south-southwest. For sample data, see tables in appendixes D and E.

Figure 55. Tertiary coal-bearing section within the Suntrana Formation (lower) and Lignite Creek Formation (upper) along Coal Creek on the northeast side of Mystic Mountain. A major NW-SE trending fault transects the area depicted on the left margin of the photograph. These deposits are within the Wood River coal basin.

group, and possibly belongs to the Healy Creek Formation. The sedimentary sequence here is believed to be relatively thin---of the order of several hundred feet. It is estimated with relative high assurance that the East Delta subbasin contains five million short tons of potentially minable coal resources (table 8).

Jarvis Creek Subbasin

The Jarvis Creek subbasin is located at the easternmost extent of the Nenana trend. Geologically, the subbasin is an eastern extension of the Nenana coal field, of which it is considered a part herein. It is about 30 miles 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 subbasin encompasses and area less than 40 mi^2, with the economically important deposits occupying a 16 mi^2 area.

The coal-bearing section of the Jarvis Creek coal field, which has been tentatively correlated in part with the Healy Creek Formation, is about 2000 ft thick and has at least 30 beds exposed over 2 ft thick. The gently folded strata has one 10 ft 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. Potentially minable coal resources of the Jarvis Creek subbasin to a projected depth of 500 ft are estimated to be at least 30 million short tons (table 8).

About 900 tons of coal were produced in 1958 at a small mining operation in the Jarvis Creek field. A new mine is planned for this area in the near future. Delta Coal Company based in Fairbanks received a mining lease from the U.S. Bureau of Land Management in 1983. The company has completed preliminary exploration drilling programs and mining feasibility studies on their lease tract. Their current mine plan proposes an initial production of 500 tons of coal per day on a seasonal basis (May - September) for domestic and business use in surrounding communities (Metz, 1981). All future development in the field will most likely be by surface mining.

Farewell-Little Tonzona Field, Western Nenana Trend

Coal deposits of the Farewell-Little Tonzona coal 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 200 mi^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 this same belt of Tertiary sedimentary rocks that are similar stratigraphically and sedimentologically. The belt is located over a 100 miles 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 110 ft thick, and at least seven other beds over 2.5 ft crop out (Sanders, 1981). Seams at Deepbank Creek range from 5 to 20 ft thick (Friedmann, 1981).

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

OVERBURDEN CHARACTER

The coal seams of the Nenana Basin are interbedded with sandstones, siltstones, claystones, conglomerates, grit, and gravel beds. Coal-bearing sections are covered by Tertiary (Nenana) gravels or by Pleistocene glacial, fluvial, and glaciofluvial sediments. Glacial till and moraine deposits, outwash gravels, colluvium and alluvium are present in the unconsolidated profile. Roof rocks are commonly sandstones (often pebbly) or conglomerate, while seatrocks are often claystones (sometimes shaley). Most overburden rocks are high chroma---whitish, buff, tan, or light gray, often with yellow to orange surficial staining; however, medium- to dark-gray (low chroma) interbeds are present. The continental fluvial coal-bearing rocks are characterized predictably by low pyrite and generally low trace element contents.

Mitchell and others (1981) analyzed overburden samples from three sites on Healy and Lignite Creeks: 1) Healy A site, substratum material overlying a coal seam; 2) Healy B site, spoil bank sample containing significant amounts of coal and shale material; and 3) overburden samples taken down to a relatively shallow coal seam at a Lignite Creek site. They conclude that a positive growth response could be expected at both Healy sites A and B with applications of nitrogen, phosphorous, and potassium fertilizer. Both sites were marginal with respect to potassium supply, but showed adequate calcium and magnesium levels. Healy A site was deficient in both the ammonium ion (NH_4^+) and nitrate (NO_3), while Healy B site demonstrated relatively high ammonium levels and slightly elevated nitrate levels. Trace metal concentrations were in the 'adequate' range; they believe it unlikely that a micronutrient deficiency would present a major problem in mine spoil revegetation. They also conclude that problems of metal phytotoxicity or accumulation of metals in plant tissue that might be toxic to wildlife are not indicated, nor should problems of excessive soil salinity or absorbed sodium be anticipated.

The overburden samples from the Lignite Creek site showed soil reaction levels that were higher than that normally associated with aluminum and manganese toxicity (Mitchell and others, 1980). Saturation extract analysis of these samples revealed no significant potential for the development of high levels of salt or sodium accumulation. Sodium absorption 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 the present study is given in table 9. Tables E1-E3 of appendix E enumerates results for individual coal overburden samples. Tables E4 and E5 of appendix E list suitability criteria for evaluating the overall character of certain parameters of concern in overburden and soil materials

Table 9. Summary geochemical and physical characteristics of 43 coal overburden samples from six general areas of the Nenana coal field.

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	
Magnesium	0.1-11.4	2.2	meq/liter
Sodium	0.4-4.9	1.8	
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)	1.1-31.5	5.9	
Phosphorous	0.4-18.9	6.0	ppm
Potassium	13-273	158	
Ammonium acetate extractable cations			
Calcium	0.2-161.2	17.5	
Magnesium	0.8-16.1	6.0	meq/100 gms
Sodium	0.0-1.5	0.4	
Potassium	0.1-0.9	0.4	
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	
Copper	0.31-32.14	10.34	
Molybdenum	0.12-0.76	0.44	ppm
Lead	0.07-68.18	11.50	
Selenium	<0.01	<0.01	

*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.

in Wyoming and Montana. No similar guideline criteria have yet been established in Alaska. Particle sizes and general textures for the samples are plotted on the ternary diagram of figure 56; those samples that fall into poor texture categories are also indicated.

Figure 57 is an acid/base account for a Shovel Creek coal-bearing section. General lithology, paste pH and total sulfur, organic matter and total organic carbon, and the lime percentage are annotated for the different sampled horizons. The samples reveal 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. Figures E1-E4 of appendix E are similar diagrams of coal-bearing sections on Bonanza Creek, one near the confluence of Bonanza and Marguerite Creeks, Emma Creek, and Mystic Creek.

Certain trace element contents for the Nenana overburden samples are given in tables E1 and E2 of appendix E. Different results for copper, lead, and molybdenum are listed in the two tables; the results for the elements in table E-1 should be relied upon as being more accurate. The results in table E2 were derived by emission spectroscopy, and should be regarded as approximate abundances. In general, the levels of trace elements do not suggest the development of a toxicity or deficiency condition in mine soils developed from these overburden materials, and hence support the conclusions of Mitchell and others (1981). Major oxide data for Nenana coal overburden samples are listed in table E3 of appendix E, and also reveal no particularly unexpected or anomalous values.

Thus, both field observations and the results of overburden analyses to date suggest that few environmental problems can be expected with regard to the quality of overburden and interburden materials. Certain amendments, particularly nitrogen and phosphorous, may need to be added to promote mine spoil revegetation. Reclamation programs at the Usibelli Coal Mine over the past 15 years have generally been very successful.

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 minable coal resources, about one-half of which are exploitable by surface mining methods. The resources occupy a series of isolated subbasins within a 140 mile by 30 mile 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 and Powder River basin coals. The most economic deposits are those near the west side of the basin, close to the Park Highway and Alaska Railroad, and adjacent to the Nenana River (particularly those of the Lignite Creek subbasin); 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

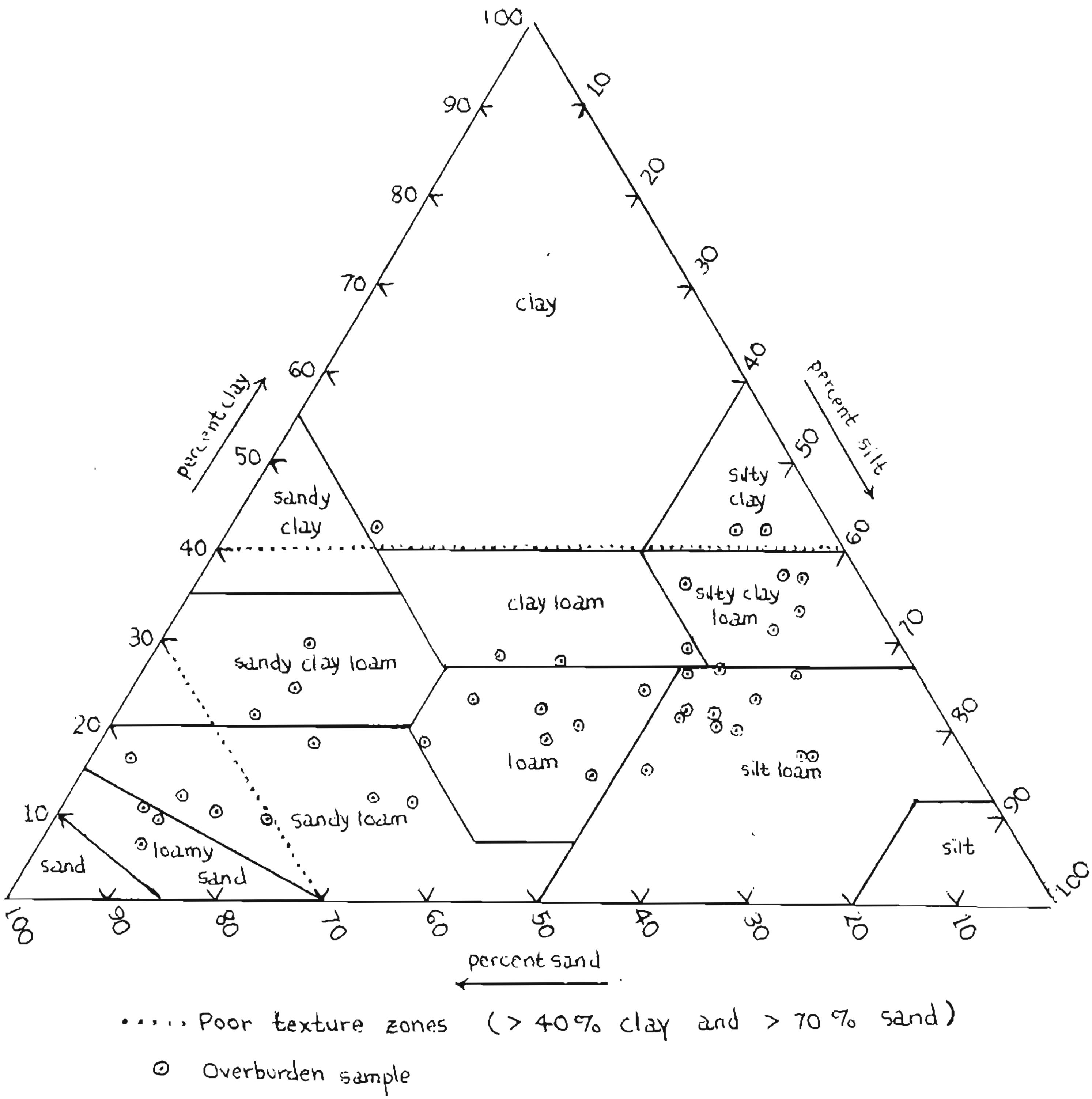
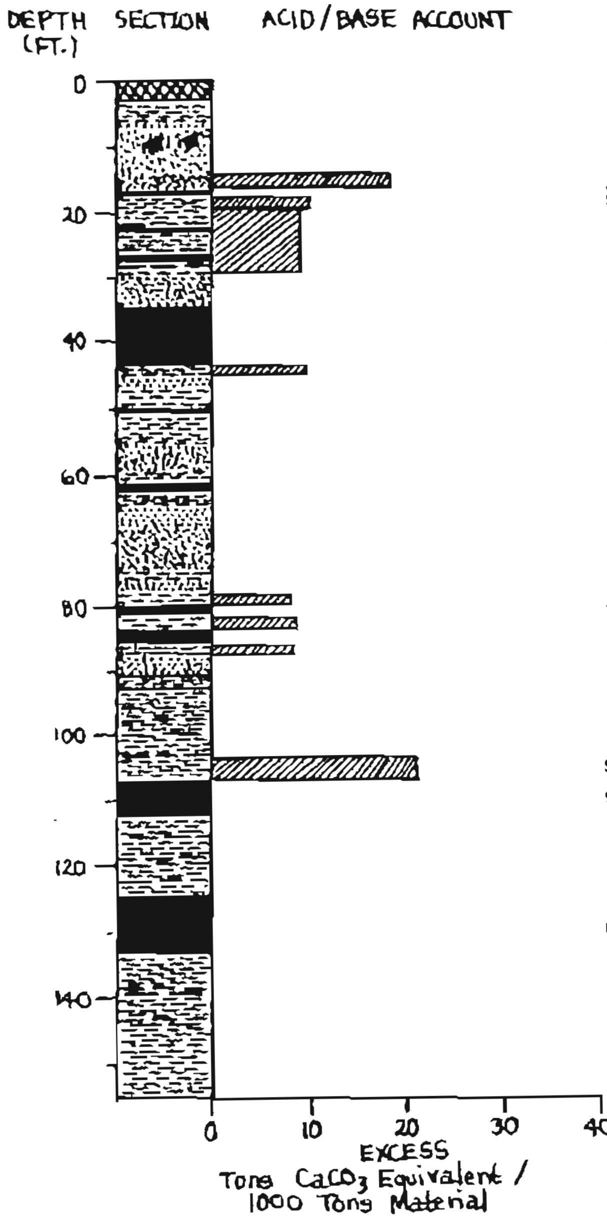


Figure 56. Particle sizes and textures for Nenana coal field overburden samples from six general areas. For sample data see appendix F.



SAMPLE NUMBER	LITHOLOGIC DESCRIPTION	PASTE pH	TOTAL SULFUR (%)	ORGANIC MATTER (%)	TOTAL ORGANIC CARBON (%)	LIME (%)
SC1-1	Sandstone, reddish brown to medium brown, medium grained	6.6	0.14	7.56	24.5	10.6
SC1-2	Coal		[illegible]			
SC1-3	Claystone, dark grayish brown, carbonaceous	6.6	0.03	5.54	10.5	5.2
SC1-4	Claystone, shale, carbonaceous, and coal, dark brownish gray to black	6.2	0.12	7.31	24.5	5.8
SC1-5	Coal		0.30			
SC1-6	Claystone, medium brown	5.7	0.02	4.98	8.9	5.1
SC1-7	Claystone, dark grayish brown	5.8	0.11	6.43	13.5	5.1
SC1-8	Coal		0.44			
SC1-9	Claystone, medium brown	6.3	0.04	4.45	8.1	4.8
SC1-10	Coal		0.37			
SC1-11	Claystone, medium grayish brown	6.3	0.04	4.23	6.9	4.6
SC1-12	Claystone, medium brown	7.0	0.04	4.97	11.1	11.1
SC1-13	Coal		0.39			
SC1-14	Coal		0.31			

Figure 57. Acid/base account and other geochemical characteristics for overburden samples of a Shovel Creek coal-bearing section.

isotopographic lows. The coals are predominantly huminitic with minor inertinite and variable liptinite contents. Liptinites tend to be somewhat more abundant in the coals of 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 the 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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Appendix A

Table A1. Coal locale summary and sample inventory. Plate 1 shows locations of sites.

Locale number	Locale name	Locale code	Township	Range	Section	Outcrop section thickness	Number of coal beds	Maximum coal bed thickness	Dip	Coal	Samples overburden	Other	Comments
1	Bonanza Creek	BC1	10S.	6W.	27	Less 20 ft exposed and accessible	1	8 ft	16°	1, BC1-2	5, BC1-1, -3, -4, -5, and -6	- -	Outcrop of Suntrana Formation strata. Coal sampled along with roof and floor materials. Weathered orange sand lense on top of coal. Brown, sandy claystone seatrock. See stratigraphic section of appendix B.
2	Bonanza-Marguerite Creek	BM1	10S.	6W.	27	300 ft +	5	12 ft	6°	4, BM1-1, -4, -7, and -9	7, BM1-2, -3, -5, -6, -8, -10, and -11	- -	Outcrop section of Suntrana and overlying Lignite Creek formations near confluence of Bonanza and Marguerite Creeks. Coals brownish black, dull, lignitic, and locally bony. See stratigraphic section of appendix B and figure 61 of text.
3	Davis Creek	DC1	11S.	5W.	35	- -	- -	- -	- -	- -	- -	Grab	Black carbonaceous slate and schist of Birch Creek Formation in area of contact with overlying coal-bearing sediments of Healy Creek Formation.
4	Davis Creek	DC2	11S.	5W.	26, 35	230 ft +	Numerous, most thin	10 ft	30°	- -	1, DC2-1	- -	Coal beds of Healy Creek Formation poorly exposed and highly weathered. Volcanic ash parting (DC2-1). Site 0.25 mile north of DC1. See stratigraphic section of appendix B.
5	Emma Creek	EC1	10S.	6W.	33	135 ft +	1	7 ft	14°	- -	- -	- -	Outcrop of strata in Lignite Creek Formation on tributary to Marguerite Creek. Dissected, "badland" topography. Coal seam locally burned.

Table A1. (con.)

Locale number	Locale name	Locale code	Township	Range	Section	Outcrop section thickness	Number of coal beds	Maximum coal bed thickness	Dip	Samples: Coal	Samples: overburden	Samples: Other	Comments
6	Emma Creek	EC2	10S.	6W.	33	150 ft +	1	7 ft	14°	1, EC2-1	4, EC2-2, -3, -4, and -5 (seat-rock)	- -	Vivianite, anhydrite(?), and resin observable along joints and bedding planes. Thin lensoidal vitrain bands in coal. Jointing 90° to bedding and prominent cleat at 15°. Claystone partings to 1 in. split seam.
7	Emma Creek	EC3	10S.	6W.	33	140 ft +	1	7 ft	14°	- -	- -	- -	Brownish black carbonaceous claystone as seatrock. Pebbly, coarse-grained sandstone overburden with conglomerate lenses, cross-beds and local distorted bedding. See geologic section of plate 5 and figures 24, 26, 29, and 30 of text.
8	Jumbo Dome area	JD1	11S.	6W.	15	- -	2	15 ft	Vari-able, 10°-25°	2, JD1-1, -2	- -	- -	Wedge of Suntrana Formation dragged up on side of Jumbo Dome. Chocolate-brown claystone seatrock and white-weathering, coarse-grained, pebbly sandstone overburden. See figure 11 of text.
9	Jumbo Dome area	JD2	11S.	6W.	22	- -	- -	- -	- -	- -	- -	JD2-1, Keevy Peak schist	Fault zone near nose of east-plunging anticline where Keevy Peak schist underlies coal-bearing sediments. Breccia zone along fault includes abundant quartz blocks and fragments.
10	Jumbo Dome area	JD3	11S.	6W.	22	- -	2	12 ft	Upper at 30° and lower at 60°	1, JD3-1	- -	- -	Coal beds in slump block of Suntrana Formation. Sanctuary Creek brown shales exposed near site along Marguerite Creek.
11	Jumbo Dome area	JD4	11S.	6W.	22	- -	1	8-10 ft	20°	1, JD4-1	- -	- -	Outcrop in apparent slump block (Suntrana Formation). Coal seam covered by unconsolidated alluvial deposits.

Table A1. (con.)

Locale number	Locale name	Locale code	Township	Range	Section	Outcrop section thickness	Number of coal beds	Maximum coal bed thickness	Dip	Coal	Samples overburden	Other	Comments
12	Jumbo Dome area	JD5	11S.	6W.	22	75 ft+	1	4 ft	28°	1, JD5-1	- -	- -	Suntrana Formation exposure. Roof rock consists of coarse-grained, pebbly sandstone and conglomerate, and seatrock of brown, sandy claystone.
13	Lignite Creek tributary	LCT1	11S.	5W.	30	380 ft +	7	22 ft	12°	4, LCT-1, -2, -3, and -4	- -	- -	Suntrana Formation section includes second 18 ft seam and is overlain by Quaternary alluvium and pediment gravel. Consolidated overburden predominantly pebbly sandstone and conglomerate interbedded with brown, sandy claystone. See geologic section of plate 5 and figure 15 of text.
14	Lignite Creek tributary	LCT2	11S.	5W.	29, 30	430 ft +	9	18 ft	10°	2, LCT2-1,	- -	- -	See LCT1, geologic section of plate 5 and figure 15 of text.
15	Lignite Creek tributary	LCT3	11S.	5W.	31	- -	- -	- -	- -	Grab	- -	Grab	Burn outcrop with mixture of coal, slate, and procellanite.
16	Lignite Creek tributary	LCT4	11S.	6W.	26	500 ft +	Several	25 ft	15° - 20°	- -	- -	- -	Site of juxtaposed, fault-bounded sections of Suntrana Formation and downdropped Lignite Creek and Grubstake Formations in large ravine on stream north of Sanderson Creek and about 3 mi south of Jumbo Dome. See figures 13 and 14 of text.
17	Lignite Creek tributary	LCT5	11S.	6W.	24, 25	365 ft	3	20 ft	5°	3, LCT5-1, -2, -3	- -	- -	Suntrana Formation strata. Hematized (replaced) logs and septarian nodules common at site (see fig. 23 of text). Stratigraphic section, appendix B.

Table A1. (con.)

Locale number	Locale name	Locale code	Township	Range	Section	Outcrop section thickness	Number of coal beds	Maximum coal bed thickness	Dip	Coal	Samples overburden	Other	Comments
18	Mystic Creek	MC1	11S.	2W.	15, 16	260 ft	8-10, most thin	11 ft	5°	5, MC1-1, -2, -3 -4, -5	- -	- -	Undifferentiated Tertiary coal-bearing unit. See stratigraphic section of appendix B. "Banded chert" unit of Wahrhaftig (Sheep Creek Member of Mississippian Totatlanika Schist) near site. Appears to include talc and chlorite schist, slate, argillite, and chert.
19	Mystic Creek	MC2	11S.	2W.	15	125 ft +	5	15 ft	10°	8, MC2-2, -5,-10, -12, -14, -16, -19, -22	15, MC2-1, -3,-4, -6,-7, -8,-9, -11,-13, -15,-17, -18,-20, -21,-23	- -	See figure 5 of text for perspective drawing of outcrop section with sample locations. MC2-6 is a volcanic ash parting (fig. 20 of text). Site 500 ft northeast of MC1.
20	Mystic Creek	MC3	11S.	2W.	21	- -	- -	- -	- -	- -	- -	- -	Black carbonaceous schist rocks of Mississippian(?) Totatlanika Schist.
21	Mystic Mountain	MM1	11S.	2W.	1	305 ft +	12, many thin	12 ft	10°	- -	- -	- -	Exposure of Suntrana Formation strata on north wall of Coal Creek canyon northeast of Mystic Mountain (Wood River coal basin) with dramatic, differentially-weathered, castellated sandstones. See geologic section of plate 5.
22	Mystic Mountain	MM2	11S.	2W.	1	545 ft +	15, many thin	12 ft	15°-20°	6, MM2-1, -2,-3, -4,-5, and -6	1, MM2-6A	- -	See figures 62 and 63 of text and geologic section of plate 5.

Table A1. (con.)

Locale number	Locale name	Locale code	Township	Range	Section	Outcrop section thickness	Number of coal beds	Maximum coal bed thickness	Dip	Coal	Samples overburden	Other	Comments
23	Mystic Mountain	MM3	11S.	2W.	1	435 ft +	10-12, many thin	8 ft	20°-30°	- -	MM3-1	- -	See geologic section of plate 5.
24	Mystic Mountain	MM4	11S.	1W.	6	280 ft +	8-10, many thin	8 ft	20°	- -	- -	- -	See geologic section of plate 5.
25	Mystic Mountain	MMa	11S.	2W.	1	- -	1	- -	- -	- -	- -	- -	Folded coal bed occupying core of small syncline and underlain by whitish Suntrana sandstone.
26	Mystic Mountain	MMb	11S.	2W.	1	- -	3(?)	30 ft	Upper beds moderate (45°), lower bed steep 70-75°	3, MMb-1, -3, -5	1, MMb-4, (white weathering sandstone)	1, MMb-2, (slate beneath baked rocks)	Jumbled Healy Creek sediments adjacent to Mystic Mountain fault about 0.5 mile south of Coal Creek. Coal beds folded and locally contorted. Overlying Sanctuary Formation and Suntrana Formation strata more regularly bedded. Baked rocks occur in interval between highly folded and more regularly bedded strata. See figure 45 of text.
27	Moose-Sheep Creeks	MS1	10S.	4W.	25	700 ft +	8	15 ft	Variable 4-22°	8, MS1-1, -2, -3, -4, -5, -6, -7, and -8	- -	- -	Suntrana Formation section, generally poorly exposed, on east side of Moose Creek near confluence with Sheep Creek. See stratigraphic section of appendix B.
28	Moose-Sheep Creeks	MS2	10S.	4W.	36	Several hundred feet but only locally exposed	4	7 ft	Variable, 6-20°	- -	- -	- -	See correlated stratigraphic sections of appendix B.

Table A1. (con.)

