MIRL REPORT NO. 85

STRATIGRAPHY, PETROLOGY, AND DEPOSITIONAL ENVIRONMENTS OF THE JARVIS CREEK COALFIELD, ALASKA

A
THESIS

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ABSTRACT

Jarvis Creek basin coals are subbituminous, low in ash, and increase upsection in moisture, most major oxides and trace elements, and vitrinite with subsequent liptinite and inertinite decreases. Sulfide mineral deposits east-southeast of the basin are responsible for the enrichment of the upper coals in sulfur and metals. Sandstones are quartzose, arkosic, and lithic in the lower, middle, and upper units respectively, and were derived from a recycled orogen provenance. Sediment transport was from the south at the base, shifting to an easterly source higher in the section. Deposition was by braided and meandering streams on mid and distal portions of alluvial fans. The lower and middle units are correlative with the Healy Creek Formation, while the upper unit probably correlates with the Lignite Creek Formation. Measured, indicated, and inferred coal reserves are 17, 37, and 227 million short tons respectively, mostly in the upper unit at shallow depths.

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INTRODUCTION

The Jarvis Creek coalfield is located in east-central Alaska and is the easternmost subfield in the Nenana Coal Province (Merritt and Hawley, 1986). The field lies on the north side of the Alaska Range, three to six miles east of the Richardson Highway and approximately 30 miles south of Delta Junction (Fig. 1). The coalfield lies entirely within the Mount Hayes C-4 quadrangle and encompasses 16 square miles; the major part is a rolling plateau that slopes gently northward. It is bounded on the east, south, and west by bluffs facing Jarvis Creek, Ruby Creek and the Delta River. Access to the coalfield is via a gravel road that leaves the Richardson highway just north of milepost 242 and meanders along a ridgetop six or seven miles to an old mine site on Ober Creek.

This coalfield is strategically located near a major thoroughfare (Richardson Highway) and several potential markets in the Eastern Interior. These include Delta Junction, Tok, Northway, Paxson, Glennallen and the military base of Fort Greeley. Although the coalfield is favorably located, and its existance has been known for over 40 years, there are few reports on its geology or economic potential. These are mainly short notes on specific topics and generalized stratigraphy and include limited studies on coal resources and coal quality.

Purpose

A primary purpose of this study was to describe the composition of the coal-bearing sequence and to interpret the geologic evolution of the coal basin. A secondary purpose was to determine lateral and vertical variations in coal quality, and to estimate coal quantity. These were accomplished by measuring and sampling every significant outcrop, and conducting chemical and petrographic analyses of coal as well as associated clastic rocks. The results were used to interpret sediment provenance, environments of deposition, and aspects of coal quality and quantity important to potential economic development.

Coal-bearing strata of roughly similar Tertiary age occur throughout the interior and southcentral portions of Alaska. There are a number of important questions about the strata at Jarvis Creek, including their relationship to other coal-bearing rocks:

(1) Is the stratigraphic succession at Jarvis Creek similar in age and composition to that of the commercially important Nenana Field to the west?

(2) Do coal and overburden properties change with stratigraphic or geographic position?

(3) What is the lateral continuity of the coal seams and which analyses are useful for correlation?

(4) Why is the reported sulfur content of the Jarvis Creek coals so much higher than most other Alaskan coals and is this related to the environment of deposition?

These questions are important to understanding the geologic setting of the Jarvis Creek coalfield for future mining developments.

Regional Geologic Setting

Structure

Tertiary coal-bearing strata are exposed in a series of stratigraphic and structural basins along the northern front of the Alaska Range for a distance of 150 miles (Fig 2). They were deposited in localized depressions caused by downdropped fault blocks in older country rock, most notably the Birch Creek Schist (Stevens, 1971). This is evident from the extreme lenticularity of the basal Healy Creek Formation sediments throughout the Nenana Coal Province trend, including Jarvis Creek (Wahrhaftig and others, 1969). Subsequent fluctuations in subsidence rates in these blocks and periodic uplift of surrounding blocks resulted in the sedimentary packages observed.

Most of these basins trend east-west parallel to the Alaska Range, in contrast to the major trend at Jarvis Creek, which is north-northwest. This marked discordance with respect to other Tertiary basins to the west was a response to a period of deformation that must have preceded the deposition of the Pliocene Nenana Gravel. Another period of deformation that followed the deposition of the Nenana Gravel resulted in the downfolding along eastward trending axes seen elsewhere (Wahrhaftig and Hickcox, 1955). These two distinct episodes of folding resulted in a regional unconformity between the Tertiary sediments of Jarvis Creek and the yellow-brown, slightly cemented Nenana Gravel. The nearest exposure of Nenana Gravel is approximately two miles northeast of the coalfield near McCumber Creek.

The initial phase of deformation at Jarvis Creek resulted in warping of the coal-bearing strata into an oval basin where they strike an average of N53°E and dipgenerally 5° to 10° toward the center of the basin (Fig. 3). Locally, strata dip as high as 30°. Most faults are minor with less than 15 feet displacement.

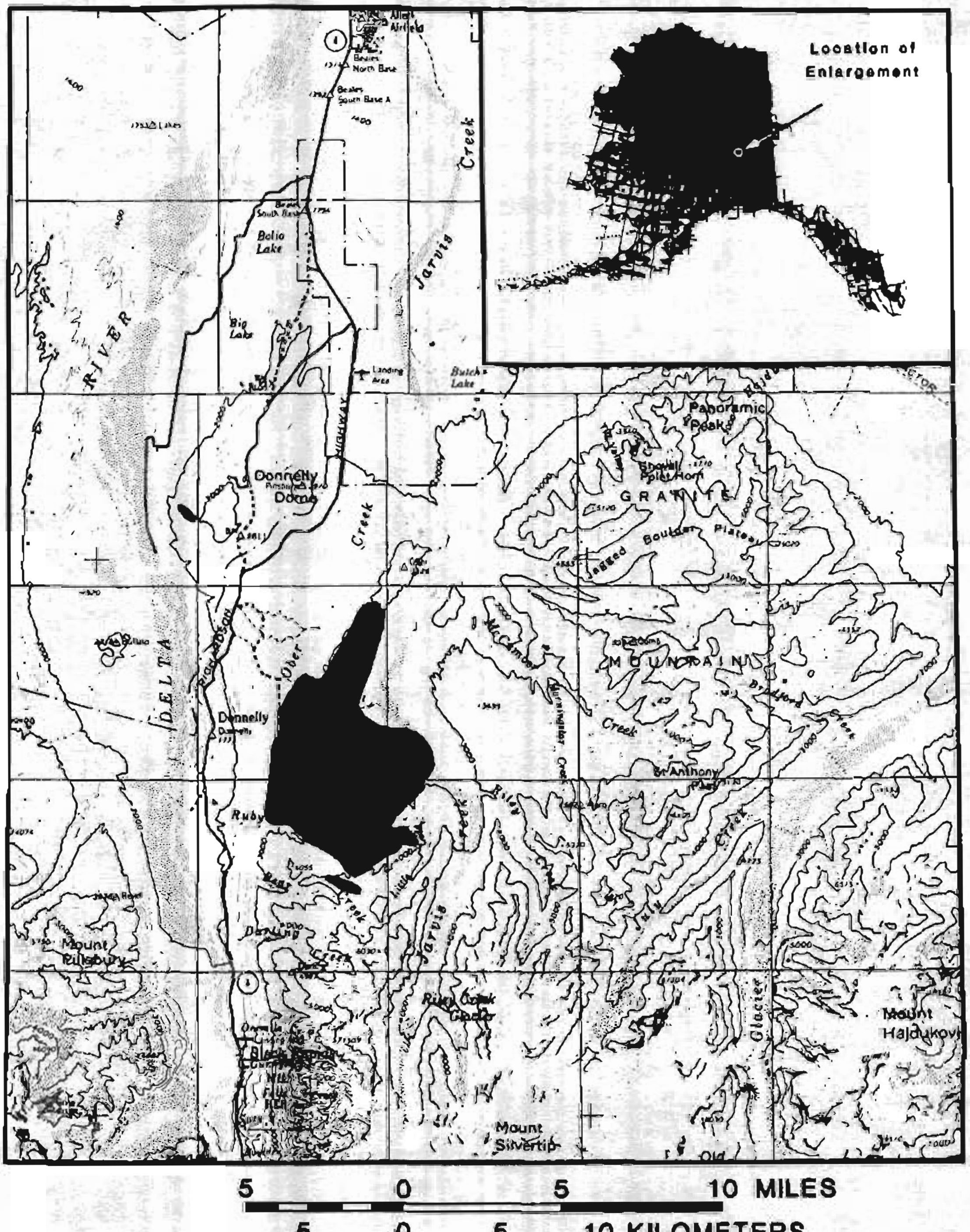


Figure 1. Location of Tertiary coal - bearing strata, Jarvis Creek coalfield, Mt. Hayes Quadrangle.

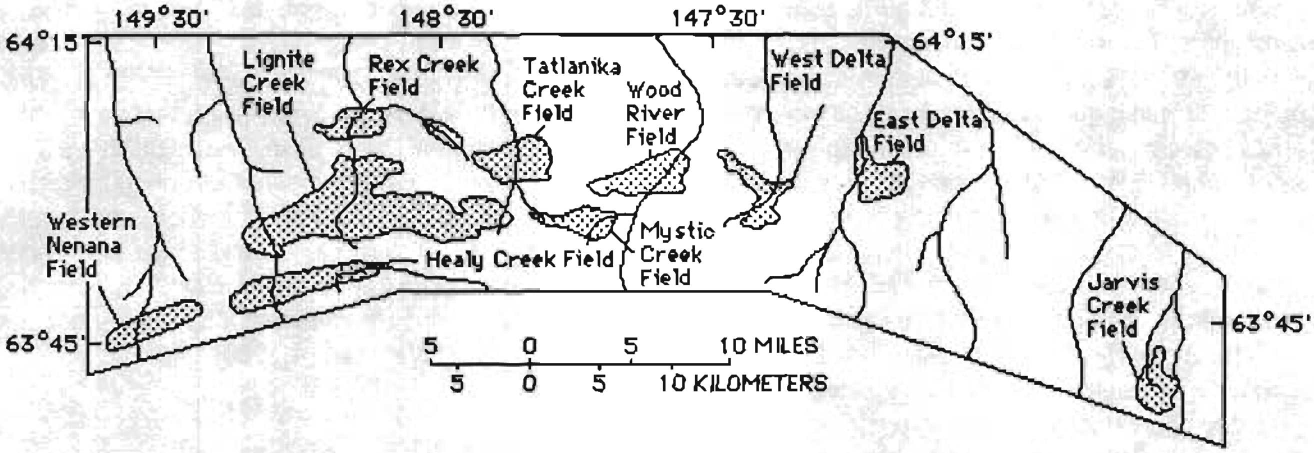


Figure 2. Map showing location of Tertiary coal-bearing basins in Nenana Coal Province.

Quaternary sediment of several types unconformably overlies the Tertiary strata of Jarvis Creek. These include fluvial gravels as well as solifluction, windblown and glacial morainal deposits. The distinctive hummocky topography north and west of the main coalfield indicate extensive and relatively recent glacial activity in the area. Erosion during the Pleistocene (Pewe and Holmes, 1964) resulted in the isolation of a small remnant of Tertiary strata west of Donnelly Dome.

Pre-Tertiary Rocks

The Tertiary strata of the Jarvis Creek Coalfield unconformably overlie a complex assemblage of multiply deformed Devonian and older metamorphic rocks. These rocks increase in age and metamorphic grade toward the north, away from the Denali fault (Richter and Jones, 1973). In the Eastern Alaska Range and north into the Yukon-Tanana uplands, metamorphic mineral assemblages range from lower

Figure 3. North-dipping Tertiary coal-bearing strata near headwaters of Ruby Creek.

greenschist facies to lower amphibolite facies (Foster and others, 1973). The metamorphic rocks in the vicinity of the coalfield are predominantly quartz-sericite schists, quartzites, sericite schists, quartz-sericite calcite schists with minor amounts of chlorite and graphitic schist, and are collectively referred to as the Birch Creek Schist (Wahrhaftig and others, 1969). This schist is a completely recrystallized sequence of clastic sediments believed to be at least 10,000 feet thick, though it is impossible to measure.

The Birch Creek Schist in the Jarvis Creek area reaches a metamorphic grade of greenschist, as reflected in mineral assemblages derived from metamorphosed bodies of intrusives and volcanics developed within it (Stevens, 1971). A distinctive feature of the Birch Creek Schist, especially near the coalfield, is the abundance of milky white vein quartz, most often observed in small contorted lenses and stringers that follow cleavage planes. The stringers are developed both parallel to platy minerals and in closely spaced fractures (Moffit, 1942). The segregation of quartz into these lenses and stringers resulted from regional metamorphism and associated recrystallizations during the Mesozoic and Tertiary. The hardness and resistance of this quartz to weathering makes it the most abundant (up to 90%) constituent in much of the unconsolidated material derived from the metamorphic basement. Vein quartz is particularly abundant in the lower part of the Tertiary strata.

Igneous rocks are present throughout the eastern Alaska Range and the Yukon-Tanana Upland to the north. Regional metamorphic rocks (including Birch Creek Schist) are intruded by a number of igneous bodies ranging in composition from quartz diorite to granite. One intrusive body, Granite Mountain, is directly northeast of the Jarvis Creek Coalfield and is composed of quartz monzonite, granodiorite and quartz diorite (Moffit, 1942; Warner, 1987, personal communication). On the basis of lead-alpha age determinations on zircons from granodiorite at four locations, Cretaceous ages are indicated for the granitic plutons (Holmes and Foster, 1968). Small stocks of ultramafic rocks and alkali-rich mafic to intermediate rocks, all with spatially related dikes of basaltic, intermediate, and felsic compositions, intrude the metamorphic and Cretaceous granitic rocks in the Eastern Alaska Range (Foley, 1985). Vertical rhyolite dikes intrude the Birch Creek Schist in the canyon of Ruby Creek on the southern border of the coalfield.

Other Pre-Tertiary igneous rocks in the vicinity include Cretaceous lamprophyres, syenites, gabbros, and clinopyroxenites near the Robertson River east of the coalfield (Foley, 1985). Several volcanogenic massive sulfide deposits occur south and east of the coalfield, as part of metavolcanic suites that have been dated at about 370 m.y. (middle Devonian) by recent U/Pb zircon isotopic studies (Nokleberg and Lange, 1983). These rocks probably correlate with the Totatlanika Schist furthur west in the Healy Quadrangle. This unit also contains abundant altered intermediate volcanic rocks (Wahrhaftig, 1968).

Tertiary Strata

The Tertiary coal-bearing formation at Jarvis Creek is approximately 2000 feet (530 m) thick, and has been tentatively correlated with the Healy Creek Formation, the lowermost of five distinctly different formations in the Nenana Coal-Bearing Group (Wahrhaftig and Hickcox, 1955; Wahrhaftig and others, 1969). In ascending order the other units in the Nenana Group include the Suntrana, Sanctuary, Lignite Creek and Grubstake Formations (Wahrhaftig and others, 1969). Uncertainty about this correlation exists, and was a major focus of the present study.

At Jarvis Creek, the coal-bearing strata can be divided into three lithologic units as first described by Wahrhaftig and Hickcox (1955). A generalized stratigraphic column of these units is shown in Figure 4. Only one exposure exhibits all three units in stratigraphic succession (Fig. 5). The following descriptions of units are taken from Wahrhaftig and Hickcox (1955).

The lower unit is characterized by angular to subangular quartz conglomerate and sandstone. Locally the unit contains beds and lenses of clay, coal, and bone. It has a maximum measured thickness of 500 feet.

The middle unit has at its base a coal-bearing zone ranging to 50 feet in thickness. The rest of the unit is characterized by medium to coarse buff arkosic sandstone, brown silty claystone, thin, lenticular coal beds and numerous iron carbonate concretions. This unit ranges to 650 feet in thickness.

The upper unit consists of lenticular dark-gray sandstones that are locally concretionary, dark-gray siltstones and claystones, and coal. The total thickness of the upper unit is not known, because its top has been removed by erosion. Structure sections, however, indicate that its maximum thickness beneath the surface of the plateau may be as much as 900 feet.

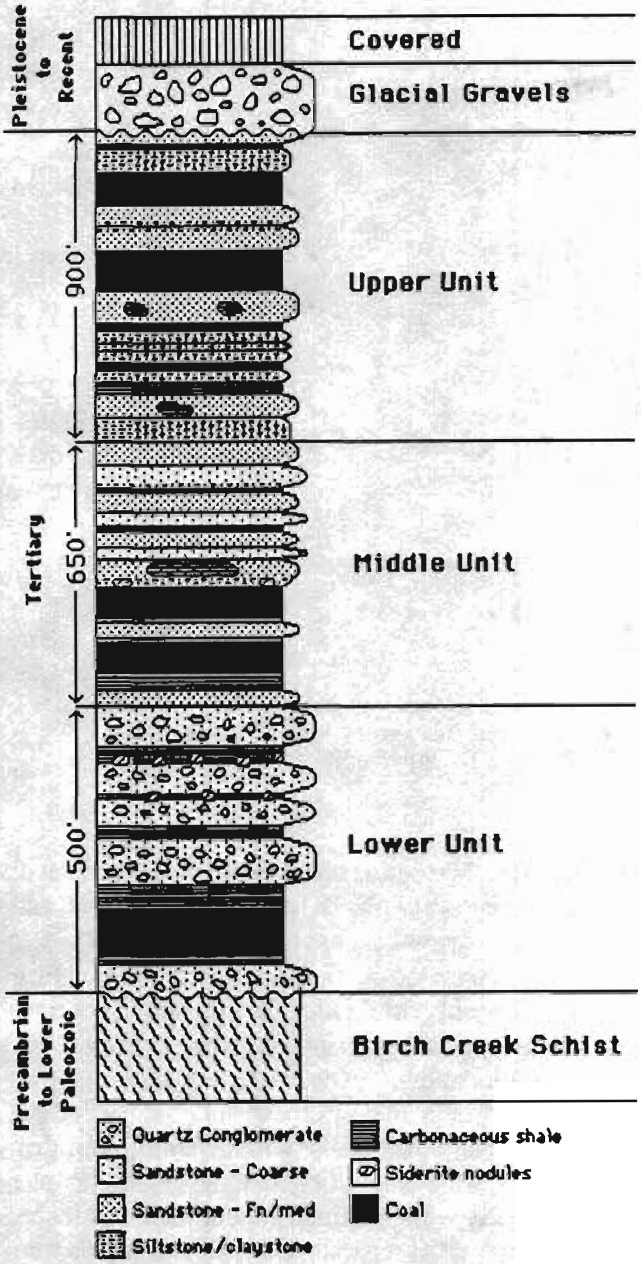


Figure 4. Generalized stratigraphic section, Jarvis Creek coalfield, Alaska

<u>Coal Deposits</u>

Over thirty coal beds have been identified in the Jarvis Creek coalfield, most of which are thin and discontinuous (Wahrhaftig and Hickcox, 1955). At least one coal bed is usually present in each exposure. The lower unit contains only one coal bed thick enough to be considered mineable. The middle unit contains some coal reserves at the base of the middle unit (B and C seams) and is laterally continuous. The upper unit has many lenticular coals but only a few of mineable thickness. Drilling by the U.S. Bureau of Mines in 1970 near the center of the field confirmed that some coal has been removed by glaciation (Warfield, 1973).

Previous Investigations

The only published geologic investigations dealing specifically with the Jarvis Creek coalfield are those of Wahrhaftig and Hickcox (1955) and Warfield (1973). The earliest reference to the coalfield is by Moffit who mapped the extent of the coal-bearing formation in 1939 and measured a few sections (Moffit, 1942; Moffit, 1954). In 1943, the Army spent time in the coalfield collecting coal samples (Thomas, 1943). This was continued in 1944 by Van Alstine and Black of the U.S. Geological Survey (Wahrhaftig and Hickcox, 1955). In the summer of 1946, Hickcox remapped the coalfield, plotted the geology on aerial photographs, and described numerous measured sections. It was largely from their data that the Wahrhaftig and Hickcox (1955) report was compiled. Wahrhaftig revisited the area in 1951, mapping geology on new base maps and adding additional measured sections.

In 1958, a 10-foot coal seam was discovered in the middle of the coalfield, leading to the first commercial development. A prospecting permit was issued in 1959 and there was sporadic mining from 1963 to 1970 (Metz and others, 1981). Mining was mostly for local use, with little tonnage produced. Exploration drilling by the U.S. Bureau of Mines was conducted in 1970 (Warfield, 1973), and includes 12 holes ranging in depth from 26.4 to 138 feet using a center sample return. A few more holes by Owen, Loveless and Associates during the winter of 1977 blocked out over 1,000,000 tons of strippable reserves in a 40 acre site near the old mine (Metz and others, 1981). In 1983 the Federal Government awarded a coal prospecting lease to the Delta Coal Company; however, as of summer, 1987, there has been no development at the Ober Creek mine site.

Present Investigation

This report is based on field work during the summer of 1985, with a short followup in August, 1986, involving one field assistant and accomplished by foot. A number of base camps were used as the

Figure 5. Photograph of southeast corner of coalfield. Only exposure where all three stratigraphic units (L-Lower unit; M-Middle unit; U-Upper unit) are in contact.

study progressed counterclockwise around the 16 square miles of the coalfield.

Laboratory work was conducted in the Mineral Industry Research Laboratory, University of Alaska at Fairbanks. This ran concurrently with employment for the State of Alaska Division of Geological and Geophysical Surveys in the Coal Investigations Program. Analyses were conducted from September 1985 to February 1987.

METHODS OF INVESTIGATION

Field Methods

A total of thirty stratigraphic sections were measured in detail during the 1985 and 1986 field seasons. These include every available outcrop where at least one coal or carbonaceous shale bed was exposed. Four outcrops (URC8, UC8A, UC10A, and JC2) were included as coal sampling spot localities (Fig. 6) because they contained a coal bed but only a limited thickness of adjacent strata.

At each stratigraphic section, samples were taken of coals, overburden, and sandstones. All coals thicker than 2.0 feet were sampled; selected thinner coals were also sampled if they appeared to be of stratigraphic significance. Sixty-nine coal samples were collected: five from the lower unit, 18 from the middle unit, and 46 from the more widely exposed upper unit. Thicker seams were sampled at closer spacings to maximize the possibility of correlation. The thick and continuous B and C seams were sampled in four localities (Fig. 6 - circled localities), over a lateral distance of two miles (3.2 km). In all cases the channelling technique was used to sample the coals. Clastic partings less than four inches were incorporated in the coal samples proportionally while partings greater than four inches were considered as separate beds. Coal samples were placed in double plastic bags and sealed to prevent moisture loss.

Overburden samples were collected for regional geologic studies and to assess environmental impacts. Included were seatrocks and roofrocks of all coal seams thicker than four feet. Smaller coal seams were included if they were laterally continuous and therefore potentially correlatable. The interburden (clastic rocks between adjacent coal seams) were sampled if they had the potential of being correlated laterally and were less than three feet thick. Overburden samples were mostly siltstones, claystones, carbonaceous shales with some sandstones; all were sampled adjacent to coal seams.