Locale number	Locale name	Locale code	Township	Range	Section	Outcrop section thickness	Number of coal beds	Maximum coal bed thickness	Dip	Coal	Samples overburden	Other	Comments
29	Moose-Sheep Creeks	MS3	10S.	3W.	31	- -	1	10 ft	20°	1, MS3-1	- -	- -	Local exposure on east side of Moose Creek south of MS1 in Healy Creek Formation.
30	Moose-Sheep Creeks	MS4	10S.	3W.	29	- -	1	9 ft	12°	1, MS4-1	- -	- -	Local exposure on tributary to Tatlanika Creek in Suntrana Formation.
31	Newman Creek	NC1	11S.	2E.	2	50 ft +	1	8-10 ft	Vari-able	1, NC1-1	- -	- -	Folded or faulted coal bed in undifferentiated Tertiary coal-bearing rocks near the confluence of Newman and Dry Creeks. See figure 18 of text.
32	Resource Associates Alaska Core (Dry Creek)	RAA	11S.	2E.	22	Core, only upper 140 ft (coal-bearing section examined)	6	10 ft	Slight	5, RAA1, -2,-3, -4,-5	- -	- -	Relatively thin coal-bearing Tertiary section (undifferentiated) above Mississippian(?) schist and quartzite. See stratigraphic section of appendix B.
33	Red Mountain Creek	RMC1	11S.	2E.	28	145 ft	6	5 ft	Near hori-zon-tal to 4°	3, RMC1-1, -2, and -3	- -	- -	Coals of undifferentiated Tertiary coal-bearing unit. See stratigraphic section of appendix B. Large (to 5 or more ft thick) differentially calcium-carbonate cemented concretions (fig. 32 of text) in sandstones of site.
34	Shovel Creek	SC1	11S.	5W.	25	155 ft +; SC1A, 120 ft +; SC1B, 50 ft +	8-10, most thin	9 ft	Vari-able, 20-50°	6, SC1-2, -5,-8, -10,-13, and -14	8, SC1-1, -3,-4, -6,-7, -9,-11, and -12	- -	Outcrop of coal-bearing strata of Healy Creek Formation between exposures of Keevy Peak and Birch Creek schists. See geologic section of plate 5 and figure 48 of text.
35	Shovel Creek	SC2	11S.	5W.	25	- -	- -	- -	- -	- -	- -	Crab	Metamorphic rocks of Keevy Peak Formation---schists, slates, and quartzite. Schists with abundant graphite, epidote, and chlorite.

Table A1. (con.)

Locale number	Locale name	Locale code	Township	Range	Section	Outcrop section thickness	Number of coal beds	Maximum coal bed thickness	Dip	Samples Coal	Samples overburden	Samples Other	Comments
36	Shovel Creek	SC3	11S.	5W.	24	- -	1	7 ft	4°	1, SC3-1	- -	- -	Local outcrop in Healy Creek Formation strata, appears to be in slump block.
37	Shovel Creel	SC4	11S.	5W.	24	55 ft	1	15 ft	8°	1, SC4-1	- -	- -	Local exposure in Healy Creek Formation strata. See stratigraphic section of appendix B.
38	Thistle Creek	TC1	11S.	5W.	28	110 ft +	1	4 ft	Near hori-zon-tal	1, TC1-1	- -	- -	Local exposure of Suntrana Formation strata. See stratigraphic section of appendix B.
39	Teklanika River	TR1	13S.	11W.	24	180 ft +	7	10 ft	6°	2, TR1-1, -2	- -	- -	Outcrop of undifferentiated Tertiary coal-bearing unit. See stratigraphic section of appendix B.

Appendix B
Coal-bearing sections from the Nenana field.

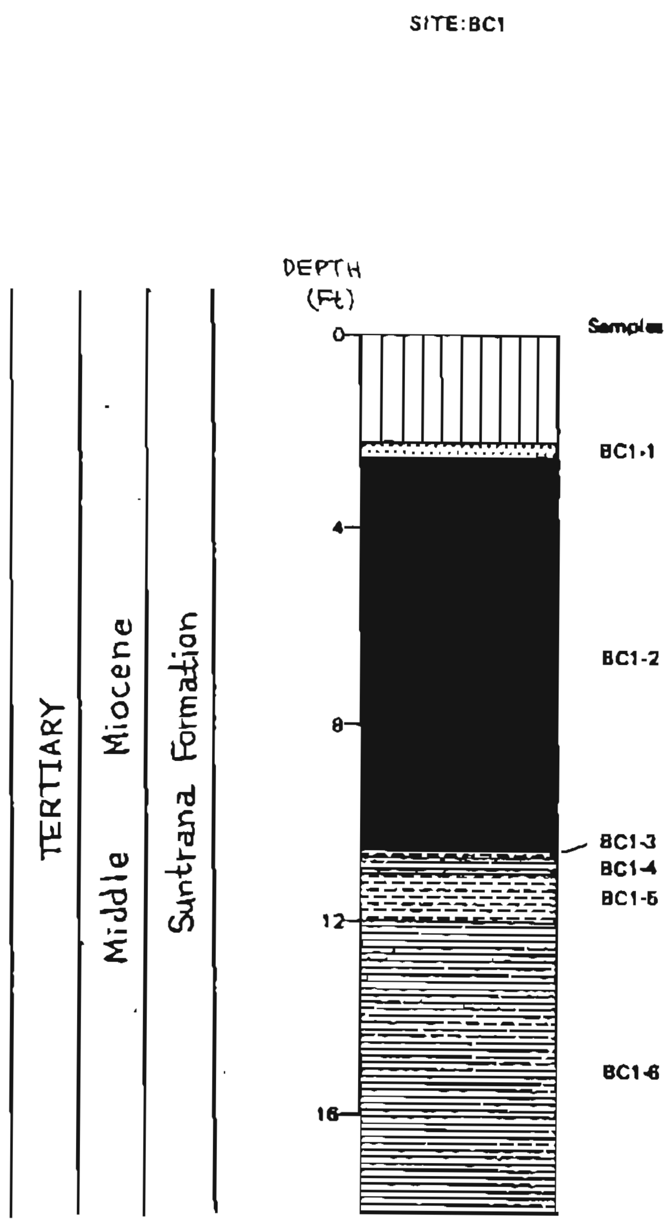


Figure B1. Bonanza Creek coal-bearing section.

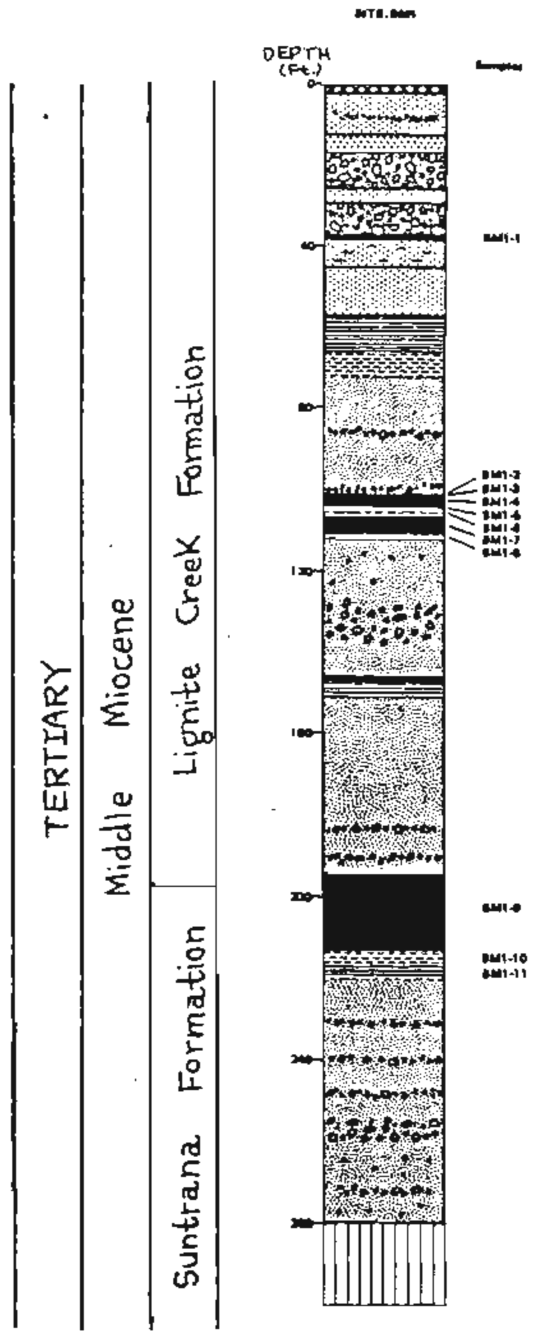


Figure B2. Coal-bearing section at confluence Bonanza-Marguerite Creeks.

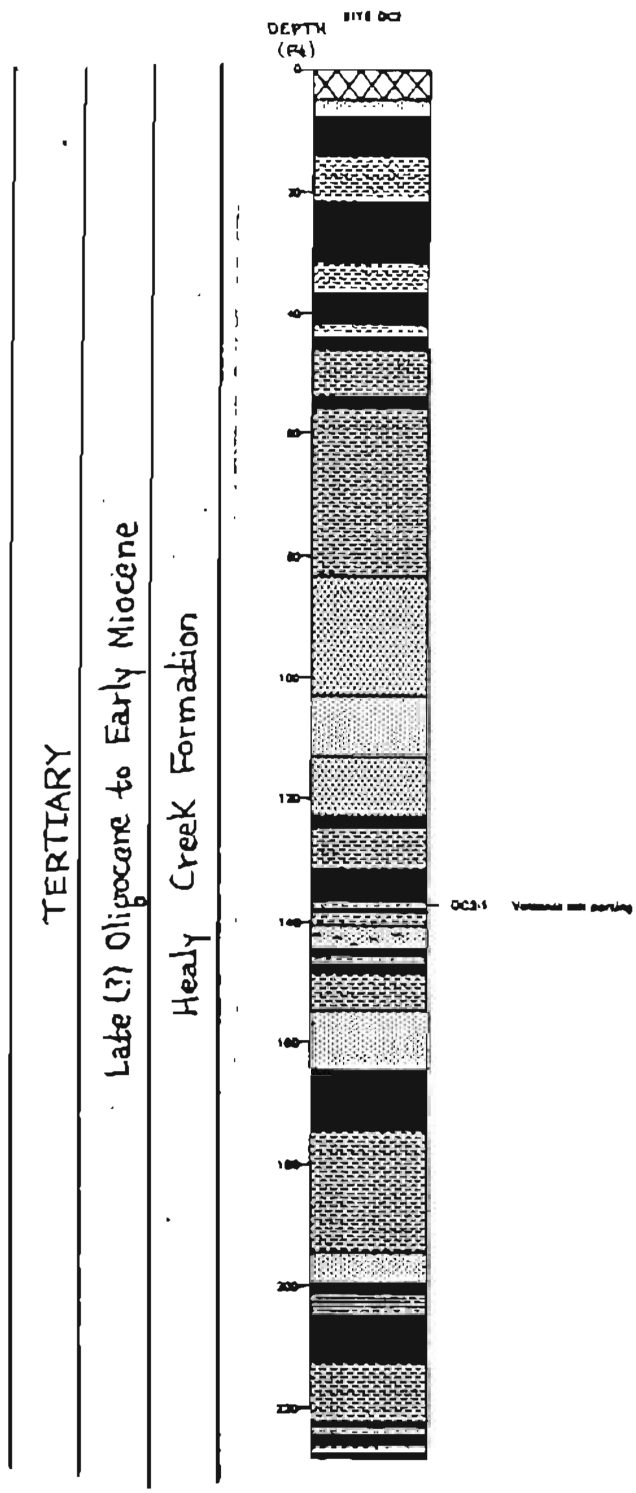


Figure B3. Davis Creek coal-bearing section.

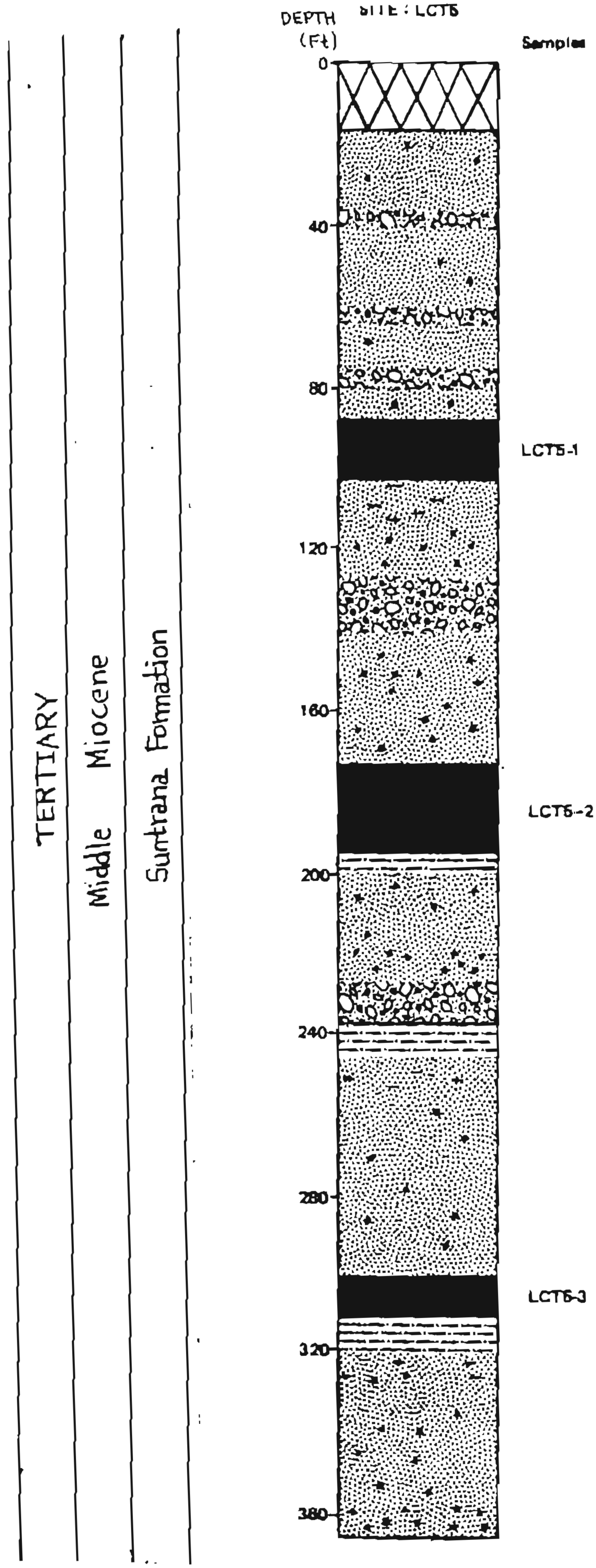


Figure B4. Lignite Creek tributary coal-bearing section.

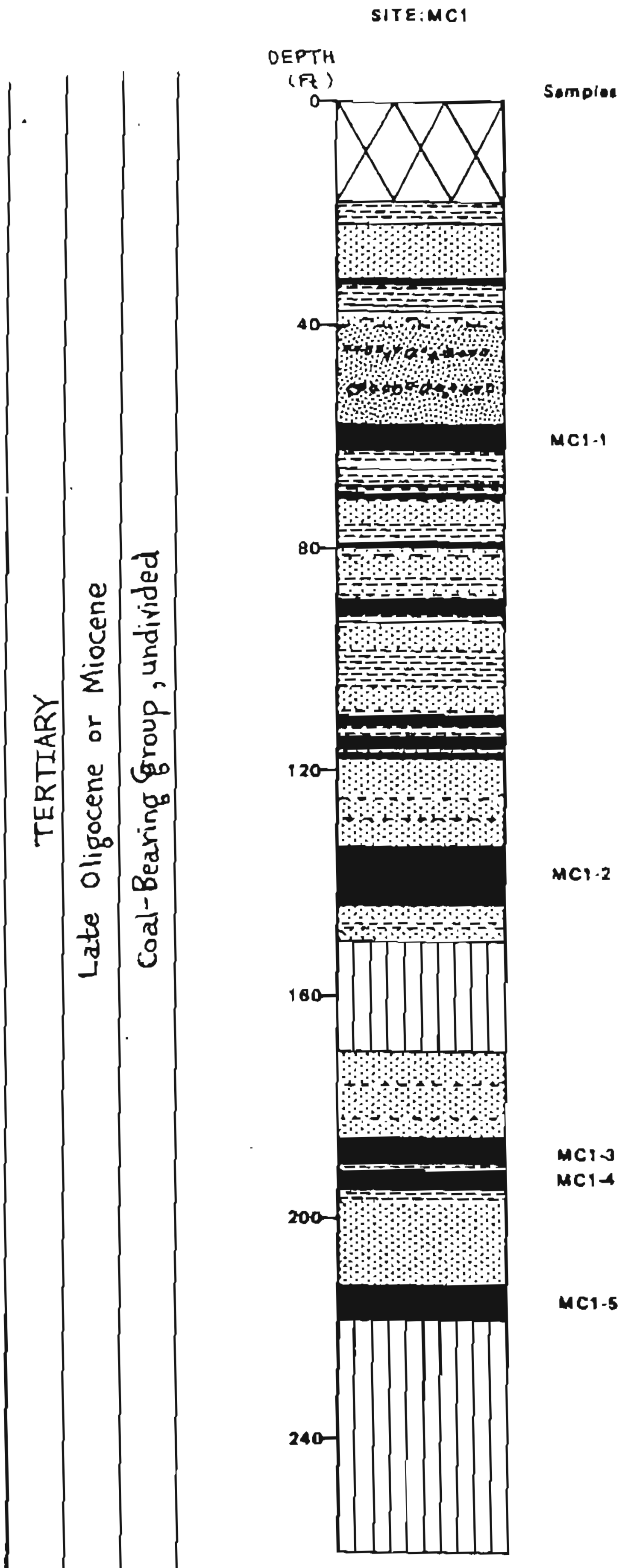


Figure B5. Mystic Creek coal-bearing section.

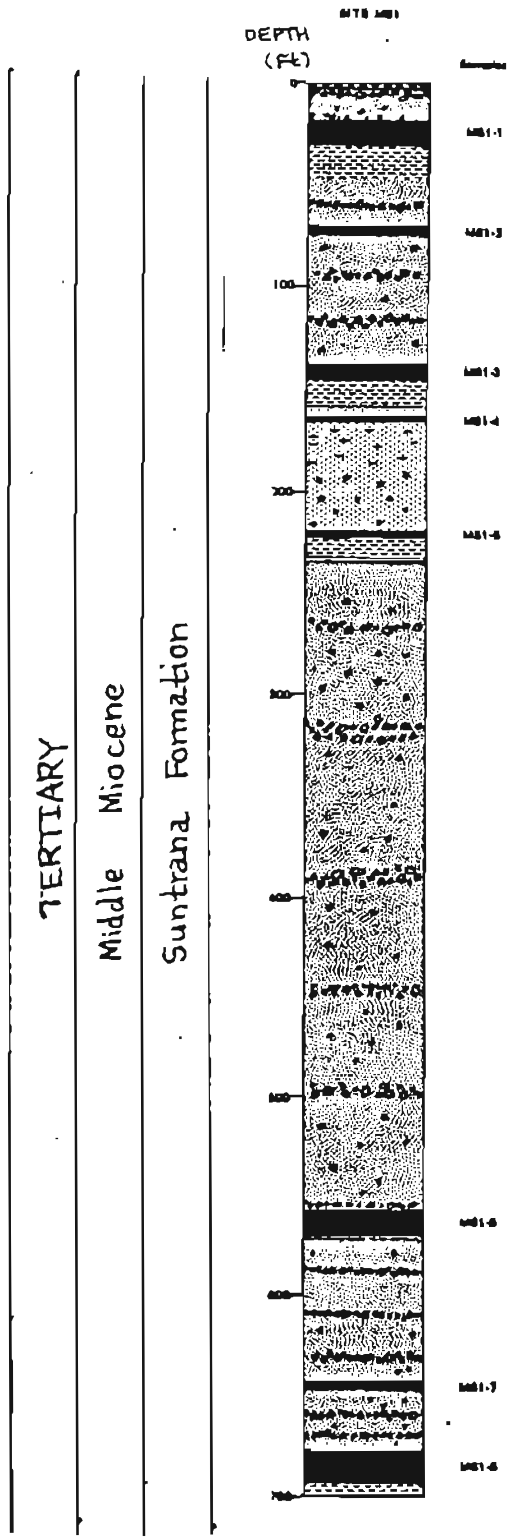


Figure B6. Coal-bearing section at confluence Moose and Sheep Creeks.

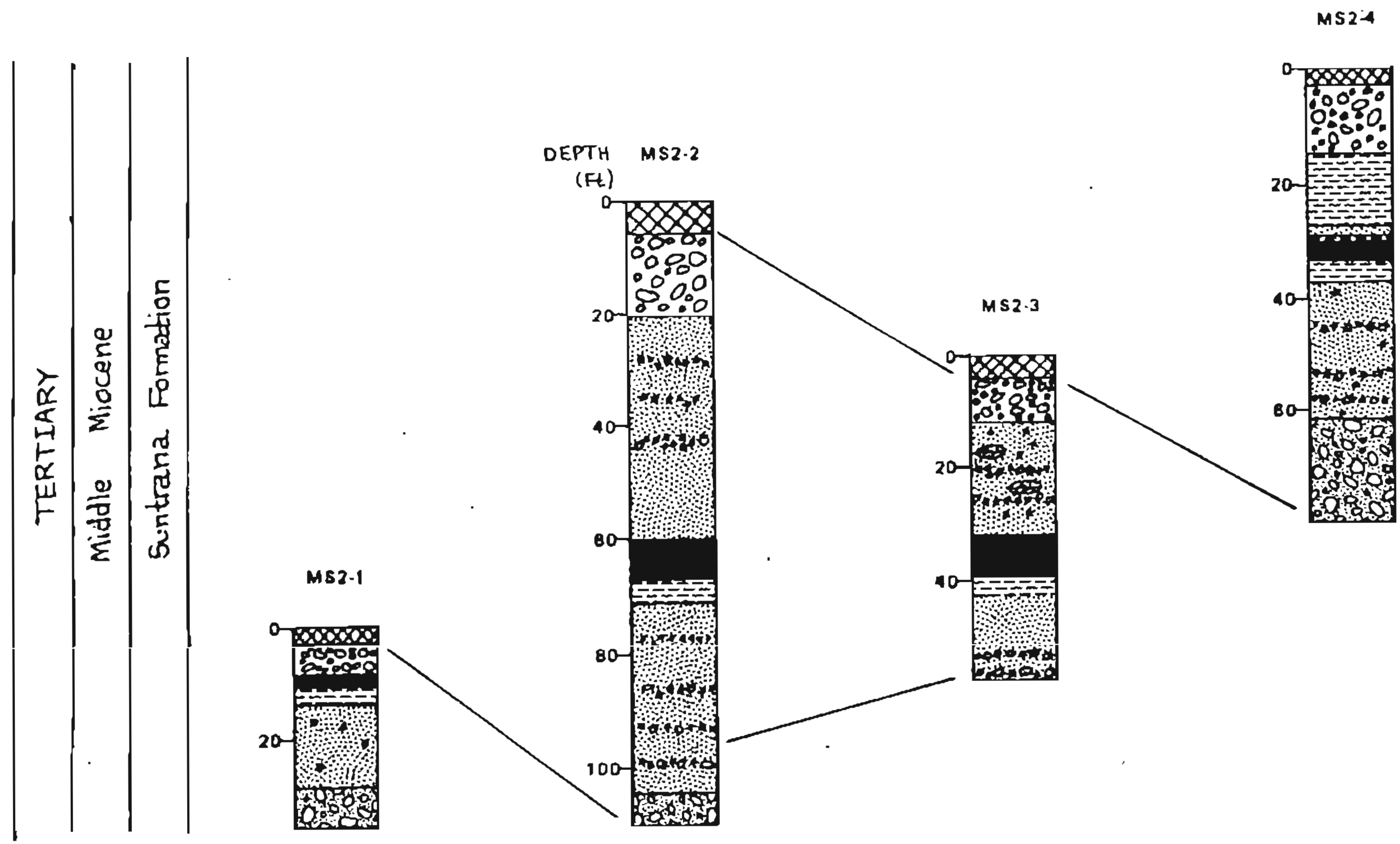


Figure B7. Coal-bearing sections west side of Sheep Creek.