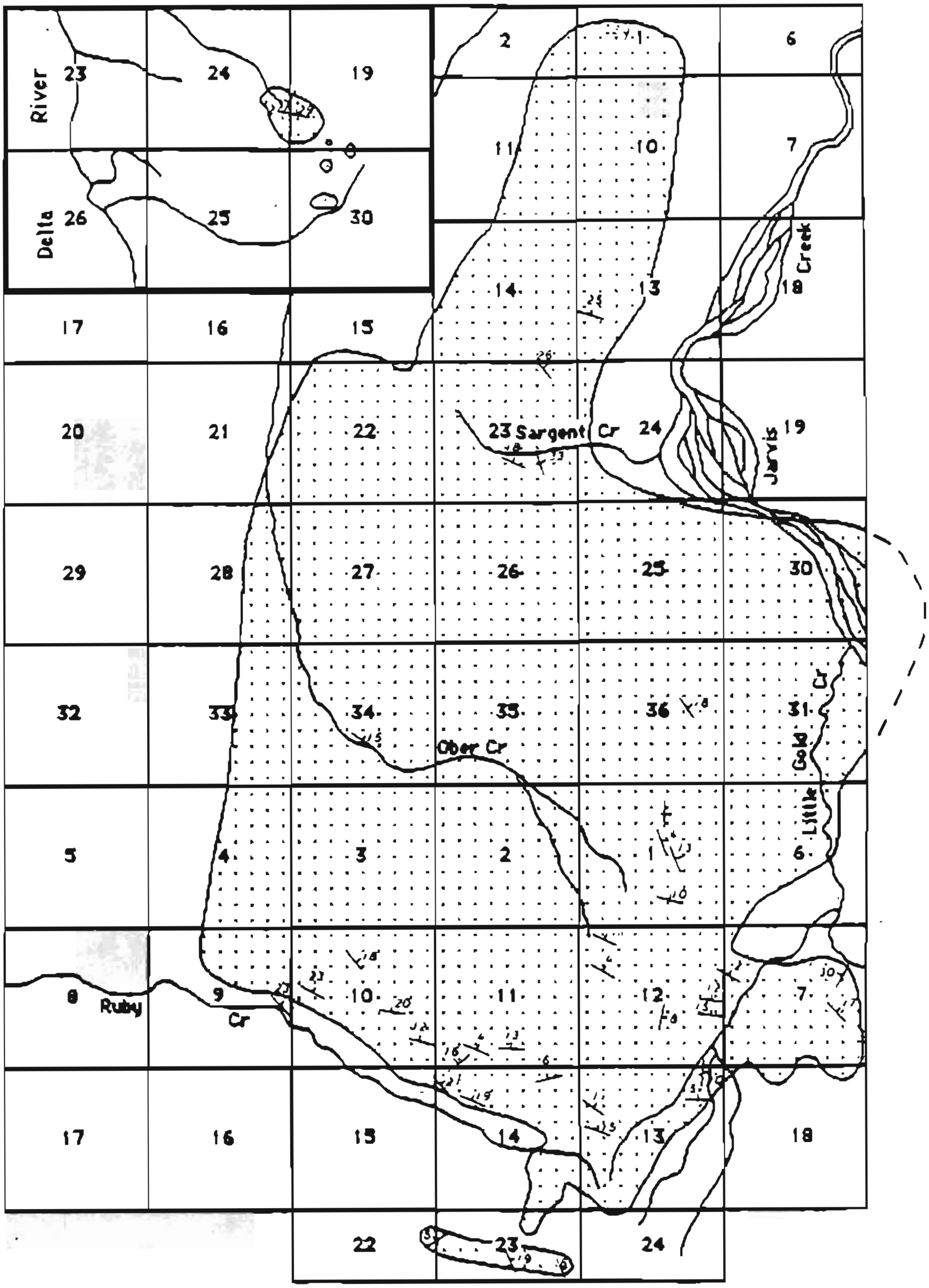


Figure 7. Map showing location and attitude of strike and dip measurements, Jarvis Creek coalfield, Mt. Hayes (C-4) quadrangle. Inset is from the adjoining Mt. Hayes (D-4) quadrangle T13S, R9E-R10E.

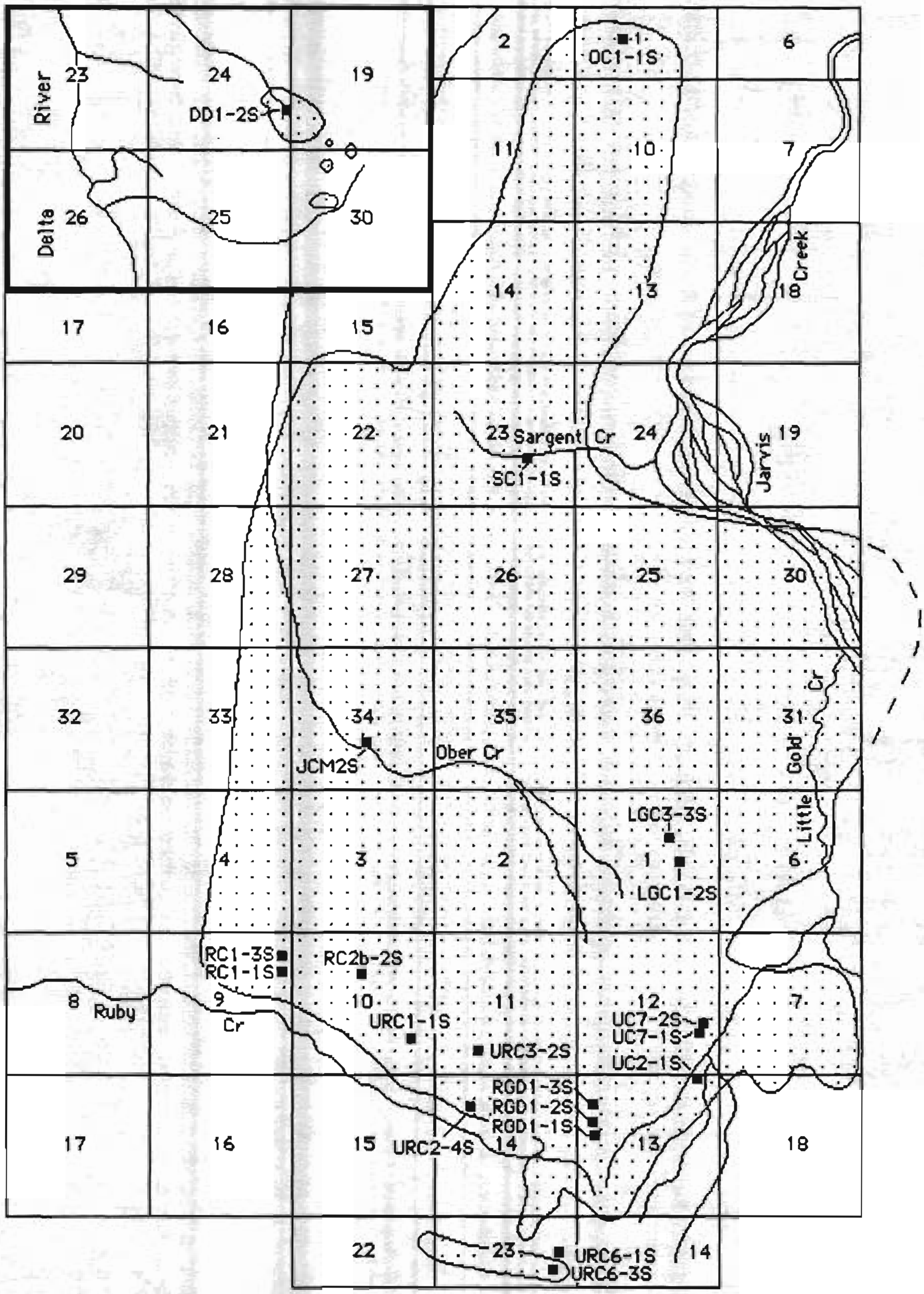


Figure 8. Map showing location of sandstones used for petrographic examination in the Jarvis Creek coalfield, Mt. Hayes (C-4) quadrangle. Inset is from the adjoining Mt. Hayes (D-4) quadrangle T13S, R9E-R10E. (Sample designation as follows: UC7-2S=Locality (UC7), sample 2S).

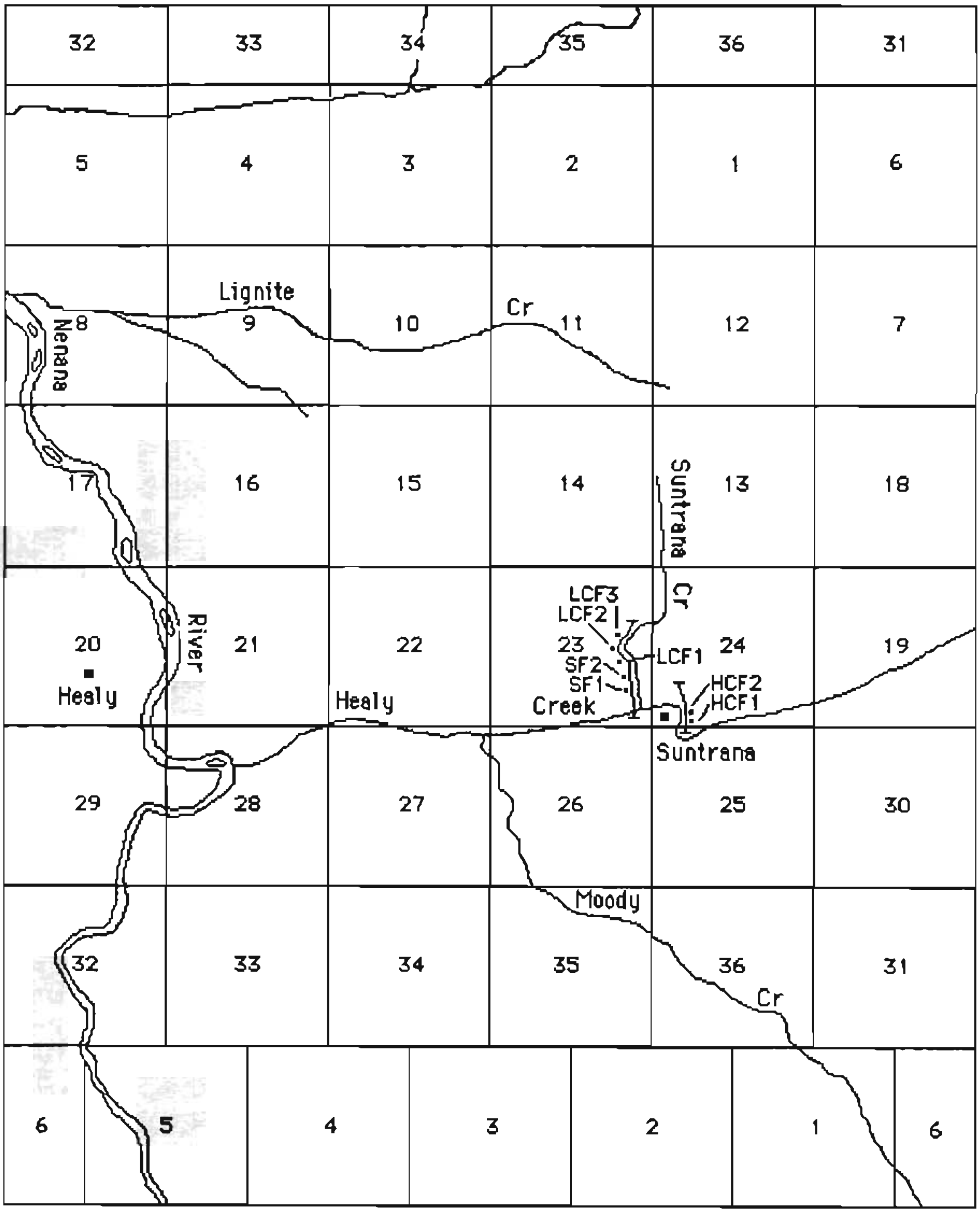


Figure 9. Map showing location of Healy type section and sandstone sampling sites, Healy (D-4) Quadrangle, T12S, R7W. (Sample designation as follows: SF2=Suntrane Formation (SF), sample 2).

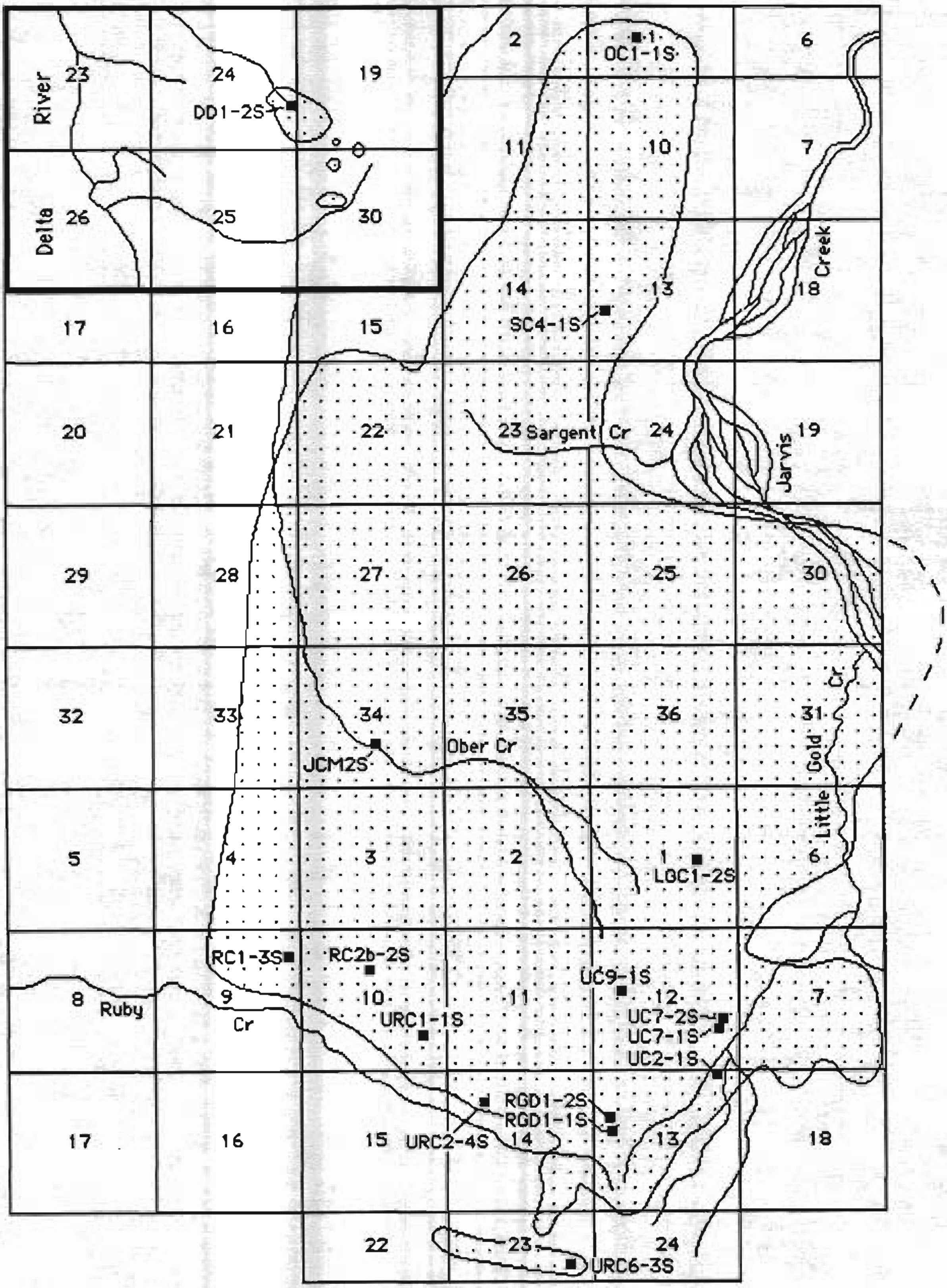


Figure 10. Map showing location of sandstone samples used for heavy mineral analysis in the Jarvis Creek coalfield, Mt. Hayes (C-4) quadrangle. Inset is from the adjoining Mt. Hayes (D-4) quadrangle T13S, R9E-R10E. (Sample designation as follows: UC9-1S=Locality (UC9), sample 1S).

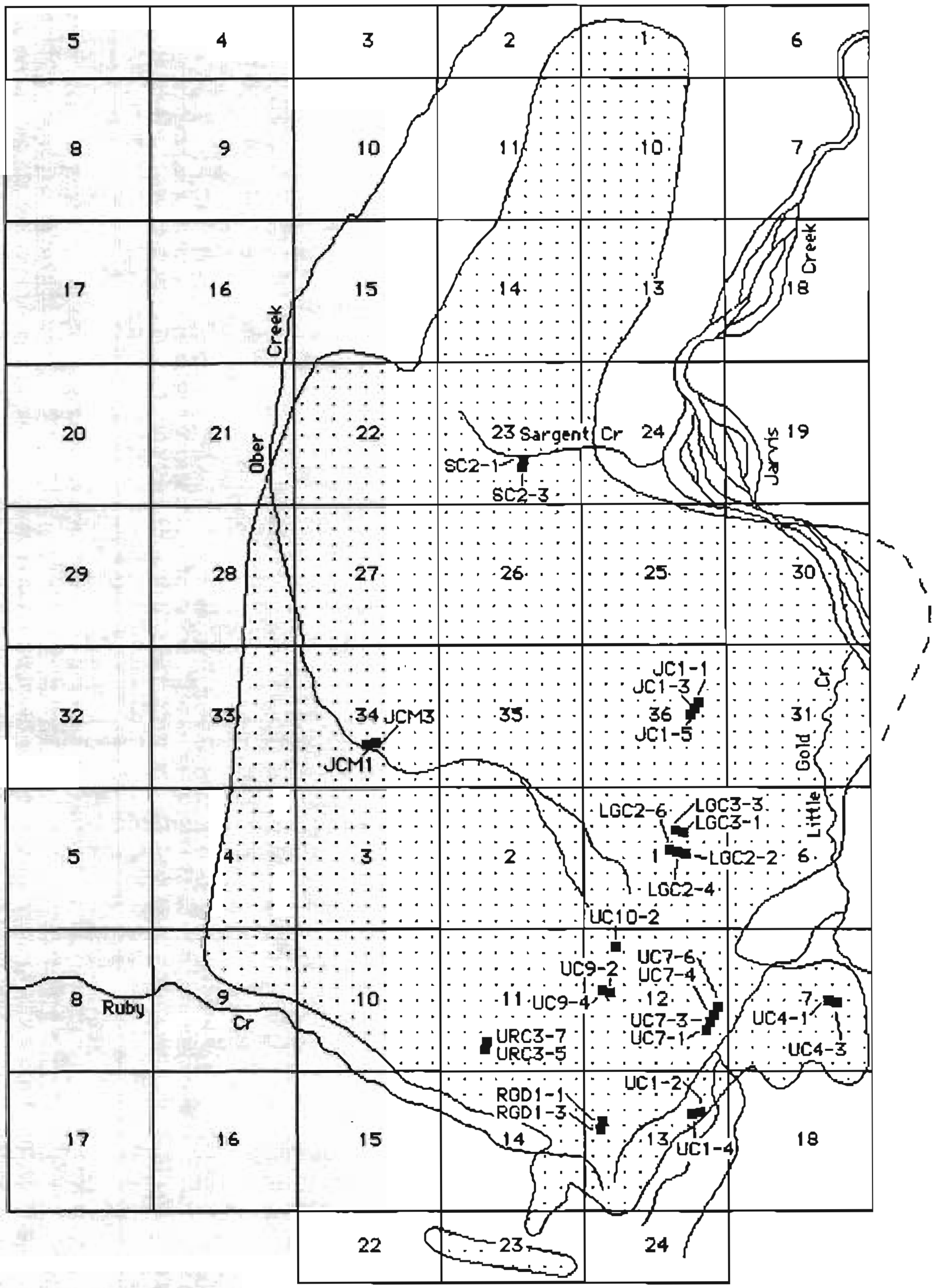


Figure 11. Map showing location of overburden samples within the Jarvis Creek coalfield, Mt. Hayes (C-4) quadrangle. (Sample designation as follows: UC9-2=Locality (UC9), sample 2).

Suhr and Gong (1983). Loss on ignition (LOI) is mostly as a measure of organic content in these overburden rocks (Johnson and Maxwell, 1981). Major oxides determined were SiO_2, Al_2O_3, Fe_2O_3, MgO, CaO, Na_2O, K_2O, TiO_2, and MnO. Minor and trace elements determined include Cr, Ni, V, Cu, Ba, Sr, P, and Be. Atomic absorption was used to determine the trace metals Zn, Co and Cd in accordance with ASTM procedure D3683.

Laboratory Methods-Coal

Sample Preparation

Sixty-nine coal samples from the Jarvis Creek coalfield were analyzed. They were prepared for analysis in accordance with ASTM procedure D2013. Most analytical techniques utilized coal crushed to -60 mesh. A small portion of each sample, crushed to -20 mesh, was used to make coal pellets for petrographic examination in accordance with ASTM procedure D2797.

Analyses performed on the coals from the Jarvis Creek coalfield include proximate, ultimate, sulfur (including its forms), petrology, vitrinite reflectance, palynology and chemical composition.

Proximate analysis

Proximate analysis, which determines the distribution of products obtained by incremental heating in a controlled atmosphere (Schmidt, 1979), consists of the following separate analyses: a) moisture; b) volatile matter; c) ash; and d) fixed carbon.

Proximate analyses were conducted in accordance with ASTM standards D3173, D3174 and D3175, respectively, except where modified by use of the Fisher Model 490 Coal Analyzer which was used as the drying and heating medium (Suhr and Gong, 1983). Fixed carbon was a recalculated value, or the difference between the original weight and the sums of moisture, volatile matter and ash. Duplicates were run on each sample to ensure precision of results. These analyses were determined on an air-dried basis and then recalculated to as-received, moisture-free and dry, ash-free bases in accordance with ASTM Standard Method D3180. The Fisher Model 490 coal analyzer is located in the Mineral Industry Research Laboratory at the University of Alaska Fairbanks.

Ultimate Analysis

Ultimate analysis was conducted on 27 representative samples from the three stratigraphic units. This analysis involves the major components of coal expressed as weight percentages of carbon, hydrogen, nitrogen, sulfur, oxygen and ash (Schmidt, 1979). Weight percentages of carbon, hydrogen and nitrogen in each sample were determined in the Perkin-Elmer Model 240B CHN analyzer, located in the Biological Oceanography Lab at the University of Alaska Fairbanks. Oxygen was a recalculatedvalue, being the difference between the original weight and the sum of C, H, N and ash. Values from this ultimate analysis were determined on an air-dried basis and recalculated to the other bases, as with proximate analysis.

Heating Value and Sulfur

The heating value of coal (Btu/lb), total sulfur, and sulfur forms were measured using facilities of the University of Alaska Mineral Industry Research Laboratory. Heating values were determined on all 69 coal samples by an adiabatic calorimeter in accordance with ASTM Standard D2015. Duplicate analyses were run for precision. Calorimeter values were derived for air-dried samples; these were recalculated to the other bases in accordance with ASTM procedure D3180.

Total sulfur was measured on all 69 coal samples in accordance with ASTM procedure D3177 using the Fisher Sulfur Analyzer located at the Mineral Industry Research Lab. Duplicates were run for precision. Total sulfur values determined on an air-dried basis were converted to other bases as previously discussed.

Forms of sulfur were determined for 12 representative coal samples and are expressed as a weight percent of total sulfur present as a) organic, b) pyritic and c) sulfate sulfur. This wet chemical analysis was conducted in accordance with ASTM Standard D2492.

Petrology

Polished sections of 69 Jarvis Creek coal samples were utilized for petrology point counts and vitrinite reflectance readings. The petrology was studied on these pellets in two phases and involved 30 representative samples.

The first phase was a maceral analysis by point counting the pellets on a Leitz orthoplan microscope equipped with an automatic counter, attached stage assembly, and flourescent capabilities. Normal incident light illumination was used for vitrinite/huminite and inertinite macerals and 500 counts were made, following the methods of Stach and others (1982). The counting was repeated using blue-light excitation for the fluorescent liptinite macerals (Rao and Smith, 1983) with 500 counts again made, excluding all non-fluorescing macerals.

The second phase in the petrographic study of the Jarvis Creek coals was a microlithotype analysis. This involved the same pellets and microscope as used in the maceral analysis study, but this time 500 counts of groupings of macerals in themicroscope field of view (microlithotypes) were recorded, again following Stach and others (1982). Normal incident light illumination was used with frequent cross checks under blue-light excitation. The latter was used for clarification of certain microlithotypes (liptinite-rich) that are difficult to determine otherwise.

Vitrinite Reflectance

The reflectance of vitrinite/huminite was determined on all 69 coal pellets and were conducted on the same orthoplan microscope as were the petrographic studies. For reflectance measurements this scope is equipped with an MPV-3 photometry system, a peak reader, and a motorized stage attachment. Normal incident light illumination was employed (Stach and others, 1982). On each pellet 50 readings were recorded.

Palynology

Palynological analysis, or the study of spores and pollen (herein referred to as sporopollenin), was conducted on 14 representative coals in the Jarvis Creek coalfield. This process is based on the resistivity of sporopollenin to almost everything but oxidation, elevated temperatures and mechanical destruction. Sample preparation was similar to that used at the Coal Research Section at Pennsylvania State University (Lamberson, 1986, personal communication). The extraction of sporopollen has been described by Moore and Webb (1978). Slides containing the sporollenin extracted through this process were then made. The predominant sporopollen taxa in these slides were determined by Michelle Lamberson, a palynology graduate student at Pennsylvania State University.

Chemical Composition

Twenty-seven representative coal samples from the three stratigraphic units at Jarvis Creek were selected for determinations of major oxide and trace elements. High-temperature ash (HTA), the ash that remains as a result of the proximate ash analysis, was utilized in this analysis. The Direct Current Plasma atomic emission spectrometer, Inductively Coupled Plasma atomic emission spectrometer and Atomic Absorption spectrograph were used as for analysis of clastics on page 8.

PRESENTATION AND INTERPRETATION OF DATA

Data obtained from the Jarvis Creek coalfield include both field observations and measurements as well as laboratory analyses. Lithologic relationships between the three major units, including coal seams, are presented first. Laboratory data are presented in three parts. First is a study of the clastic lithologies, subdivided into sections on sediment dispersal patterns (paleocurrents), petrography, and heavy mineral and elemental composition. Second, are the results of coal analyses subdivided into sections on proximate analysis, ultimate analysis, sulfur, petrology, vitrinite reflectance, palynology and elemental composition. Last, is a section on coal seam correlation using coal analyses.

Stratigraphic Field Observations

The lower unit is composed mostly of mildly indurated, white, angular to subangular, quartz conglomerate (68%), friable fine- to medium-grained, brownish-white quartz sandstone (23%), and lesser amounts of brown-black siltstone, black carbonaceous shale, white sericitic clay, bony coal and coal. A major lenticular 8-foot coal bed, the A seam of Wahrhaftig and Hickcox (1955), occurs near the base of the lower unit. The lower unit is thickest, coarsest, and best exposed in the southeastern part of the coalfield (Fig. 12), thinning rapidly both westward and toward the north. The extreme lenticularity of this unit suggests deposition in a localized depression in the Birch Creek schist, typical of Healy Creek Formation rocks (Wahrhaftig and others, 1969). The quartz in the

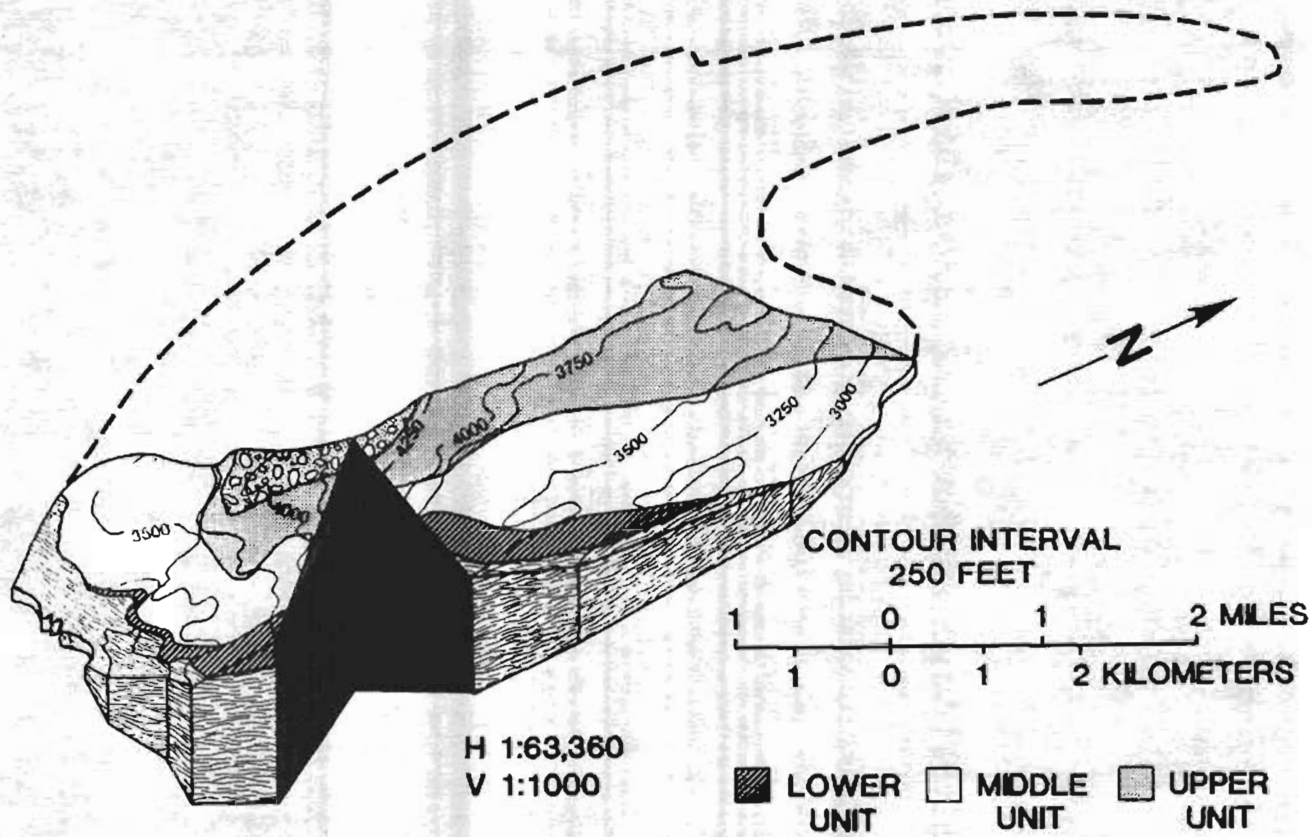


Figure 12. Block diagram - Southeastern part of Jarvis Creek coalfield.

conglomerates and sandstones of this unit is milky white and poorly sorted, especially in the coarser horizons. Quartz clasts reach diameters to 4 inches although 1/2 to 1 inch are more common. Angular schist fragments are common but not abundant. The sandstone lenses occasionally show planar crossbedding and are often pebbly. The pebbles consist primarily of angular to subrounded quartz and schist fragments. The finer-grained beds are extremely micaceous and highly carbonaceous, and contain abundant plant fragments. In several places, sandstones adjacent to these finer beds are also black and micaceous. Siderite nodules to four feet in diameter are also common in the upper part of this unit, and are located in the finer sediments. There are several thin bony coals in the carbonaceous shale zones which reach thicknesses to 12 feet. These impure coals are by far the thickest developed anywhere in the coalfield. The maximum thickness of this lower unit is approximately 500 feet.

The middle unit is mostly alternating beds of brown to buff, medium- to coarse-grained, arkose and white coarse-grained quartzose sandstone (immature quartz arenite), with subordinate amounts of siltstone, claystone, siderite nodules, carbonaceous shale and coal. It is best exposed in the southeastern corner of the coalfield, and in the steep bluffs north of Ruby Creek (Fig. 12). It is covered by Quaternary deposits and vegetation to the northeast. Both of these middle unit sandstone facies contain pebbly horizons, and are generally subangular to subrounded, well sorted, and often stained by iron oxide. The arkose beds, however, are often calcite cemented, form resistant ledges and occasionally show small scale planar crossbedding. The white quartzose sands are similar except that they are rarely cemented. These white sands are massive and contain minor organics. Importantly, they are the only sands that do not contain cross stratification. The finer-grained strata, which include siltstone, claystone, siderite nodules and carbonaceous shale, composes 8% of the middle unit, in contrast to their slightly greater abundance (9%) in the lower unit. Approximately 89 % of this unit is sandstone. Siderite nodules to three feet in diameter are again quite common in the finer-grained sediments. Coal beds in this middle unit are generally thin and sparse, but a major coal zone characterizes the base of this unit. This coal zone is composed of two major coal seams, named B and C by Wahrhaftig and Hickcox (1955), and is laterally continuous for at least two miles. The maximum thickness of the middle unit is 650 feet.

The upper unit is distinguished by lenticular light gray to gray, fine- to medium-grained, immature, well sorted and moderately well rounded, lithic-rich sandstone that is locally concretionary. This is the most widely exposed unit in the Jarvis Creek coalfield, with outcrops from the top of the bluffs north of Ruby Creek on the south to the northern part of the coalfield (Fig. 12). Planar and trough cross-stratification are common in the sandstones, with tabular sets of planar beds by far the most abundant stratification style. Pebble zones are common. The unit also contains a substantial amount of greenish-gray siltstone and claystone as well as numerous coal seams. The siltstone beds are locally concretionary and often contain plant fragments and leaf impressions. Siderite nodules were not observed in this unit, in contrast to their presence in the other two units.

The increased quantity and relative thickness of finer horizons, the lenticular nature and composition of the lithic sandstones, and larger numbers of coals distinguish this upper unit from the underlying units. This suggests a different environment of deposition for the upper unit. The original thickness of the upper unit is purely speculative as its top has been removed by Holocene glacial activity (Wahrhaftig and Hickcox, 1955; Pewe and Holmes, 1964). Structural sections indicate that it may be as much as 900 feet thick in the subsurface. Figure 13 is a view of the topography with its many kettle lakes, that overlies the coal-bearing strata.

Coals in the Jarvis Creek coalfield range in thickness from less than one foot up to 10 feet; the latter maximum occurs at the Ober Creek mine. Of seven beds that exceed six feet, four are in the upper unit and close enough to the surface for mining considerations.

Drilling by the U.S. Bureau of Mines was undertaken in 1970 to determine the lateral continuity of the 10-foot Ober Creek mine seam (Warfield, 1973). Although only three of these drill holes (spaced up to 500 feet apart) intersected this seam, these intersections plus geologic evidence from other holes indicate

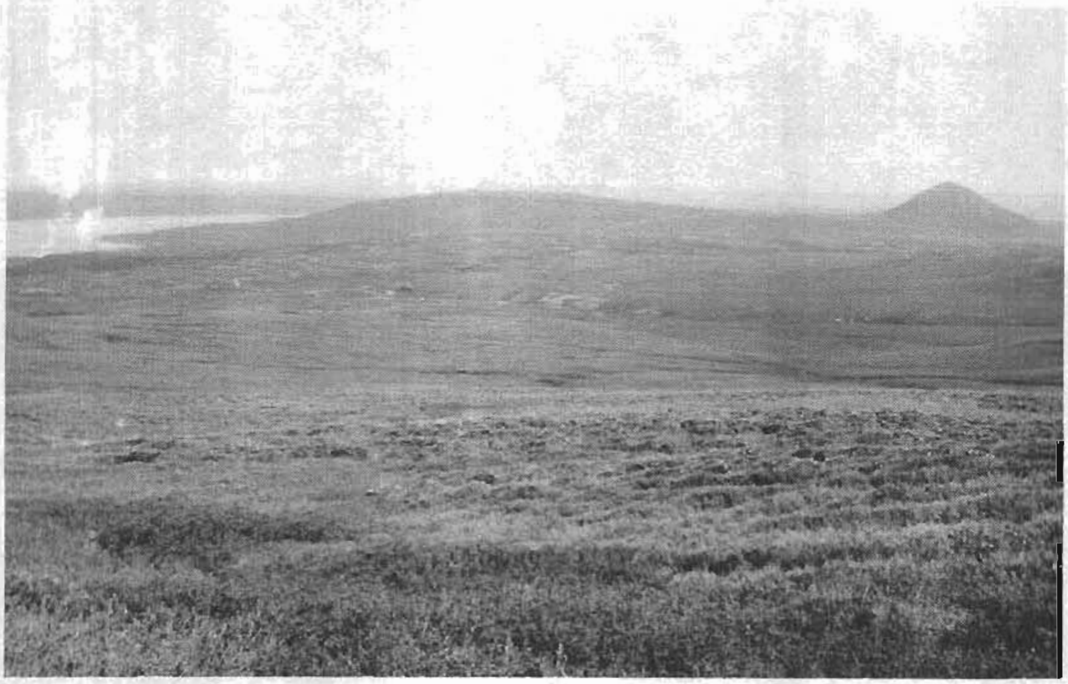


Figure 13. Photograph of the surface topography of the Jarvis Creek coalfield looking north. Notice old mine site on Ober Creek near the middle of the photo and Donnelly Dome in the background.

continuity for at least 1/4 mile.

The thickest and most laterally continuous coal zone exposed in the Jarvis Creek coalfield is at the base of the middle unit. Maximum observed thickness is approximately 20 feet in its most westerly exposure (URC2) where it is composed of 11 feet of coal in two separate beds (B and C seams), and nine feet of bony coal or fissile carbonaceous shale (Fig. 14). It is split toward the east by an interburden of highly indurated, arkosic sandstone. The B seam is thickest, up to eight feet, in the east whereas C seam is thickest, up to seven feet, in the west.

Other thick coalbeds include: a lenticular eight foot bed near the base of the lower unit; a seven foot bed facing Ruby Creek near the top of the steep bluff; and two beds, nine feet and six feet thick, facing Little Gold Creek, also near the top of the bluff. The latter three beds are all in the upper unit and relatively close to the surface.

Measured stratigraphic sections from the Jarvis Creek coalfield are shown in Plate 1. The plate is divided vertically into three sections depicting the three stratigraphic units. Correlated coal beds are shown by tie lines. Sample numbers indicate specific locations within the sections where each was taken. Plate 2 contains the lithologic symbols used in Plate 1 as well as lithologic descriptions of the three Jarvis Creek units.

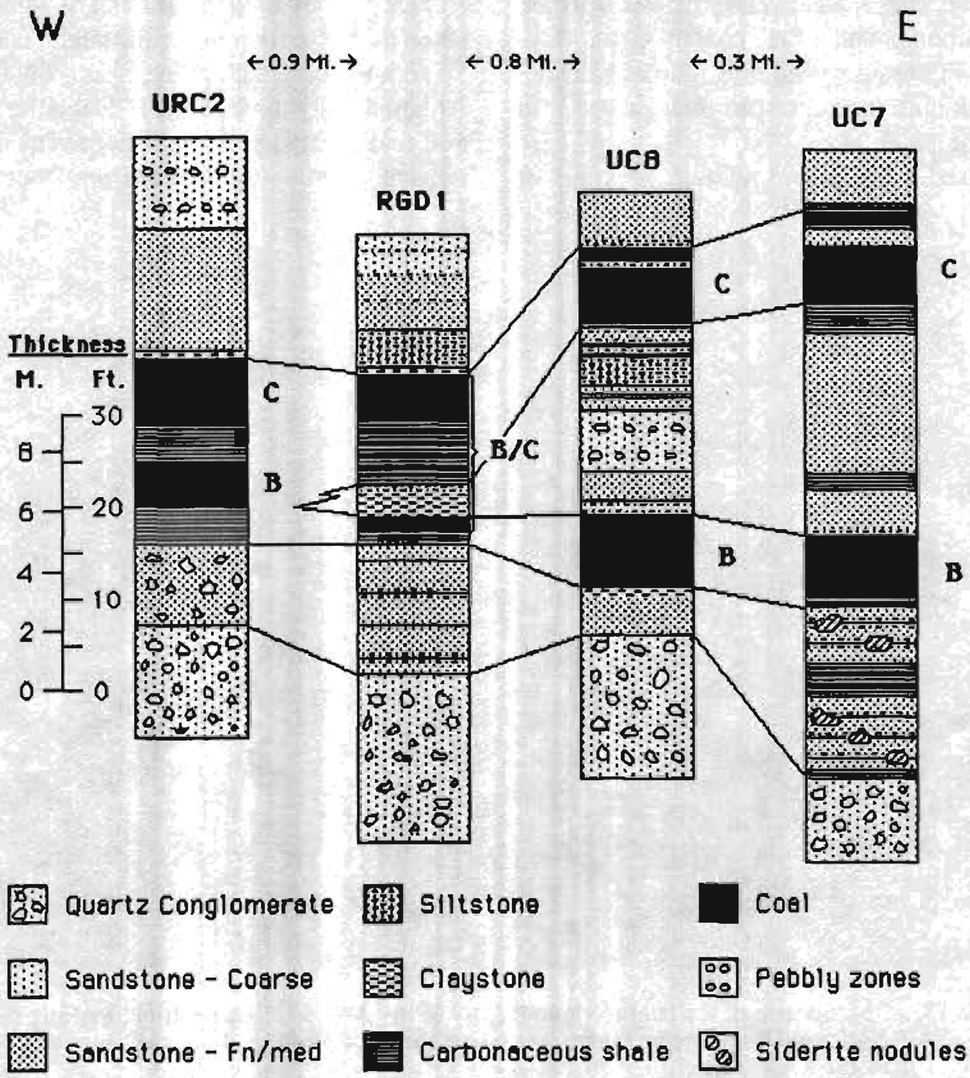


Figure 14. Stratigraphic columns of four B and C seam outcrop exposures, southeastern portion, Jarvis Creek coalfield. See Figure 6 for locations.

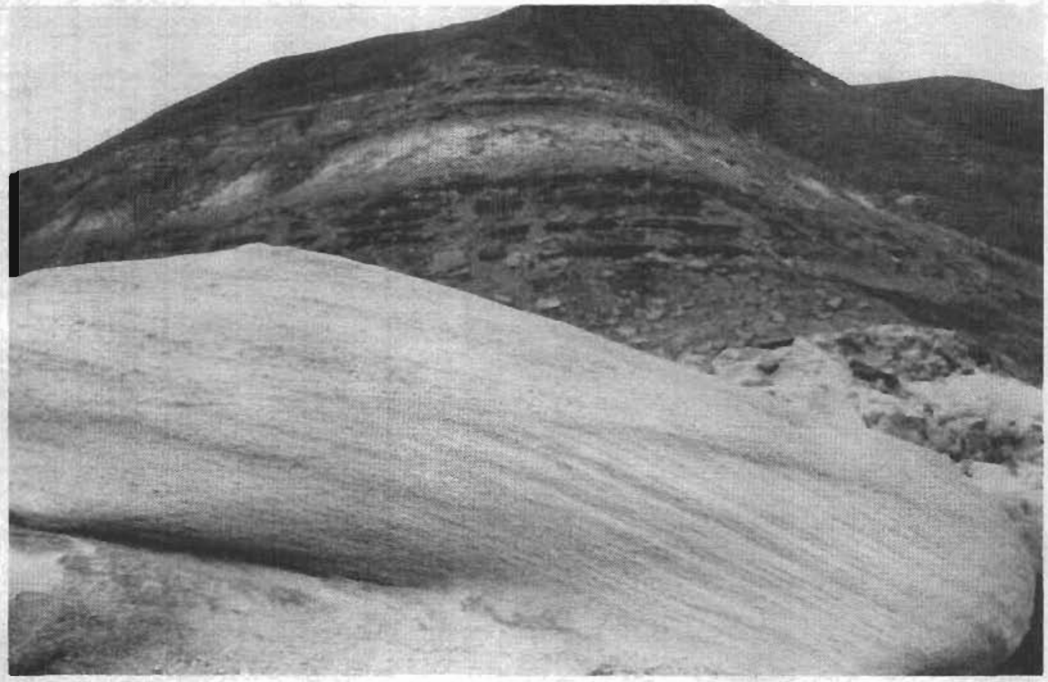


Figure 15. Photograph of planar crossbedding in a lower unit sandstone near headwaters of Ruby Creek.

Analysis - Clastics

Sediment Dispersal Patterns

The coarseness, general lack of induration, and relative sparcity of sandstone outcrops made it impossible to acquire sufficient paleocurrent measurements to satisfy tests of statistical significance. Therefore only provisional, or tentative, interpretation of provenance should be made from the data, to be evaluated in the light of other geologic information.

Sedimentary structures, with the exception of crossbedding, are not common in Jarvis Creek sandstones. These sands are generally massive, but crossbedding as well as rippled and convoluted bedding occur. Crossbedding is generally rare in the coarse middle unit, and only slightly more abundant in the conglomeratic lower unit. Only planar crossbedding was observed in the lower and middle stratigraphic units, while the upper unit had planar and trough crossbedding, as well as rippled and convoluted bedding . Figure 15 shows one such planar crossbedded sand in the lower unit while Figure 16 shows both planar and trough crossbedding in an upper unit sandstone.

Paleocurrent data obtained from available crossbedded sandstones is presented in Figure 17. This figure lists the measured sections where the paleocurrent measurements were taken and the uncorrected strike and dip of the crossbeds, as well as the corrected (for tectonic tilt) paleocurrent directions.

Sediments supplied to the Jarvis Creek basin apparently were derived from several directions as shown in the rose diagram (Fig. 17). Lower unit sand forsets prograded from the southeast while the only two measurements from the middle unit arkoses trend toward the southwest. The highly crossbedded and convoluted (Fig. 18) upper unit sands show greater variability, but generally prograded westward.