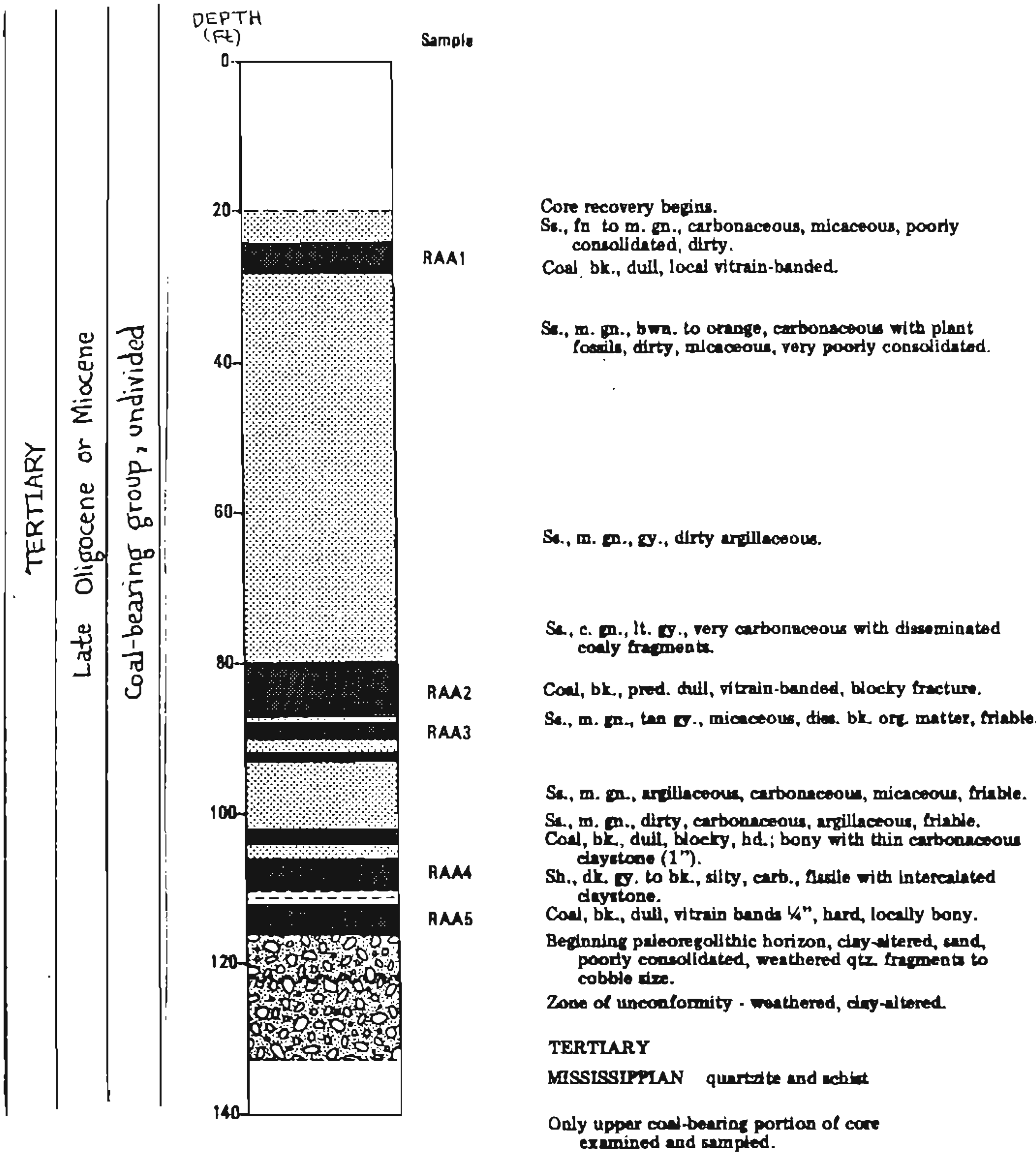


Figure 88. Dry Creek, Bonnifield region, section (Resource Associates of Alaska core).

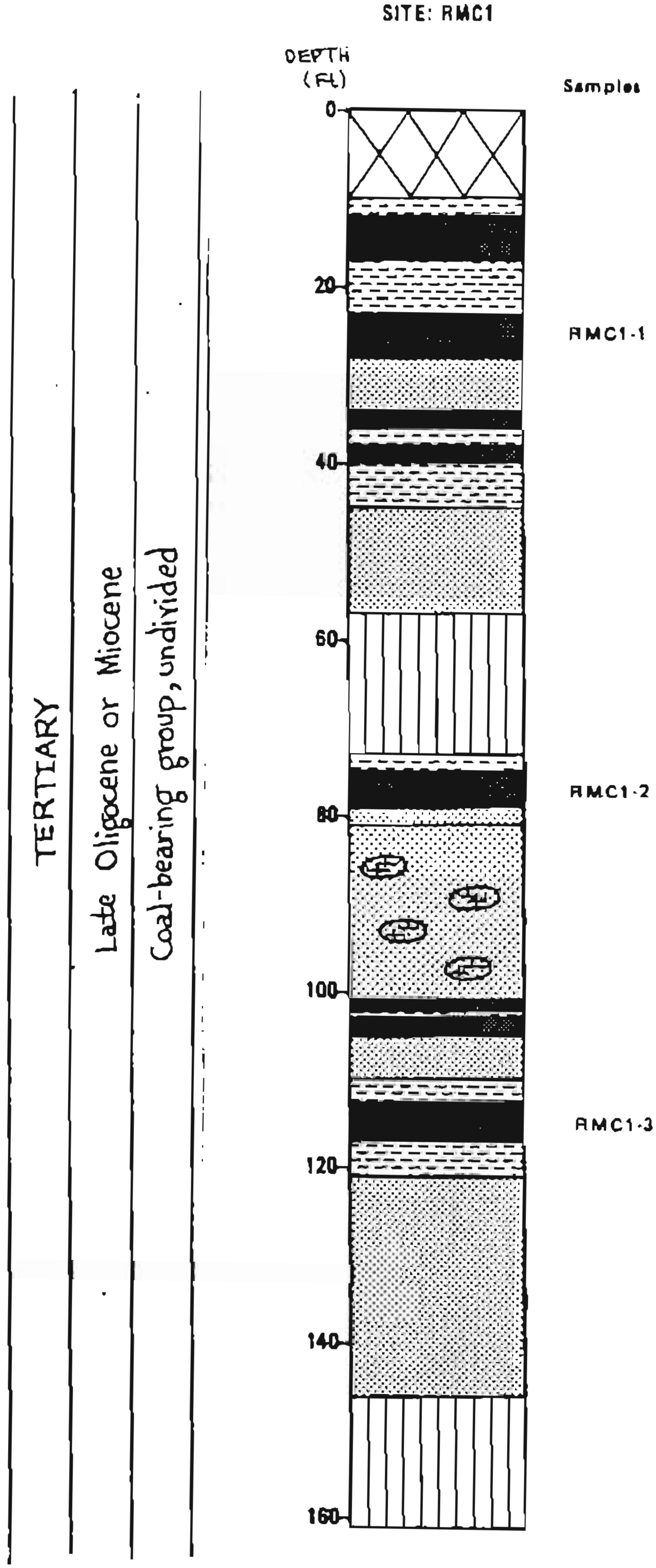


Figure B9. Red Mountain Creek coal-bearing section.

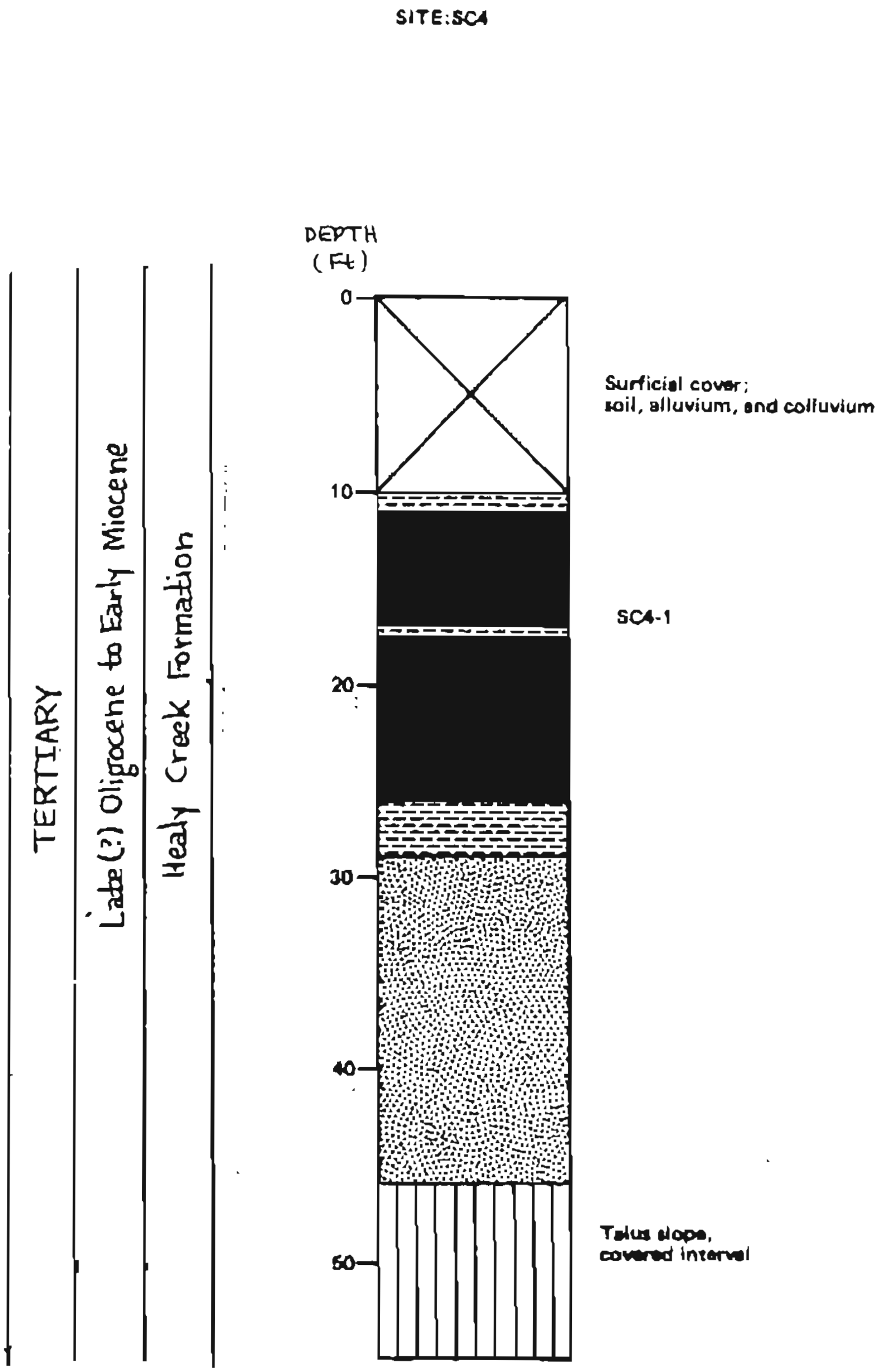


Figure B10. Shovel Creek coal-bearing section.

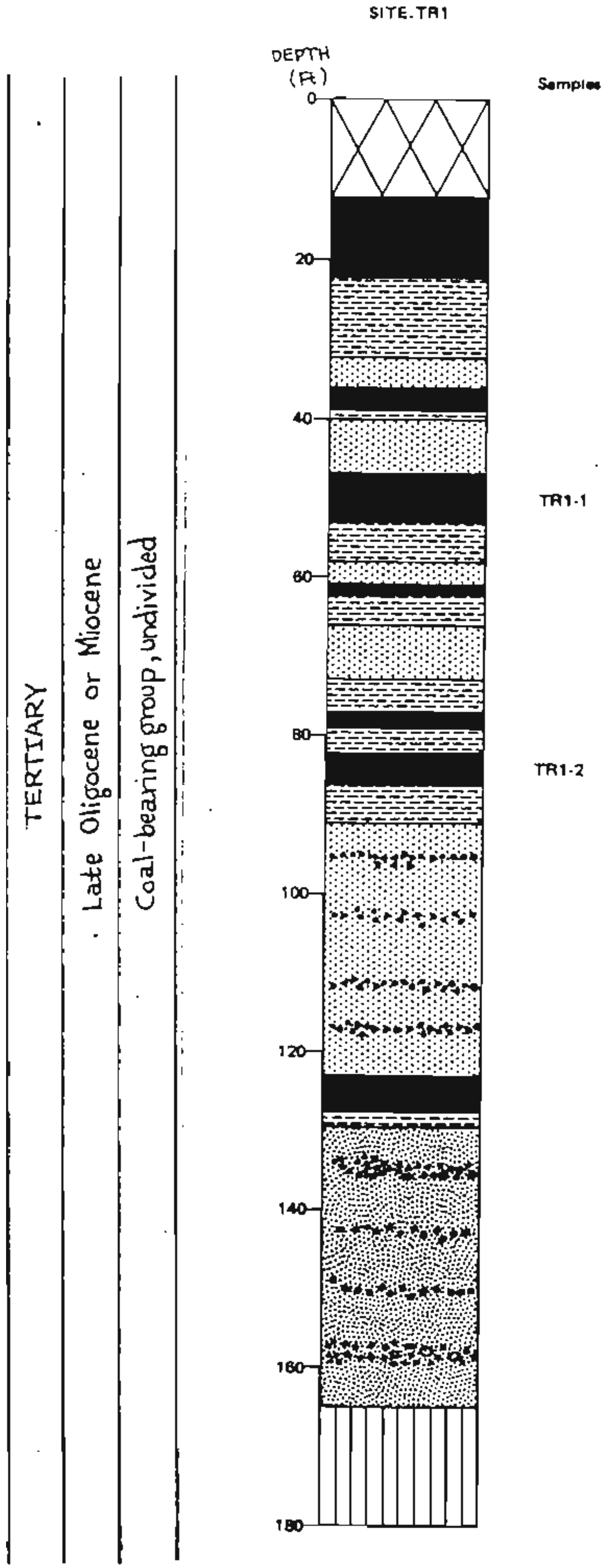


Figure B11. Teklanika River coal-bearing section.

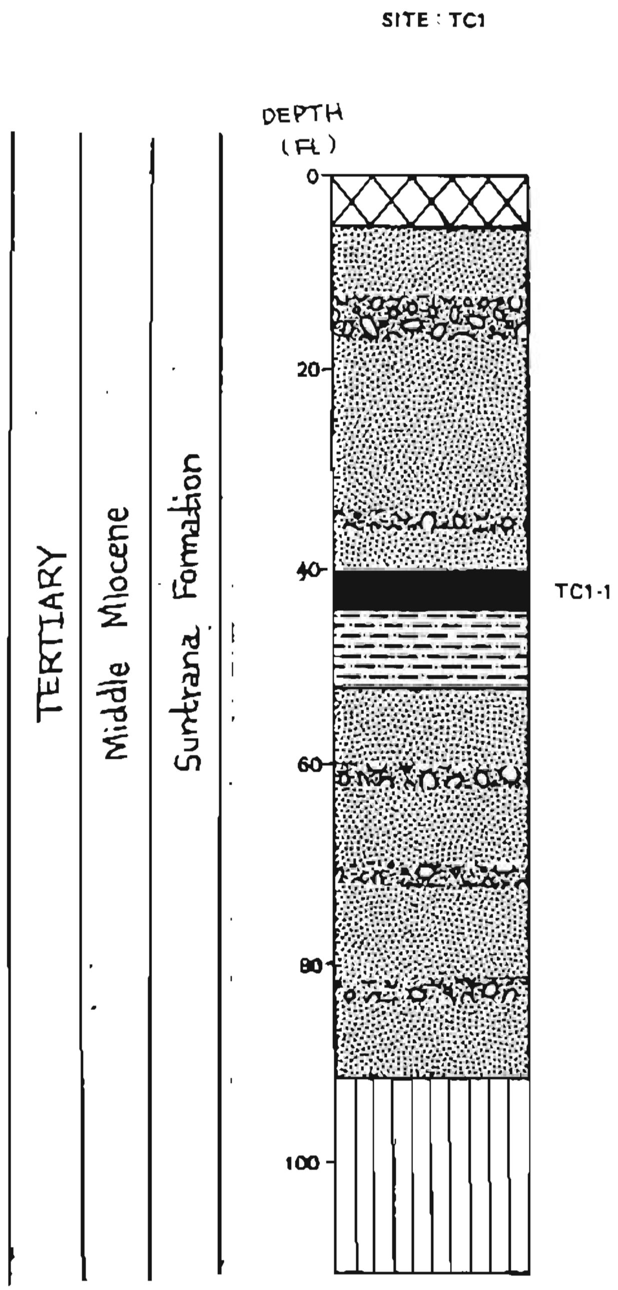


Figure B12. Thistle Creek coal-bearing section.

Appendix C

Table C1. State of Alaska coal leases Healy and Lignite Creeks area, Nenana coal field.*

Name	Alaska Division of Lands (ADL) number	Description	Total acres	Date issued
Arctic Coal Company	16925	T. 11S., R. 7W., F.M. Sec. 23: S½ 24: S½SW¼, SE¼ 25: All 26: All 35: N½, N½SE¼, NW¼SW¼ 36: N½NW¼, N½NE¼	2,440±	6/1/54 8/31/61 (with state)
B & G Shallit	(1) 16927	T. 12S., R. 6W., F.M. Sec. 16: N¼, SE¼	480±	7/3/61 (with state)
	(2) 327217	T. 12S., R. 6W., F.M. Sec. 15: All 14: SW¼ 21: N½NE¼	880±	7/5/50
Dan Renshaw	50699	T. 12S., R. 7W., F.M. Sec. 22: N½S½, N½S½S½ 23: NW¼, W½NE¼ N½SW¼, NW¼SE¼	600±	8/1/74
Meadow-lark	(1) 53048	T. 11S., R. 6W., F.M. Sec. 7: SE¼ 8: SW¼SW¼, N½SW¼ 16: SW¼NW¼ 17: N½SE¼, S½NE¼, W½ 18: NE¼, E½SE¼ 20: All 21: All	2,320±	2/1/75
	(2) 55259	T. 11S., R. 6W., F.M. Sec. 5: All 7: NE¼ 8: N½, SE¼, SE¼SW¼	1,320±	2/1/76
	(3) 58957	T. 10S., R. 6W., F.M. Sec. 21: S½ 28: N½, SW¼, N½SE¼, SW¼SE¼ 29: E½ 32: All	1,880±	5/1/79

*See figure 60 for plot of leases.

Name	Alaska Division of Lands (ADL) number	Description	Total acres	Date issued
	(4) 58959	T. 10S., R. 6W., F.M. Sec. 22: E½E½, SW¼, W½NW¼ 23: All 26: All 27: E½NE¼, SE¼, SE¼SW¼, SW¼NW¼, N½NW¼ 34: All 35: All	3,360±	12/1/76 5/1/79
	(5) 61957	T. 11S., R. 6W., F.M. Sec. 13: All 14: All 15: S½	1,600±	5/1/79
	(6) 61958	T. 11S., R. 6W., F.M. Sec. 3: NW¼ 4: All 9: All	1,440±	5/1/79
	(7) 62985	T. 10S., R. 6W., F.M. Sec. 33: N of 64° North Latitude	500±	5/1/79
	(8) 64830	T. 11S., R. 6W., F.M. Sec. 16: NE¼, E½NW¼, N½SE¼ 17: NW¼NE¼, SW¼SE¼	400±	5/1/79
Usibelli Coal Mine, Inc.	(1) 16926	T. 12S., R. 6W., F.M. Sec. 16: SW¼	160±	3/1/49 6/30/61 (with State)
	(2) 20633	T. 11S., R. 7W., F.M. Sec. 33: All 34: All T. 12S., R. 7W., F.M. Sec. 3: All 4: E½, N½NW¼	2,320±	5/1/67
	(3) 21545	T. 11S., R. 7W., F.M. Sec. 29: SE¼SE¼ 32: All T. 12S., R. 7W., F.M. Sec. 4: S½NW¼, SW¼ 5: NW¼, E½	1,400±	11/1/67

Name	Alaska Division of Lands (ADL) number	Description	Total acres	Date issued
	(4) 22721	T. 12S., R. 6W., F.M. Sec. 17: S½ 18: SE¼ 19: NE¼ 20: N½	960±	12/2/48
	(5) 24295	T. 12S., R. 6W., F.M. Sec. 10: All 11: All 12: S½ 13: N½	1,893±	7/8/64
	(6) 24296	T. 12S., R. 6W., F.M. Sec. 14: N½	320±	9/11/64
	(7) 56505	T. 11S., R. 6W., F.M. Sec. 25: All 26: All 27: All 34: All 35: All	3,200±	4/13/72
	(8) 60496	T. 11S., R. 6W., F.M. Sec. 28: All 29: All 30: All 31: N½ 32: N½ 33: N½	3,019±	12/1/72
	(9) 62753	T. 11S., R. 6W., F.M. Sec. 36: All	640±	5/1/79
	(10) 62754	T. 11S., R. 6W., F.M. Sec. 22: All 23: All 24: All	1,920±	5/1/79

Appendix D
Coal quality, petrologic, and geochemical data.

Table D1. Proximate analysis, Nenana coal field samples. See plate 1 and appendix B.

Sample number	Basis*	Moisture percent	Volatile matter percent	Fixed carbon percent	Ash percent	Heating value Btu/lb
BC1-2	1	25.58	36.75	29.93	7.74	7908
	2	26.71	36.19	29.47	7.63	7788
	3	- -	49.38	40.21	10.41	10626
	4	- -	55.11	44.89	- -	11861
BM1-4	1	31.67	20.79	9.29	38.25	3803
	2	24.53	22.96	10.26	42.25	4200
	3	- -	30.43	13.59	55.98	5565
	4	- -	69.13	30.87	- -	12643
BM1-7	1	25.99	20.32	12.27	41.42	3407
	2	22.79	21.20	12.80	43.21	3555
	3	- -	27.46	16.58	55.97	4604
	4	- -	62.35	37.65	- -	10456
BM1-9	1	23.30	34.78	26.67	15.25	6965
	2	24.22	34.36	26.35	15.07	6882
	3	- -	45.35	34.77	19.88	9081
	4	- -	56.60	43.40	- -	11335
EC2-1	1	28.32	26.77	16.86	28.05	4736
	2	25.23	27.92	17.59	29.26	4940
	3	- -	37.34	23.53	39.13	6607
	4	- -	61.35	38.65	- -	10854
JD1-1	1	25.12	36.57	35.25	3.06	8382
	2	23.99	37.12	35.78	3.11	8508
	3	- -	48.84	47.07	4.09	11194
	4	- -	50.92	49.08	- -	11671
JD1-2	1	22.17	39.36	31.83	6.65	7758
	2	25.82	37.51	30.33	6.34	7394
	3	- -	50.57	40.89	8.54	9968
	4	- -	55.29	44.71	- -	10899

*1-As received
2-Equilibrium moisture
3-Moisture free
4-Moisture and ash free

Sample number	Basis*	Moisture percent	Volatile matter percent	Fixed carbon percent	Ash percent	Heating value Btu/lb
JD3-1	1	23.90	36.97	35.10	4.03	8025
	2	22.66	37.57	35.67	4.10	8156
	3	- -	48.58	46.12	5.30	10545
	4	- -	51.30	48.70	- -	11136
JD4-1	1	30.67	36.31	28.50	4.52	7626
	2	27.63	37.91	29.75	4.72	7960
	3	- -	52.38	41.10	6.52	11000
	4	- -	56.03	43.97	- -	11767
JD5-1	1	28.53	36.93	31.88	2.66	8068
	2	26.48	37.99	32.79	2.73	8299
	3	- -	51.68	44.60	3.72	11288
	4	- -	53.67	46.33	- -	11724
LCT1-1	1	30.53	35.74	29.61	4.12	7641
	2	29.85	36.09	29.90	4.16	7716
	3	- -	51.45	42.62	5.93	10999
	4	- -	54.69	45.31	- -	11693
LCT1-2	1	30.18	36.26	30.41	3.15	7704
	2	23.35	39.80	33.38	3.46	8458
	3	- -	51.93	43.55	4.51	11035
	4	- -	54.39	45.61	- -	11556
LCT1-3	1	28.33	36.01	31.92	3.73	7762
	2	27.86	36.25	32.13	3.76	7812
	3	- -	50.25	44.54	5.21	10830
	4	- -	53.01	46.99	- -	11425
LCT1-4	1	23.98	39.74	32.49	3.79	8522
	2	24.26	39.59	32.37	3.78	8491
	3	- -	52.28	42.73	4.99	11211
	4	- -	55.02	44.98	- -	11800
LCT2-1	1	32.92	35.76	27.77	3.56	7383
	2	28.81	37.95	29.47	3.77	7836
	3	- -	53.30	41.40	5.30	11007
	4	- -	56.29	43.71	- -	11623
LCT2-2	1	28.20	34.75	31.82	5.22	7770
	2	28.05	34.82	31.89	5.23	7786
	3	- -	48.40	44.32	7.28	10821
	4	- -	52.20	47.80	- -	11670