Petrography

The petrographic study of the Jarvis Creek coalfield sandstones and others from the Healy Creek type section suggests some provenances not recog-

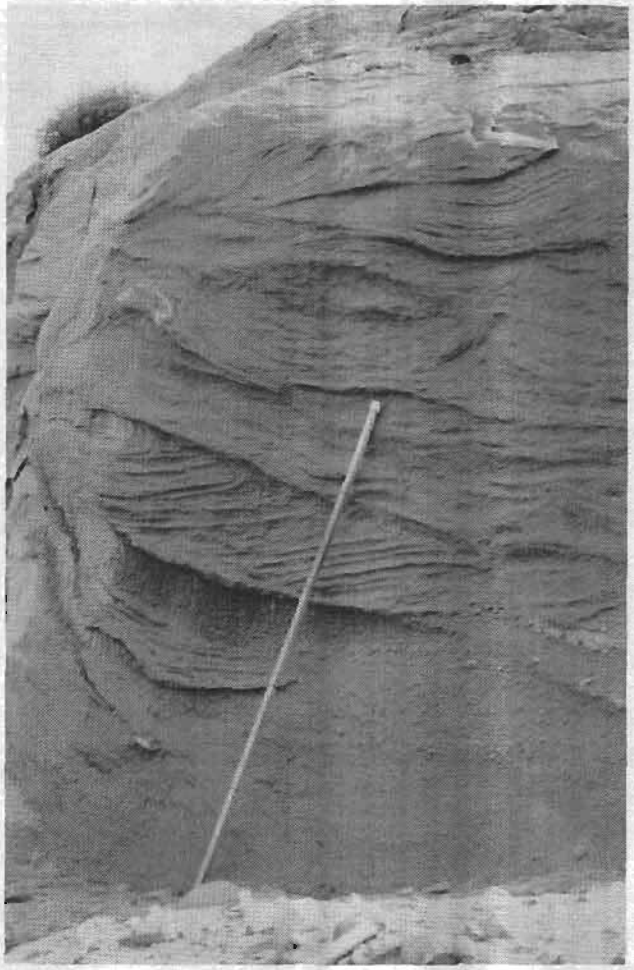


Figure 16. Photograph of planar and trough crossbedding in an upper unit sandstone near Jarvis Creek.

LITHOLOGIC UNIT	SECTION NUMBER	ORIENTATION		RESTORED	TYPE
		STRIKE	DIP	STRIKE	
Upper	JCM	N69W	31NE	N89W	Planar crossbed
	UC10	N58E	12NE	N66W	Planar crossbed
	UC10	N40E	32NW	N59W	Planar crossbed
	UC10	N65E	25NW	N24W	Planar crossbed
	LGC1	N73E	22NW	N14E	Planar crossbed
	LGC1	N25W	14NE	S65W	Planar crossbed
	LGC1	Due N	18N	S52W	Planar crossbed
	LGC1	N15E	32NW	N80W	Planar crossbed
	LGC1	N5W	15NE	S25W	Trough crossbed
	LGC1	N20E	15NW	N70W	Trough crossbed
	LGC2	N38W	19NE	S39W	Planar crossbed
	LGC2	N70W	30NE	S3W	Planar crossbed
	LGC2	N30W	20NE	S20W	Trough crossbed
	SC4	N35E	45NW	N83W	Planar crossbed
Middle	RGD1	N45E	15NW	S58W	Planar crossbed
	UC7	N46W	15NE	S21W	Planar crossbed
Lower	URC6	N47W	10NE	N58W	Planar crossbed
	UC6	N88E	23NW	N2E	Planar crossbed
	UC6	N88W	12NE	N9E	Planar crossbed
	UC7	N85E	45NW	N3W	Planar crossbed
	UC7	N45W	14NE	N20E	Planar crossbed
	UC8	N78E	23NW	N76E	Planar crossbed
	RGD1	N50W	20NE	N83E	Planar crossbed
	RGD1	N68W	14NE	N89E	Planar crossbed

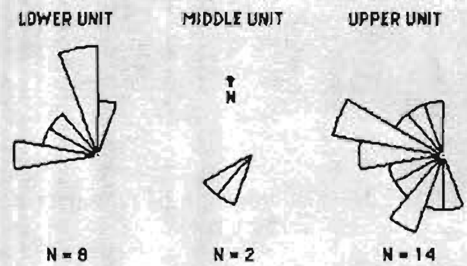


Figure 17. Directional data and corresponding Rose Diagrams for the crossbedded sandstones at Jarvis Creek. N = number of readings

nized by Wahrhaftig and Hickcox (1955). The number and location of thinsection point counts are as follows: Jarvis Creek - lower unit (4), middle unit (6), upper unit (9), Birch Creek Schist (1); Healy Creek - Healy Creek Fm. (2), Suntrana Fm. (2), Lignite Creek Fm. (3). Jarvis Creek will be discussed first, followed by Healy Creek. Raw petrographic data are listed in Table 1.

Jarvis Creek

The Jarvis Creek lower unit is quartz-rich, containing an average of 81 percent quartzose grains. Lithic grains, mainly quartz-mica schist/gneiss rock fragments and sericite flakes, constitute the remaining 19 percent. Feldspars were negligible in this unit.

The middle unit contained both white quartzose sands and brown arkoses. Only the arkoses were studied petrographically because the white lower unit sands and the white middle unit sands are apparently identical. It is assumed that both were derived from the same parent rock and thus would yield similar petrographic data. Middle unit arkoses contained an average of 23 percent feldspar, mostly potassium feldspar (not including microline), with very minor amounts of plagioclase, altered feldspar and microcline. The rest of the grains in these arkoses consisted of an average of 60 percent quartzose and 17 percent lithic grains, the latter being mostly plutonic and metamorphic rock fragments and cherty argillite.

The upper unit sands are mineralogically immature, containing an average of 40 percent lithic fragments. These included chert and cherty argillites, and metamorphic rock fragments, mostly quartz-mica phyllites. Quartzose grains constituted 53 percent of the upper sands, with seven percent feldspar, again mostly potassium feldspar. Figure 19 shows photomicrographs of typical sandstone detrital assemblages from the three separate Jarvis Creek units.

The two supplementary sandstone samples, one from the northern part of the coalfield (OC1-1S) and

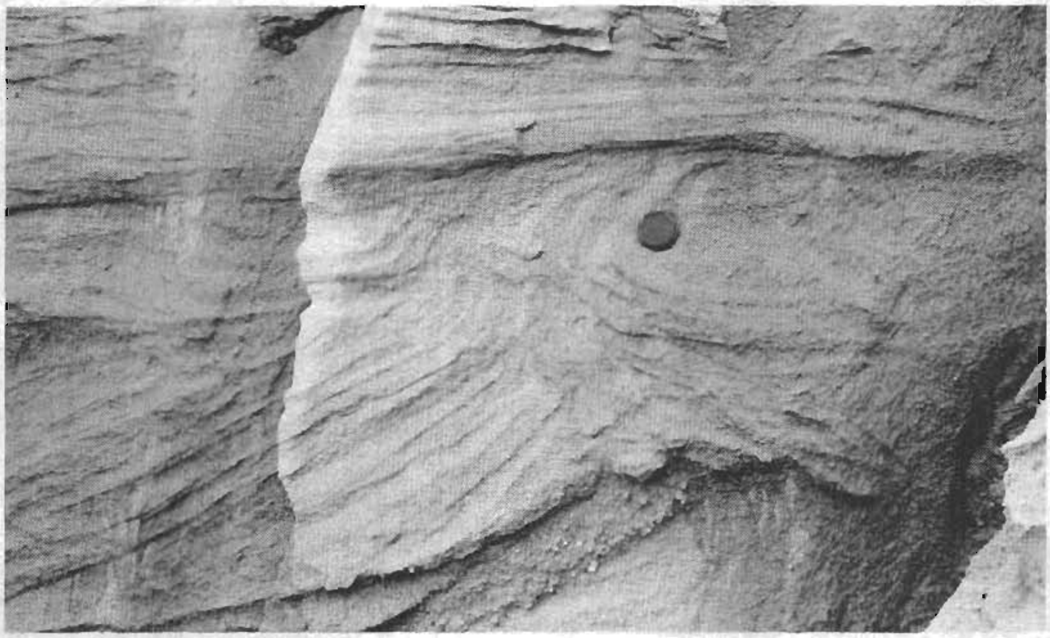


Figure 18. Photograph of convoluted bedding in an upper unit sandstone near Jarvis Creek.

TABLE 1

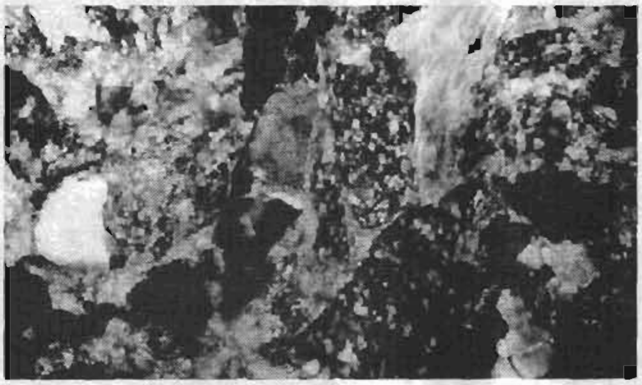
Petrographic data calculated on a volumetric basis for the Healy Creek type section and Jarvis Creek sandstones following methods given by Dickinson and Suczek (1979). Unit designation as follows: U=Upper unit; M=Middle unit; L=Lower unit, all from Jarvis Creek. HC=Healy Creek Fm.; S=Suntrana Fm.; LC=Lignite Creek Fm; all from the Typesection at Healy Creek. BCS=Birch Creek Schist sample. Grain categories are: Q=total quartzose grains; F= monocrystalline feldspar; L=polycrystalline lithics; Qm=monocrystalline quartz; Lt=total lithics plus quartzose lithics; Qp=polycrystalline quartz; Lv=volcanic and metavolcanic lithics; Ls=sedimentary and metasedimentary lithics; P=plagioclase; K=potassium feldspar (k-spar).

Sample	Unit	Q	F	L	Qm	F	Lt	Qp	Lv	Ls	Qm	P	K
URC6-1S	BCS	74	0	26	45	0	55	54	0	46	100	0	0
URC6-3S	L	93	0	7	76	0	24	71	0	29	100	0	0
RGD1-1S	L	84	0	16	60	0	40	61	0	39	100	0	0
UC2-1S	L	69	0	31	50	0	50	39	0	61	100	0	0
UC7-1S	L	79	0	21	51	0	49	57	0	43	100	0	0
RC1-1S	M	60	29	11	41	29	30	63	0	37	60	0	40
RC1-3S	M	56	24	20	30	24	46	55	2	43	60	3	37
URC2-4S	M	58	25	17	35	25	40	58	0	42	64	2	34
RGD1-2S	M	62	15	23	32	15	53	57	0	43	70	0	30
UC7-2S	M	64	24	12	46	24	30	60	0	40	67	0	33
OC1-1S	M?	76	11	13	27	11	62	79	0	21	73	0	27
RC2b-2S	U	53	6	41	10	6	84	52	0	48	67	7	26
URC1-1S	U	50	9	41	20	9	71	42	1	57	74	7	19
RGD1-3S	U	62	6	32	19	6	75	57	0	43	79	4	17
LGC3-3S	U	44	11	45	16	11	73	38	0	62	64	12	24
SC1-1S	U	55	5	40	18	5	77	48	0	52	78	4	18
DD1-2S	U?	46	14	40	20	14	66	39	0	61	61	0	39
HCF1	HC	54	9	37	31	9	60	39	0	61	79	0	21
SF1	S	48	14	38	27	14	59	36	0	64	66	5	29
LCF2	LC	52	19	29	28	19	53	45	0	55	61	7	32
JCM2S*	U	49	4	47	12	4	84	44	0	56	86	0	14
URC3-2S*	U	46	2	52	3	2	95	45	0	55	75	0	25
LGC1-2S*	U	42	2	56	4	2	94	40	1	59	100	0	0
HCF2*	HC	63	15	22	47	15	38	41	0	59	76	0	24
SF2*	S	67	2	31	17	2	81	61	1	38	89	0	11
LCF1*	LC	49	12	39	26	12	62	37	0	63	72	3	25
LCF3*	LC	42	4	54	12	4	84	35	1	64	80	0	20

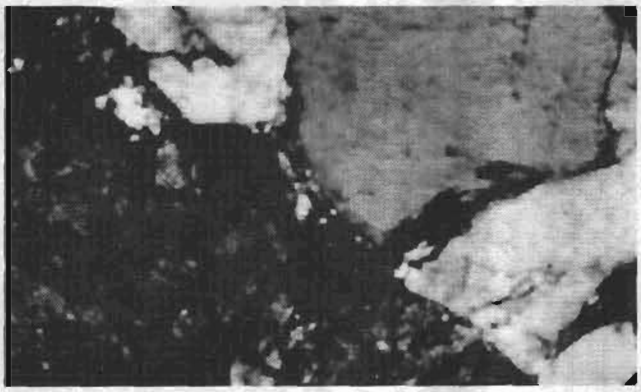
* denotes pebble counts.

the other from near Donnelly Dome (DD1-2S), show compositional affinities with the Jarvis Creek stratigraphic units (Table 1). The northern sample OC1-1S is extremely quartz-rich, with 76 percent quartzose grains, with 11 percent feldspar and 13 percent lithics. In its conglomeratic nature and clast composition, this sandstone strongly resembles sandstones near the top of the lower stratigraphic unit; perhaps it is a transition between the white quartzose sands and the brown arkoses. Its position just above the Birch Creek Schist substantiates such a correlation, as noted earlier by Wahrhaftig and Hickcox (1955). The sample from near Donnelly Dome (DD1-2S) has a much different composition. It contains 46 percent quartzose grains, 14 percent feldspar and 40 percent lithics, which is very similar to theupper unit sandstones. Although it has slightly more feldspar, this sandstone probably is an erosional remnant of a once much larger expanse of the upper unit.

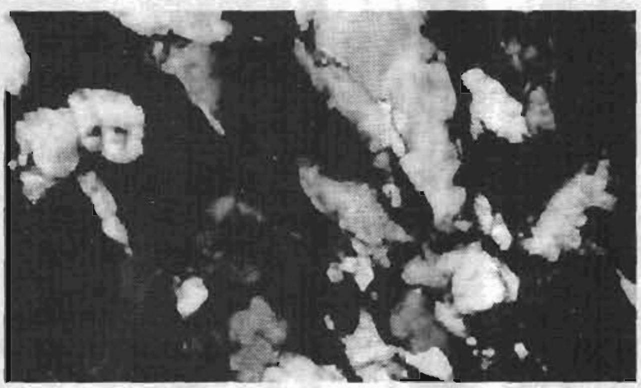
Point counts were also made on three granule samples from the upper unit. They show that quartzose clasts, mainly polycrystalline quartz and chert, constitute an average of 46 percent of the sample (Table 1), while lithic clasts constitute 51 percent. The latter are mainly plutonic and metamorphic rock fragments, sandstone and shale. Feldspar clasts comprise 3 percent of the samples. In general, granule data show great similarity to point counts for sandstones except that the sandstones contain over twice as much feldspar.



U



M



L

Figure 19. Photomicrograph of typical detrital assemblages from L-Lower; M-Middle; and U-Upper unit sandstones. Photomicrograph taken in transmitted light. Width of field for upper and lower units is .43 mm, 1.06 mm for middle unit.

Healy Type Section

Seven sandstones from the Healy Creek type section were sampled to compare them petrographically with those at Jarvis Creek. The lowermost unit at Healy, the Healy Creek Formation, shows the most quartzose grains (54%) and the least feldspar grains (9%), which is similar to the Jarvis Creek lower unit sands (Table 1). However, the large amount of lithic grains (37%) is quite different. The Suntrana Formation, overlying the Healy Creek Formation, is also similar in these aspects except that it contains more feldspar and thus fewer quartzose grains. The overlying Lignite Creek Formation, on the other hand, is more similar to the upper unit Jarvis Creek sands, both in field appearance and clast composition. Compared to the Jarvis Creek units, there is an overall trend toward more quartzose grains downsection and more feldspar upsection at the Healy Creek type section. Content of lithics is variable with no particular trends.

Granule counts of the Healy Creek section show similar trends to those observed in sandstones from the same localities. Healy Creek and Suntrana Formations contain considerably more quartzose granules than the Lignite Creek Formation: 65 percent compared to 46 percent (Table 1). Healy Creek Formation quartzose granules are predominantly monocrystalline while those in the Suntrana Formation are mostly polycrystalline. Lithic clasts such as plutonic and metamorphic rock fragments, chert, cherty argillite, argillite and sandstone are, on the average, much more abundant in the Lignite Creek Formation than in the lower and older Healy Creek and Suntrana Formations. In fact, large clasts in the Lignite Creek Formation occur in very similar percentages to those in the upper unit at Jarvis Creek.

Conventional pebble counts have been made in the Healy Creek area, most recently by Stevens (1971). She found similar trends toward more quartzose pebbles in the older formations and more lithics in the younger Lignite Creek Formation pebbles. Her percentages for quartzose clasts were appreciably higher in all cases but were based on identification of large uncut pebbles under a binocular microscope. Identification of clasts in thin section, as in the present study, probably results in more accurate rock fragment identification and in any case involves a smaller grain size than Stevens' (1971) study. Raw point count and granule count data are listed in Appendix 1.

Tectonic Implications

Studies of sandstone suites from different basins reveals that clast composition is a function of provenance that is largely governed by plate tectonics according to Dickinson and Suczek (1979). They used triangular diagrams to show that the framework proportions of quartz, the two feldspars, polycrystalline quartzose lithics, and unstable lithics of volcanic and sedimentary parentage can successfully distinguish the key provenance types. Their techniques and interpretations were followed in the present study.

In practice, four triangular diagrams are used; QFL, QmFLt, QpLvLs and QmPK diagrams. The QFL diagram is the standard for discrimination of provenace and the other three plots are auxiliary in that they augment and amplify the criteria for distinction among tectonic settings (Dickinson and Suczek, 1979). These diagrams use recalculated sandstone modal compositions as volumetric proportions of the following categories of grains: (1) stable quartzose grains, Q, including both monocrystalline quartz grains, Qm, and polycrystalline quartzose lithic fragments, Qp, which are chiefly chert grains; (2) monocrystalline feldspar grains, F, which includes plagioclase, P, and potassium feldspar (K-spar), K; and (3) unstable polycrystalline lithic fragments, L, of two kinds; (a) Lv, volcanic and metavolcanic types, and (b) Ls, sedimentary and metasedimentary types. The total lithic fragments, Lt, then equal the sum of unstable lithic fragments, L, plus stable quartzose lithic fragments, Qp. Extraneous constituents, such as heavy minerals and calcareous grains, are disregarded.

According to Dickinson and Suczek (1979), three main types of provenances are determined from these plots. They include; (1) continental block provenances which incorporate the cratonic interior, transitional and uplifted basement sources; (2) magmatic arc provenances which include undissected, transitional and dissected arc sources, and (3) recycled orogen provenances which include subduction complexes, collision orogens and foreland uplifts.

Jarvis Creek and Healy Creek type section modal sandstone proportions plotted on triangular diagrams of Dickinson and Suczek (1979), fall into tight clusters or at least have limited distribution. The QFL diagram, where emphasis is on grain stability in terms of weathering, provenance relief, and transport mechanism, as well as source rock, shows that almost all samples fall within the recycled orogen provenance field (Fig. 20A). Source rocks from this provenance are generally from uplifted terranes of folded and faulted strata from which recycled detritus of sedimentary or metasedimentary origin is especially prominent (Dickinson and Suczek, 1979).

The three units at Jarvis Creek fall into separate, non-overlapping fields in Figure 20A. The lower unit and Birch Creek Schist sample plot along the QL line because feldspar is negligible, while the upper unit clusters nearer the lithic end member. The middle unit sands, although generally in the recycled orogen province, show a continental block influence. The increase in feldspar is probably due to sources in uplifted basement with associated plutonic rocks. High relief and rapid erosion then gave rise to the quartzo-feldspathic sands. The northern coal field sand (OC1), plots halfway between the clusters for the lower and middle units at Jarvis Creek, while the Donnelly Dome sand (DD1), is unmistakably related to the upper unit sands. Healy Creek type section rocks also plot in the recycled orogen province field and generally near the cluster for the Jarvis Creek upper unit with its high lithic content . This suggests that depositional conditions were relatively uniform in the western part of the Nenana Coal Province while at Jarvis Creek local changes occurred in provenance and depositional setting. As for granules, they plot similarly to related sandstone grain counts on the QFL diagram although they may be slightly more quartzose in the cases of the Healy Creek and Suntrana Formations.

The QmFLt triangular diagram (Figure 20B), which lumps all lithic fragments together, emphasizes the grain size of the source rocks. Importantly, finer-grained rocks yield more lithic fragments in the sand-size range. As with the QFL plot (Fig. 20A), most sands fall within recycled orogen provenance field. The Jarvis Creek middle unit and the Lignite Creek sandstone are exceptions in that they fall near the magmatic arc province. According to Dickinson and Suczek (1979) such occurrences are probably due to uplifted igneous terranes or basement blocks in a foreland uplift or collision orogen rather than an island arc. Although most sands collected were lithic rich, the upper unit Jarvis Creek sands were particularly so, and thus probably had a finer grained source rock. Healy Creek type section sands all plot near each other, substantiating the uniform conditions as suggested above. It may be significant that two granule counts, one from the upper unit at Jarvis Creek and the other from the Lignite Creek Formation, plot in exactly the same position. Although this may be a coincidence,

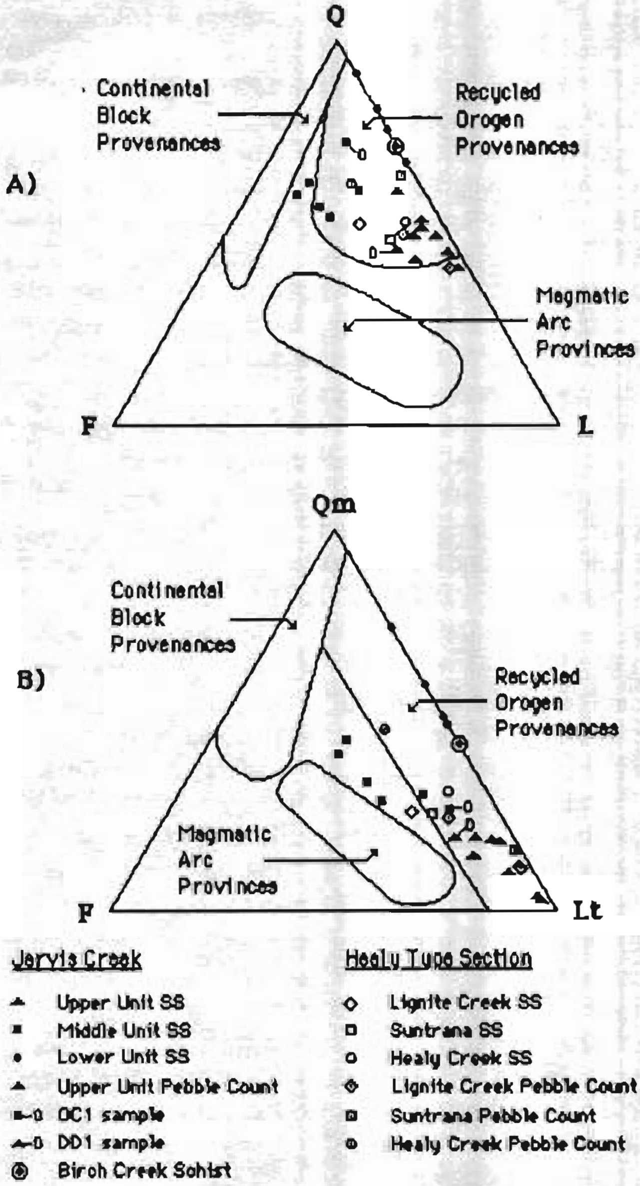


Figure 20. QFL / QmFLt diagrams for Healy Creek type section and Jarvis Creek sandstones.

these units also appeared very similar in the field, as noted earlier.

The QpLvLs and QmPK plots (Figures 21A and 21B), show only partial grain populations but reveal the character of the polycrystalline and monocrystalline components of the sandstone framework. In the QpLvLs diagram (Fig, 21A), all sandstone samples studied plot along the QpLs border, within the field for a collision orogen source. They are essentially half polycrystalline quartz and half lithics. Volcanic grains were uncommon; this is somewhat surprising in view of their increased presence at the Healy type section. This was also noted by Stevens (1971) for the entire Yukon-Tanana Uplands . She states that prior to uplift and subsequent erosion of this area, volcanic grains may have been common. Most extrusives reported are Paleozoic basalts in the northwestern Yukon-Tanana Upland and Tertiary basalts in the Tanacross quadrangle (Stevens, 1971), but these occurrences are quite isolated. There are other scattered basic and ultrabasic sills and dikes in the Yukon-Tanana Upland but detrital grains from them are rare (Foley, 1985; Stevens, 1971).

A collision orogen source for the Tertiary sandstones at Jarvis Creek and the Healy Creek type section is consistant with present theories of plate tectonics and Alaskan geology. According to Csejtey and others (1982), Hickman and others (1977), and Reed and Lanphere (1973), collision of the Yukon-Tanana Terrane with the Talkeetna superterrane, associated movement along the Denali Fault, and resultant Tertiary plutonism, gave rise in the Miocene to the differential uplift of crustal blocks. Numerous fault and other crustal displacements had also occurred in the Mesozoic; they are related to this collision but to its earlier stages.

A QmPK diagram (Fig. 21B), where monocrystalline grains are compared, shows trends in maturity or stability of grains in continental block and magmatic arc provinces. All sands studied were generally quartz-rich, especially those from the lower unit at Jarvis Creek, and plotted near the increased maturity end of the diagram. Least quartz-rich was the middle unit which had substantial potassium feldspar. Plagioclase in all cases was minor. There is no simple pattern of changing maturity at Jarvis Creek: the lower unit sands show the greatest maturity (quartz content) followed by the upper unit and then the middle unit. For the Healy Creek type section, maturity increases downsection toward the Healy Creek Formation. For both areas, trends in compositional maturity are opposite to trends in textural maturity. The upper units in both coal fields show the most texturally mature sands in terms of rounder grains and better sorting while the lower units are the least texturally mature based on angularity of the monocrystalline quartz grains and poorer sorting. Evidently higher quartz content (compositional maturity) here is not necessarily correlated with higher textural maturity.

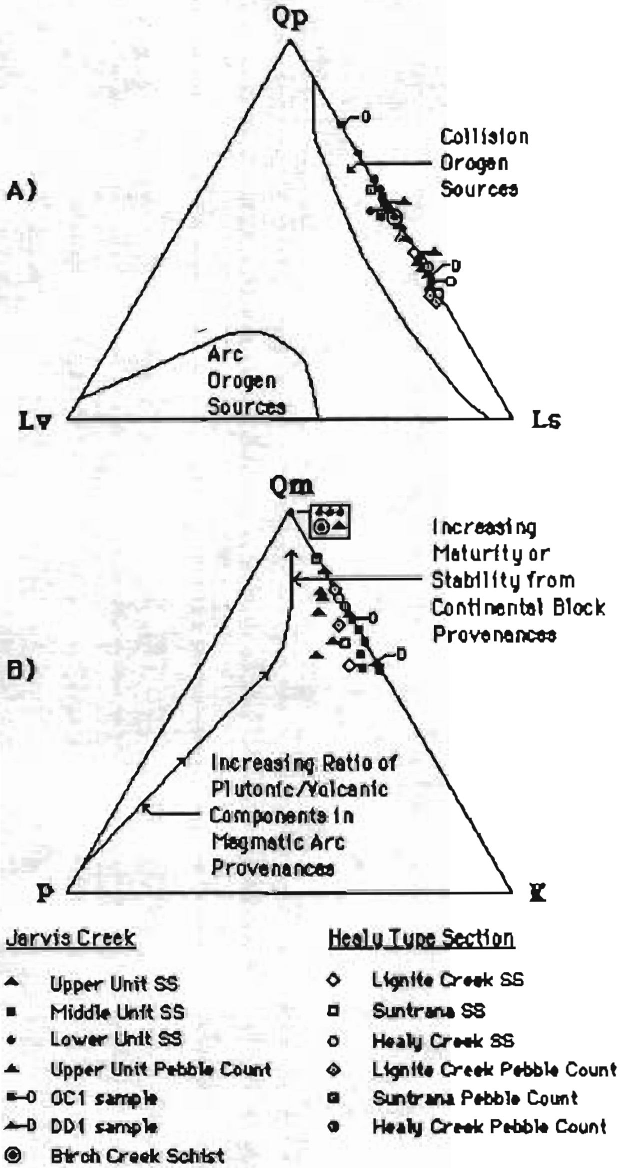


Figure 21. QpLvLs / QmPK diagrams for Healy Creek type section and Jarvis Creek sandstones.

Heavy Minerals

Heavy mineral analyses were made on the 3 to 4 phi fraction of 16 sand samples representing each of the three units. Table 2 shows the heavy fraction and light fraction weights after bromoform separation. It is evident from the table that heavy minerals in these sands increase upsection. The lower unit sands contain only 0.83 percent of heavy minerals, while the middle unit shows 1.63 percent. Samples URC2-4S and UC7-2S (marked by asterisks in Table 2) from the middle unit were not counted because incomplete disaggregation of these carbonate cemented samples resulted in anomolously high concentrations of impure heavy fractions. Heavy mineral concentration in the upper unit sands, however, increases to 4.83 percent. This increase will be an important point in the proposed interpretation of differing depositional conditions between the middle and upper units.

Weight percentages of opaque and nonopaque heavy minerals as percent of the total heavy mineral fraction are also shown in Table 2. Heavy minerals are generally angular to subangular and were predominantly opaque in all units. Average opaque heavy mineral contents for the lower, middle and upper units were 66%, 54%, and 72%, respectively. The low opaque count for OC1-1S was due to incomplete dissolution and the quartz contamination of this sample.

The various heavy mineral species in the three units are listed in Figure 22. Several heavy minerals are common to all three Jarvis Creek units while others characterize certain units. Incomplete separation of heavy minerals is indicated by the presence of the light minerals indicated in Figure 22.

TABLE 2

Raw weight and petrographic data for 16 Jarvis Creek heavy mineral samples. Sample weights are in grams.

UNIT	SAMPLE	WEIGHT HEAVYS	WEIGHT LIGHTS	TOTAL SAMPLE WEIGHT	% HEAVYS	% OPAQUE	% NONOPAQUE
U	RC2b-2S	.1726	5.9177	6.0903	2.83	90	10
U	URC1-1S	.2133	5.9928	6.2061	3.44	74	26
U	UC9-1S	.6967	4.6684	5.3651	12.99	86	14
U	LGC1-2S	.4915	3.4592	3.9507	12.44	87	13
U	JCM2S	.0450	5.3152	5.3602	0.84	67	33
U	SC4-1S	.0345	5.3363	5.3708	0.64	48	52
U	DD1-2S	.0443	6.7119	6.7562	0.66	51	49
M	RC1-3S	.0339	3.3243	3.3582	1.01	53	47
M	*URC2-4S	.4739	2.9795	3.4534	13.72	87	13
M	RGD1-2S	.1512	3.9124	4.0636	3.72	73	27
M	*UC7-2S	1.1361	4.9891	6.1252	18.55	87	13
M	OC1-1S	.0075	4.7848	4.7923	0.16	36	64
L	RGD1-1S	.0695	6.9310	7.0005	0.99	73	27
L	URC6-3S	.0377	7.9739	8.0116	0.47	56	44
L	UC2-1S	.0475	4.3134	4.3609	1.09	68	32
L	UC7-1S	.0436	5.5328	5.5764	0.78	65	35

* denotes cemented sandstones where incomplete dissolution of cement resulted in abnormal amounts of iron-stained grains.

MINERALS / SAMPLES	URC6-3S	RDG1-1S	UC2-1S	UC7-1S	RC1-3S	URC2-4S	RGD1-2S	UC7-2S	OC1-1S	RC2b-2S	URC1-1S	UC9-1S	LOC1-2S	UCM2S	SC4-1S	DD1-2S
*Feldspar/Quartz	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
*Micas	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Chlorite	X	X	X	X						X	X	X	X	X		X
*Clays (Mont.+Ill)		X							X				X			
Zircon		X	X		X		X			X	X				X	X
Tourmaline	X	X	X	X	X		X		X	X	X		X	X		X
Rutile	X	X	X	X			X		X	X		X	X			X
Sphene										X	X	X	X	X	X	
Hornblende							X									
Epidote												X	X	X	X	X
Flourapatite							X						X	X		
Anatase			X										X			
Idocrase			X							X						
Spinel						X	X				X					
Diopside		X														
Garnet (Alm)						X										
Zoisite										X	X	X				
Clinozoisite							X									
Scapolite															X	
Jarosite				X												
Hematite								X				X	X			
Magnetite		X								X						
Ilmenite		X	X	X		X	X	X		X		X				
Enargite												X				
Manganite										X	X					
Pyrolusite													X			
Pyrite		X											X			X
Psilomelane	X		X	X												
Siderite						X	X	X								X
Dolomite							X									

LOWER UNIT — MIDDLE UNIT — UPPER UNIT

* Not heavy minerals, present due to incomplete separation

Figure 22. Heavy mineral assemblages from 16 Jarvis Creek sandstones.

Detrital heavy minerals from the lower unit include significant amounts of chlorite, tourmaline, rutile, ilmenite and psilomelane. There are minor amounts of zircon, anatase, idocrase, diopside and magnetite. Jarosite and pyrite are also present, but are authigenic and not related to provenance.

Detrital heavy minerals from the middle unit include significant amounts of ilmenite and tourmaline with minor or trace amounts of zircon, rutile, spinel, hornblende, flourapatite, almandine garnet, clinozoisite, and dolomite. Siderite and hematite are authigenic and again not related to provenance.

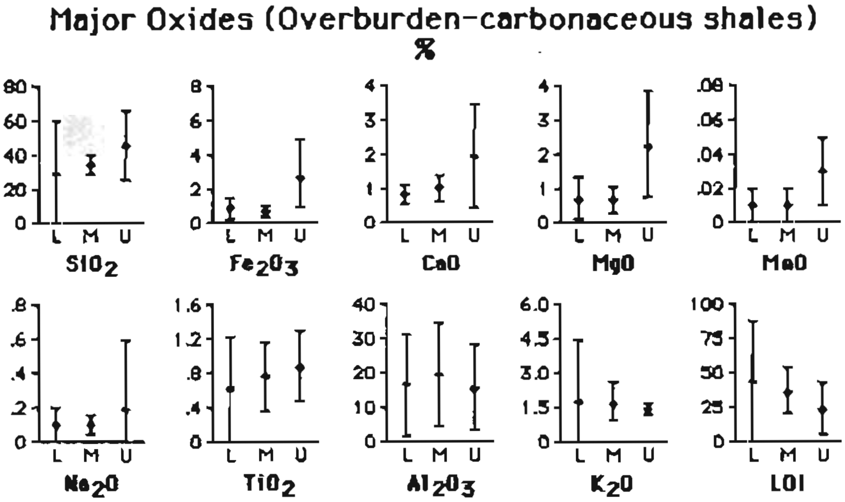
Detrital heavy minerals from the upper unit include significant amounts of chlorite, zircon, tourmaline, rutile, sphene and epidote. Present as traces are zoisite, flourapatite, hematite, Ilmenite, manganite, pyrite, montmorillonite, anatase, idocrase, spinel, magnetite, enargite, pyrolusite, scapolite and siderite. Hematite, pyrite and siderite again are authigenic and not provenance related.

It is evident from Figure 22, that the largest variety (23) of detrital heavy minerals occurs in the upper unit. Minerals such as sphene, epidote, chlorite, zoisite, manganite, pyrolusite, scapolite, and enargite were either found only in the upper unit or are markedly more abundant than in other units. Many of these are metallic minerals commonly associated with epithermal and hydrothermal replacement deposits (Chesterman, 1978), or oxides of these metallic minerals. This suggests that weathering and erosion of base metal mineralization zones near the Jarvis Creek coalfield and subsequent transport of grains by streams, resulted in enrichment in the upper unit sands. This phenomenon is local, however, as these metallic minerals and their oxides are not observed in the heavy mineral suites in the Nenana Coal fields to the west (Stevens, 1971).

Chemical Composition

Changes in overburden geochemistry throughout the Tertiary coal-bearing formation at Jarvis Creek can best be studied by looking at vertical trends through the separate units. Twenty-seven samples of roof, seat and interburden clastics from the coal measures were examined for such trends. These included four samples from the lower stratigraphic unit, six from the middle unit, and seventeen from the upper unit which contained the most coal seams (Fig. 11). Types of clastic rocks examined were claystones, carbonaceous shales, siltstones, and sandstones. Claystone and carbonaceous shales were the only clastics sampled in the lower unit while all four clastic types were sampled from the other two units.

Compositional data and statistical trends for sampled carbonaceous shales within the three stratigraphic units are shown in Figure 23; raw data for all samples are listed in Appendix 5a. Nine major oxides (SiO_2, Fe_2O_3, CaO, MgO, MnO, Na_2O, TiO_2, Al_2O_3, and K_2O) along with the previously determined percentage of loss on ignition (LOI) were compared. Carbonaceous shale, common to all three stratigraphic units and sampled at least three times in each unit, was compared statistically. The lack of or insufficient sampling of the other three lithologies (claystone, siltstone, and sandstone) in all three units precluded



* No. of samples from units as follows: L–Lower unit (3); M–Middle unit (3); U–Upper unit (4).

	Lower Unit			Middle Unit			Upper Unit		
	R	M	S	R	M	S	R	M	S
SiO_2	16.7–46.3	28.10	15.90	31.2–37.20	34.00	3.00	38.6–55.20	45.50	9.70
Fe_2O_3	0.34–0.92	0.65	.30	0.29–0.70	0.54	.22	1.64–3.80	2.64	1.15
CaO	0.69–0.96	0.83	.14	0.86–1.17	1.03	.16	1.53–2.88	1.95	.76
MgO	0.32–0.86	0.67	.31	0.46–0.83	0.68	.20	1.36–2.98	2.23	.78
MnO	0.00–0.01	0.01	.01	0.00–0.01	0.01	.01	0.02–0.04	0.03	.01
Na_2O	0.06–0.16	0.10	.05	0.08–0.14	0.10	.03	0.08–0.42	0.19	.20
TiO_2	0.42–0.96	0.60	.31	0.53–0.94	0.74	.20	0.69–1.04	0.86	.20
Al_2O_3	10.2–24.90	16.50	7.50	10.8–25.50	19.30	7.60	12.4–23.10	15.60	6.30
K_2O	3.34–0.99	1.80	1.30	1.26–1.99	1.70	.40	1.35–1.60	1.47	.12
LOI	17.3–59.35	42.70	22.30	30.7–43.86	36.30	8.30	17.2–31.55	24.30	9.40

* R=Range; M=Mean; S=Standard Deviation

Figure 23. Statistical trends and data of major oxides from overburden/carbonaceous shales, Jarvis Creek coalfield.

their use for statistical reasons. For example, only one claystone, siltstone and sandstone was sampled in each of the lower and middle units (Table 3). Sampling in the upper unit was better due to the increased number of coal seams. Figure 23 is broken down into two parts. The top half shows the mean concentrations of major oxides within each stratigraphic unit +/- two standard deviations, while the bottom half lists range, mean and standard deviation data. No definitive relationships between major oxide concentrations and stratigraphic units can be made due to large standard deviations. Given the limited number of samples, it is possible that additional samples might produce some trends that are only suggested by the available data. For example, Fe, Ca and Mg all appear to be enriched upsection (Figure 23), but the large standard deviations preclude any more exact correlation.

Trends in chemical composition of these overburden rocks in relation to grain size were also examined (Table 3). The highest major oxide percentages generally occur in the finer clastics; SiO_2 is the exception, and as expected, is highest in the sandstones or coarser clastics. Similar compositional trends are also observed in the Beluga Coalfield rocks in South-Central, Alaska, in the Paleocene Fort Union Formation of the Northern Plains, the Cretaceous Kimbeto Coalfield of New Mexico, and various other Cretaceous coal-bearing strata from Colorado, Utah, New Mexico and Wyoming (Hinkley and others, 1982).

Major oxide concentrations also vary with lithology. Comparison of clastic lithologies (Fig. 24) show that claystones contained the highest concentration (37%) of maximum major oxides in each stratigraphic unit. This is followed by siltstone (27%), carbonaceous shale (20%) and sandstone (17%). The highest Ca and Mn concentrations are in the claystones while Al, Mg, and Ti occur in all three finer lithologies. High Fe, Na and K contents occur in all four lithologies including sandstone. As expected, Si was highest in sandstones, with the exception of an unusual white clay seatrock beneath a large coalbed, just above the Birch Creek Schist/Tertiary boundary. This sample

TABLE 3

Chemical composition of overburden rocks in relation to lithology at the Jarvis Creek coalfield, East-Central Alaska. Values are arithmetic means, n = number of samples used in calculation. C = Claystone, CS = Carbonaceous shale, S = Siltstone, and SS = Sandstone.

Chemical Species	Lower Unit		Middle Unit				Upper Unit				Averages			
	n=1	n=3	n=1	n=3	n=1	n=1	n=3	n=4	n=2	n=8				
	C	CS	C	CS	S	SS	C	CS	S	SS	C	CS	S	SS
SiO_2	76.0	28.1	48.6	34.0	53.0	67.8	57.9	45.5	57.6	64.1	59.7	36.8	56.1	64.5
Al_2O_3	13.0	16.5	33.0	19.3	28.9	17.2	15.5	15.6	17.0	15.0	18.5	17.0	21.0	15.3
Fe_2O_3	0.3	0.7	0.8	0.5	0.8	1.2	2.8	2.6	3.4	1.7	1.9	1.4	2.5	1.6
MgO	0.4	0.7	0.5	0.7	0.4	0.3	3.2	2.2	3.6	1.6	2.1	1.5	2.5	1.5
CaO	0.9	0.8	1.1	1.0	0.9	1.0	2.8	2.0	2.5	2.1	2.1	1.3	1.9	2.0
Na_2O	0.1	0.1	<0.1	0.1	0.1	0.1	0.2	0.2	0.6	0.4	0.2	0.1	0.4	0.4
K_2O	1.8	1.8	1.6	1.7	1.8	2.4	1.8	1.5	1.9	1.8	1.7	1.6	1.9	1.9
TiO_2	1.0	0.6	0.6	0.7	0.8	0.6	1.1	0.9	1.1	0.8	1.0	0.8	1.0	0.8
MnO	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.1	<0.1	0.1	<0.1	<0.1	<0.1	<0.1	<0.1
* Ba	643	2040	434	1786	336	737	2711	2437	2867	2192	1842	2133	2023	2030
* Be	1.6	3.5	4.2	3.7	3.2	1.5	1.8	2.4	2.0	1.9	2.3	2.9	2.4	1.9
* Cd	0.0	0.3	1.0	0.3	0.0	0.0	1.3	1.5	2.0	1.3	0.9	0.7	1.3	1.1
* Co	35	16	27	18	14	28	37	30	41	35	35	22	37	34
* Cr	58	63	51	77	36	31	155	422	207	96	115	211	150	89
* Cu	0	32	47	38	42	26	111	147	106	65	76	80	84	61
* Ni	7	12	25	11	13	18	62	57	83	34	43	30	60	32
* Sr	53	140	993	107	35	69	75	73	96	82	254	103	75	81
* V	65	73	80	103	52	61	279	286	323	160	197	167	232	149
* Zn	35	340	100	365	525	645	642	665	253	422	412	478	343	447
* Zr	282	163	45	141	172	126	174	242	160	216	170	148	146	206

* denotes readings in parts per million, while others are in percentages.

variation and might be used for correlation. Vertical trends are more apparent than lateral trends at Jarvis Creek, although lateral variations did occur and were studied in the thicker coal seams. Lateral and vertical trends from the B and C seams of the middle unit turned out to be particularly important, as will be discussed later.

Proximate Analysis

Several vertical trends are apparent in the proximate analysis. Average values for proximate analyses are shown in Figure 26 and raw data are included in Appendix 2. Moisture increases upsection, in the younger coals, as expected. Ash values show no vertical trend: they are lowest in the middle unit, with somewhat higher and nearly equal values above and below. Overall, ash levels are low, with a coalfield average of 9 percent. Volatile matter shows a trend opposite to that expected: instead of increasing upsection along with moisture, values increase toward older coals. This is probably related to the increased liptinite

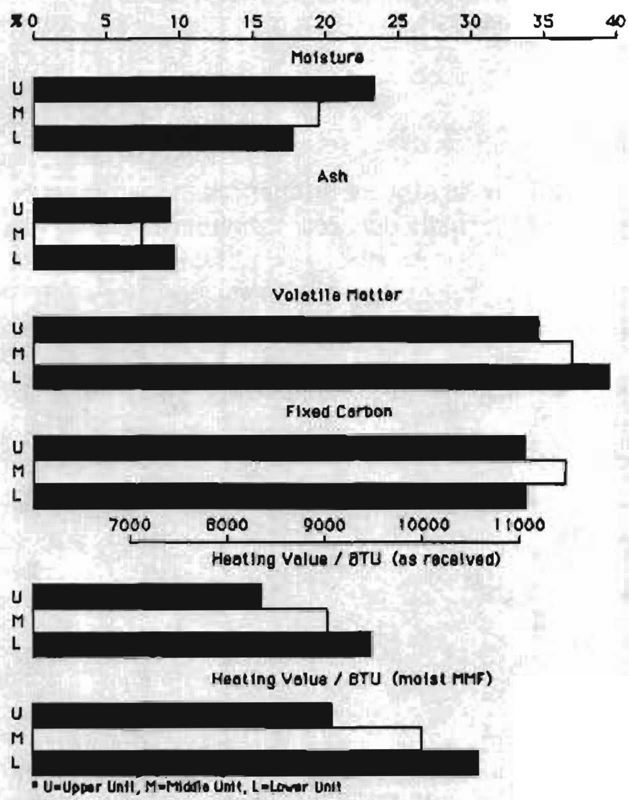


Figure 26. Bar graphs showing trends in proximate analysis (average values for each unit).

content of the coals downsection, based on the fact that liptinite macerals are normally high in volatiles, especially hydrogen (Stach and others, 1982). Fixed carbon would be expected to increase downsection toward older coals, but this not evident in Figure 26. It is probably masked in the lower unit by the somewhat high volatile matter of that unit.