Sample number	Basis*	Moisture percent	Volatile matter percent	Fixed carbon percent	Ash percent	Heating value Btu/lb
LCT5-1	1	27.15	36.67	28.54	7.64	7406
	2	25.45	37.53	29.20	7.82	7578
	3	- -	50.34	39.17	10.49	10165
	4	- -	56.24	43.76	- -	11357
LCT5-2	1	19.74	39.37	30.01	10.88	7849
	2	21.48	38.52	29.36	10.64	7679
	3	- -	49.06	37.39	13.55	9779
	4	- -	56.75	43.25	- -	11312
LCT5-3	1	23.75	38.49	33.29	4.47	8220
	2	24.13	38.30	33.12	4.45	8179
	3	- -	50.48	43.66	5.86	10780
	4	- -	53.62	46.38	- -	11452
MC1-1	1	20.66	31.67	23.98	23.70	6819
	2	20.53	31.72	24.02	23.74	6830
	3	- -	39.91	30.22	29.87	8594
	4	- -	56.91	43.09	- -	12255
MC1-2	1	25.16	35.66	32.09	7.09	8216
	2	23.97	36.23	32.60	7.20	8346
	3	- -	47.65	42.87	9.47	10978
	4	- -	52.64	47.36	- -	12126
MC1-3	1	22.77	38.22	31.94	7.07	8661
	2	23.55	37.83	31.61	7.00	8574
	3	- -	49.49	41.35	9.16	11215
	4	- -	54.48	45.52	- -	12346
MC1-4	1	22.90	36.37	29.50	11.24	8331
	2	21.54	37.01	30.02	11.44	8478
	3	- -	47.17	38.26	14.58	10806
	4	- -	55.21	44.79	- -	12650
MC1-5	1	24.38	34.21	33.35	8.06	8286
	2	23.09	34.79	33.92	8.20	8427
	3	- -	45.23	44.10	10.66	10958
	4	- -	50.63	49.37	- -	12266
MC2-2	1	17.50	37.04	35.03	10.43	8848
	2	20.55	35.67	33.74	10.04	8521
	3	- -	44.89	42.47	12.64	10725
	4	- -	51.39	48.61	- -	12277
MC2-5	1	18.78	37.90	28.61	14.71	8422
	2	19.88	37.38	28.22	14.52	8308
	3	- -	46.66	35.23	18.12	10369
	4	- -	56.98	43.02	- -	12664

Sample number	Basis*	Moisture percent	Volatile matter percent	Fixed carbon percent	Ash percent	Heating value Btu/lb
MC2-10	1	25.22	36.44	32.95	5.40	8529
	2	23.27	37.39	33.80	5.54	8752
	3	- -	48.73	44.06	7.21	11406
	4	- -	52.52	47.48	- -	12293
MC2-12	1	24.28	33.60	35.25	6.87	8385
	2	24.27	33.61	35.25	6.87	8386
	3	- -	44.38	46.55	9.08	11073
	4	- -	48.81	51.19	- -	12179
MC2-14	1	18.62	42.36	29.75	9.28	9492
	2	21.80	40.70	28.58	8.92	9121
	3	- -	52.05	36.55	11.40	11663
	4	- -	58.74	41.26	- -	13164
MC2-16	1	22.48	36.69	35.35	5.47	9021
	2	22.40	36.73	35.39	5.49	9030
	3	- -	47.33	45.60	7.07	11636
	4	- -	50.93	49.07	- -	12522
MC2-19	1	24.79	37.27	32.86	5.08	8944
	2	24.91	37.21	32.81	5.07	8930
	3	- -	49.55	43.69	6.76	11892
	4	- -	53.14	46.86	- -	12754
MC2-22	1	24.04	35.26	36.74	3.96	8986
	2	23.95	35.30	36.79	3.96	8996
	3	- -	46.42	48.37	5.21	11830
	4	- -	48.97	51.03	- -	12480
MM2-1	1	20.35	37.56	32.39	9.70	8322
	2	21.58	36.98	31.89	9.55	8193
	3	- -	47.16	40.66	12.18	10448
	4	- -	53.70	46.30	- -	11897
MM2-2	1	23.77	34.27	30.60	11.36	7547
	2	24.49	33.95	30.31	11.25	7476
	3	- -	44.96	40.14	14.90	9901
	4	- -	52.83	47.17	- -	11634
MM2-3	1	25.36	35.65	27.74	11.26	7725
	2	24.16	36.22	28.18	11.44	7849
	3	- -	47.76	37.16	15.08	10350
	4	- -	56.24	43.76	- -	12188
MM2-4	1	23.48	34.70	32.56	9.27	7904
	2	23.28	34.79	32.64	9.29	7924
	3	- -	45.35	42.55	12.11	10329
	4	- -	51.59	48.41	- -	11752

Sample number	Basis*	Moisture percent	Volatile matter percent	Fixed carbon percent	Ash percent	Heating value Btu/lb
MM2-5	1	22.84	34.60	26.25	16.31	7238
	2	22.20	34.88	26.47	16.45	7298
	3	- -	44.84	34.02	21.14	9381
	4	- -	56.86	43.14	- -	11896
MM2-6	1	24.70	36.27	31.54	7.49	8114
	2	24.61	36.32	31.57	7.50	8124
	3	- -	48.17	41.88	9.95	10775
	4	- -	53.49	46.51	- -	11966
MMb-1	1	27.57	34.48	32.22	5.73	7771
	2	18.92	38.60	36.07	6.41	8699
	3	- -	47.60	44.49	7.91	10729
	4	- -	51.69	48.31	- -	11650
MMb-2	1	6.13	5.90	0.00	87.97	52
	2	- -	- -	- -	- -	- -
	3	- -	- -	- -	- -	- -
	4	- -	- -	- -	- -	- -
MMb-3	1	19.38	38.72	40.09	1.81	9379
	2	17.55	39.60	41.00	1.85	9592
	3		48.03	49.72	2.25	11634
	4	- -	49.13	50.87	- -	11902
MMb-5	1	18.03	39.29	36.56	6.12	8958
	2	16.32	40.10	37.32	6.25	9145
	3	- -	47.93	44.60	7.47	10928
	4	- -	51.80	48.20	- -	11811
MS1-1	1	20.87	40.26	33.40	5.46	8483
	2	21.59	39.90	33.10	5.41	8405
	3	- -	50.88	42.21	6.91	10720
	4	- -	54.66	45.34	- -	11515
MS1-2	1	26.43	32.41	27.10	14.06	6931
	2	24.37	33.32	27.86	14.46	7125
	3	- -	44.05	36.83	19.11	9421
	4	- -	54.46	45.54	- -	11647
MS1-3	1	20.08	30.34	24.31	25.28	6180
	2	20.25	30.27	24.25	25.22	6167
	3	- -	37.96	30.41	31.63	7733
	4	- -	55.52	44.48	- -	11309
MS1-4	1	24.95	33.25	30.42	11.38	7548
	2	23.93	33.70	30.83	11.54	7650
	3	- -	44.30	40.53	15.17	10057
	4	- -	52.22	47.78	- -	11855

Sample number	Basis*	Moisture percent	Volatile matter percent	Fixed carbon percent	Ash percent	Heating value Btu/lb
MS1-5	1	27.46	32.12	30.83	9.59	7327
	2	25.64	32.93	31.61	9.83	7511
	3	- -	44.28	42.51	13.22	10101
	4	- -	51.02	48.98	- -	11639
MS1-6	1	26.44	35.03	34.47	4.06	8218
	2	26.23	35.13	34.57	4.07	8241
	3	- -	47.62	46.86	5.52	11172
	4	- -	50.40	49.60	- -	11825
MS1-7	1	26.03	34.41	34.04	5.52	8067
	2	25.34	34.73	34.36	5.57	8142
	3	- -	46.52	46.02	7.46	10906
	4	- -	50.27	49.73	- -	11785
MS1-8	1	26.70	35.53	31.89	5.88	8222
	2	25.12	36.29	32.58	6.01	8399
	3	- -	48.47	43.51	8.02	11216
	4	- -	52.70	47.30	- -	12195
MS3-1	1	24.03	38.48	32.98	4.51	9036
	2	22.64	39.19	33.58	4.59	9201
	3	- -	50.66	43.41	5.93	11894
	4	- -	53.85	46.15	- -	12644
MS4-1	1	18.38	41.72	36.01	3.89	8898
	2	19.96	40.91	35.31	3.82	8726
	3	- -	51.11	44.12	4.77	10902
	4	- -	53.67	46.33	- -	11448
NC1-1	1	27.59	35.11	27.36	9.94	7548
	2	21.86	37.89	29.53	10.72	8145
	3	- -	48.49	37.79	13.72	10424
	4	- -	56.20	43.80	- -	12082
RAA-1	1	10.97	41.46	38.83	8.75	10819
	2	20.00	37.25	34.89	7.86	9721
	3	- -	46.56	43.61	9.83	12152
	4	- -	51.64	48.36	- -	13476
RAA-2	1	9.12	37.64	36.20	17.04	9714
	2	19.25	33.86	32.57	15.32	8738
	3	- -	41.42	39.84	18.75	10689
	4	- -	50.97	49.03	- -	13155
RAA-3	1	9.58	38.07	41.94	10.41	10459
	2	20.22	33.59	37.00	9.18	9229
	3	- -	42.11	46.38	11.51	11568
	4	- -	47.58	52.42	- -	13072

Sample number	Basis*	Moisture percent	Volatile matter percent	Fixed carbon percent	Ash percent	Heating value Btu/lb
RAA-4	1	8.64	27.67	24.70	38.99	6550
	2	14.84	25.79	23.03	36.34	6106
	3	- -	30.29	27.04	42.67	7170
	4	- -	52.83	47.17	- -	12507
RAA-5	1	6.58	24.14	24.04	45.24	5994
	2	15.18	21.92	21.83	41.07	5442
	3	- -	25.84	25.73	48.43	6416
	4	- -	50.11	49.89	- -	12440
RMC1-1	1	22.17	34.27	31.96	11.60	8450
	2	20.61	34.96	32.60	11.83	8620
	3	- -	44.03	41.06	14.91	10857
	4	- -	51.75	48.25	- -	12759
RMC1-2	1	25.39	34.28	34.77	5.56	8508
	2	24.34	34.76	35.26	5.64	8627
	3	- -	45.94	46.60	7.46	11403
	4	- -	49.65	50.35	- -	12322
RMC1-3	1	21.01	38.89	34.42	5.68	9550
	2	19.04	39.86	35.28	5.83	9788
	3	- -	49.23	43.57	7.20	12090
	4	- -	53.05	46.95	- -	13028
SC1-2	1	18.89	34.60	31.87	14.64	8855
	2	18.43	34.80	32.05	14.73	8905
	3	- -	42.66	39.29	18.05	10917
	4	- -	52.05	47.95	- -	13322
SC1-5	1	20.13	35.43	34.98	9.47	9017
	2	20.29	35.36	34.91	9.45	8999
	3	- -	44.36	43.79	11.85	11290
	4	- -	50.32	49.68	- -	12808
SC1-8	1	14.78	35.92	27.55	21.75	8384
	2	14.36	36.10	27.68	21.86	8426
	3	- -	42.15	32.33	25.53	9838
	4	- -	56.59	43.41	- -	13210
SC1-10	1	13.93	26.98	21.17	37.92	6208
	2	11.48	27.74	21.78	39.00	6384
	3	- -	31.34	24.60	44.06	7212
	4	- -	56.03	43.97	- -	12893

Sample number	Basis*	Moisture percent	Volatile matter percent	Fixed carbon percent	Ash percent	Heating value Btu/lb
SC1-13	1	14.96	34.31	30.07	20.66	8392
	2	15.30	34.17	29.95	20.58	8359
	3	- -	40.34	35.36	24.30	9869
	4	- -	53.29	46.71	- -	13036
SC1-14	1	9.50	30.38	20.70	39.42	6650
	2	9.23	30.47	20.76	39.54	6670
	3	- -	33.57	22.87	43.56	7348
	4	- -	59.48	40.52	- -	13020
SC3-1	1	30.11	29.66	26.43	13.80	7000
	2	24.63	31.99	28.50	14.88	7549
	3	- -	42.44	37.81	19.74	10016
	4	- -	52.89	47.11	- -	12479
SC4-1	1	26.76	33.36	30.32	9.55	7885
	2	25.66	33.87	30.78	9.69	8004
	3	- -	45.56	41.40	13.04	10766
	4	- -	52.39	47.61	- -	12381
TC1-1	1	36.00	28.77	25.49	9.74	5838
	2	30.77	31.12	27.57	10.53	6315
	3	- -	44.96	39.82	15.22	9122
	4	- -	53.03	46.97	- -	10760
TR1-1	1	20.54	41.01	29.58	8.87	8183
	2	22.08	40.22	29.01	8.70	8024
	3	- -	51.61	37.22	11.16	10298
	4	- -	58.10	41.90	- -	11592
TR1-2	1	19.12	36.41	25.21	19.25	7064
	2	21.87	35.18	24.35	18.60	6824
	3	- -	45.02	31.17	23.81	8734
	4	- -	59.09	40.91	- -	11462

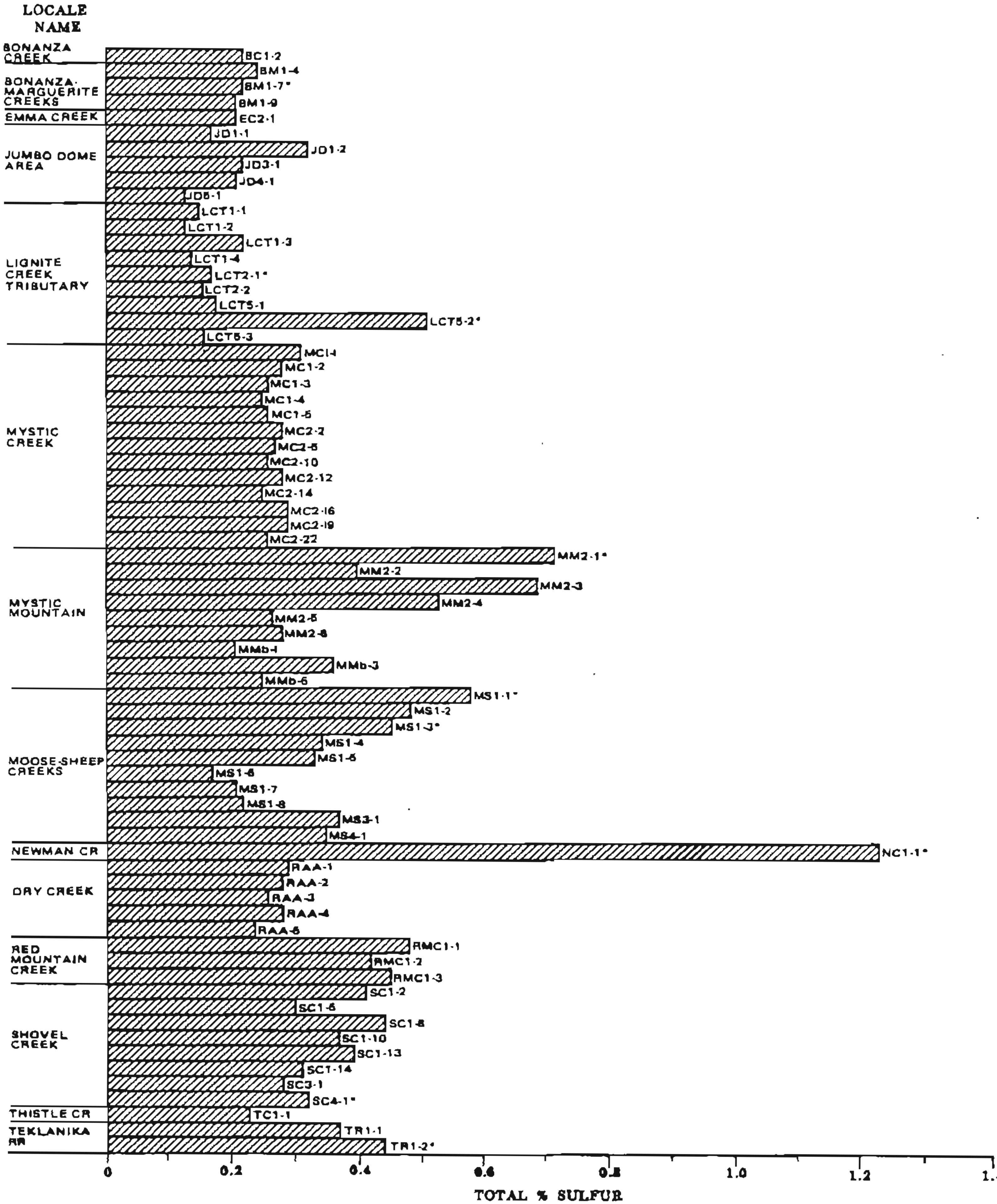


Figure D1. Total sulfur bar graph for Nenana field coal samples. Individual samples are indicated by the code after each bar. An asterisk indicates a sample in which framboidal pyrite was identified.

Table D2. Ultimate analysis, Nenana coal field samples.
See plate 1 and appendix B.

Sample number	Basis	Carbon %	Hydrogen %	Nitrogen %	Oxygen %	Sulfur %	Ash %
BC1-2	1	46.52	6.28	0.57	38.67	0.22	7.74
	2	45.81	6.35	0.56	39.43	0.22	7.63
	3	62.50	4.59	0.77	26.03	0.29	10.41
	4	69.76	5.13	0.86	23.93	0.33	- -
BM1-9	1	41.18	5.80	0.61	36.95	0.21	15.25
	2	40.68	5.86	0.60	37.57	0.21	15.07
	3	53.68	4.16	0.80	25.36	0.28	19.88
	4	67.00	5.20	1.00	26.46	0.35	- -
EC2-1	1	28.10	5.64	0.38	37.63	0.20	28.05
	2	29.31	5.40	0.40	35.42	0.21	29.26
	3	39.20	3.45	0.53	20.86	0.28	39.13
	4	64.40	5.66	0.88	28.60	0.46	- -
LCT1-1	1	45.40	6.77	0.51	43.05	0.15	4.12
	2	48.85	6.73	0.51	42.60	0.15	4.16
	3	65.36	4.83	0.73	27.77	0.21	5.93
	4	69.48	5.13	0.78	24.39	0.23	- -
LCT1-3	1	45.47	6.54	0.57	43.48	0.22	3.73
	2	45.77	6.50	0.57	43.18	0.22	3.76
	3	63.44	4.69	0.79	30.25	0.31	5.21
	4	66.93	4.95	0.83	26.96	0.32	- -
LCT2-1	1	43.93	6.99	0.48	44.88	0.16	3.56
	2	46.62	6.73	0.50	42.19	0.17	3.77
	3	65.49	4.93	0.71	28.26	0.24	5.30
	4	69.16	5.20	0.75	24.63	0.26	- -
LCT2-2	1	45.91	6.49	0.59	41.63	0.16	5.22
	2	46.01	6.48	0.59	41.53	0.16	5.23
	3	63.94	4.56	0.82	27.74	0.22	7.28
	4	68.96	5.01	0.89	24.91	0.23	- -
LCT5-1	1	43.94	6.44	0.52	41.29	0.17	7.64
	2	44.96	6.33	0.53	40.18	0.18	7.82
	3	60.31	4.67	0.71	28.25	0.24	10.49
	4	67.38	5.22	0.79	26.34	0.26	- -

*1-As received
2-Equilibrium moisture
3-Moisture free
4-Moisture and ash free

Sample number	Basis	Carbon %	Hydrogen %	Nitrogen %	Oxygen %	Sulfur %	Ash %
LCT5-2	1	46.82	5.82	0.62	35.33	0.53	10.88
	2	45.81	5.94	0.61	36.49	0.51	10.64
	3	58.34	4.50	0.78	26.68	0.65	13.55
	4	67.48	5.21	0.40	26.65	0.76	- -
LCT5-3	1	48.84	6.28	0.54	39.71	0.16	4.47
	2	48.60	6.31	0.54	39.95	0.16	4.45
	3	64.06	4.75	0.71	29.16	0.21	5.86
	4	68.05	5.05	0.75	25.93	0.22	- -
MC2-2	1	51.01	5.89	0.76	31.63	0.29	10.43
	2	49.12	6.08	0.73	33.75	0.28	10.04
	3	61.82	4.76	0.92	24.27	0.35	12.64
	4	70.77	5.45	1.05	22.32	0.40	- -
MC2-5	1	47.41	6.20	0.10	31.31	0.27	14.71
	2	46.77	6.27	0.10	32.08	0.27	14.52
	3	58.37	5.05	0.12	23.06	0.34	18.12
	4	71.29	6.17	0.15	21.99	0.41	- -
MC2-19	1	51.52	6.85	0.73	35.54	0.29	5.08
	2	51.43	6.86	0.73	35.62	0.29	5.07
	3	68.50	5.42	0.97	23.40	0.38	6.76
	4	73.46	5.81	1.04	19.28	0.41	- -
MM2-1	1	48.62	6.09	0.77	34.09	0.73	9.70
	2	47.87	6.17	0.75	34.93	0.72	9.55
	3	61.04	4.79	0.96	24.90	0.92	12.18
	4	69.51	5.45	1.09	22.90	1.04	- -
MM2-2	1	44.32	6.02	0.63	37.27	0.41	11.36
	2	43.90	6.07	0.62	37.76	0.40	11.25
	3	58.14	4.41	0.83	25.60	0.54	14.90
	4	68.31	5.18	0.97	24.91	0.63	- -
MM2-6	1	48.23	6.38	0.66	36.96	0.28	7.49
	2	48.29	6.37	0.66	36.90	0.28	7.50
	3	63.05	4.80	0.88	24.75	0.38	9.95
	4	71.12	5.33	0.98	22.15	0.42	- -
MMb-2	1	0.65	1.33	0.01	9.93	0.08	87.97
	2	- -	- -	- -	- -	- -	- -
	3	- -	- -	- -	- -	- -	- -
	4	- -	- -	- -	- -	- -	- -
MS1-6	1	48.73	6.45	0.60	39.99	0.17	4.06
	2	48.87	6.44	0.60	39.85	0.17	4.07
	3	66.25	4.75	0.81	27.19	0.23	5.52
	4	70.12	5.02	0.86	23.76	0.24	- -

Sample number	Basis	Carbon %	Hydrogen %	Nitrogen %	Oxygen %	Sulfur %	Ash %
MS1-8	1	48.39	6.63	0.61	38.28	0.21	5.88
	2	49.43	6.53	0.63	37.19	0.22	6.01
	3	66.01	4.96	0.83	24.84	0.29	8.02
	4	71.77	5.40	0.91	21.61	0.32	- -
RAA-1	1	60.34	6.14	0.89	23.56	0.32	8.75
	2	54.22	6.65	0.80	30.18	0.29	7.86
	3	67.77	5.51	1.01	21.04	0.36	9.83
	4	75.16	6.11	1.11	17.22	0.40	- -
RAA-3	1	59.64	5.59	0.83	23.24	0.30	10.41
	2	52.62	6.25	0.73	30.95	0.26	9.18
	3	65.96	5.00	0.91	21.29	0.33	11.51
	4	74.54	5.65	1.03	18.41	0.37	- -
RMC1-1	1	48.82	6.40	0.75	31.96	0.47	11.60
	2	49.80	6.31	0.76	30.82	0.48	11.83
	3	62.72	5.04	0.96	20.80	0.61	14.91
	4	73.71	5.92	1.13	18.53	0.71	- -
RMC1-2	1	50.40	6.41	0.79	36.42	0.41	5.56
	2	51.11	6.34	0.80	35.68	0.42	5.64
	3	67.56	4.78	1.06	23.37	0.55	7.46
	4	73.00	5.16	1.15	20.09	0.60	- -
SC1-5	1	52.01	6.25	0.85	31.11	0.30	9.47
	2	51.91	6.26	0.85	31.23	0.30	9.45
	3	65.12	5.01	1.07	21.58	0.38	11.85
	4	73.87	5.68	1.21	18.80	0.43	- -
SC1-13	1	47.70	5.55	0.68	25.01	0.40	20.66
	2	47.51	5.57	0.68	25.26	0.39	20.58
	3	56.09	4.56	0.80	18.34	0.47	24.30
	4	74.09	6.02	1.06	18.21	0.62	- -
SC1-14	1	37.44	4.56	0.55	17.72	0.31	39.42
	2	37.55	4.54	0.56	17.51	0.31	39.54
	3	41.36	3.86	0.61	14.12	0.34	43.56
	4	73.29	6.84	1.09	18.18	0.61	- -
TC1-1	1	36.37	6.54	0.51	46.62	0.21	9.74
	2	39.23	6.16	0.55	43.18	0.23	10.53
	3	56.83	3.93	0.80	26.82	0.34	15.22
	4	67.03	4.63	0.94	27.00	0.40	- -
TR1-1	1	48.58	6.21	0.58	35.38	0.38	8.87
	2	47.63	6.31	0.57	36.42	0.37	8.70
	3	61.13	4.93	0.73	26.50	0.48	11.16
	4	68.82	5.55	0.82	24.28	0.54	- -

Table D3. Coal quality calculations, Nenana coal field samples.