Heating value (BTU) trends are included with proximate analysis in Figure 26 because heating values fluctuate with varying amounts of the basic coal compounds. In Figure 26, the heating value of the coals increases downsection, a normal pattern. Calculated on a moist-mineral matter-free basis, the lower unit coals average 10,593 Btu/lb, giving an apparent rank of subbituminous A. The middle unit coals average 10,006 Btu/lb, corresponding to subbituminous B; the upper unit coals average 9,094 Btu/lb equivalent to an apparent rank of subbituminous C. Rank is cited as "apparent" for outcrop samples because degradation due to weathering results in functional group loss (Youtcheff, 1986 personal communication) and, therefore, unreliable estimates of original coal bed conditions needed for true rank determinations (ASTM Standard procedure D388).

Ultimate Analysis

Ultimate analysis of the coals also exhibit minor vertical trends. Average values are shown in Figure 27; raw data are in Appendix 2. In Figure 27, carbon content decreases upsection toward younger coals while oxygen increases. These are normal trends. Hydrogen, however, shows almost no change, or a slight increase downsection, contrary to normal coalification trends. This anomaly can be explained by noting the increased liptinite (reported later, under coal petrology) content, a hydrogen rich component, in the lower unit. Nitrogen, a minor component of coals, also shows no change, or a slight increase downsection.

Sulfur Analysis

Sulfur values, typically quite low and consistant in Alaska Tertiary coals, are unusually variable and sometimes high in the Jarvis Creek coalfield. Averages of total sulfur and forms of sulfur are shown in Figure 28; the raw data are in Appendix 2. Although the middle and lower units have sulfur contents near the norm (about 0.5 or less) for continental coals, some

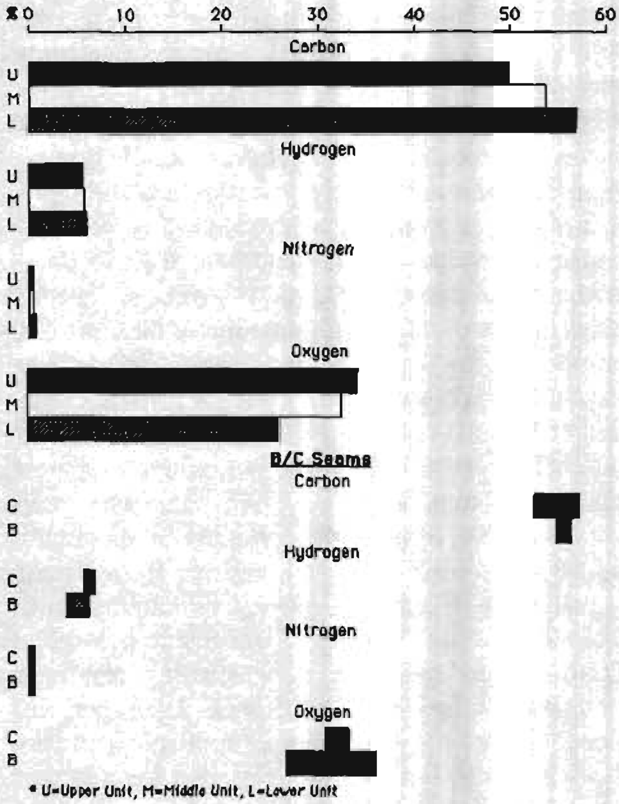


Figure 27. Bar graphs showing trends in ultimate analysis (average values for each unit).

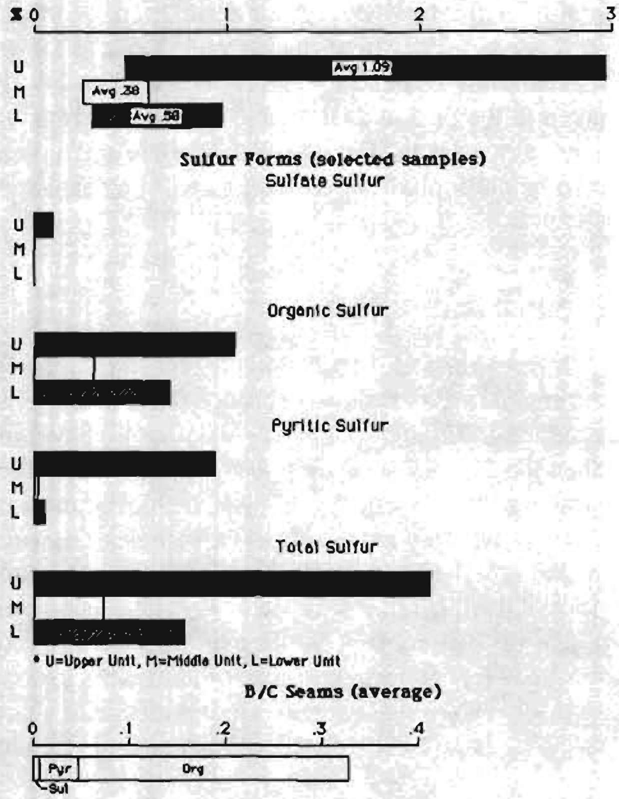


Figure 28. Bar graphs showing trends in sulfur analysis.

upper unit coals approached 3 percent (Fig. 28). Such relatively high values are not characteristic of Alaskan Tertiary coals, and rival sulfur contents from the Cretaceous lower delta plain coals at Chignik-Herendeen Bay (R. D. Merritt, 1986, personal communication).

When total sulfur values for each unit are allocated among the different forms of sulfur, sulfate sulfur is negligible (below detection limits) in both the lower and middleunits and is even low in the sulfur-rich upper unit. Organic sulfur is the predominant form in all three units but in the upper unit there is also a large amount of pyritic sulfur, mostly framboidal (Fig. 29). This is another indication that depositional conditions for the upper unit were quite different from those earlier. A source for this sulfur must have been uncovered, as no evidence of marine conditions are observed at Jarvis Creek.

<u>Petrology</u>

There are significant differences in maceral percentages of the individual coalbeds at Jarvis Creek (for

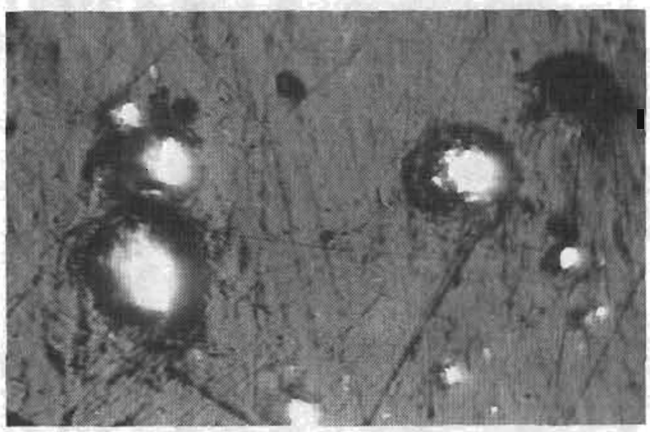


Figure 29. Photomicrograph of framboidal pyrite from an upper unit coal bed. Photomicrograph taken in normal incident light, oil immersion, width of field 140 microns.

an explanation of terminology of coal petrology, see Stach and others, 1982). In Figure 30, a ternary diagram showing the major maceral groups as end members, each stratigraphic unit plots in a different field, and, upsection, the fields shift progressively toward the vitrinite axis. Raw data for maceral composition are shown in Appendix 3a.

Macerals of the vitrinite group clearly increase upsection. The vitrinite group of macerals, which represents the more oxygenated woody portions of the trees, includes vitrinite (the most common), pseudovitrinite, phlobaphinite, pseudophlobaphinite, gelinite and vitrodetrinite. Figure 31 is a photomicrograph of vitrinite macerals including vitrinite, phlobaphinites and porogelinite.

The liptinite group macerals, sometimes called exinites, increase downsection, as shown in the bar graph in Figure 30. This is mostly an inverse relationship with vitrinite. Liptinites, which are rich in hydrogen and comprise the resins, waxes, fats and oils of the plants, include sporinite, resinite, cutinite, suberinite, alginite, exsudatinite and liptodetrinite. An increase in these macerals is responsible for the downsection increase in volatile matter and hydrogen noted earlier. The main liptinites observed were sporinite and resinite (Fig. 32). These specific macerals also show vertical changes in abundance, with sporinite increasing downsection while resinite in-

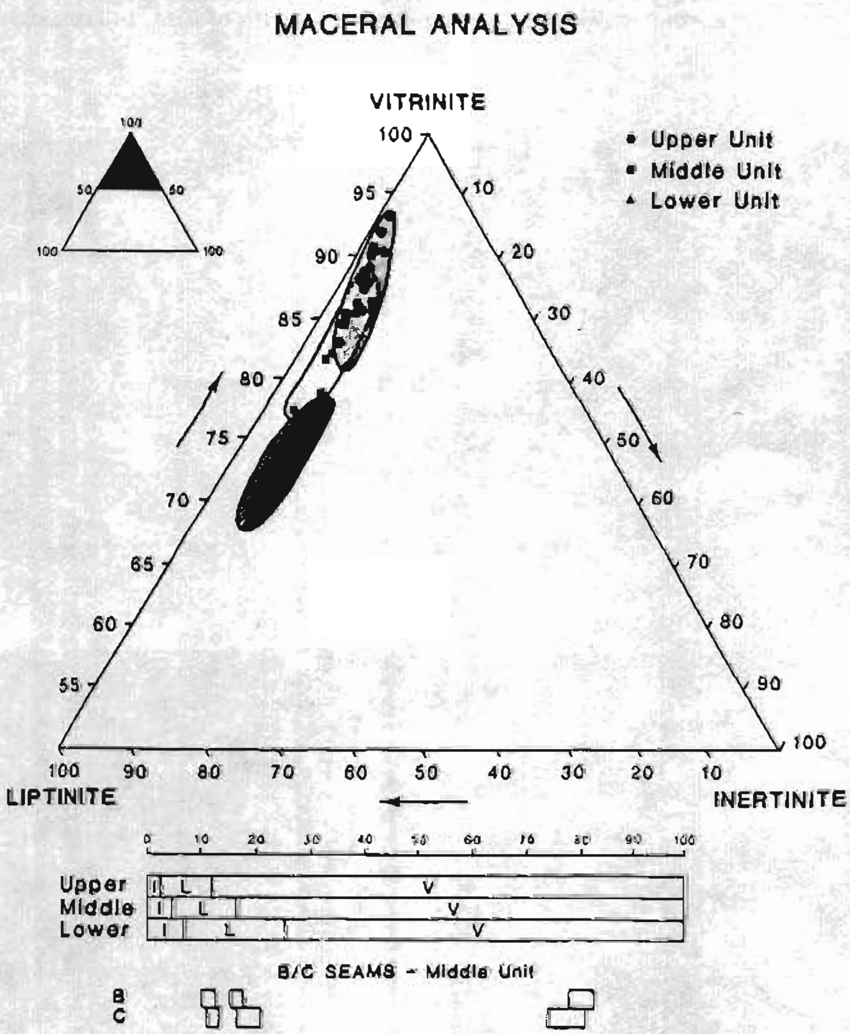


Figure 30. Ternary diagram showing maceral percentage fields. Bar graphs show trends in the three major maceral groups. Ranges of maceral groups in B and C seams are shown at bottom.

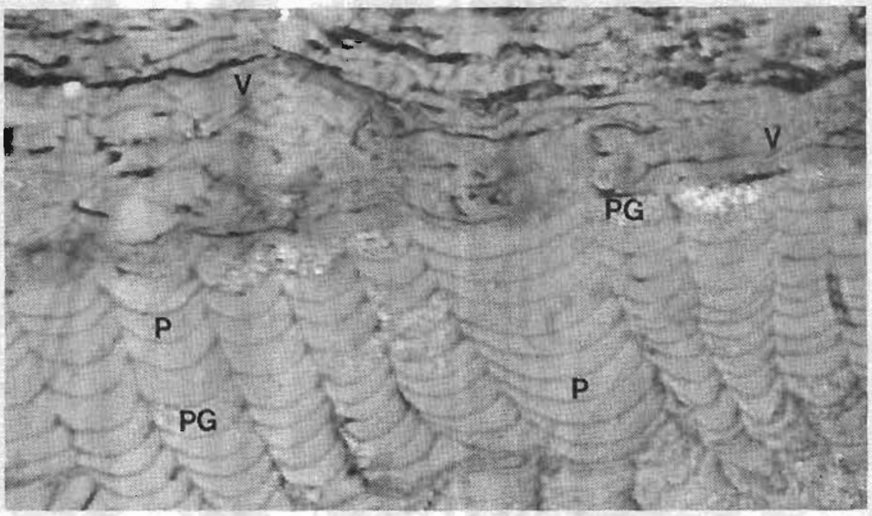


Figure 31. Photomicrograph of main vitrinite macerals. V-vitrinite/huminite; P-phlobaphinite, PG-porigelinite. Photomicrograph taken in normal incident light, oil immersion, width of field, 140 microns.

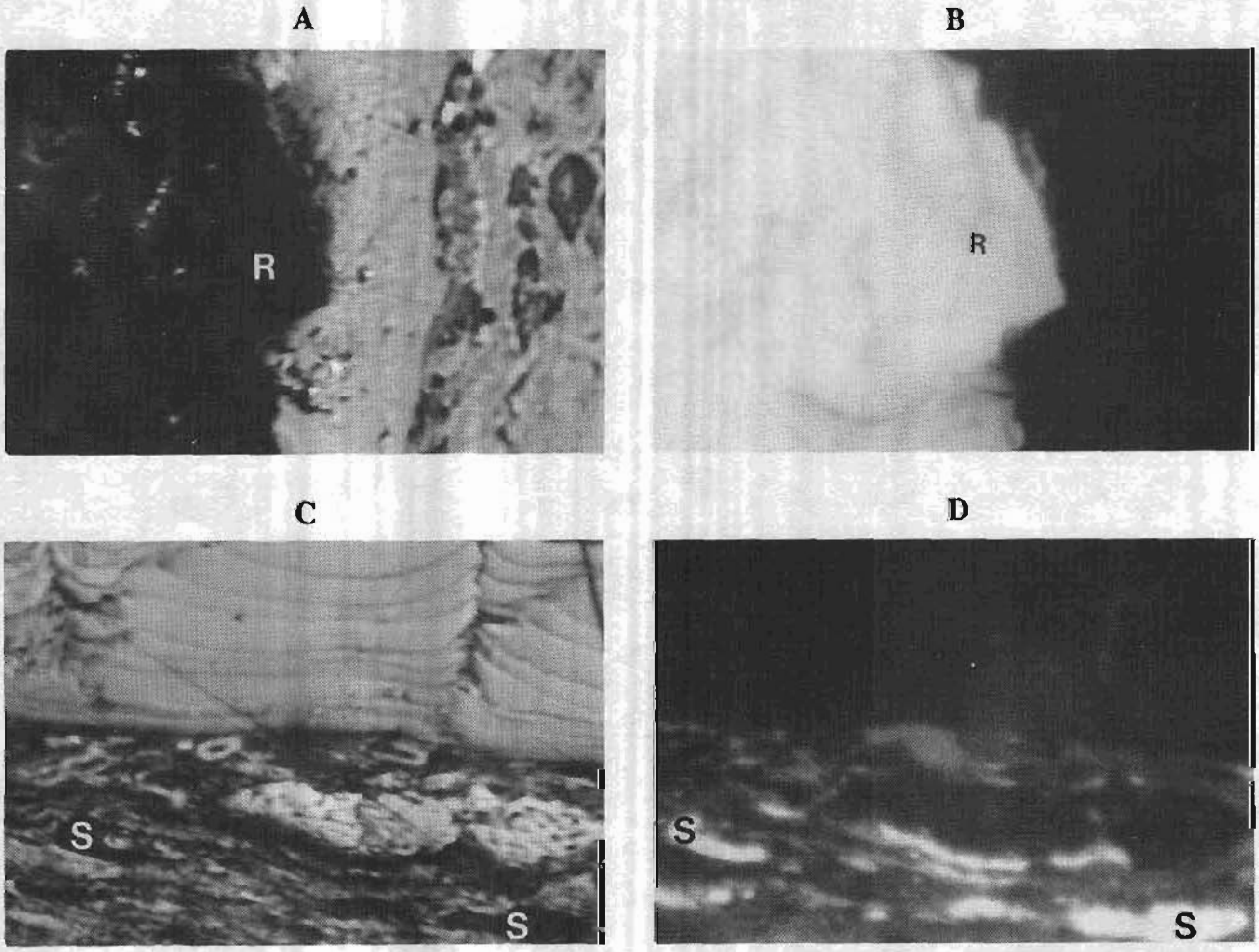


Figure 32. Photomicrograph of main liptinite macerals (S-sporinite and R-resinite) at Jarvis Creek. Photomicrographs A and C, are taken in normal incident light. B & D, are taken with blue-light excitation. Yellow macerals are fluorescing liptinites. Photomicrographs taken in oil immersion, width of field, 64 microns (B and D); 85 microns (A and C).

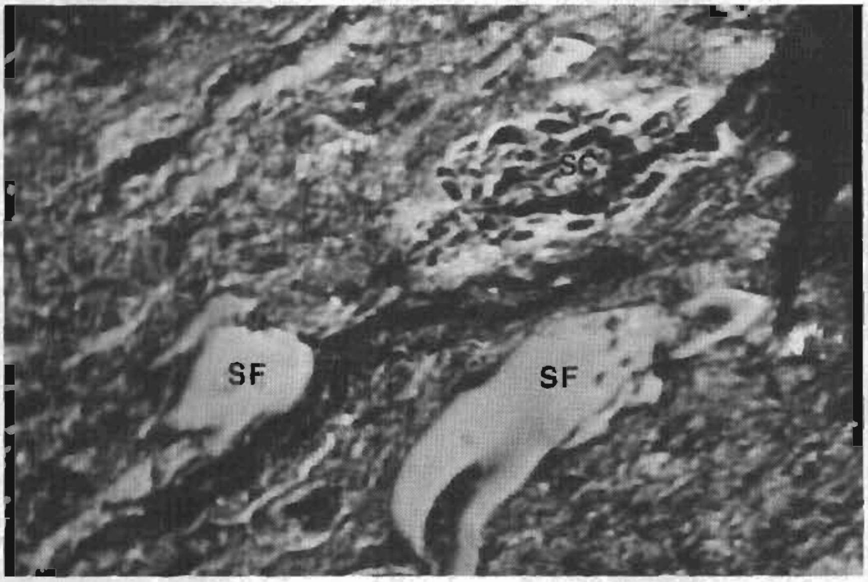


Figure 33. Photomicrograph of main inertinite macerals (SF-semifusinite, and SC-sclerotinite) at Jarvis Creek. Photomicrograph taken in normal incident light, oil immersion, width of field, 140 microns. Petrographic view of shattered monocrystalline quartz grains from a lower unit sandstone.

creases upsection. This increase in resinite is reflected in the higher amber contents of the upper unit coals observed in the field.

Inertinite macerals, formed from plant material degraded by fire, fluctuating water levels (oxidation) or fungal attack (Stach and others, 1982) increase substantially downsection. As shown in Figure 30 bar graphs, this is parallel to the trend for liptinite but less pronounced. These macerals, which contain high levels of carbon, include fusinite, semifusinite, macrinite, sclerotinite, and inertodetrinite. The main inertinite macerals present here were semifusinite and sclerotinite (Fig. 33). The predominance of these particular inertinite macerals indicates that the Jarvis Creek coal swamps were not affected much by fire but did have fluctuating water levels during the earlier swamp episodes, resulting in some oxidation and fungal degradation.

Microlithotype analysis also provides evidence of significant vertical changes in the coals here. Microlithotypes are groupings of macerals in a microscope field of view. They are studied because the macerals of coal rarely occur individually, and are usually associated with other macerals of the same or the two other maceral groups (Stach and others, 1982), in monomaceral, bimaceral and trimaceral microlithotypes. These microlithotypes are frequently used for determining environments of deposition and can be valuable in seam correlation. Figure 34 shows average microlithotype values; the raw data are in Appendix 3b.

There are several vertical trends in microlithotype composition shown in Figure 34. Vitrite, composed entirely of vitrinite, shows a dramatic increase upsection; a trend similar to that seen for vitrinite. This, of course, is due to the increase in woody material of the coals upsection. Clarite, defined as a microlithotype composed of vitrinite and at least 5 percent liptinite, shows a substantial increase (from 14% to 30%) downsection due to the increase in liptinites in that direction. Vitrinertite, the vitrinite and inertinite combination, increases downsection toward the older coals, and again is due to the increased inertinite in the older coals. Trimacerite, a mixture of all three maceral groups, also increases downsection due to the increase in both liptinites and inertinites. Finally, the carbomineralites, which constitute the mineral matter in the coals, show no consistant vertical trend (low in the middle unit, with subequal amounts above and below). This is similar to the distribution of ash noted earlier. The main carbomineralites in the Jarvis Creek coals are carbargillite (clays), which is the most common,

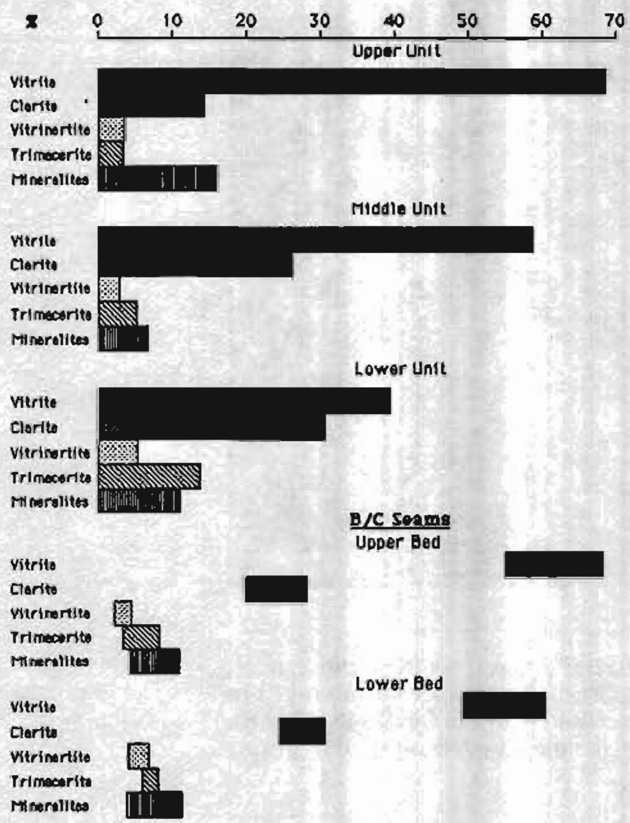


Figure 34. Bar graphs showing trends in microlithotypes (average values-upper part; range-B/C seams)

carbosilicates (quartz), carbankerite (calcite, dolomite, siderite and ankerite), and carbopyrite. Carbargillites and carbosilicates are generally detrital through overbank flooding while the others are generally authogenic. The lower and middle unit carbomineralites are mostly carbargillites, perhaps related to the proximity of the Birch Creek Schist with its abundance of weathered feldspars and mica. In the upper unit, however, the predominant carbomineralite is carbopyrite. This should be expected because of the high sulfur contents of the upper unit coals, alluded to earlier. Figure 35 shows photomicrographs of the five main microlithotypes. Of the carbomineralites, only carbargillite is shown in Figure 35. Complete data from the microlithotype analysis are in Appendix 3b.