Coal sample no.	Fuel ratio F.C. / V.M.	Carbon ratio F.C. / (F.C. + V.M.) x 100	Perch & Russell ratio R = moist, Mm-free Btu / dry, Mm-free Btu	H value (Lord) H = Btu-40505 / (100-(M+A+S)) x 100	Mineral matter (%) Parr Formula 1.08 + 0.55S	DuLong's equation (Approx. heating value calc. ultimate anal. data) Q = 1/100 (14,544 x % C + 62028 (%H-%O/8) +4050 x %S)	Moist Mm-free Btu (Btu-50S x 100) / (100-(1.08A + 0.55S)) x 100	Rank
BC1-2	0.81	44.88	0.72	105.39	8.5	7552	8486	subbit C
BM1-4	0.45	30.88	0.61	97.88	41.4		7721	lig A
BM1-7	0.60	37.65	0.64	78.86	44.8		6660	lig A
BM1-9	0.77	43.40	0.72	99.69	16.5	6644	8219	lig A
EC2-1	0.63	38.65	0.66	90.28	30.4	4873	7220	lig A
JD1-1	0.96	49.08	0.75	107.51	3.4		8803	subbit C
JD1-2	0.81	44.71	0.73	90.31	7.4		7936	lig A
JD3-1	0.95	48.70	0.77	99.49	4.5		8533	subbit C
JC4-1	0.78	43.97	0.71	105.42	5.0		8387	subbit C
JD5-1	0.86	46.33	0.73	110.00	2.9		8551	subbit C
LCT1-1	0.83	45.31	0.69	107.97	4.5	7549	8078	lig A
LTC1-2	0.84	45.61	0.76	108.56	3.5		8786	subbit C
LCT1-3	0.88	46.99	0.71	101.54	4.2	7348	8141	lig A
LCT1-4	0.82	44.98	0.75	110.33	4.2		8852	subbit C
LCT2-1	0.78	43.71	0.70	106.28	3.9	7693	8167	lig A
LCT2-2	0.92	47.80	0.71	107.24	5.7	7498	8252	lig A
LCT5-1	0.78	43.76	0.73	102.92	8.4	7359	8277	lig A
LCT5-2	0.76	43.25	0.77	83.32	12.0	7539	8674	subbit C
LCT5-3	0.86	46.37	0.75	105.68	4.9	7894	8592	subbit C
MC1-1	0.76	43.09	0.75	100.59	25.8		9185	subbit C
MC1-2	0.90	47.36	0.75	105.21	7.8		9050	subbit C
MC1-3	0.84	45.52	0.75	108.70	7.8		9274	subbit C
MC1-4	0.81	44.78	0.76	111.81	12.3		9675	subbit B
MC1-5	0.97	49.37	0.75	107.73	8.8		9246	subbit C
MC2-2	0.94	48.61	0.77	106.86	11.4	8309	9453	subbit C
MC2-5	0.75	43.02	0.78	110.43	16.0	8215	9854	subbit B
MC2-10	0.90	47.48	0.76	108.54	6.0		9309	subbit C

Table D3. (con.)

Coal sample no.	Fuel ratio $\frac{F.C.}{V.M.}$	Carbon ratio $\frac{F.C.}{F.C. + V.M.} \times 100$	Perch & Russell ratio R = $\frac{\text{moist, Mm-free Btu}}{\text{dry, Mm-free Btu}}$	H value (Lord) H = $\frac{Btu-40505}{100-(M+A+S)} \times 100$	Mineral matter (%) Parr Formula 1.08 + 0.55S	DuLong's equation (Approx. heating value calc. ultimate anal. data) Q = $\frac{1}{100}$ [14,544 x % C + 62028 (%H-%0/8) +4050 x %S]	Moist Mm-free Btu $\frac{Btu-50S \times 100}{100-(1.08A + 0.55S)} \times 100$	Rank
MC2-12	1.05	51.19	0.74	105.74	7.6		9058	subbit C
MC2-14	0.70	41.25	0.77	117.46	10.2		10095	subbit B
MC2-16	0.96	49.07	0.77	109.38	6.1		9600	subbit B
MC2-19	0.88	46.86	0.74	111.22	5.6	8987	9448	subbit C
MC2-22	1.04	51.03	0.75	110.58	4.4		9398	subbit C
MM2-1	0.86	46.30	0.77	77.43	10.9	8108	9135	subbit C
MM2-2	0.89	47.17	0.73	91.70	12.5	7238	8508	subbit C
MM2-3	0.78	43.76	0.73	79.34	12.5		8955	subbit C
MM2-4	0.94	48.40	0.75	86.36	10.3		8806	subbit C
MM2-5	0.76	43.14	0.75	101.58	17.8		8875	subbit C
MM2-6	0.87	46.50	0.74	303.39	8.2	8126	8839	subbit C
MMb-1	0.93	48.31	0.80	105.40	6.3		9346	subbit C
MMb-3	1.04	50.87	0.82	101.37	2.1		9789	subbit B
MMb-5	0.93	48.20	0.83	105.37	6.6		9808	subbit B
MS1-1	0.83	45.34	0.78	83.62	6.2		8926	subbit C
MS1-2	0.84	45.54	0.72	85.37	15.4		8442	subbit C
MS1-3	0.80	44.48	0.75	80.33	27.8		8474	subbit C
MS1-4	0.91	47.78	0.74	97.72	12.5		8738	subbit C
MS1-5	0.96	48.98	0.72	96.18	10.5		8393	subbit C
MS1-6	0.98	49.60	0.73	108.62	4.5	8020	8628	subbit C
MS1-7	0.99	49.73	0.74	105.86	6.1		8663	subbit C
MS1-8	0.90	47.31	0.74	109.37	6.5	8364	8982	subbit C
MS3-1	0.86	46.14	0.76	106.39	5.1		9682	subbit B
MS4-1	0.86	46.33	0.79	96.33	4.4		9101	subbit C
NC1-1	0.78	43.80	0.76	47.79	11.4		9213	subbit C
RAA-1	0.94	48.36	0.79	118.95	9.6	9684	10626	hvC bit-subbit A
RAA-2	0.96	49.03	0.80	114.95	18.6		10472	subbit B
RAA-3	1.10	52.42	0.78	116.24	11.4	9140	10246	subbit B
RAA-4	0.89	47.37	0.80	102.43	42.3		10053	subbit B

Table D3. (con.)

Coal sample no.	Fuel ratio F.C. / V.M.	Carbon ratio F.C. / (F.C. + V.M.) x 100	Perch & Russell ratio R = moist, Mm-free Btu / dry, Mm-free Btu	H value (Lord) H = Btu-40505 / 100-(M+A+S) x 100	Mineral matter (%) Parr Formula 1.08 + 0.55S	DuLong's equation (Approx. heating value calc. ultimate anal. data) Q = 1/100 [14,544 x % C + 62028 (%H-%O/8) +4050 x %S]	Moist Mm-free Btu (Btu-50S x 100) / (100-(1.08A + 0.55S)) x 100	Rank
RAA-5	1.00	49.90	0.79	102.74	49.0		9782	subbit B
RMC1-1	0.93	48.25	0.77	99.52	12.8	8788	9885	subbit B
RMC1-2	1.01	50.36	0.74	99.51	6.2	8616	9186	subbit C
RMC1-3	0.88	46.95	0.80	106.66	6.4		10450	subbit B
SC1-2	0.92	47.94	0.80	109.05	16.0		10593	hvC bit-subbit A
SC1-5	0.99	49.68	0.78	111.26	10.4	9026	10023	subbit B
SC1-8	0.77	43.40	0.84	104.89	23.7		11036	hvC bit-subbit A
SC1-10	0.78	43.98	0.86	99.40	41.2		11036	hvC bit-subbit A
SC1-13	0.88	46.71	0.82	106.38	22.5	8420	10752	hvC bit-subbit A
SC1-14	0.68	40.52	0.89	106.33	42.7	6931	11648	hvB bit
SC3-1	0.89	47.12	0.69	106.54	15.0		8994	subbit C
SC4-1	0.91	47.61	0.72	104.27	10.5		8939	subbit C
TC1-1	0.88	46.98	0.66	92.06	10.6	6202	7122	lig A
TR1-1	0.72	41.90	0.76	94.78	9.8	8034	8856	subbit C
TR1-2	0.69	40.90	0.74	85.33	21.0		8538	subbit C

Table D-4. Classification of coals by rank (from American Society for Testing and Materials, 1981).[a]

Class	Group	Fixed carbon limits, percent (dry, mineral-matter-free basis): Equal or greater than	Fixed carbon: Less than	Volatile matter limits, percent (dry, mineral-matter-free basis): Greater than	Volatile matter: Equal or less than	Calorific value limits, Btu per pound (moist,[b] mineral-matter-free basis): Equal or greater than	Calorific value: Less than	Agglomerating character
I. Anthracitic	1. Meta-anthracite	98	- - -	- - -	2	- - -	- - -	
	2. Anthracite	92	98	2	8	- - -	- - -	nonagglomerating
	3. Semianthracite[c]	86	92	8	14	- - -	- - -	
II. Bituminous	1. Low volatile bituminous coal	78	86	14	22	- - -	- - -	
	2. Medium volatile bituminous coal	69	78	22	31	- - -	- - -	
	3. High volatile A bituminous coal	- - -	69	31	- - -	14 000[d]	- - -	commonly agglomerating[e]
	4. High volatile B bituminous coal	- - -	- - -	- - -	- - -	13 000[d]	14 000	
	5. High volatile C bituminous coal	- - -	- - -	- - -	- - -	11 500	13 000	
						10 500	11 500	agglomerating
III. Subbituminous	1. Subbituminous A coal	- - -	- - -	- - -	- - -	10 500	11 500	
	2. Subbituminous B coal	- - -	- - -	- - -	- - -	9 500	10 500	
	3. Subbituminous C coal	- - -	- - -	- - -	- - -	8 300	9 500	nonagglomerating
IV. Lignitic	1. Lignite A	- - -	- - -	- - -	- - -	6 300	8 300	
	2. Lignite B	- - -	- - -	- - -	- - -	- - -	6 300	

[a] This classification does not include a few coals, principally nonbanded varieties, which have unusual physical and chemical properties and which come within the limits of fixed carbon or calorific value of the high-volatile bituminous and subbituminous ranks. All of these coals either contain less than 48% dry, mineral-matter-free fixed carbon or have more than 15 500 moist, mineral-matter-free British thermal units per pound.

[b] Moist refers to coal containing its natural inherent moisture but not including visible water on the surface of the coal.

[c] If agglomerating, classify in low-volatile group of the bituminous class.

[d] Coals having 69% or more fixed carbon on the dry, mineral-matter-free basis shall be classified according to fixed carbon, regardless of calorific value.

[e] It is recognized that there may be nonagglomerating varieties in these groups of the bituminous class, and that there are notable exceptions in high volatile C bituminous group.

Table D-5. Reflectance data for Nenana field coal samples.

Sample no.	Frequency class distribution						$\bar{R}om$
	V1	V2	V3	V4	V5	V6	
BM1-9		69	31				0.27
EC2-1	45	51	4				0.21
JD1-1		72	23	5			0.28
JD1-2		20	76	4			0.32
LCT1-2		85	15				0.27
LCT1-4		57	43				0.32
LCT5-1	2	67	31				0.28
LCT5-2		34	51	15			0.32
LCT5-3		85	15				0.27
MC1-2		4	91	5			0.36
MC2-2			32	64	4		0.42
MC2-19			20	69	11		0.44
MM2-1		85	15				0.26
MM2-2		91	9				0.26
MM2-6		52	48				0.29
MMb-1			51	49			0.39
MMb-3			15	61	24		0.45
MMb-5			35	56	9		0.41
MS1-1		39	45	16			0.32
MS1-6		7	76	17			0.35
MS1-8		4	56	39	1		0.39
RAA2			15	81	4		0.44
RMC1-1				47	51	2	0.50
RMC1-2				34	61	5	0.53
RMC1-3			2	60	38		0.48
SC1-5				72	28		0.48
SC1-8			62	38			0.38
SC1-10			16	83	1		0.42
SC1-13			21	79			0.42
SC1-14			74	26			0.37
TC1-1		21	67	12			0.34
TR1-1		65	33	2			0.28

Table D-6. Relationship between ASTM rank and vitrinite reflectance (from Rao, 1976).

ASTM rank	Reflectance ($\bar{R}om$, %)
Lignite	0.2 - 0.3
Subbituminous	0.3 - 0.4
High volatile C bituminous	0.4 - 0.6
High volatile B bituminous	0.6 - 0.8
High volatile A bituminous	0.8 - 1.1
Medium volatile bituminous	1.1 - 1.5
Low volatile bituminous	1.5 - 2.0

Table D7. Quantitative maceral analysis, Nenana coal fields samples.

Sample	Ulminite/ vitrinite	Pseudo-vitri-nite	Pori-geli-nite	Phloba-phi-nite	Pseudo-phloba-phi-nite	Humode-trinite	Total humi-nite	Fusi-nite	Semi-fusi-nite	Sclero-tinite	Macri-nite	Inerto-detri-nite	Total inerti-nite	Cuti-nite	Spori-nite	Resinite/ suberi-nite/ exsuda-tinite	Algi-nite	Lipto-detri-nite	Total lipti-nite
BC1-2	74.4	0.0	0.4	1.1	0.6	7.4	83.9	0.2	1.3	0.5	0.5	0.9	3.4	0.0	0.1	12.6	0.0	0.0	12.7
BM1-4	46.3	0.0	0.1	2.3	1.0	27.6	77.3	1.8	4.7	0.0	7.9	5.7	20.1	0.0	0.0	2.5	0.0	0.1	2.6
BM1-7	35.8	0.0	0.3	0.9	0.3	34.3	71.6	0.3	0.5	0.0	0.9	1.8	3.5	0.0	0.0	24.9	0.0	0.0	24.9
BM1-9	74.1	0.0	0.0	0.5	0.6	6.2	81.4	0.4	1.2	0.6	1.8	6.4	10.4	0.0	0.0	8.2	0.0	0.0	8.2
EC2-1	58.4	0.0	0.1	0.3	0.6	18.9	78.3	0.3	0.2	0.0	1.8	5.3	7.6	0.0	0.1	14.0	0.0	0.0	14.1
JD1-1	75.5	0.0	0.1	0.7	0.7	3.6	80.6	0.1	0.4	0.2	0.4	0.9	2.0	0.0	0.2	17.2	0.0	0.0	17.4
JD1-2	70.3	0.0	0.3	0.0	0.3	13.5	84.4	0.3	0.8	0.1	1.3	2.8	5.3	0.0	0.1	10.2	0.0	0.0	10.3
JD3-1	76.0	0.0	0.5	0.9	0.2	3.1	80.7	0.6	0.6	0.5	0.2	0.3	2.2	0.0	0.2	16.9	0.0	0.0	17.1
JD4-1	72.0	0.0	1.3	0.8	0.2	4.6	78.9	0.0	0.1	0.2	0.4	0.6	1.3	0.0	0.2	19.6	0.0	0.0	19.8
JD5-1	70.5	0.0	1.0	1.4	1.0	7.3	81.2	0.1	0.0	0.3	0.0	0.2	0.6	0.0	0.6	17.6	0.0	0.0	18.2
LCT1-1	69.1	0.0	0.5	1.6	2.3	9.1	82.6	0.0	0.4	0.2	1.2	0.5	2.3	0.0	0.1	14.9	0.1	0.0	15.1
LCT1-2	85.4	0.0	0.0	0.3	0.8	5.5	92.0	0.1	0.0	0.5	0.5	1.2	2.3	0.0	0.0	5.7	0.0	0.0	5.7
LCT1-3	75.8	0.0	0.3	0.1	0.6	6.3	83.1	0.5	0.5	0.3	0.4	1.1	2.8	0.0	0.0	14.1	0.0	0.0	14.1
LCT1-4	72.4	0.0	0.0	0.4	0.3	2.8	75.9	0.6	0.7	0.3	1.2	2.2	5.0	0.1	0.0	19.0	0.0	0.0	19.1
LCT2-1	76.9	0.0	0.4	0.1	0.1	12.8	90.3	0.2	0.2	0.9	0.7	0.1	2.1	0.0	0.8	6.8	0.0	0.0	7.6
LCT2-2	77.7	0.0	0.6	0.1	0.1	5.7	84.2	0.2	0.2	0.7	0.1	0.1	1.3	0.0	0.3	14.0	0.0	0.2	14.5
LCT5-1	75.5	0.1	0.0	0.3	0.3	7.0	83.2	0.3	0.5	0.1	0.8	4.8	6.5	0.0	0.2	10.1	0.0	0.0	10.3
LCT5-2	79.5	0.1	0.0	0.5	0.0	5.3	85.4	0.0	0.1	0.4	0.1	3.0	3.6	0.0	0.1	10.9	0.0	0.0	11.0
LCT5-3	89.3	0.0	0.0	0.1	0.1	3.4	92.9	0.0	0.0	0.0	0.2	0.7	0.9	0.0	0.0	6.2	0.0	0.0	6.2
MC1-1	51.5	0.0	0.0	0.0	0.0	20.4	71.9	0.5	0.0	0.1	0.8	1.1	2.5	0.0	0.1	25.5	0.0	0.0	25.6
MC1-2	78.7	0.0	0.1	0.1	0.1	3.6	82.6	0.0	0.0	0.4	0.3	0.6	1.3	0.0	0.1	15.9	0.1	0.0	16.1
MC1-3	71.5	0.0	1.0	0.2	0.3	4.6	77.6	0.1	0.0	0.8	0.7	0.1	1.7	0.0	1.1	19.5	0.0	0.0	20.6
MC1-4	73.6	0.0	1.4	0.6	1.2	4.4	81.2	0.0	0.0	1.0	0.0	0.0	1.0	0.0	0.0	17.8	0.0	0.0	17.8
MC1-5	76.6	0.0	0.4	0.3	0.3	5.6	83.2	0.0	0.0	0.8	0.0	0.0	0.8	0.0	0.6	15.1	0.1	0.1	15.9
MC2-2	73.9	0.0	0.1	1.0	0.6	4.9	80.5	0.0	0.0	0.6	0.5	0.2	1.3	0.0	0.5	17.7	0.0	0.0	18.2
MC2-5	79.1	0.0	0.5	0.9	0.3	6.9	87.7	0.0	0.1	0.9	0.5	0.8	2.3	0.0	0.5	9.5	0.0	0.0	10.0
MC2-10	81.1	0.0	0.3	0.2	0.3	3.7	85.6	0.0	0.0	1.4	0.0	0.2	1.6	0.0	0.2	12.6	0.0	0.0	12.8
MC2-12	81.4	0.0	0.4	1.0	0.0	4.2	87.0	0.0	0.0	0.4	0.2	0.2	0.8	0.0	0.4	11.8	0.0	0.0	12.2
MC2-16	78.3	0.0	0.2	0.2	0.3	2.2	81.2	0.0	0.0	0.5	0.4	0.1	1.0	0.0	0.4	17.4	0.0	0.0	17.8
MC2-19	90.9	0.0	0.0	0.0	0.5	1.8	93.2	0.0	0.0	0.1	0.0	0.1	0.2	0.0	0.7	5.9	0.0	0.0	6.6
MC2-22	79.2	0.0	0.3	0.1	0.2	1.4	81.2	0.0	0.0	0.4	0.0	0.1	0.5	0.0	0.2	18.1	0.0	0.0	18.3

Table D7. (con.)

Sample	Ulminite/ vitrinite	Pseudo-vitri-nite	Pori-geli-nite	Phloba-phi-nite	Pseudo-phloba-phi-nite	Humode-trinite	Total humi-nite	Fusi-nite	Semi-fusi-nite	Sclero-tinite	Macri-nite	Inerto-detri-nite	Total inerti-nite	Cuti-nite	Spori-nite	Resinite/ suberi-nite/ exsuda-tinite	Algi-nite	Lipto-detri-nite	Total lipti-nite
MM2-1	90.1	0.0	0.0	0.2	0.0	3.6	93.9	0.0	0.0	0.1	0.4	0.9	1.4	0.0	0.0	4.7	0.0	0.0	4.7
MM2-2	81.6	0.0	0.0	0.5	0.0	4.5	86.6	0.1	0.0	0.0	0.2	1.8	2.1	0.0	0.0	11.3	0.0	0.0	11.3
MM2-3	68.0	0.0	1.0	1.8	0.7	7.6	79.1	0.0	0.6	0.0	0.0	0.0	0.6	0.0	0.5	19.8	0.0	0.0	20.3
MM2-4	77.5	0.0	1.6	0.2	0.1	3.9	83.3	0.0	0.1	0.0	0.1	0.0	0.2	0.7	0.1	15.5	0.0	0.2	16.5
MM2-5	68.1	0.0	0.8	1.1	0.5	7.2	77.7	0.8	2.6	0.2	2.4	3.1	9.1	0.0	0.1	13.1	0.0	0.0	13.2
MM2-6	77.3	0.0	0.0	0.4	0.1	3.9	81.7	0.2	0.1	0.0	0.3	2.6	3.2	0.0	0.0	15.1	0.0	0.0	15.1
MMb-1	78.5	0.0	0.1	0.1	0.8	4.8	84.3	0.0	0.0	0.2	0.1	0.8	1.1	0.0	0.3	14.3	0.0	0.0	14.6
MMb-3	81.9	0.0	0.1	0.0	0.5	0.6	83.1	0.0	0.0	0.0	0.3	0.1	0.4	0.0	0.3	16.2	0.0	0.0	16.5
MMb-5	83.2	0.0	0.9	0.0	1.2	1.3	86.6	0.1	0.0	0.7	0.0	0.3	1.1	0.0	0.3	12.0	0.0	0.0	12.3
MS1-1	83.7	0.0	0.0	0.4	0.3	2.8	87.2	0.4	0.3	0.1	0.5	1.4	2.7	0.0	0.4	9.7	0.0	0.0	10.1
MS1-2	71.6	0.0	0.5	0.4	0.4	8.3	81.2	0.1	0.1	0.0	0.0	0.0	0.2	0.2	0.0	18.4	0.0	0.0	18.6
MS1-3	51.2	0.0	0.4	0.9	0.9	15.1	68.5	0.6	1.1	0.0	1.0	1.2	3.9	0.0	0.0	27.6	0.0	0.0	27.6
MS1-4	79.3	0.0	0.1	0.7	0.2	5.7	86.0	0.2	0.3	0.1	1.0	0.7	2.3	0.0	0.6	11.1	0.0	0.0	11.7
MS1-5	72.8	0.0	0.0	1.2	0.6	9.8	84.4	0.6	1.8	0.0	0.6	1.2	4.2	0.0	0.0	11.4	0.0	0.0	11.4
MS1-6	76.7	0.0	0.1	0.3	0.5	3.4	81.0	0.2	0.7	0.4	0.4	1.0	2.7	0.0	0.4	15.9	0.0	0.0	16.3
MS1-7	79.8	0.0	0.4	1.1	0.1	4.0	85.4	0.2	0.2	1.0	0.5	0.3	2.2	0.1	0.3	11.9	0.1	0.0	12.4
MS1-8	79.9	0.0	0.0	0.4	0.0	7.3	87.6	0.0	0.2	0.1	0.4	0.9	1.6	0.0	0.2	10.5	0.0	0.0	10.7
MS3-1	74.6	0.0	0.5	1.2	0.2	2.7	79.2	0.1	0.0	1.0	0.0	0.1	1.2	0.0	0.4	19.2	0.0	0.0	19.6
MS4-1	77.4	0.0	1.3	0.7	0.4	5.0	84.8	0.0	0.2	0.3	0.0	0.0	0.5	0.1	0.3	14.3	0.0	0.0	14.7
NC1-1	70.7	0.0	0.1	0.6	0.8	10.5	82.7	0.1	1.2	0.1	0.6	1.7	3.7	0.0	0.4	13.2	0.0	0.0	13.6
RAA-1	87.0	0.0	1.2	0.2	0.9	2.3	91.6	0.0	0.1	0.8	0.4	0.7	2.0	0.0	0.9	5.5	0.0	0.0	6.4
RAA-2	79.5	0.0	0.0	0.1	1.1	3.1	83.8	0.2	0.1	0.7	1.4	3.1	5.5	0.0	0.1	10.6	0.0	0.0	10.7
RAA-3	76.9	0.0	1.0	0.1	0.2	5.6	83.8	0.0	0.0	0.1	0.2	0.0	0.3	0.0	0.5	14.9	0.1	0.4	15.9
RAA-4	58.7	0.0	1.9	1.5	2.0	11.4	75.5	0.1	0.2	0.8	0.8	0.9	2.8	0.0	0.0	21.7	0.0	0.0	21.7
RAA-5	68.4	0.0	1.6	0.7	2.5	8.6	81.8	0.0	0.5	0.2	0.2	1.5	2.4	0.0	0.0	15.8	0.0	0.0	15.8
RMC1-1	85.8	0.0	0.0	0.1	0.2	4.2	90.3	0.0	0.0	0.1	1.0	0.8	1.9	0.2	0.0	7.5	0.1	0.0	7.8
RMC1-2	91.4	1.1	0.0	0.0	0.4	4.7	87.6	0.0	0.1	0.9	1.6	3.2	5.8	0.0	0.2	6.4	0.0	0.0	6.6
RMC1-3	77.1	0.0	0.0	0.1	0.6	1.7	79.5	0.0	0.0	0.3	1.1	2.3	3.7	0.0	0.2	16.6	0.0	0.0	16.8
SC1-2	69.3	0.0	0.2	0.4	0.8	3.7	74.4	0.0	0.1	0.6	0.1	0.1	0.9	0.0	0.2	24.5	0.0	0.0	24.7
SC1-5	85.8	0.0	0.0	0.0	0.4	3.9	90.1	0.0	0.0	0.2	0.2	0.2	0.6	0.0	0.2	9.1	0.0	0.0	9.3
SC1-8	69.4	0.0	0.1	0.2	0.3	7.6	77.6	0.1	0.0	0.2	0.5	0.4	1.2	0.0	0.5	20.7	0.0	0.0	21.2
SC1-10	60.7	0.0	0.4	0.1	0.9	18.5	80.6	0.0	0.0	0.0	0.3	0.7	1.0	0.0	0.1	28.3	0.0	0.0	18.4
SC1-13	80.1	0.0	0.1	0.0	0.9	5.1	86.2	0.0	0.0	0.0	0.0	0.4	0.4	0.0	0.2	13.2	0.0	0.0	13.4
SC1-14	69.1	0.0	0.0	0.0	0.8	14.1	84.0	0.1	0.1	0.1	0.1	0.2	0.6	0.0	0.0	15.3	0.1	0.0	15.4
SC3-1	71.7	0.0	1.3	1.7	2.2	10.4	87.3	0.0	0.1	0.4	0.5	0.1	1.1	0.0	0.1	11.5	0.0	0.0	11.6
SC4-1	72.2	0.0	1.5	0.4	0.5	5.4	80.0	0.3	0.4	0.6	0.1	0.7	2.1	0.0	0.1	17.8	0.0	0.0	17.9

Table D7. (con.)

Sample	Ulminite/ vitrinite	Pseudo- vitri- nite	Pori- geli- nite	Phloba- phi- nite	Pseudo- phloba- phi- nite	Humode- trinite	Total humi- nite	Fusi- nite	Semi- fusi- nite	Sclero- tinite	Macri- nite	Inerto- detri- nite	Total inerti- nite	Cuti- nite	Spori- nite	Resinite/ suberi- nite/ exsuda- tinite	Algi- nite	Lipto- detri- nite	Total lipti- nite
TC1-1	65.3	0.0	0.0	0.2	0.2	17.6	83.3	0.0	0.5	0.0	0.9	5.0	6.4	0.0	0.0	10.3	0.0	0.0	10.3
TR1-1	77.8	0.1	0.0	0.3	0.0	2.4	80.6	0.8	0.4	0.1	1.0	2.9	5.2	0.0	0.0	14.2	0.0	0.0	14.2
TR1-2	68.3	0.0	0.5	1.5	0.7	8.8	79.8	0.1	0.2	0.4	0.7	0.1	1.5	0.0	0.5	18.2	0.0	0.0	18.7

Table D8-A. Coal quality data on certain coal samples from the Nenana coal field and related areas (from Rao and Wolff, 1981).

Coal field	Seam	ASTM rank	Thickness, meters (ft)	Basis*	Proximate analysis of raw coals: Moisture, %	Volatile matter, %	Fixed carbon, %	Ash, %	Heating value Btu/lb	Ultimate analysis of raw coals: Carbon %	Hydrogen, %	Nitrogen, %	Oxygen %	Sulfur: Pyritic	Sulfur: Total
Nenana	No. 6	Subbit.C	0.98	1	23.61	32.80	26.54	17.05	7022	40.59	5.93	0.56	35.70	0.01	0.17
(Poker	Seam,		(3.2)	2	- -	42.94	34.74	22.32	9193	53.14	4.30	0.73	19.29	0.01	0.22
Flats	top			3	- -	55.28	44.72	----	11834	68.40	5.54	0.94	24.84	0.01	0.28
Pit)															
Nenana	No. 6	Subbit.C	5.58	1	25.23	35.71	31.40	7.66	8136	46.08	6.30	0.60	39.24	0.01	0.12
(Poker	Seam,		(18.3)	2	- -	47.76	41.99	10.25	10882	61.64	4.65	0.80	22.50	0.01	0.16
Flats	middle			3	- -	53.22	46.78	-----	12124	68.68	5.18	0.89	25.07	0.01	0.18
Pit)															
Nenana	No. 6	Subbit.C	1.00	1	25.68	34.12	29.83	10.37	7516	43.87	6.05	0.59	38.99	0.01	0.13
(Poker	Seam,		(3.3)	2	- -	45.91	40.14	13.95	10113	59.03	4.28	0.80	21.77	0.01	0.17
Flats	lower			3	- -	53.36	46.64	-----	11752	58.60	4.97	0.93	25.30	0.01	0.20
Pit)															
Nenana	Moose	Subbit.C	6.58	1	21.42	36.02	34.88	7.68	8953	51.69	6.34	0.81	33.33	0.01	0.15
	Seam		(21.6)	2	- -	45.85	44.38	9.77	11393	65.78	5.02	1.03	18.25	0.01	0.15
				3	- -	50.81	49.19	-----	12627	72.90	5.56	1.15	20.18	0.01	0.21
Nenana	Caribou	Subbit.C	5.06	1	21.93	35.88	32.85	9.34	8567	49.44	6.10	0.69	34.30	0.02	0.13
	Seam		(16.6)	2	- -	45.96	42.08	11.96	10973	63.33	4.67	0.88	18.99	0.02	0.17
				3	- -	52.20	47.80	-----	12464	71.93	5.30	1.00	21.57	0.03	0.20
Nenana	No. 2	Subbit.C	8.47	1	26.76	33.12	32.25	7.87	7966	46.41	6.42	0.63	38.50	0.02	0.17
	Seam		(27.8)	2	- -	45.23	44.03	10.74	10876	63.38	4.68	0.86	20.11	0.02	0.23
				3	- -	50.67	49.33	-----	12185	71.01	5.24	0.96	22.54	0.03	0.25
Nenana	No. 4	Subbit.C	7.3	1	25.29	32.51	32.55	9.85	7739	45.28	6.30	1.13	37.11	0.02	0.33
(Poker	Seam		(24.0)	2	- -	43.52	43.30	13.18	10412	60.61	4.64	1.51	19.62	0.02	0.44
Flats				3	- -	50.13	49.87	-----	11993	69.81	5.34	1.74	22.60	0.03	0.51
Pit)															
Nenana	Ober	Subbit.C	3.05	1	20.58	36.20	34.16	9.06	8746	49.83	5.84	0.80	33.42	0.31	1.05
(Jarvis	Creek		(10.0)	2	- -	45.58	43.01	11.41	11012	62.75	4.45	1.00	19.07	0.39	1.32
Creek)				3	- -	51.45	48.55	-----	12430	70.83	5.02	1.13	21.53	0.44	1.49
Little	Main	Subbit.C	38.7	1	21.21	37.59	30.36	10.84	7663	45.02	5.80	0.64	36.59	0.06	1.11
Tonzona	coal		(127.0)	2	- -	47.72	38.53	13.75	9725	57.14	4.34	0.81	22.56	0.08	1.40
River	bed			3	- -	55.33	44.67	-----	11277	66.25	5.03	0.94	26.15	0.09	1.63

*1 = Equilibrium bed moisture basis; 2 = Moisture-free basis; and 3 = Moisture- and ash-free basis.

Table D8-B. Vitrinite reflectance data on certain coal samples from the Nenana coal field and related areas (from Rao and Wolff, 1981).

Coal field	Seam	Vitrinite reflectance: Mean maximum reflectance $\bar{R}omax$	Frequency class distribution V_1	V_2	V_3	V_4	V_5
Nenana (Poker Flats Pit)	No. 6 Seam, top	0.29	4	57	23	16	
Nenana (Poker Flats Pit)	No. 6 Seam, middle	0.32	5	40	33	22	
Nenana (Poker Flats Pit)	No. 6 Seam, lower	0.33	1	31	60	8	
Nenana	Moose Seam	0.41		1	28	71	
Nenana	Caribou Seam	0.42			25	74	1
Nenana	No. 2 Seam	0.32	11	26	49	14	
Nenana (Poker Flats Pit)	No. 4 Seam	0.25	24	58	18		
Nenana (Jarvis Creek)	Ober Creek	0.39		3	51	46	
Little Tonzona River	Main coal bed	0.27	26	47	25	7	

Table D8-C. Coal petrologic data for certain coals of the Nenana coal field and related areas (from Rao and Wolff, 1981).

		Petrology of raw coals																	
Coal field	Seam	Ulmi-nite	Geli-nite	Corpo-humi-nite	Humo-detri-nite	Fluores-cent humi-nite	Total humi-nite	Suberi-nite	Cuti-nite	Algi-nite	Spori-nite	Resi-nite	Lipri-nite	Semi-fusi-nite	Fusi-nite	Scleroti-nite	Macri-nite	Inerto-detri-nite	Total inerti-nite	Total
Nenana (Poker Flats Pit)	No. 6 Seam, top	37.6	18.9	1.8	12.3	9.4	80.0	0.8	0.4	0	2.4	0.6	4.2	0.9	3.1	0.3	1.1	10.4	15.8	100.0
Nenana (Poker Flats Pit)	No. 6 Seam, middle	49.5	12.9	1.6	13.4	6.8	84.2	0.4	0.2	0	3.6	0.4	4.6	1.0	0.7	0.2	0	9.3	11.2	100.0
Nenana (Poker Flats Pit)	No. 6 Seam, lower	61.3	9.4	3.0	5.8	0.6	80.1	0.7	0.4	0	4.6	0.8	6.5	3.2	1.2	0	0	9.0	13.4	100.0
Nenana	Moose Seam	80.3	11.6	0.3	2.4	0	94.6	0	0.2	0	4.2	0.4	4.8	0	0	0.6	0	0	0.6	100.0
Nenana	Caribou Seam	81.3	7.6	1.8	1.8	0.2	92.7	0	0	0	3.8	0.4	4.2	0	0.2	0.8	0	2.1	3.1	100.0
Nenana	No. 2 Seam	69.7	12.4	0.9	3.8	0.2	87.0	0.4	0.1	0	4.8	0.8	6.1	1.0	0.8	0.3	0	4.8	6.9	100.0
Nenana (Poker Flats Pit)	No. 4 Seam	54.6	26.3	2.0	1.1	0	84.0	0.2	0.3	0	3.3	0.4	4.2	0.9	1.3	0	0	9.6	11.8	100.0
Nenana (Jarvis Creek)	Ober Creek	81.7	9.3	0.6	2.5	0	94.1	0.1	0.1	0	3.5	0.6	4.3	0	0	0.2	0	1.4	1.6	100.0
Little Tonzona River	Main coal bed	36.4	34.0	0.4	3.0	15.4	89.2	0.8	0.8	0	5.8	1.4	8.8	0.3	0.4	0.2	0	1.1	2.0	100.0

Table D8-D. Concentration of major elements in certain raw coals (A, moisture-free basis) and raw coal ashes (B) from the Nenana coal field and related areas (from Rao and Wolff, 1981).

Coal field	Seam		Major oxide (%)									
			SiO_2	Al_2O_3	Fe_2O	MgO	CaO	Na_2O	K_2O	TiO_2	MnO	SO_3
Nenana (Poker Flats Pit)	No. 6 Seam, top	A	12.34	4.31	1.58	0.49	2.10	0.036	0.40	0.22	0.098	- -
		B	55.3	19.3	7.1	2.2	9.4	0.16	1.8	1.0	0.44	3.1
Nenana (Poker Flats Pit)	No. 6 Seam, middle	A	3.86	2.32	0.96	0.39	2.34	0.012	0.11	0.09	0.038	- -
		B	37.7	22.6	9.4	3.8	22.8	0.12	1.1	0.9	0.37	5.0
Nenana (Poker Flats Pit)	No. 6 Seam, lower	A	5.51	2.99	0.92	0.35	3.36	0.015	0.15	0.14	0.027	- -
		B	39.5	21.4	6.6	2.5	24.1	0.11	1.1	1.0	0.19	3.5
Nenana	Moose Seam	A	3.39	2.44	0.51	0.75	1.63	0.047	0.16	0.12	0.0059	- -
		B	34.7	25.0	5.2	7.7	16.7	0.48	1.6	1.2	0.06	7.2
Nenana	Caribou Seam	A	5.15	2.56	1.08	0.62	1.76	0.038	0.22	0.13	0.0084	- -
		B	43.1	21.4	9.0	5.2	14.7	0.32	1.8	1.1	0.07	5.6
Nenana	No. 2 Seam	A	5.08	2.22	0.96	0.30	1.39	0.083	0.13	0.10	0.047	- -
		B	47.3	20.7	8.9	2.8	12.9	0.77	1.2	0.9	0.44	6.3
Nenana (Poker Flats Pit)	No. 4 seam	A	5.72	2.99	0.88	0.36	2.19	0.12	0.290	0.15	0.028	- -
		B	43.4	22.7	6.7	2.7	16.6	0.93	2.2	1.1	0.21	6.5
Jarvis Creek	Ober Creek	A	4.87	1.89	1.28	0.25	2.37	0.009	0.08	0.12	0.013	- -
		B	42.7	16.6	11.2	2.2	20.8	0.08	0.7	1.1	0.12	21.7
Little Tonzona River	Main coal bed	A	4.10	2.67	0.95	0.45	3.12	0.034	0.17	0.12	0.069	- -
		B	29.8	19.4	6.9	3.3	22.7	0.25	1.2	0.9	0.05	17.2

Table D8-E. Concentration of trace elements in certain raw coals (A) and raw coal ashes (B) from the Nenana coal field and related areas (from Rao and Wolff, 1981).

Coal field	Seam		Elements (ppm) Ag	B	Ba	Co	Cr	Cu*	Ga	Mo	Ni*	Pb	Sn	V	Zn*	Zr
Nenana (Poker Flats Pit)	No. 6 Seam, top	A	ND	25	ND	ND	33	32	8.0	ND	25	5.1	ND	54	13	69
		B	ND	110	ND	ND	150	142	36	ND	62	23	ND	240	57	310
Nenana (Poker Flats Pit)	No. 6 Seam, middle	A	ND	16	440	ND	11	16	2.5	ND	9.0	ND	ND	19	6.3	13
		B	ND	160	4,300	ND	110	152	24	ND	111	ND	ND	190	61	130
Nenana (Poker Flats Pit)	No. 6 Seam, lower	A	ND	25	670	ND	22	21	3.6	ND	12	21	5.4	39	11	25
		B	ND	180	4,800	ND	160	150	26	ND	101	150	39	280	80	180
Nenana	Moose Seam	A	ND	H	1,800	4.8	15	21	3.8	ND	40	31	ND	29	11	43
		B	ND	H	18,000	49	150	215	39	ND	200	320	ND	300	110	440
Nenana	Caribou Seam	A	0.16	230	1,400	4.8	19	18	4.1	ND	22	11	ND	36	8.5	43
		B	1.3	1,900	12,000	40	160	150	34	ND	130	93	ND	300	71	360
Nenana	No. 2 Seam	A	ND	15	500	ND	13	18	23	ND	15	ND	ND	27	18	30
		B	ND	140	4,700	ND	120	170	21	ND	150	ND	ND	250	170	280
Nenana (Poker Flats Pit)	No. 4 Seam	A	ND	41	780	12	21	40	4.2	2.5	21	3.8	ND	71	66	46
		B	ND	310	5,900	90	160	300	32	17	145	29	ND	540	50	350
Nenana (Jarvis Creek)	Ober Creek	A	0.17	15	1,700	6.8	16	21	2.5	11	19	ND	ND	32	18	57
		B	1.5	130	15,000	60	140	180	22	94	145	ND	ND	280	160	500
Little Tonzona River	Main coal bed	A	0.40	45	1,700	10	28	60	3.0	11	25	7.8	ND	77	55	44
		B	2.9	330	12,000	73	200	434	22	79	175	57	ND	560	403	320

*Atomic absorption.

Table D9-A. Proximate and ultimate analyses, heating value, and sulfur forms for eight coal samples from the Healy area, Nenana coal field (from Conwell, 1976).

Sample	Proximate analyses (%)* Moisture	Volatile matter	Fixed carbon	Ash	Heating value Btu/lb
C1	24.0	35.9	33.4	6.7	8460
C2	22.6	35.3	31.9	10.2	8240
C3	23.5	36.4	33.2	6.9	8750
P1	14.8	27.3	23.4	34.5	6130
M1	26.8	36.4	31.6	5.2	8660
M2	24.8	36.9	29.3	9.0	8310
M3	24.9	35.5	31.4	8.2	8460
M4	23.0	38.1	32.2	6.7	9210

Ultimate analyses (%)*

Sample	Hydrogen	Carbon	Nitrogen	Oxygen	Sulfur	Ash
C1	6.4	49.1	0.9	36.8	0.2	6.7
C2	6.1	47.7	0.8	35.0	0.2	10.2
C3	6.4	50.4	0.8	35.3	0.2	6.9
P1	4.6	35.6	0.6	24.5	0.2	34.5
M1	6.9	49.3	0.8	37.6	0.2	5.2
M2	6.5	47.6	0.7	36.0	0.2	9.0
M3	6.6	48.2	0.7	36.1	0.2	8.2
M4	6.4	52.2	0.8	33.7	0.2	6.7

Forms of sulfur (%)*

Sample	Sulfate	Pyritic	Organic
C1	0.01	0.07	0.13
C2	0.01	0.09	0.07
C3	0.01	0.07	0.12
P1	0.01	0.07	0.17
M1	0.01	0.10	0.09
M2	0.01	0.08	0.14
M3	0.01	0.07	0.11
M4	0.01	0.11	0.12

*Analyses performed by the U.S. Bureau of Mines.

Table D9-B. Major oxide and elemental analyses on certain coals and coal ashes from the Healy area, Nenana coal field (from Conwell, 1976).

On coal as received (ppm)*

Sample	Ash (%)	As[1]	F[2]	Hg[3]	Sb[4]	Se[5]
C1	8.74	2	90	0.03	2.0	0.4
C2	11.4	2	105	0.03	2.2	0.6
C3	9.3	3	95	0.05	2.5	0.3
P1	37.5	5	335	0.30	8.1	11.0
M1	6.83	2	95	0.04	1.8	3.2
M2	11.6	2	115	0.04	3.1	4.3
M3	11.2	2	110	0.05	1.8	3.5
M4	8.5	2	130	0.05	2.0	0.1

Delayed neutron determinations, on coal as received*

Sample	Th (ppm)	U (ppm)	Th:U (to 1)
C1	4.2273	1.3038	3.24
C2	6.3308	1.5114	4.19
C3	3.0593	1.8910	1.61
P1	17.5245	5.1602	3.40
M1	2.9800	1.32	2.27
M2	9.5127	1.9741	4.82
M3	7.0165	1.4205	4.94
M4	4.1957	1.4291	2.94

On coal ash (%)*

Sample	Al_2O_3[6]	SO_3[6]	Cl[6]	CaO[6]	SiO_2[6]	P_2O_5[6]	TiO_2[6]	MnO[6]	K_2O[6]	MgO[7]	Na_2O[7]	Fe[7]
C1	18	1.6	0.10	14	32	0.52	0.70	0.020	0.78	4.69	0.53	1.0
C2	19	1.2	0.10	10	48	0.27	0.78	0.020	1.2	5.65	0.36	1.0
C3	19	1.7	0.10	11	37	0.14	0.82	0.034	1.3	4.13	0.42	2.0
P1	23	0.32	0.10	2.0	51	0.10	1.0	0.020	2.8	1.90	0.28	1.0
M1	19	2.3	0.14	17	22	0.79	0.75	0.020	0.72	7.35	0.15	3.0
M2	22	1.2	0.15	9.3	38	0.34	1.1	0.020	1.4	3.95	0.14	1.5
M3	20	1.2	0.10	9.9	31	0.71	0.85	0.068	1.3	3.53	0.13	5.0
M4	23	1.4	0.12	11.0	32	1.2	1.1	0.024	1.0	2.60	0.12	2.0

On coal ash (ppm)*

Sample	Cd[7]	Cu[7]	Li[7]	Pb[7]	Zn[7]	Mn[8]	Ag[8]	B[8]	Ba[8]	Be[8]	Co[8]	Cr[8]	Cu[8]
C1	1.0	158	35	50	26	70	1	1,000	7,000	5	70	150	100
C2	1.0	86	36	55	30	70	1	500	3,000	- -	70	150	100
C3	1.5	266	40	50	46	200	1.5	1,000	5,000	7	70	150	200
P1	1.5	130	85	40	99	70	- -	200	1,500	7	30	200	100
M1	1.0	202	43	50	37	150	1	1,500	10,000	3	100	150	300
M2	1.0	180	68	50	35	70	1	700	7,000	3	20	150	300
M3	1.0	148	51	40	70	500	- -	700	10,000	3	15	150	200
M4	1.5	210	56	55	76	150	1.5	700	15,000	3	50	150	300

Table D9-B. (con.)

Sample	La[8]	Mo[8]	Nb[8]	Ni[8]	Pb[8]	Sc[8]	Sr[8]	V[8]	Y[8]	Zr[8]	Ce[8]	Ga[8]	Yb[8]	Nd[8]
	On coal ash (ppm)*													
C1	- -	15	20	150	70	30	1,500	200	30	200	- -	30	5	- -
C2	100	15	20	100	70	20	700	200	30	150	<500	30	3	- -
C3	100	15	20	150	70	30	700	300	70	150	<500	30	7	<150
P1	100	- -	20	70	70	30	200	300	50	150	<500	30	7	<150
M1	150	15	20	150	70	30	3,000	300	70	150	<500	30	7	<150
M2	100	10	20	100	70	30	1,000	300	30	150	<500	30	7	<150
M3	100	10	20	150	70	30	2,000	200	30	150	<500	30	7	- -
M4	100	15	20	150	70	30	3,000	300	50	150	<500	30	7	- -

[1] Determined by spectrophotometry.
[2] Determined by specific ion electrode method.
[3] Determined by wet oxidation and atomic absorption.
[4] Determined by Rhodamine-B method.
[5] Determined by X-ray fluorescence.
[6] Determined by X-ray fluorescence.
[7] Determined by atomic absorption.
[8] Determined by semiquantitative G-step spectrographic analysis.
*Analyses by U.S. Geological Survey.

Table D9-C. Comparison of 34 elements in three coal seams from near Healy, Alaska (Nenana coal field) with average values for the same elements in shale and the earth's crust (from Conwell, 1976).

Element	Abundance of element in coal seam			Shale,	Crust,
	Caribou	Parting	Moose	average*	average**
Si (%)	18.7	51.0	39.0	7.3	28.15
Al (%)	18.7	23.0	21.0	8.0	8.23
Ca (%)	11.7	2.0	21.5	2.21	4.15
Mg (%)	4.8	1.9	4.4	1.5	2.33
Na (%)	0.4	0.3	0.13	0.96	2.36
K (%)	1.1	2.8	1.1	2.66	2.09
Fe (%)	1.5	1.0	2.9	4.72	5.63
Ti (%)	0.8	1.0	0.95	0.46	0.57
As (ppm)[1]	2.3	5.0	2.0	13.0	1.8
Cd (ppm)	1.3	1.5	1.0	0.3	0.2
Cu (ppm)	170.0	130.0	185.0	45.0	55.0
F (ppm)[1]	97.0	335.0	112.0	740.0	625.0
Hg (ppm)[1]	0.04	0.3	0.04	0.4	0.08
Li (ppm)	0.0	0.0	0.0	66.0	20.0
Pb (ppm)	52.0	40.0	48.0	20.0	12.5
Sb (ppm)[1]	2.2	8.1	2.2	1.5	0.2
Se (ppm)[1]	0.4	11.0	2.75	0.6	0.05
Th (ppm)[1]	4.5	17.5	5.9	12.0	9.6
U (ppm)[1]	1.6	5.2	1.5	3.7	2.7
Zn (ppm)	34.0	99.0	54.5	95.0	70.0
B (ppm)	833.0	200.0	900.0	100.0	10.0
Ba (ppm)	5000.0	1500.0	10,500.0	580.0	425.0
Be (ppm)	4.0	7.0	3.0	3.0	2.8
Co (ppm)	70.0	70.0	70.0	19.0	25.0
Cr (ppm)	150.0	200.0	150.0	90.0	100.0
Ga (ppm)	30.0	30.0	30.0	19.0	15.0
Mo (ppm)	15.0	- -	15.0	2.6	1.5
Ni (ppm)	133.0	70.0	137.0	68.0	75.0
Se (ppm)	27.0	30.0	30.0	13.0	22.0
Sr (ppm)	907.0	200.0	2,250.0	300.0	375.0
V (ppm)	233.0	300.0	300.0	130.0	135.0
Y (ppm)	43.0	50.0	45.0	26.0	33.0
Yb (ppm)	5.0	7.0	7.0	2.5	3.0
Zr (ppm)	167.0	150.0	150.0	160.0	165.0

*Turekian and Wedepohl (1961)
*Taylor (1964)
[1] Means calculated from analyses on whole coal; all others from determinations made on coal ash.

Table D10-A. U.S. Geological Survey sample numbers, locations, thicknesses, and sample types for 20 samples from the Healy Quadrangle, Alaska (from Affolter, Simon, and Stricker, 1981).