Microlithotype analysis of the Jarvis Creek coals indicates that the earliest swamps probably contained substantial reed and sphagnum plant material in floating mats. This type of swamp produces coal rich in liptinite and trimacerite, with a large amount of desmocollinite, a type of vitrinite common in the lower unit and basal B and C seams of the middle unit. The presence of large angular quartz fragments "floating" in beds of carbonaceous shale beneath these coal beds (Fig. 36), implies relatively high relief close to the swamps. Similar floating quartz fragments are observed below the basal coals in the Nenana Coal field to the west (Triplehorn, 1987, personal communication). The high proportion of resinite-rich clarites in the upper unit suggests that the vegetation in the forest part of the swamps changed through time, with an increase in gymnosperms or coniferous trees relative to angiosperms or deciduous trees. This is borne out by the increase in amber in the upper unit coals.

Vitrinite Reflectance

The discovery of the interdependence of the reflectance of vitrinite and the rank of coal was of fundamental importance to the field of coal petrology (Stach and others, 1982). At Jarvis Creek reflectance studies of coals also proved to be important, here in distinguishing the separate stratigraphic units. There is very little difference in reflectance of the vitrinite macerals (huminites in subbituminous coals) between the lower and middle units (Fig 37). These average around 0.4 and suggest that they are very similar in age. However, there is a decrease in vitrinite reflectance in the upper unit more sudden than would be expected from normal coalification processes acting on continuously deposited sediments. This abrupt change, which is most apparent on the steep bluff facing Little Gold Creek (bottom coal-.438, top coal-.324), is evidence for a possible age difference between the upper and middle coal-bearing units. Complete vitrinite reflectance data are in Appendix 4.

Palynology

Palynological results are limited, but available data suggest that environmental conditions and plant types were different during deposition of the lower or older coals relative to the upper or younger coals. In the older coals, only pollen from ferns and sphagnum moss was seen. This suggests that early peat swamps were highly specialized raised bogs with an extremely high water table that allowed only reeds, sedges, ferns and sphagnum to flourish (Stach and others, 1982). Such swamp peats develop into relatively liptinite-rich coals with exinite-rich clarites, trimacerites and high desmocollinite contents (Stach and others, 1982), such as the lower unit and middle unit coals at Jarvis Creek.

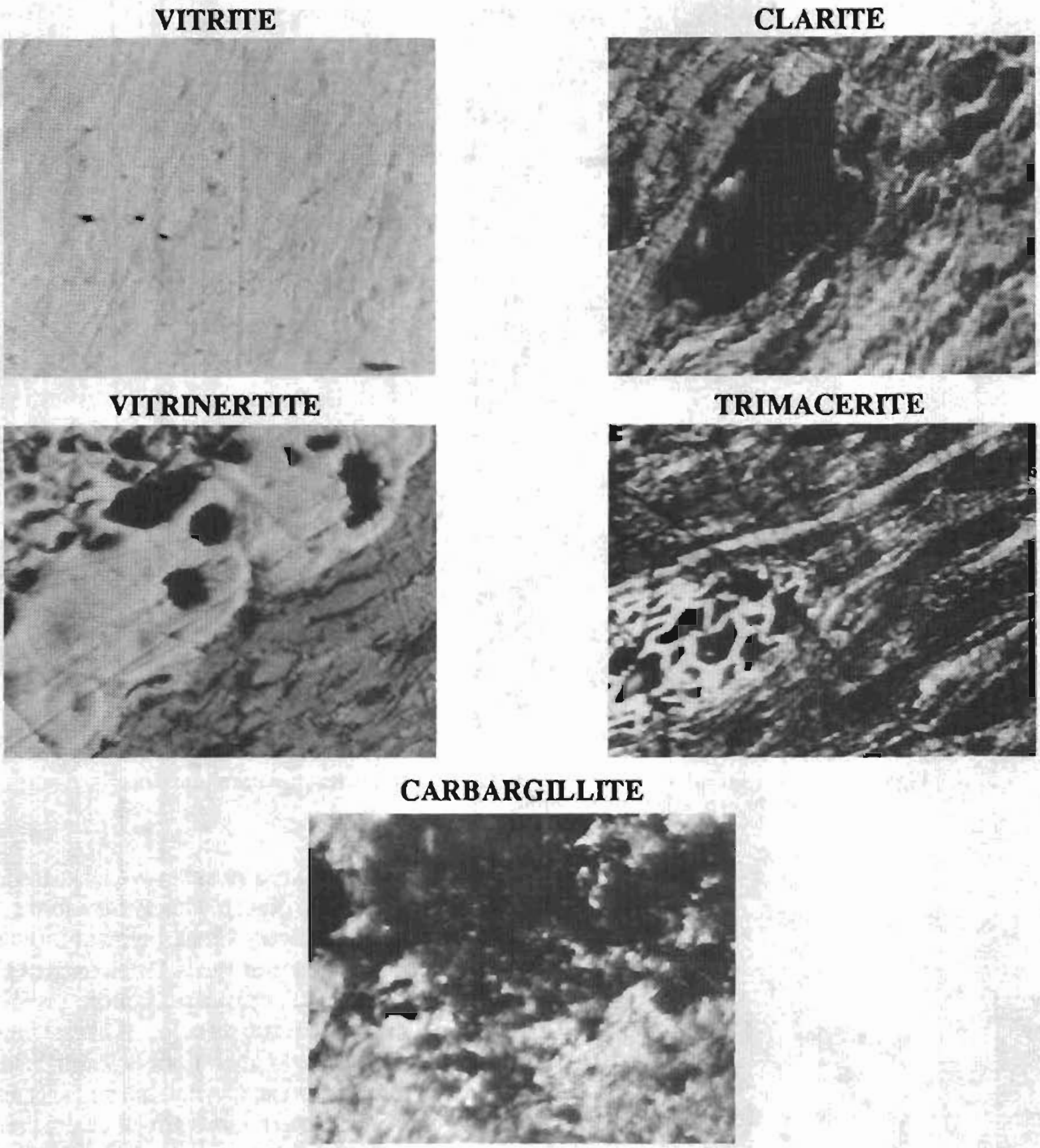


Figure 35. **Photomicrographs of the five main microlithotypes at Jarvis Creek. Photomicrograph taken in normal incident light, oil immersion, width of field 85 microns.**

Pollen from the younger or upper unit coals indicates a substantially different flora. The presence of the angiosperms *Juglans* (Walnut), *Betulaceae* (Birch), *Pterocarya* (Chinese Walnut), *Alnus* (Alder), and *Erica* (Heath), along with the gymnosperm *Pinus* (Pine) indicate that the swamps of the upper unit or younger coals were of the forest type. The large increase in vitrinite, the corresponding decrease in liptinites and the frequent occurrence of macroscopic amber all support this suggestion. Elsewhere in Alaska, *Juglans*, *Betula*, *Pterocarya*, and *Pinus* are characteristically prominant in upper Seldovian to Homerian floras (Wolfe and others, 1966) which are late Miocene to Pliocene in age. This difference in plant types with age supports the suggestion that there is an age difference between the upper

Figure 36. Photograph of "floating" angular quartz detritus in a carbonaceous shale beneath B seam, upper Ruby Creek.

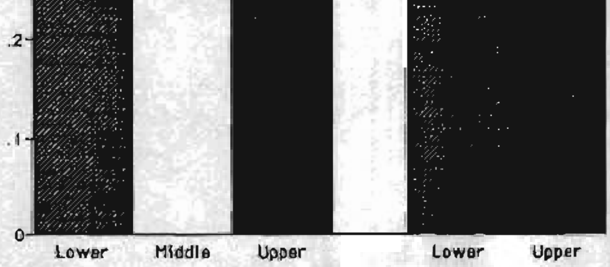


Figure 37. Bar graphs showing trends in vitrinite reflectance (average values for each unit).

unit and the lower two units at Jarvis Creek. If so, these lower two units are probably equivalent to the Healy Creek Formation. Healy Creek Formation floras can be divided into the lower Healy Creek (or Rex Creek) flora and the upper Healy Creek flora (Wolfe and others, 1966). The Rex Creek flora is latest Oligocene and the upper Healy Creek flora is lower Seldovian (earliest Miocene) in age. Although no exact age can be given for the lower Jarvis Creek coals, the flora, proximity to the Birch Creek Schist, and higher apparent rank in comparison with similar coals at Healy all suggest a latest Oligocene age. If so, lower and middle Miocene strata are missing at Jarvis Creek; such an unconformity is more likely due to non-deposition as there is no field evidence for erosion.

Chemical Composition

Changes in the Jarvis Creek coal swamps through time are documented by vertical trends in major and trace elements in coal ash. Eleven major oxides were determined: SiO_2, Fe_2O_3, CaO, MgO, MnO, Na_2O, TiO_2, Al_2O_3, K_2O, SO_3 and P_2O_5. Average values are shown in Figure 38; raw data are listed in Appendix 5c. In Figure 38, the alumino-silicate or lithophile elements Si, Al, K, Ti decrease substantially upsection. These elements, normally abundant in the sand and clay fraction of the mineral matter, probably decline upsection in the coals due to waning influence from the weathered Birch Creek Schist as a source of feldspars, micas and quartz veins. A corresponding decrease in the abundance of carbonaceous shale upsection supports this suggestion.

Other minerals, including those associated with carbonate, also show vertical trends. The carbonate minerals in coals occur primarily as epigenetic fracture fillings (Gluskoter, 1975). Mn, Mg, Fe and Ca are often associated in these fillings. Ca and Mn, in contrast to the lithophile elements above, increase upsection. According to Gluskoter and others (1977), these two elements show a positive correlation with each other, with Mn commonly substituting for Ca in calcite ($CaCO_3$). As previously mentioned, there is an upsection increase in carbonate concretions, so increasing Ca in calcite is expected. Orheim (1978)

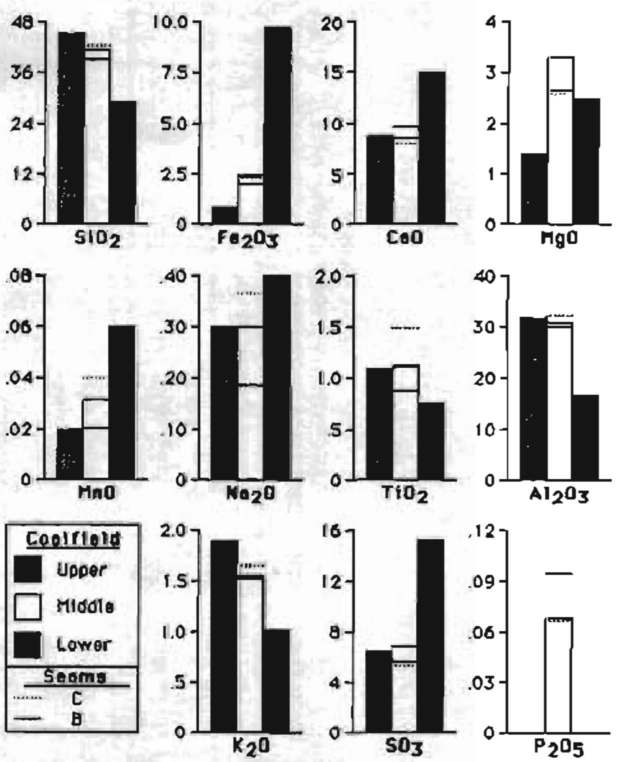


Figure 38. Bar graphs showing trends of major oxides in coal ash, on a weight percentage basis. Average values for each unit are shown.

states that Ca is concentrated in the wood structure and bark of trees so the upsection increase in vitrinite of the coals is probably at least in part responsible for the increase in Ca. Ca is also present as a cation in Ca-humates formed during the humification process (Stach and others, 1982; Rao, 1987, personal communication), one of the most significant steps in vitrinite formation. According to Gluskoter and others(1977), Mg shows a positive correlation not only with the alumino-silicate elements in the clay fraction but also with the carbonate fraction. At Jarvis Creek, Mg is quite variable, showing the highest values in the middle unit. The reason for this is unclear but may be due to its substitution for Ca in some of the extensive carbonate cemented arkose beds. Na, a lithophile element, shows trends similar to those of Ca, and like Ca, also forms important humates in the humification process (Stach and others, 1982). Na shows an upsection increase that is probably due, again, to the increase in vitrinite in this direction. Fe in the Jarvis coals shows a four-fold increase from the middle to upper units and SO_3 shows a two-fold increase. Because of the large amount of pyrite in coals of the upper unit, this is not surprising.

Phosphorus (P), on the other hand, does not show any vertical trend. There is negligible phosphorus in the lower unit and most of the middle and upper units with the exception of three coals in the upper unit. The B/C seams, however, always contained notable phosphorus, in contrast to other seams which contained none. Thus the phosphorous content is a possible basis for correlation here. Phosphorus, according to Orheim (1978), plays a major role in plant growth and is enriched in leaves, seeds and pollen. Its presence in B and C seams suggests that the vegetation or the conditions of swamp growth were different at this time.

The coals were also analyzed for 13 trace elements. Averages for eleven of these are shown in Figure 39; raw data are in Appendix 5d. P and Cd are omitted because they were at or below detection limits. The inverse relationship between Ba and Sr is unusual because these two elements usually follow similar trends, often substituting together for other cations, especially Ca. Ba and Sr cations also commonly adsorb on clay minerals (Levinson, 1974). Since Sr readily substitutes for K and Al in muscovite and other micas and, since both K and Al decrease upsection away from the Birch Creek Schist, Sr might also be expected to decrease. The Ba increase upsection may have several causes. Ba is often associated with the

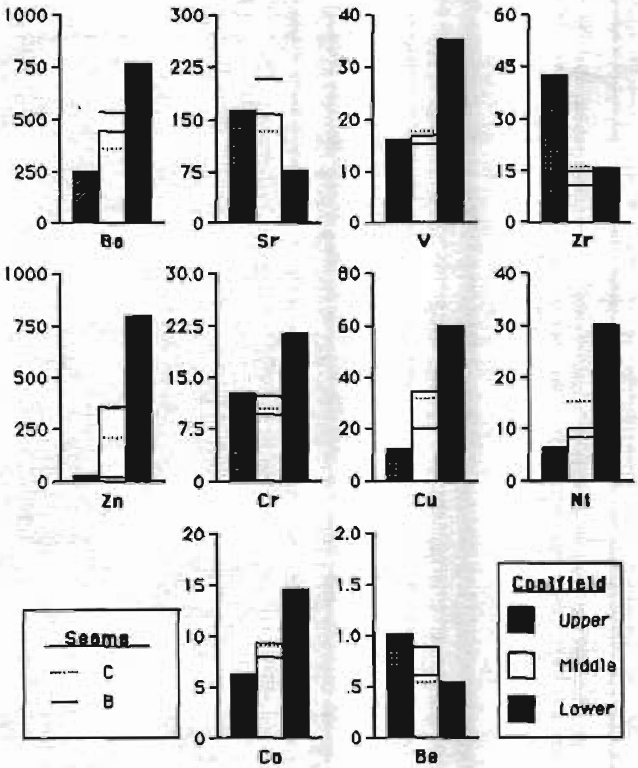


Figure 39. Bar graphs showing trends of trace elements in coal ash, in ppm on a whole coal basis. Average values for each unit are shown.

carbonate or organic fraction in coal (Hatch and Swanson, 1977), and Ca in coal shows an increase upsection at Jarvis Creek. Ba is also common in vitrinite (Orheim, 1978) and sulfate-bearing deposits, and both of these increase upsection. And finally, high Ba contents in this case may be following zinc, pyrite and cadmium, as from a sulfide deposit, and all three of these increase in the upper unit. Two other elements that decrease upsection are Zr and Be. These are most often derived from regionally metamorphic rocks and plutonic intrusives, and thus should be higher in the lower units where detrital clastic material from those rock types predominate.

The rest of the trace elements (V, Zn, Cr, Cu, Ni, and Co) shown in Figure 39, can all be considered metallic trace elements. Their substantial increase in the upper unit suggests that they were deposited secondarily, probably from solution, in the developing peat swamps and came from a base metal sulfide source. In fact, volcanogenic sulfide deposits have been reported throughout the eastern interior of Alaska, both north and east of the Jarvis Creek coalfield. Concentrations of those sulfide minerals are reported for the eastern part of the Alaska Range (Zehner and others, 1985), and for the Delta ore deposits between Delta Junction and Tok (Chou, 1987). Erosion of these deposits by west-flowing streams would have resulted in the transport of metal ions or mineral grains into the Jarvis Creek area. West-trending paleocurrent readings of the upper unit sands support this suggestion.

Trace elements in 27 coals from the Jarvis Creek coalfield were compared with those in 295 Rocky Mountain coals and 20 coals from the Healy Quadrangle, Alaska (Hatch and Swanson, 1977). Ranges in trace elements from these coals are shown in Figure 40. Both bituminous and subbituminous coals are included in the Rocky Mountain samples, whereas the Healy Quadrangle and Jarvis Creek samples are all subbituminous. Ba and Sr concentrations at Jarvis Creek exhibit generally smaller ranges, but tend to exhibit higher than average values than Rocky Mountain coals. V, Zr and Be also show smaller ranges but generally similar concentrations as the other coals. Trace metals with the exception of Cr, show higher maximum values at Jarvis Creek. Zn concentrations, in particular, are notably high at Jarvis Creek, espe-

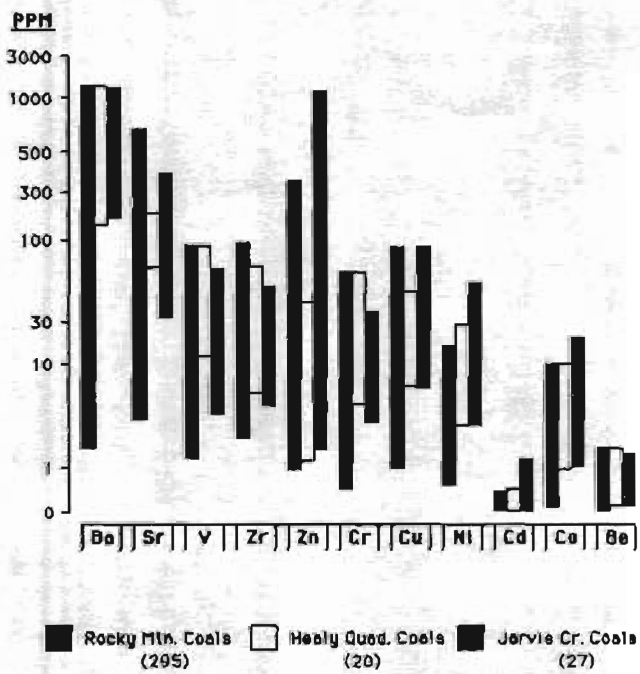


Figure 40. Bar graphs comparing average ranges in trace element concentrations of Jarvis Creek coals and other coals (Hatch and Swanson, 1977).

cially in the upper unit, with zinc forming over one percent of the coal ash. The high zinc and pyrite (p. 58) contents in Jarvis Creek coals are similar to those in the Interior Coal Province of northwestern Illinois (Hatch and Swanson, 1977). In the Interior Province, however, the high concentrations of these elements were caused by marine incursions over the peat swamps and that is not the case for the non-marine section at Jarvis Creek.

Use of Laboratory Analyses for Coal Seam Correlation

Previous sections dealt with vertical changes in coal composition; the present section deals with lateral trends from laboratory data for the most laterally continuous coal seams in the coalfield (B and C seams).

Samples were collected at four sites in the B and C seams over a distance of two miles (Fig. 6 - circled localities). The same data are involved as in earlier discussion of vertical trends. Data from the B and C seams were examined to see which analyses showed the least lateral variation and/or showed values distinct enough from the other coal seams to correlate between localities.

Proximate analyses for the B and C seams are shown in Figure 41, along with heating values. Ash content of the B and C seam coals was quite variable, ranging from 3 to 11 percent on an as-received basis. Because the ash content of a coal directly affects the heating value, the Btu/lb values also are highly variable, especially in the C seam. Volatile matter and fixed carbon are slightly less variable but not significantly different from those of other coals in the field. Moisture content, however, is quite uniform in the B and C (middle unit) seams, averaging between 18 and 20 percent for all samples: upper unit coals always have more moisture and lower unit coals always have less. Other coals in the same unit with the B and C seams (the middle unit) were variable. This limited variation in B and C seam moisture (and related rank) could be important in correlation.

Ultimate analyses show both differences and similarities between the B and C seams (Fig. 27, lower part). B seam shows a relatively large range in oxygen while C seam shows a similar tendency in carbon. Hydrogen and nitrogen levels, are not sufficiently different to distinguish B and C seams from each other or from other coals. The carbon content of B seam and the oxygen content of C seam show some consistancy laterally (as indicated by the narrow width of the bars in Fig. 27) but again are not sufficiently different from other coals be used for correlation. Overall, ultimate analyses indicate that the B and C seams are generally similar to other middle unit coals.

Sulfur levels in the B and C seams (Fig. 28, lower part), show little variation and are consistantly low, averaging about .33 percent. Studies of sulfur forms indicate that most of this is organic. Because the coalfield as a whole showed erratic sulfur concentrations, the uniformly low values in the B and C seams stood out from the other coals and may be useful for correlation. Other coals in the upper and lower stratigraphic units are also possibly correlatable by sulfur content, but this will be discussed later.

There is considerable vertical variation in the sulfur content of a given seam, especially if pyrite is present in the coals, and this may affect the use of sulfur in correlation. Separate analyses of the upper, middle, and lower thirds of the main mine seam on Ober Creek, for example, showed that the highest sulfur content is in the base of the seam where the

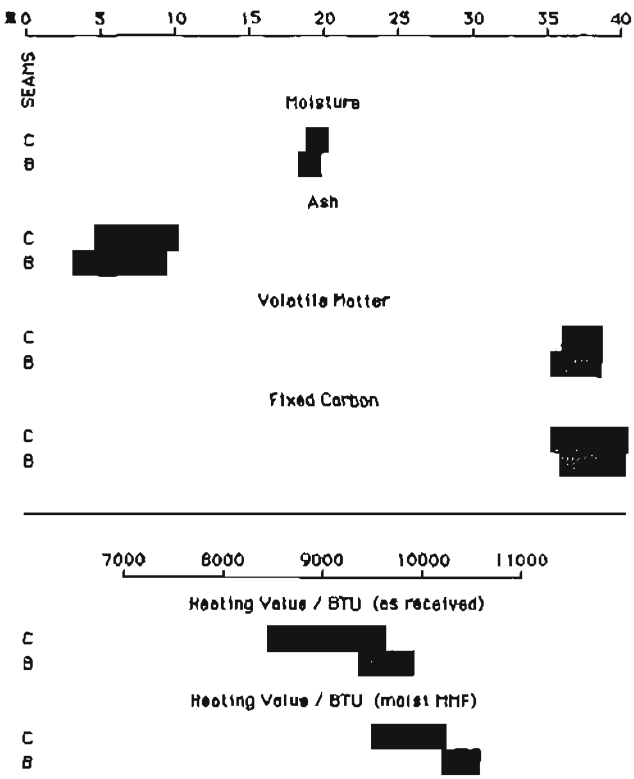


Figure 41. Bar graphs showing trends in proximate analysis from the B and C seams.

pyrite concentration was the highest. Reasons for this localized concentration will be discussed later but it seems to be post-depositional. Similarly, sulfur content appears to be higher in the thickest part of a lenticular coal bed and lower in its thinner limbs; an example of this is the 8-foot seam in the lower unit. Rimmer (1984) mentions similar sulfur trends in the lower Kittanning seam in Western Pennsylvania and Eastern Ohio.