USGS sample number	Latitude	Longitude	Thickness (feet)	Sample type
D172389	63°55'09"	148°40'00"	5.0	Channel
D172390	Do.	Do.	5.0	Do.
D172391	Do.	Do.	5.6	Do.
D172392	Do.	Do.	3.0	Do.
D172393	Do.	Do.	5.0	Do.
D172394	Do.	Do.	5.0	Do.
D172395	Do.	Do.	5.0	Do.
D172396	Do.	Do.	5.0	Do.
D175053	63°58'12"	148°45'00"	5.0	Do.
D175054	Do.	Do.	5.0	Do.
D175055	Do.	Do.	5.0	Do.
D175056	Do.	Do.	5.0	Do.
D175057	Do.	Do.	7.1	Do.
D186043	63°54'10"	148°56'16"	10.5	Core
D186044	Do.	Do.	10.0	Do.
D186045	Do.	Do.	6.0	Do.
D186046	Do.	Do.	9.3	Do.
D186047	Do.	Do.	9.5	Do.
D186048	63°58'36"	147°16'22"	7.0	Channel
D186049	Do.	Do.	7.0	Do.

Table D10-B. Summary of proximate and ultimate analyses, heats of combustion, forms of sulfur, and ash-fusion temperatures for 12 coal samples from the Healy Quadrangle compared to similar values in Powder River region samples. All values are in percent except for heats of combustion (kcal/kg and Btu/lb), ash fusion temperatures (°C) and geometric deviation, and are reported on an as-received basis (from Affolter, Simon, and Stricker, 1981).

	Arithmetic mean	Observed range		Geometric mean	Geometric deviation	Powder River region geometric mean*
		Minimum	Maximum			
	Proximate and ultimate analyses					
Moisture	24.1	14.8	32.7	23.6	1.2	23.1
Volatile matter	35.5	27.3	38.8	35.3	1.1	32
Fixed carbon	30.1	23.4	33.4	29.9	1.1	36
Ash	10.2	5.2	34.5	9.1	1.6	7.5
Hydrogen	6.3	4.6	6.9	6.2	1.1	6.2
Carbon	46.4	35.6	52.2	46.1	1.1	50.3
Nitrogen	0.7	0.5	0.8	0.7	1.2	0.9
Oxygen	36.0	24.5	44.6	35.7	1.1	32.9
Sulfur	0.2	0.1	0.7	0.2	1.6	0.8
	Heat of combustion					
Kcal/kg	4,465	3,410	5,120	4,430	1.1	4,860
Btu/lb	8,030	6,130	9,210	7,970	1.1	8,740
	Forms of sulfur					
Sulfate	0.01	0.01	0.04	0.01	1.7	0.02
Pyritic	0.08	0.01	0.12	0.07	1.9	0.29
Organic	0.16	0.07	0.51	0.14	1.7	0.31
	Ash-fusion temperatures					
Initial deformation	1,230	1,170	1,270	1,230	1.0	--
Softening temperature	1,280	1,210	1,320	1,280	1.0	--
Fluid temperature	1,340	1,270	1,390	1,340	1.0	--

*Geometric means for 33 samples from Swanson and others, 1976, tables 31b and 32b.

Table D10-C. Summary of the ash content (525°C) and major oxide analysis for 20 coal samples from the Healy Quadrangle compared to geometric means for similar values in Powder River region samples (from Affolter, Simon, and Stricker, 1981).

Oxide	Arithmetic mean (%)	Observed range Minimum (%)	Maximum (%)	Geometric mean (%)	Geometric deviation	Powder River region geometric mean (%)*
(Ash)	12.6	6.5	37.5	11.5	1.5	9.0
SiO_2	35	16	51	33	1.4	28
Al_2O_3	17	8	23	16	1.4	14
CaO	20	2	37	16	2.0	15
MgO	3.3	1.6	7.3	3.1	1.5	3.56
Na_2O	0.18	<0.09	0.53	0.15	1.9	0.93
K_2O	1.1	0.29	2.8	0.95	1.7	0.28
Fe_2O_3	4.6	1.7	9.1	3.9	1.8	5.8
TiO_2	0.87	0.57	1.1	0.86	1.2	0.61
SO_3	7.0	1.0	27	5.2	2.2	14
P_2O_5	0.26	<0.11	1.2	0.09	4.5	- -

*Geometric means for 410 samples from Hatch and Swanson, 1977, table 6a.

Table D10-D. Summary of elemental analyses for 20 coal samples from the Healy Qaudrangle, Alaska. All analyses are on a whole-coal basis except As, F, Hg, Sb, Se, Th, and U which are on coal ash (from Affolter, Simon, and Stricker, 1981).

Element	Arithmetic mean	Observed range Minimum	Observed range Maximum	Geometric mean	Geometric deviation	Powder River region geometric mean*
Si	2.3	0.51	8.9	1.8	2.0	1.2
Al	1.1	0.44	4.6	0.97	1.8	0.66
Ca	1.5	0.54	2.7	1.3	1.7	0.98
Mg	0.22	0.11	0.43	0.21	1.4	0.195
Na	0.02	<0.007	0.077	0.012	2.3	0.063
K	0.14	0.01	0.87	0.091	2.5	0.022
Fe	0.38	0.12	0.84	0.32	1.9	0.37
Ti	0.067	0.022	0.23	0.059	1.7	0.035
P	0.010	<0.004	0.045	0.003	5.3	- -
			Parts per million			
Ag	0.09	0.07	0.3	0.06	2.4	- -
As	3	1	10	2.6	1.8	2
B	50	15	100	30	2.1	50
Ba	500	150	1,500	500	1.8	300
Be	0.5	<0.2	3	0.2	3.2	0.5
Cd	0.15	<0.06	0.56	0.07	3.2	- -
Co	5	1.5	10	3	1.9	2
Cr	20	7	70	15	1.7	5
Cu	20	8.2	58	17	1.7	9.5
F	95	35	340	82	1.7	40
Ga	3	1.5	10	3	1.7	2
Hg	0.07	0.02	0.30	0.06	1.9	0.08
La	7	10	20	7	1.5	- -
Li	5	1.3	32	3.7	2.2	3.9
Mn	88	6.1	220	46	3.1	34
Mo	1.5	0.7	3	1.5	1.5	1.5
Nb	2	<1.5	7	1.5	1.9	1
Ni	10	5	30	10	1.5	3
Pb	5.4	<2	15	4.5	1.8	5.1
Sb	1.9	0.3	8.1	1.3	2.3	0.4
Sc	3	1.5	10	3	1.6	1.5
Se	1.6	0.3	11	8	3.5	0.7
Sr	150	70	200	100	1.5	150
Th	4.5	0.7	18	2.5	3.0	3.3
U	1.3	0.4	5.2	1.1	2.0	0.6
V	30	15	100	20	1.7	10
Y	7	3	20	7	1.8	3
Yb	0.7	0.3	3	0.7	1.7	0.3
Zn	14	2.3	46	8.8	2.6	12.5
Zr	15	7	70	15	1.7	15

*Geometric means for 410 samples from Hatch and Swanson, 1977, table 6b.

Appendix E
Overburden characterization data.

Table E1. Geochemical and physical analyses of certain coal overburden samples from the Nenana coal field. Refer to appendixes A and B and plate 5 for sample locations.

Sample	O.M. %	TOC %	NO3-N ppm	P ppm	K ppm	Lime %	Bulk density	Sand %	Silt %	Clay %	Text
BC1-1	0.14	4.5	3.6	8.2	13	5.2	1.33	81	8	11	LS
BC1-3	7.81	46.5	1.6	1.3	83	7.3	0.83	75	15	10	SL
BC1-4	8.64	34.5	1.9	1.2	106	10.1	0.87	77	11	12	SL
BC1-5	2.24	11.5	1.2	3.1	184	6.7	1.02	38	40	22	L
BC1-6	1.34	6.1	1.7	5.4	170	6.1	1.15	38	48	14	L
BM1-2	10.41	45.5	2.8	3.1	131	20.3	0.91	71	20	9	SL
BM1-3	11.67	50.5	1.9	2.4	130	25.1	0.81	83	10	7	LS
BM1-5	5.07	15.9	1.8	6.7	207	10.3	0.95	66	13	21	SCL
BM1-6	2.28	11.9	1.4	8.5	211	8.8	0.95	61	15	24	SCL
BM1-8	0.91	7.5	2.3	5.5	229	5.8	1.06	23	51	26	SiL
BM1-10	1.21	7.9	3.4	11.7	204	6.6	1.03	44	33	23	L
BM1-11	0.29	7.5	3.1	10.9	213	7.1	1.17	56	33	11	SL
DC2-1	8.33	43.5	3.7	8.9	116	9.2	0.93	80	4	16	SL
EC2-2	6.87	18.9	31.5	10.9	198	9.4	1.01	44	14	42	C
EC2-3	1.02	7.9	5.4	15.6	180	5.6	1.16	23	57	20	SiL
EC2-4	0.57	6.5	2.2	15.2	189	5.8	1.21	27	52	21	SiL
EC2-5	0.84	3.9	1.1	8.7	128	6.3	1.15	33	52	15	SiL
MC2-1	4.36	14.5	10.8	1.4	169	8.8	1.16	21	50	29	CL
MC2-3	7.26	21.5	3.3	4.3	233	6.3	1.04	18	46	36	SiCL
MC2-4	6.24	10.9	1.3	2.6	157	5.8	1.15	36	44	20	L
MC2-6	5.81	23.5	2.1	10.8	88	6.9	1.13	57	14	29	SCL
MC2-7	7.99	38.9	2.1	1.8	185	8.3	0.83	34	39	27	CL
MC2-8	7.94	25.9	1.6	2.8	212	7.1	0.97	28	48	24	L
MC2-9	2.17	6.5	1.4	3.3	199	5.1	1.17	18	59	23	SiL
MC2-11	4.62	11.9	1.1	10.8	273	4.8	1.09	10	48	42	SiC
MC2-13	3.41	8.5	5.8	7.2	212	5.1	1.21	12	62	26	SiL
MC2-15	7.67	24.5	9.1	2.1	190	6.3	0.98	39	33	28	CL
MC2-17	2.47	7.5	6.8	5.4	206	4.9	1.16	19	54	27	SiL
MC2-18	4.19	9.1	5.9	9.5	201	5.8	1.21	8	59	33	SiCL
MC2-20	0.66	3.9	6.2	1.9	167	5.1	1.23	10	57	33	SiCL
MC2-21	4.19	9.5	6.9	13.6	207	5.4	1.16	8	55	37	SiCL
MC2-23	1.76	6.1	7.7	3.4	231	4.6	1.17	7	51	42	SiC
MM2-6A	5.45	13.5	6.9	8.6	99	6.5	1.09	40	42	18	L
MM3-1	5.65	19.9	26.7	18.9	137	9.2	1.08	81	10	9	LS
MMb-4	0.2	2.9	10.1	6.5	63	4.6	1.39	51	31	18	L

*TOC - Total organic carbon

Table E1. (con.)

SC1-1	7.56	24.5	8.8	0.4	114	10.6	1.12	59	29	12	SL
SC1-3	5.54	10.5	6.5	2.1	129	5.2	1.21	15	68	17	SiL
SC1-4	7.31	24.5	8.8	0.9	158	5.8	1.05	62	20	18	SL
SC1-6	4.98	8.9	7.5	8.1	98	5.1	1.25	16	67	17	SiL
SC1-7	6.43	13.5	7.3	0.5	82	5.1	1.18	22	56	22	SiL
SC1-9	4.45	8.1	7.1	1.3	155	4.8	1.08	6	57	37	SiCL
SC1-11	4.23	6.9	6.9	1.3	74	4.6	1.32	21	59	20	SiL
SC1-12	4.97	11.1	7.5	1.7	89	11.1	1.23	25	53	22	SiL

Table E1. (con.)

Sample	pH	E.C. mmhos/cm	Water soluble cations Sat %	Ca meq/l	Mg meq/l	Na meq/l	SAR
BC1-1	5.5	0.2	35.6	0.5	1.1	1.3	1.4
BC1-3	5.4	0.7	60.9	4.7	2.8	0.9	0.5
BC1-4	5.6	0.8	55.4	5.2	3.4	1.1	0.5
BC1-5	6.1	0.5	44.1	2.3	1.6	1.2	0.9
BC1-6	6.5	0.3	40.4	1.3	0.9	1.2	1.1
BM1-2	6.4	0.3	92.4	42.2	11.4	1.6	0.3
BM1-3	6.3	0.7	101.6	6.9	0.2	0.7	0.3
BM1-5	6.5	1.3	44.4	15.1	4.9	1.9	0.6
BM1-6	6.6	1.2	51.1	14.3	4.6	1.6	0.5
BM1-8	6.9	0.5	42.3	3.1	1.1	1.7	1.2
BM1-10	6.7	0.9	38.4	9.1	3.6	1.6	0.6
BM1-11	7.3	0.9	43.4	7.9	2.8	1.1	0.5
DC2-1	5.6	0.2	54.8	0.9	1.1	0.7	0.7
EC2-2	6.3	0.3	53.7	1.6	1.1	0.9	0.8
EC2-3	6.4	0.3	44.3	1.6	0.9	1.1	0.9
EC2-4	6.3	0.4	44.1	1.9	1.1	1.2	0.9
EC2-5	6.2	0.2	47.5	0.2	0.1	0.4	1.1
MC2-1	6.4	1.6	49.8	8.7	5.4	4.9	1.8
MC2-3	5.7	0.8	57.3	2.4	2.1	3.7	2.5
MC2-4	6.3	0.4	50.8	0.4	0.3	2.3	3.9
MC2-6	5.7	0.8	43.1	7.1	4.2	4.1	1.7
MC2-7	5.8	0.6	59.2	1.2	0.9	3.1	3.1
MC2-8	5.7	0.6	62.1	0.8	0.5	2.4	2.9
MC2-9	6.2	0.4	53.2	1.3	1.1	3.2	2.9
MC2-11	5.7	0.5	60.7	1.9	1.4	1.5	1.2
MC2-13	6.1	0.2	62.7	0.3	0.3	1.1	2.1
MC2-15	5.8	0.5	48.1	1.9	1.6	1.8	1.4
MC2-17	6.1	0.3	53.4	0.6	0.5	1.5	2.1
MC2-18	5.8	0.3	56.9	1.1	0.9	1.8	1.8
MC2-20	6.5	0.3	45.6	0.4	0.6	1.5	2.1
MC2-21	5.9	0.4	57.7	1.4	1.1	1.4	1.2
MC2-23	6.1	0.3	50.4	0.6	0.5	1.5	2.1
MM2-6A	5.2	0.4	43.6	1.6	1.1	1.3	1.1
MM3-1	5.6	1.6	50.4	9.5	11.2	3.1	0.9
MMb-4	6.8	0.3	20.7	0.3	0.4	1.2	2.1
SC1-1	6.6	0.8	42.5	1.2	8.1	1.1	0.5
SC1-3	6.6	0.3	47.9	0.5	1.1	1.5	1.7
SC1-4	6.2	0.6	32.1	1.2	2.5	2.8	2.1
SC1-6	5.7	0.2	43.9	0.3	0.4	1.2	2.1
SC1-7	5.8	0.3	43.4	0.6	0.6	1.3	1.7
SC1-9	6.3	0.3	56.2	0.1	0.2	2.1	5.4
SC1-11	6.3	0.2	37.3	0.3	0.4	1.3	2.2
SC1-12	7.0	0.6	40.1	0.8	2.6	3.1	2.4

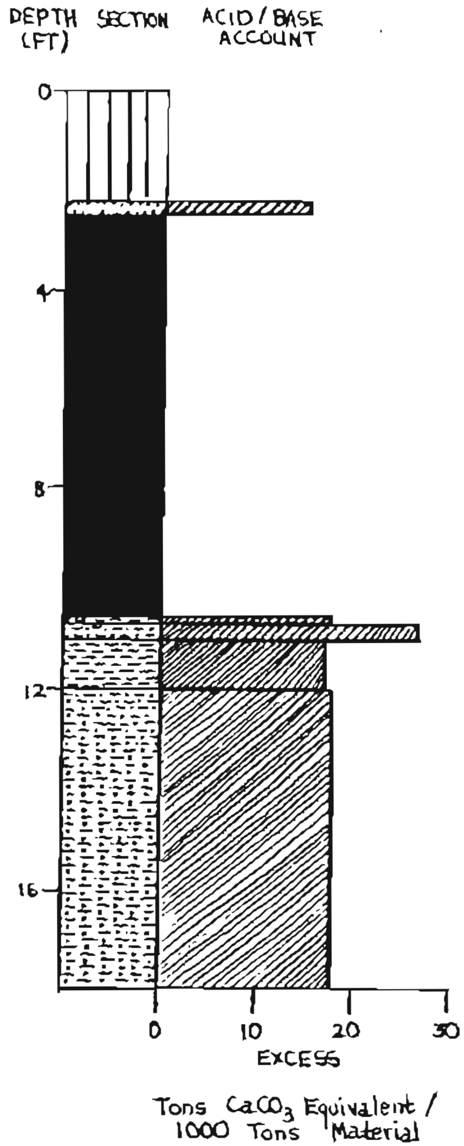
Table E1. (con.)

Sample	Ammonium acetate extractable cations Ca meq/100g	Mg meq/100g	Na meq/100g	K meq/100g	CEC meq/100g	ESP	Base sat %
BC1-1	0.4	0.8	0.2	0.1	4.4	4.5	34
BC1-3	50.3	12.7	0.3	0.2	69.2	0.4	92
BC1-4	40.7	11.8	0.3	0.3	35.9	0.8	100
BC1-5	15.3	7.1	0.3	0.5	18.2	1.6	100
BC1-6	7.2	4.4	0.2	0.4	11.4	1.7	100
BM1-2	161.2	15.7	0.0	0.4	77.9	0.5	100
BM1-3	107.4	16.1	0.3	0.4	79.7	0.4	100
BM1-5	33.9	7.4	0.4	0.6	22.5	3.2	100
BM1-6	24.4	6.2	0.4	0.6	19.2	1.8	100
BM1-8	20.9	6.4	0.3	0.7	11.9	2.5	100
BM1-10	12.3	4.9	0.2	0.6	13.4	1.5	100
BM1-11	12.9	5.7	0.2	0.6	13.3	1.5	100
DC2-1	16.9	9.9	0.2	0.3	31.8	0.6	85
EC2-2	33.5	10.5	0.3	0.6	25.3	1.2	100
EC2-3	9.1	4.4	0.3	0.5	11.7	2.6	100
EC2-4	7.5	3.9	0.3	0.5	10.9	2.7	100
EC2-5	5.3	4.1	0.6	0.3	8.9	6.7	100
MC2-1	6.4	3.4	0.3	0.3	12.7	2.4	82
MC2-3	11.9	5.5	0.9	0.5	22.3	4.1	84
MC2-4	10.6	6.4	1.1	0.6	12.7	8.7	100
MC2-6	13.6	5.8	0.9	0.2	21.4	4.2	96
MC2-7	22.5	9.3	1.5	0.5	31.9	4.7	100
MC2-8	22.9	8.8	1.5	0.6	28.1	5.3	100
MC2-9	4.7	3.6	0.7	0.5	10.6	6.6	90
MC2-11	11.1	6.7	0.4	0.9	15.9	2.5	100
MC2-13	6.3	4.5	0.3	0.6	11.5	2.6	100
MC2-15	15.4	6.7	0.5	0.6	21.9	2.3	100
MC2-17	4.5	3.6	0.3	0.5	9.5	3.2	100
MC2-18	4.9	3.8	0.2	0.5	11.8	1.7	80
MC2-20	1.9	2.3	0.3	0.4	4.3	6.9	100
MC2-21	6.1	4.1	0.3	0.6	12.3	2.4	90
MC2-23	4.1	3.4	0.2	0.7	9.1	2.2	92
MM2-6A	10.9	4.4	0.3	0.3	19.8	1.5	80
MM3-1	15.8	9.9	0.8	0.3	21.7	3.7	100
MMb-4	0.2	1.3	0.2	0.2	2.7	7.4	70
SC1-1	4.2	11.7	0.2	0.3	15.5	1.3	100
SC1-3	1.4	4.2	0.3	0.3	8.3	3.6	75
SC1-4	3.1	5.5	0.6	0.5	14.1	4.3	69
SC1-6	0.8	2.4	0.2	0.3	7.9	2.5	47
SC1-7	2.1	2.3	0.2	0.3	10.5	1.9	47
SC1-9	1.3	2.8	0.6	0.4	7.3	8.2	70
SC1-11	0.7	1.8	0.2	0.2	5.4	3.7	54
SC1-12	1.8	4.2	0.5	0.3	6.6	7.6	100

Table E1. (con.)

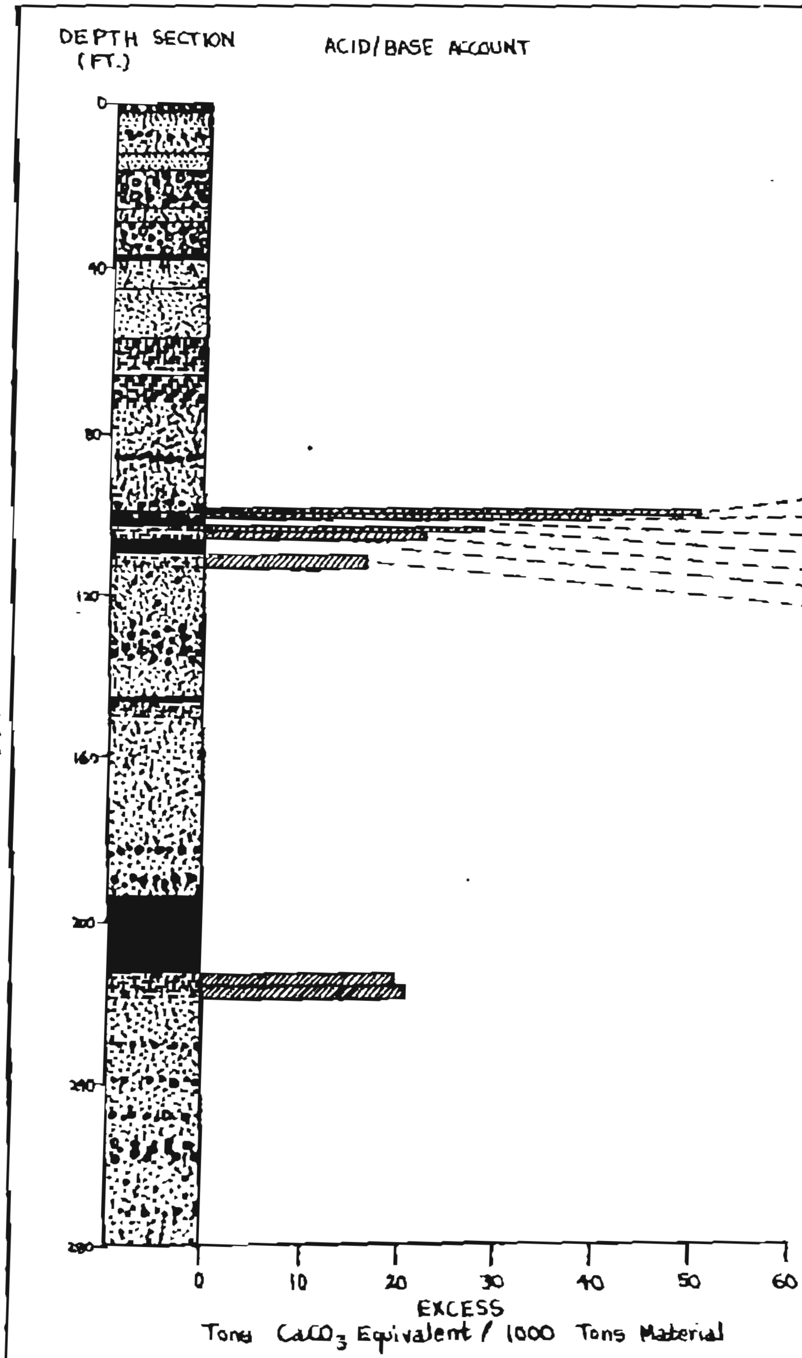
Sample	B ppm	Cu ppm	Mo ppm	Pb ppm	Se ppm	Total-S %	Acid potential meq H+/100g	Neut. potential	Acidity** potential T. $CaCO_3$/1000T
BC1-1	0.65	0.31	0.15	0.07	<.01	0.03	1.88	15.6	14.7
BC1-3	1.49	6.75	0.21	4.24	<.01	0.16	10.01	22.5	17.5
BC1-4	1.32	11.08	0.23	11.51	<.01	0.18	11.25	31.9	26.3
BC1-5	1.17	19.46	0.12	10.89	<.01	0.08	5.01	19.4	16.9
BC1-6	0.61	18.64	0.52	4.61	<.01	0.02	1.25	18.1	17.5
BM1-2	1.54	6.44	0.23	2.04	<.01	0.32	20.01	60.6	50.6
BM1-3	1.51	8.58	0.49	13.41	<.01	0.34	21.25	50.1	39.5
BM1-5	0.96	17.28	0.21	6.98	<.01	0.06	3.75	30.5	28.6
BM1-6	0.81	19.98	0.24	7.14	<.01	0.12	7.51	26.3	22.6
BM1-8	0.61	14.94	0.51	2.19	<.01	0.03	1.88	17.5	16.6
BM1-10	0.62	14.21	0.31	4.65	<.01	0.01	0.63	19.9	19.6
BM1-11	0.45	17.18	0.46	5.33	<.01	0.02	1.25	21.3	20.7
DC2-1	6.85	13.34	0.13	1.96	<.01	0.26	16.25	27.5	19.4
EC2-2	0.91	29.55	0.43	11.59	<.01	0.02	1.25	28.1	27.5
EC2-3	0.56	15.71	0.48	2.53	<.01	0.01	0.01	16.9	16.9
EC2-4	0.59	12.79	0.26	1.74	<.01	0.02	1.25	17.5	16.9
EC2-5	0.79	16.71	0.22	0.92	<.01	0.02	1.25	18.8	18.2
MC2-1	1.21	8.42	0.23	2.35	<.01	0.06	3.75	26.3	24.4
MC2-3	3.46	8.19	0.42	34.01	<.01	0.08	5.01	18.8	16.3
MC2-4	1.96	4.08	0.47	2.33	<.01	0.05	3.13	17.5	15.9
MC2-6	3.52	32.14	0.69	57.67	<.01	0.11	6.25	20.6	17.5
MC2-7	6.14	4.59	0.57	27.51	<.01	0.21	12.51	24.9	18.6
MC2-8	4.82	4.43	0.53	11.93	<.01	0.16	10.01	21.3	16.3
MC2-9	1.82	5.62	0.51	6.26	<.01	0.06	3.75	14.9	13.1
MC2-11	3.01	11.04	0.41	66.46	<.01	0.05	3.13	14.4	12.8
MC2-13	2.61	6.08	0.41	7.08	<.01	0.02	1.25	15.1	14.5
MC2-15	4.66	3.53	0.63	11.96	<.01	0.11	6.25	18.8	15.7
MC2-17	2.37	4.33	0.49	6.26	<.01	0.02	1.25	14.9	13.6
MC2-18	1.83	12.03	0.51	7.14	<.01	0.02	1.25	17.5	16.9
MC2-20	1.34	17.41	0.73	17.51	<.01	0.01	0.01	15.1	15.1
MC2-21	1.75	16.34	0.63	13.14	<.01	0.01	0.01	16.3	16.3
MC2-23	2.31	13.63	0.31	13.85	<.01	0.01	0.01	13.8	13.8
MM2-6A	1.21	19.31	0.47	1.11	<.01	0.06	3.75	19.4	17.5
MM3-1	2.07	2.24	0.67	2.18	<.01	0.08	5.01	27.5	25.1
MMb-4	1.51	0.84	0.53	1.47	<.01	0.01	0.63	13.8	13.5
SC1-1	5.43	1.93	0.41	6.26	<.01	0.14	8.75	31.9	27.5
SC1-3	2.77	2.25	0.45	3.82	<.01	0.03	1.88	15.6	14.7
SC1-4	6.02	2.31	0.45	3.81	<.01	0.12	7.51	17.5	13.7
SC1-6	2.48	7.85	0.49	11.16	<.01	0.02	1.25	15.1	14.5
SC1-7	2.15	2.34	0.67	9.43	<.01	0.11	6.25	15.1	11.9
SC1-9	2.33	7.64	0.59	68.18	<.01	0.04	2.51	14.4	13.1
SC1-11	1.36	1.67	0.67	7.68	<.01	0.04	2.51	13.8	12.5
SC1-12	1.72	1.66	0.76	1.93	<.01	0.04	2.51	33.1	31.8

**Positive values indicate excess $CaCO_3$, or basic overburden material.



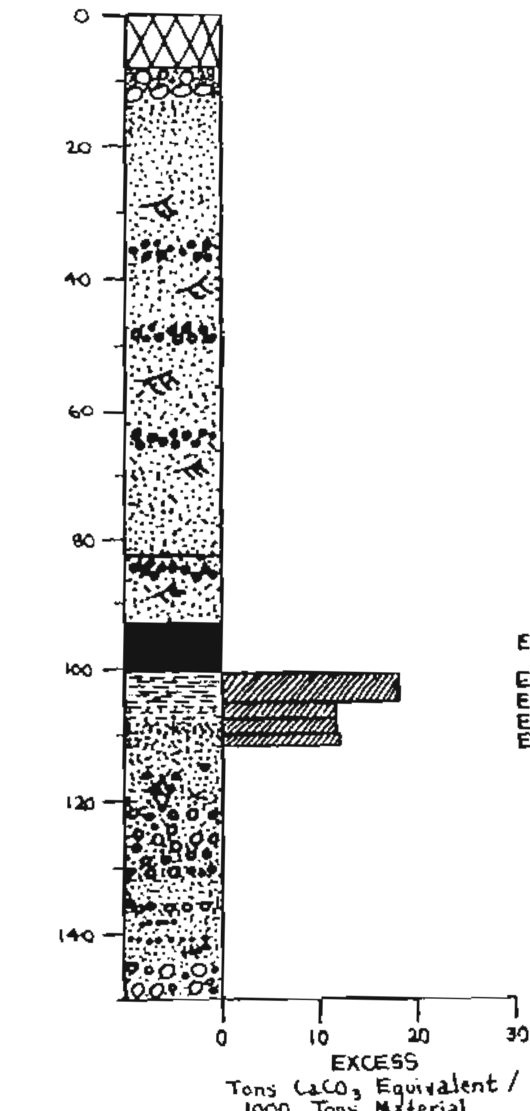
SAMPLE NUMBER	LITHOLOGIC DESCRIPTION	PASTE pH	TOTAL SULFUR (%)	ORGANIC MATTER (%)	TOTAL ORGANIC CARBON (%)	LIME (%)
BC1-1	Sand, weathered, orange color	5.5	0.03	0.14	4.5	5.2
BC1-2	Coal		0.22			
BC1-3	Smut, black, carbonaceous	5.4	0.16	7.81	46.5	7.3
BC1-4	Claystone, brown, sandy	5.6	0.18	8.64	34.5	10.1
BC1-5	Claystone, brown, silty	6.1	0.08	2.24	11.5	6.7
BC1-6	Claystone, medium gray, sandy	6.5	0.02	1.84	6.1	6.1

Figure E1. Acid/base account and other geochemical characteristics for overburden samples of a Bonanza Creek coal-bearing section.



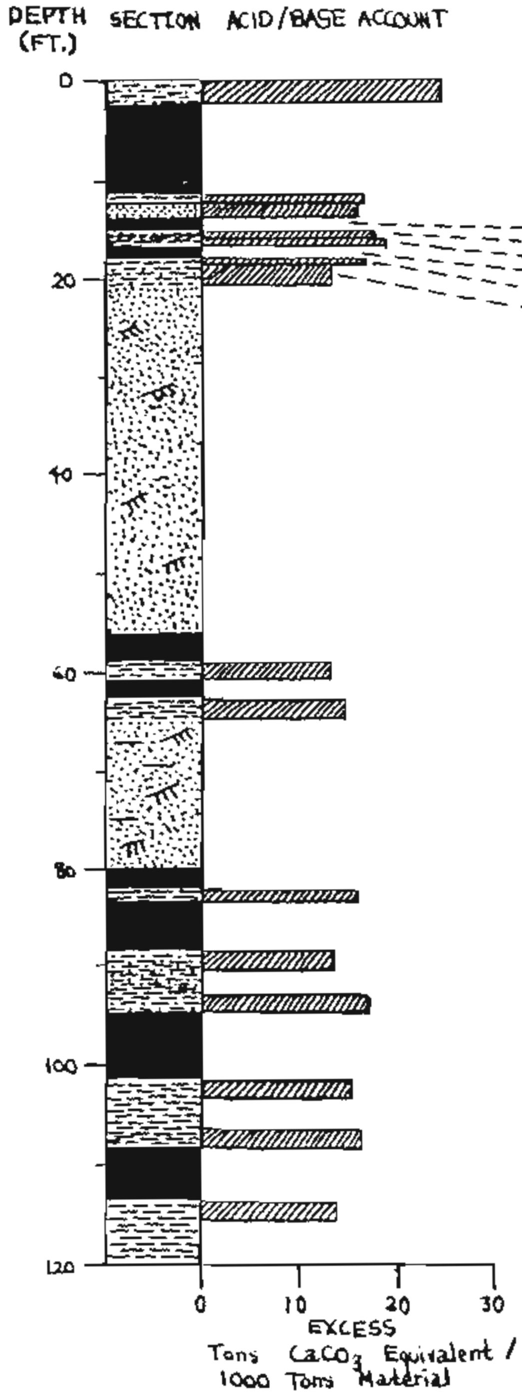
SAMPLE NUMBER	LITHOLOGIC DESCRIPTION	PASTE pH	TOTAL SULFUR (%)	ORGANIC MATTER (%)	TOTAL ORGANIC CARBON (%)	LIME (%)
BMI-1	Coal					
BMI-2	Smut, black, carbonaceous	6.4	0.32	10.41	45.5	20.3
BMI-3	Shale, black, carbonaceous	6.3	0.34	11.67	50.5	25.1
BMI-4	Coal		0.24			
BMI-5	Claystone, dark grayish brown	6.5	0.06	5.07	15.9	10.3
BMI-6	Claystone, dark gray, sandy	6.6	0.12	2.28	11.9	8.8
BMI-7	Coal		0.22			
BMI-8	Claystone, brownish gray, sandy	6.9	0.03	0.91	7.5	5.8
BMI-9	Coal – No. 6 (?) Seam		0.21			
BMI-10	Claystone, medium brown, sandy	6.7	0.01	1.21	7.9	6.6
BMI-11	Claystone, brownish yellow, sandy	7.3	0.02	0.29	7.5	7.1

Figure E2. Acid/base account and other geochemical characteristics for overburden samples of a coal-bearing section near the confluence of Bonanza and Marguerite Creeks.



SAMPLE NUMBER	LITHOLOGIC DESCRIPTION	PASTE pH	TOTAL SULFUR (%)	ORGANIC MATTER (%)	TOTAL ORGANIC CARBON (%)	LIME (%)
EC2-1	Coal		0.21			
EC2-2	Claystone, dark brown, silty	6.3	0.02	6.87	18.9	9.4
EC2-3	Claystone, grayish brown, sandy	6.4	0.01	1.02	7.9	5.6
EC1-4	Sandstone, light brownish gray, clayey	6.3	0.02	0.57	6.5	5.8
EC2-5	Sandstone, light greenish gray, slightly clayey	6.2	0.02	0.84	3.9	6.3

Figure E3. Acid/base account and other geochemical characteristics for seatrock samples of an Emma Creek coal-bearing section.



SAMPLE NUMBER	LITHOLOGIC DESCRIPTION	PASTE pH	TOTAL SULFUR (%)	ORGANIC MATTER (%)	TOTAL ORGANIC CARBON (%)	LIME (%)
MC2-1	Claystone, medium gray, sandy	6.4	0.06	4.36	14.5	8.8
MC2-2	Coal		0.28			
MC2-3	Shale, black, carbonaceous	5.7	0.08	7.26	21.5	6.3
MC2-4	Sandstone, medium brown to yellowish gray	6.3	0.05	6.24	10.9	5.8
MC2-5	Coal		0.27			
MC2-6	Ash parting	5.7	0.11	5.91	23.5	6.9
MC2-7	Shale, black, carbonaceous	5.8	0.21	7.99	38.9	8.3
MC2-5	Coal		0.27			
MC2-8	Claystone, dark gray to black	5.7	0.16	7.94	25.9	7.1
MC2-9	Claystone, light gray, sandy	6.2	0.06	2.17	6.5	5.1
MC2-10	Coal		0.26			
MC2-11	Claystone, medium brown	5.7	0.05	4.62	11.9	4.8
MC2-12	Coal		0.28			
MC2-13	Claystone, dark grayish brown	6.1	0.02	3.41	8.5	5.1
MC2-14	Coal		0.25			
MC2-15	Shale, black, carbonaceous	5.8	0.11	7.67	24.5	6.3
MC2-16	Coal		0.29			
MC2-17	Claystone, light brownish gray, sandy	6.1	0.02	2.47	7.5	4.9
MC2-18	Claystone, medium gray	5.8	0.02	4.19	9.1	5.8
MC2-19	Coal		0.29			
MC2-20	Claystone, light gray	6.5	0.01	0.66	3.9	5.1
MC2-21	Claystone, dark gray, carbonaceous	5.9	0.01	4.19	9.5	5.4
MC2-22	Coal		0.26			
MC2-23	Claystone, light gray	6.1	0.01	1.76	6.1	4.6

Figure E4. Acid/base account and other geochemical characteristics for overburden samples of a Mystic Creek coal-bearing section.

Table E2. Nenana coal field---overburden trace elements.

Sample	Cu	Pb	Zn	Ag	Mo	Sb	As	Co	Ni	Fe	Mn	Cd	Cr
BC1-1	6	3	27	<0.1	1	<1	<10	<10	16	48,300	141	<1	173
BC1-3	64	17	3	0.3	2	<1	<10	<10	<10	4,050	185	<1	69
BC1-4	56	17	5	0.2	2	<1	<10	<10	10	4,030	170	1	101
BC1-5	40	25	45	0.2	1	<1	<10	<10	17	13,700	164	1	60
BC1-6	38	16	114	<0.1	2	<1	<10	<10	32	15,500	191	2	66
BM1-2	56	13	51	0.2	3	<1	<10	29	228	11,200	1,360	2	542
BM1-3	66	16	43	0.1	4	<1	<10	<10	16	8,890	246	2	264
BM1-5	64	18	135	0.2	2	<1	<10	<10	33	20,800	201	1	86
BM1-6	61	17	141	0.2	1	<1	<10	<10	34	22,400	213	1	83
BM1-8	42	13	136	<0.1	2	<1	<10	<10	35	27,300	264	<1	87
BM1-10	42	13	47	<0.1	1	<1	<10	<10	15	8,500	83	<1	35
BM1-11	47	14	123	<0.1	1	<1	<10	<10	23	14,900	135	<1	49
DC2-1	52	51	20	0.2	3	<1	<10	<10	15	1,400	22	3	17
EC2-2	87	22	74	0.3	2	<1	<10	<10	34	13,100	125	2	66
EC2-3	37	14	76	0.2	1	<1	<10	<10	15	7,760	79	1	39
EC2-4	43	12	165	0.2	1	<1	<10	<10	47	21,700	195	1	68
EC2-5	52	11	130	0.1	2	<1	<10	23	82	21,500	225	1	54
MC2-1	39	16	120	0.2	2	<1	<10	12	48	125,000	1,770	<1	60
MC2-3	26	30	58	0.2	2	<1	<10	<10	16	14,100	121	1	41
MC2-4	13	21	110	0.1	2	<1	<10	<10	22	31,700	418	<1	69
MC2-6	107	29	32	0.2	3	<1	<10	17	25	2,400	47	5	<10
MC2-7	25	22	14	0.3	2	<1	<10	<10	12	4,060	21	1	38
MC2-8	17	24	21	<0.1	2	2	<10	<10	12	4,840	78	1	116
MC2-9	13	21	40	<0.1	1	<1	<10	<10	10	11,800	104	<1	39
MC2-11	25	38	35	<0.1	1	<1	<10	<10	<10	5280	32	1	39
MC2-13	13	31	9	<0.1	1	<1	<10	<10	<10	3,890	24	<1	24
MC2-15	21	26	7	0.1	2	<1	<10	<10	<10	2,850	21	1	38
MC2-17	10	19	41	<0.1	1	<1	<10	<10	12	9,930	78	<1	29
MC2-18	24	22	112	0.2	2	<1	<10	<10	25	22,100	201	<1	58
MC2-20	49	22	124	0.2	1	<1	<10	<10	32	19,500	128	<1	59
MC2-21	32	24	130	0.1	2	<1	<10	11	26	21,600	198	1	58
MC2-23	43	22	41	0.2	2	<1	<10	<10	20	12,900	81	1	77
MM2-6A	60	7	10	0.3	2	<1	<10	<10	<10	6,250	73	<1	60
MMb-4	1	9	12	<0.1	2	<1	<10	<10	<10	1,835	<10	<1	109
MM3-1	<1	7	45	<0.1	3	<1	<10	<10	11	11,000	77	3	<10
SC1-1	24	30	96	<0.1	3	<1	<10	<10	15	82,000	695	<1	78
SC1-3	6	27	3	0.2	1	<1	<10	<10	<10	1,800	<10	<1	41
SC1-4	23	45	19	0.2	2	<1	<10	<10	11	2,930	20	1	35
SC1-6	18	44	43	0.3	2	<1	<10	<10	<10	5,560	28	<1	41
SC1-7	14	21	14	0.1	2	<1	<10	<10	<10	266	13	<1	41
SC1-9	17	22	93	<0.1	1	<1	<10	<10	<10	2,030	10	1	38
SC1-11	13	22	38	0.2	15	<1	<10	<10	17	61,200	282	<1	46
SC1-12	7	21	12	0.1	3	<1	<10	<10	<10	7,050	36	<1	49
SC2-1	2	8	3	0.4	12	<1	<10	<10	<10	1,910	13	<1	162
SC2-2	3	12	2	0.5	16	<1	<10	<10	<10	734	11	1	99

Table E3. Major oxide analysis data (%) of coal overburden samples from the Nenana coal field.

Field/lab number	SiO_2	Al_2O_3	Total Fe as Fe_2O_3	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	MnO	Total
BC1-1	85.62	5.42	6.33	0.35	0.36	1.00	1.62	0.19	0.10	0.02	101.01
BC1-3	67.98	20.83	1.91	1.34	2.69	0.25	2.38	1.31	0.04	0.05	98.78
BC1-4	68.79	21.26	1.74	1.26	1.77	0.33	2.51	1.24	0.04	0.03	98.97
BC1-5	68.79	20.79	3.23	1.64	0.77	0.37	2.71	1.11	0.04	0.03	99.48
BC1-6	71.48	18.50	3.11	1.55	0.68	0.69	2.67	1.03	0.03	0.03	99.77
BM1-2	57.96	18.64	3.35	1.84	11.90	0.84	1.75	0.97	0.04	0.31	97.60
BM1-3	61.69	20.50	3.39	1.93	6.18	1.03	1.80	0.96	0.05	0.06	97.59
BM1-5	66.33	20.42	4.51	2.04	1.39	1.05	2.18	1.06	0.03	0.03	99.04
BM1-6	66.85	19.66	4.53	2.08	1.16	1.19	2.19	1.05	0.04	0.03	98.78
BM1-8	68.09	18.87	4.47	2.14	0.93	1.40	2.27	1.05	0.03	0.04	99.29
BM1-10	72.21	18.53	2.82	1.12	0.59	0.52	2.12	1.12	0.03	0.02	99.08
BM1-11	71.34	18.55	3.65	1.40	0.71	0.91	2.18	1.00	0.06	0.03	99.83
DC2-1	50.10	35.96	0.30	0.74	2.05	0.29	1.10	1.21	3.19	0.00	94.94
EC2-2	65.22	24.06	2.96	1.54	1.20	0.34	2.00	1.07	0.04	0.02	98.45
EC2-3	70.68	19.63	2.32	0.94	0.65	1.15	2.46	0.98	0.03	0.02	98.86
EC2-4	68.52	19.30	3.94	1.67	0.89	1.51	2.50	0.95	0.08	0.04	99.40
EC2-5	69.83	17.14	3.64	1.56	1.18	1.77	2.48	0.84	0.10	0.04	98.58
MC2-1	53.51	18.76	19.48	1.84	0.87	0.36	2.84	0.82	0.19	0.26	98.93
MC2-3	60.74	28.92	2.57	1.33	0.68	0.35	3.24	1.01	0.04	0.02	98.90
MC2-4	66.81	21.25	4.58	1.31	0.48	0.35	3.62	0.87	0.06	0.06	99.39
MC2-6	53.07	42.31	0.00	0.60	1.02	0.33	0.24	0.55	1.95	0.01	100.08
MC2-7	62.95	27.76	1.45	1.26	1.15	0.53	3.27	1.05	0.07	0.01	99.50
MC2-8	64.36	26.42	1.60	1.19	1.11	0.68	3.60	1.16	0.07	0.02	100.21
MC2-9	67.04	23.74	2.32	1.26	0.39	0.69	3.97	1.05	0.10	0.02	100.58
MC2-11	60.70	31.19	1.33	1.10	0.55	0.62	3.50	1.12	0.07	0.01	100.19
MC2-13	65.58	26.55	1.44	1.12	0.44	0.90	4.05	1.07	0.11	0.01	101.27
MC2-15	61.82	30.61	1.01	1.01	0.85	0.38	3.61	1.00	0.06	0.01	100.36
MC2-17	66.59	25.43	1.89	1.05	0.49	0.32	3.59	1.06	0.06	0.02	100.50
MC2-18	62.64	26.54	3.50	1.71	0.62	0.36	3.66	1.04	0.22	0.03	100.32
MC2-20	72.03	19.02	3.07	1.79	0.30	0.40	3.01	1.08	0.08	0.02	100.80
MC2-21	63.07	26.37	3.64	2.04	0.75	0.52	3.67	1.04	0.25	0.03	101.38
MC2-23	71.54	20.44	2.17	1.60	0.38	0.54	3.10	1.09	0.06	0.01	100.93
MM2-6a	75.91	17.26	1.79	0.99	0.60	0.97	2.87	1.23	0.07	0.02	101.71
MMb-4	89.87	7.99	0.52	0.20	0.11	0.47	1.66	1.04	0.11	0.00	101.97
MM3-1	53.75	38.04	2.43	0.93	2.16	1.38	0.29	0.83	0.49	0.03	100.33
SC1-1	59.52	19.52	14.04	1.87	0.71	0.45	3.61	0.81	0.24	0.12	100.89
SC1-3	70.12	22.21	1.36	1.00	0.22	0.39	4.33	0.87	0.07	0.01	100.56
SC1-4	63.11	28.64	1.49	1.21	0.46	0.45	3.99	1.11	0.13	0.01	100.60
SC1-6	70.82	22.01	1.82	1.01	0.21	0.49	4.38	0.76	0.21	0.01	101.72
SC1-7	74.68	19.97	0.62	0.62	0.24	0.36	3.32	0.94	0.04	0.01	100.80
SC1-9	69.35	24.35	0.90	0.91	0.21	0.41	4.01	0.98	0.08	0.00	101.20
SC1-11	67.83	16.62	9.05	1.58	1.37	0.30	2.79	0.78	0.85	0.04	101.21
SC1-12	76.50	18.37	1.40	0.49	0.17	0.33	2.44	0.88	0.05	0.01	100.64
SC2-1	91.15	7.66	0.34	0.42	0.10	0.37	1.92	0.35	0.07	0.00	102.34
SC2-2	89.41	8.70	0.23	0.40	0.09	0.25	2.05	0.43	0.06	0.00	101.62

Table E4. Suitability ratings for soils as sources of topsoiling material. (From Wyoming Department of Environmental Quality, 1978.)

Soil parameter	Degree of soil suitability: Good	Fair	Poor	Unsuitable
pH	6.0–8.4	5.5–6.0 8.4–8.8	5.0–5.5 8.8–9.0	Under 5.0 Over 9.0
Conductivity (Ec) mmhos/cm at 25°	Under 4	4–8	8–16	Over 16
Saturation percentage (SP)	25–80		Over 80; under 25	
Texture class	sl, l, sil, scl	cl, sicl, sc, ls	c, sic, s	
Sodium adsorption ratio (SAR)	Under 6	6–10	10–15	Over 15
Calcium carbonate	low (none-slight) 0–15%	moderate 15–30%	high Over 30%	
Moist consistence	friable	loose, firm	very firm	
Dry consistence	loose, soft	slightly hard, hard	very hard	
Selenium	2 ppm or less		greater than 2 ppm	
Boron	5 ppm or less		greater than 5 ppm	
Molybdenum	5 ppm or less		greater than 5 ppm	
NO_3-N	50 ppm or less (suspect)		greater than 50 ppm (suspect)	

Table E5. Guideline for suspect levels in overburden material. (Montana Department of State Lands; from Dollhopf and others, 1978, v. 1, p. 43.)

Parameter		Suspect level
Conductance (Ec)		>4-6 mmhos/cm
Sodium adsorption ratio (SAR)		>12
Mechanical analysis		
Clay		>40%
Sand		>70%
Saturation %		None
pH		>8.8-9.0
PO_4-P		None
NO_3-N		>10-20 ppm
NH_4-N		>10-20 ppm
Cd		>0.1-1.0 ppm
Cu		>40 ppm
Fe		Unknown
Pb		(1) pH <6, >10-15 ppm
		(2) pH >6, >15-20 ppm
Mn		>60 ppm
Hg		>0.4-0.5 ppm
Se		>2.0 ppm
Mo		>0.3 ppm
B		>8.0 ppm
Zn		>30-40 ppm
Ni	(1) DTPA extraction	>1.0 ppm
	(2) Acid extraction	>5.0 ppm