The main maceral groups (vitrinites/huminites, liptinites, and inertinites), show very uniform values laterally in the B and C seams (Fig. 30, lower part), and are different enough from those in other coal beds to be a good correlation tool. B and C seams showed intermediate levels between the lower unit coals (high sporinite, moderate vitrinite and semifusinite) and the upper unit coals (high resinite, high vitrinite and low inertinite). Evidently progressively evolving peat swamps left specific signatures in each member of a coal sequence.

Although there is some variability in the microlithotypes, especially vitrite, there is an unmistakeable difference between content of different microlithotypes in the B and C seams and those in any other coal seam at Jarvis Creek (Fig. 34, lower part). All four main microlithotypes except carbominerallites occur in distinct amounts that set the B and C seams apart from the other coal seams. This is in keeping with Stach and others (1982) statement that microlithotypes are becoming more important in the field of applied coal petrology for determining depositional environments and correlating seams.

The B and C seams show little lateral variability in vitrinite reflectance, averaging slightly above .4 percent (Fig. 37). Unfortunately, numerous samples in the lower and middle units also gave similar values, thus reducing the value of reflectance for correlation. Many individual beds in the other units, however, do seem to show a promising lateral consistancy in vitrinite reflectance and it may be of use for correlation of these seams. However, on a world-wide basis, lignites and subbituminous coals tend to have low reflectance values with narrow ranges; thus it may be mainly applicable to correlation of higher rank coals.

Lateral trends in chemical composition were also studied. Average concentrations of major oxides in the B and C seams are displayed in Figure 38 relative to the middle unit averages as solid lines (B seam) and dotted lines (C seam). It is apparent that B and C seams generally display representative values for middle unit coals. C seam is usually higher in major oxides than B seam. Also evident from Figure 38 is the fact that the higher P_2O_5 content of B and C seams distinquishes them from all other coals. This is the most striking difference, but other ash oxides also can be used for correlation. Approximately 40 percent SiO_2 is common in Jarvis Creek coal ash, and this in combination with values of 2.5 percent Fe_2O_3 and 2.7 percent MgO, uniquely characterize the B and C seams. Thus correlation may be possible using combinations of major oxides rather than individual values.

Trace element variations in these coal seams were also examined. Figure 39 shows average concentrations of trace elements in the B and C seams displayed relative to middle unit averages as solid lines (B seam) and dotted lines (C seam). The trace element concentrations for these two seams are characteristic of middle unit coals in general. The C seam usually has a higher concentration of trace elements, especially metals, than the B seam, reflecting the overall upward increase in trace element content in the coalfield. Once again combinations of elements distinguish B and C seams. In this case, concentrations of V (17 ppm), Ba (500 ppm) and Zr (15 ppm), combined with a low zinc concentration, appear to distinguish the B and C seams from all others at Jarvis Creek and thus could be used to correlate these seams laterally. As shown above for major oxides, correlation may be possible using combinations of trace elements rather than individual values.

DISCUSSION

This section will focus on two derived aspects of this study of the Jarvis Creek coalfield. First is a look at the economic geology of the coalfield itself. This includes discussions of volcanogenic sulfide enrichment, coal seam correlation of other seams, coal reserves and quality, as well as overburden implications and reclamation. Second is a discussion of the geologic implications of the study. This includes discussions of the clastic provenance, depositional environments, as well as relationship of the Jarvis Creek coal-bearing strata to the Healy coal-bearing strata.

Economic Geology

Volcanogenic Sulfide Enrichment

The unusually high levels of major and minor elements, especially trace metals, in the Jarvis Creek coals and overburden, suggest something unusual about the Miocene depositional setting in the vicinity of the coalfield. In particular, this resulted in general increases in most elements between the middle and upper stratigraphic units. Specifically, there are some sharp increases in trace element concentrations between those units.

Although these are the first studies of chemical composition for the Jarvis Creek coalfield, such studies of nearby rocks in the Eastern Alaska Range have in recent years resulted in discoveries of numerous mineralized localities. These were determined to be volcanogenic massive sulfides and are quite common in the Jarvis Creek Glacier Tectonostratigraphic terrane southeast and east of the coalfield. The following description of these deposits is summarized from Zehner and others, 1985; Nockleberg and Lange, 1983; and Lange and others, 1987. The mineralization consists of massive pyrite and pyrrhotite, with minor chalcopyrite, sphalerite, galena and bornite distributed in lenses, pods, and stringers. These lenses and pods, which can be as thick as two meters, parallel the schistosity and foliation of the enclosing metavolcanic and metasedimentary rocks. Quartz-mica schists with locally abundant graphitic muscovite-chlorite-quartz schists are the main host rock type. Rocks here are intensely deformed and metamorphosed former marine shales, siltstones, marl, volcanic graywacke and limestones. Recent U/Pb zircon isotopic studies indicate extrusion of the volcanic protoliths at about 370 m.y. (middle Devonian). This metavolcanic-rich part of the Jarvis Creek Glacier Terrane probably correlates with the Totatlanika Schist which crops out to the west in the Healy Quadrangle. The latter unit also contains abundant former intermediate volcanic rocks (Wahrhaftig, 1968).

According to Lange and others (1987), these sulfide occurrences are interpreted as Kuroko-type deposits that formed along the submarine volcanic part of a Devonian continental margin igneous arc. Their submarine origin is indicated by interlayering of the metavolcanic rocks and sulfide lenses and pods with former shale, siltstone, quartzite and marl. However, lead isotopic studies on sulfide samples, mostly Pb, from these deposits indicate a component of first cycle sediments derived largely from a Precambrian crystalline terrane.

Incorporation of sulfides or other metals in coal or peat-bearing strata is not common, but occurs in a few localities, most notably in bogs in Ireland and Scotland, peat in Montana, Colorado and New York, and in bogs and muskeg in the Yukon, Quebec and British Columbia (Levinson, 1974). Enriched metals include Cu, Zn, U, V, Fe, Pb and Mn. In the Canadian localities zinc in particular is concentrated in unusual amounts. Zinc is common in the high sulfur coals of Illinois as sphalerite (Zns) where it is found along with pyrite, calcite and kaolinite in vertical cleats or fractures (Hatch and Swanson, 1977; Gluskoter and others, 1977). Concentrations of zinc in these Illinois coals reach 6000 ppm on a whole-coal basis, or about 3 percent of the ash, almost qualifying for byproduct recovery.

At Jarvis Creek, zinc and associated trace elements in coals are concentrated in the upper stratigraphic unit where Zn levels reach 1480 ppm. Although these levels are much less than Illinois coals, they are still higher than any others reported in Alaska or the western United States. Other elevated trace metals at Jarvis Creek include Cu, Ni, Cd, and Co, all of which have values at or above those reported in similar western U.S. coals (Hatch and Swanson, 1977). Gluskoter and others (1977) reported a positive correlation coefficient of 0.94 between Zn and Cd in Illinois coals. They state that Ba, which occurs in the mineral barite ($BaSO_4$), is also closely correlated with zinc and cadmium. The occurrance of barite in amounts large enough to be identified with sphalerite in coals has only been observed in a few instances (Gluskoter and others, 1977). Thus the combination of high values for both Ba and Zn in the upper stratigraphic unit at Jarvis Creek is an unusual characteristic, and one that serves to distinguish this unit. Barium concentrations reach 1420 ppm on a whole-coal basis in the upper unit and almost always follow high zinc levels. In contrast to this trend are the low strontium levels in this same, upper, unit. According to Rao and Smith (1986) Sr and Ba are covariant in coals. At Jarvis Creek, however, this is not observed. Here only Sr and Be are covariant, while Ba follows the other trace metals; that is, contrary to its reported relationship to Sr and Ba. This suggests that the relatively high barium levels here can be attributed to a base metal sulfide source as such deposits consist mainly of pyrite and sphalerite with some barite.

Sulfide mineral deposits on the Robertson River 20 miles east-south-east of the coalfield contain substantial ZnS and FeS_2 (Foley, 1985). In these deposits, the most abundant sulfides are FeS_2 and ZnS, with one sample showing concentrations of approximately 67 and 11 percent, respectively (Chou, 1987). In the Jarvis Creek upper unit coals, the highest metal concentrations are also Fe (as pyrite) and Zn. This observation supports the hypothesis, therefore, that the high trace metal values have their source in older sulfide occurrences to the south and east. Such a suggestion is supported by paleocurrent studies showing a prominent westerly transport direction for sandstones.

According to Levinson (1974) geochemical studies from Canada and Western Europe show that trace elements, including metals, are mobilized by ground water and are transported into peat swamps or bogs where they are easily adsorbed. He states that in these areas metals entered the peaty horizons by upward movement by capillary action. If so, highest concentrations should be in the lower part of the peats or in the clays underlying the peats. At Jarvis Creek, seat rocks which were fine-grained (i.e., claystones, carbonaceous shales or siltstones), almost invariably contained the highest trace element concentrations compared to other fine-grained overburden rocks (Table 3). The only coal examined for vertical compositional changes (ie., the 10-foot mine seam) also showed similar distributions. Coarse-grained clastics such as sandstones usually had lower concentrations, even when they were the seat rocks. The high Zn values, moderately high Cu, Ni, Cr, Co, and V levels as well as low Pb concentrations at Jarvis Creek attest to the relative mobility of these metals. Zinc is highly mobile and can be transported large distances, while copper and the others are less mobile. Lead is particularly immobile and thus quite restricted in its distribution (Hawkins, 1986, personal communication).

Trace element concentrations here, especially zinc and other metals, are of mostly geologic interest as related to the deposition of the upper unit; no byproduct economic recovery is foreseen.

Coal Seam Correlation (other than B and C)

Numerous coal seams at the Jarvis Creek coalfield are considered to be of mineable thickness, but only a few are sufficiently continuous to be recognized in more than one outcrop. These outcrops were sometimes separated by covered intervals of vegetation or Quaternary deposits for up to one mile. Correlation of coal seams for long distances is often difficult due to splitting and merging of beds that are discontinous and lenticular; this is a general problem with coals everywhere (Sholes and Cole, 1981). Discontinuous crevasse splays and channel deposits are the usual causes of discontinuity, but where close to basin margins with their increased detrital influx coals may split or grade into carbonaceous shale and other fine-grained clastic rocks (Rimmer, 1984). At Jarvis Creek, five zones of potentially mineable coal consist of either single beds or double beds in close proximity (Fig. 42). The thickest and most laterally continuous zone (B and C seams from the middle unit) was discussed earlier (pp. 41-42) and will not be considered further. The other four include the main coal seam of the lower unit and three from the upper unit. As was the case with B and C seams, correlation was attempted by lithologic association and similarities in coal composition.

The lower unit coal seam (A seam of Wahrhaftig and Hickcox, 1955) is approximately eight feet thick at two sampling locations (UC1 and UC2), about 1/3 of a mile apart. It pinches out quickly to the south and is covered by Quaternary alluvium to the north. Although clearly the same bed in terms of observed physical continuity, the correlation is also supported by laboratory data. Proximate and ultimate analysis and elemental composition show very similar values at both localities; coal petrology shows slight, but insignificant differences.

Of the three upper unit coal zones, the first (J of Wahrhaftig and Hickcox, 1955) is located near the top of the bluff overlooking Ruby Creek. It is three feet thick at locality URC1, thickening to seven feet at locality URC3. Proximate analysis, ultimate analysis, coal petrology and trace element data are all very similar at both localities, indicating that it is probably the same bed. Lateral distance between exposures containing these beds is 1/3 mile. A five-foot bed farther east at locality URC5 (Fig. 6) was discounted as an extension of this bed because of differing composition. In addition the strike and dip were different, suggesting some structural disturbance.

The second upper unit coal zone is located near the top of the bluff one mile north of the divide between Ruby and Little Gold Creeks. It is approximately nine feet thick at locality UC9, becoming two coal seams (five feet and two feet thick, separated by a three-foot carbonaceous shale parting) at locality UC10. Furthur north this bed pinches out entirely while to the south it is covered or probably absent due to Pleistocene glacial erosion. Proximate and ultimate analyses and maceral composition for these beds are very similar, but the other analyses show some variation. This variability, mostly in microlithotypes and chemical composition, suggests that, compared to the UC9 sample, the UC10 sample was taken nearer the margin of the peat swamp (which explains the carbonaceous

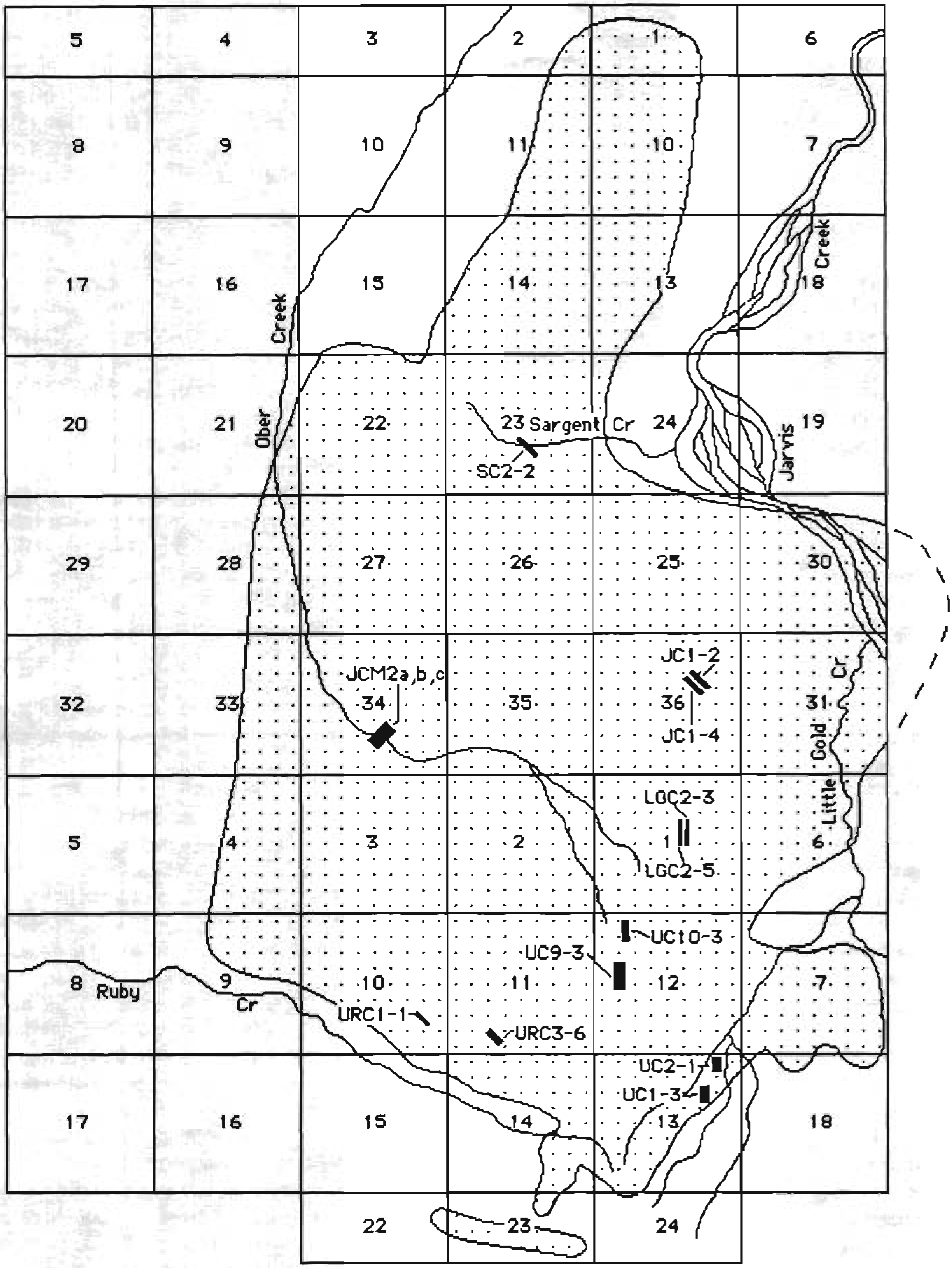


Figure 42. Map showing location of potentially correlatible coal seams, other than B and C seams, Jarvis Creek coalfield, Mt. Hayes (C-4) quadrangle. (Sample designation as follows: UC9-3=Locality (UC9), Sample 3).

shale parting) and therefore received detrital influx of larger quantity and different composition. Also, the vegetation was probably different near the edge of the peat swamp, which could explain the observed differences in microlithotypes, especially clarite. Lateral distance between these two exposures is only about 1/3 mile, indicating a rapid lateral change in this bed.

The third coal zone of the upper unit and the one that presents the most challenging correlation problem is located further north. At three locations, it consists of two beds (informally referred to as the "sandwich" seam), each between three and four feet thick separated by a parting of two to six feet of gray, fine-to medium-grained sandstone with subordinate amounts of carbonaceous shale and siltstone. These localities and corresponding coal thicknesses are: LGC2 (3.0' and 3.5'); and JC1 (4.0' and 4.0') in Figure 42, and LGC1 (3.3' and 3.5') in Figure 6, and are located in the low bluffs facing Jarvis Creek. Other localities possibly correlative to these are the 10-foot thick mine seam on Ober Creek (JCM), and a four foot seam of clean coal on Sargent Creek (SC2). Although the latter two localities are up to two miles from the "sandwich" seams, similar structural attitudes, quality of coal (lack of significant partings), and the fact that two other coal beds at Jarvis Creek (B and C seams) show lateral continuity of up to two miles, suggest a possible correlation. Wahrhaftig and Hickcox (1955) correlated the beds at the LGC1 and LGC2 localities, labling them "G" bed, but did not observe the coals at JCM and JC1. The four-foot bed at locality SC2, mentioned by Wahrhaftig but not placed in stratigraphic sequence, may be part of this "sandwich" seam. For the purpose of determining the lateral extent of the third upper unit coal zone in the absence of drilling data, petrologic and compositional data of coals from the five localities (LGC1, LGC2, JC1, JCM and SC2) were compared. Proximate, ultimate, maceral and microlithotype data all appeared very consistent. Total sulfur for these coals was among the highest in the coalfield, with the exception of low (0.62%) sulfur for sample SC2. This is in keeping with their inclusion as part of the sulfur-enriched upper unit. The somewhat lower sulfur content in the SC2 sample may be only a local occurrence. Where sulfur variability does occur, it occurs between the upper and lower coals of the "sandwich"; individually these coals are laterally consistant in their sulfur contents. Chemical composition shows the most variability of all the analyses but again this is mainly between the two components of the "sandwich" seams. The upper member of this pair almost invariably shows higher contents of major oxides and trace elements, suggesting an increasing influence of a base metal sulfide source later in the peat forming cycle of this zone. It seems evident from analytical data, structural attitudes and lithologic association that the "sandwich" coals at localities LGC1, LGC2 and JC1 are the same bed. If so, it is laterally continuous for over one mile, making it the second most continuous coal interval in the Jarvis Creek coalfield, and extends over a distance much farther than Wahrhaftig and Hickcox (1955) recognized. Correlation with the mine seam (JCM) and SC2 locality coals, however, is less certain, even though characteristics are very similar. Warfield (1973) gives drill hole data showing that the mine seam is laterally continuous for almost 1/4 mile from the actual mine pit. One of his most northerly holes, however, and closest to the SC2 bed, showed only dirty coal approximately the same thickness of the mine seam. He contended that, based on coal quality, this could not be the mine seam. On the other hand, coal seams often split and merge due to crevasse splays and channel migration (Sholes and Cole, 1981), or grade into poorer quality coals due to overbank deposits and proximity to basin margins (Rimmer, 1984). Therefore this drill hole may have encountered the mine seam where quality was locally reduced due to one of the above causes. If so, the mine seam might correlate with the "sandwich" seams if projected towards the low bluffs facing Sargent and Jarvis Creeks.

The SC2 coal at Sargent Creek also is very similar to the "sandwich" coals and the mine seam. In particular, the JCM, SC2 and JC1 localities provided the only coal samples, other than the B and C seams of the middle unit, that show appreciable P_2O_5, suggesting that they may be from the same seam. In addition, trace element data from the lower seam at JC1 and the SC2 coal are almost identical, which possibly indicates that the four-foot SC2 coal is the bottom coal of the double coal "sandwich". If so, the upper coal was either covered or glacially eroded. Although these more distant correlations may be questionable, there is evidence that a major coal zone here may cover a minimum of more than two square miles. This is important to consider because it would greatly increase the reserve base for the Jarvis Creek coalfield. However, additional drilling must be performed to substantiate its continuity.

Coal Reserves

Although the Jarvis Creek coalfield is rather small, covering roughly 16 square miles, interest in the amount and quality of its coal resources goes back nearly 50 years. Starting with the United States Geological Survey's investigations in 1939 (Moffit, 1942), reports include: the Army studies of 1943 (Thomas, 1943); U.S. Bureau of Mines studies of 1944 (Thomas, 1943; Toenges and Jolley, 1949); U.S. Geological Survey studies again in 1946 and 1951 (Wahrhaftig and Hickcox, 1955); and finally, rotary drilling by the Bureau of Mines in 1970 (Warfield, 1973). All investigators believed that this field could supply coal to markets from Fairbanks to Valdez, including the Army base south of Delta Junction, thus alleviating dependence on Healy coal.

Earliest reserve estimates for the coalfield were by Wahrhaftig and Hickcox (1955); they estimated a potential reserve of 75 million tons, with 5.9 million tons indicated and 7.5 million tons inferred. These figures were based mostly on the laterally continuous B and C seams at the base of the middle unit. With the discovery of the 10-foot seam on Ober Creek later in the 1950's and subsequent sporadic mining from this seam, reserve estimates for the coalfield increased dramatically. Metz and others (1981) estimated, with the help of recent drill holes by Owen, Loveless and Associates in 1977, that 100 million tons can be inferred from the 10-foot Ober Creek mine seam and three small beds overlying it. This is based on the assumption that the beds are continuous throughout the five sections at the center of the basin.

Coal reserve estimates by the author were conducted in accordance with the United States Geological Survey standards (Wood and others, 1983). They were calculated using the following formula: Square miles of coal x thickness of coal x 1770 short tons per acre foot x 640 acres per square mile. In these calculations, 1770 short tons per acre foot is the standard weight of coal per unit volume for subbituminous coals and 2.5 feet is the minimum thickness of coal beds considered. Measured reserves include all those coals within a radius of 1/4 mile of a point of thickness of coal measurement, indicated reserves are from a radius of 1/4 to 3/4 miles, inferred reserves from 3/4 to 3 miles and hypothetical reserves are over 3 miles.

The calculated coal reserves for the Jarvis Creek coalfield are shown in Table 5. Measured coal reserves are 17,317,680 short tons, indicated reserves are 36,993,000 short tons, and inferred reserves are 227,409,600 short tons. In terms of the individual stratigraphic units, the upper unit contains most of the Jarvis Creek coal reserves. This is advantageous from a mining standpoint as the upper unit is close to the surface and potentially strippable.

The figures in Table 5, with the exception of hypothetical reserves, are based on actual coal thickness measured in the field and distances between outcrops that contain the same coal bed as determined by analytical, petrological and elemental composition. In contrast the hypothetical reserve estimate of 533,548,800 short tons was calculated on the assumption that the JCM, LGC1 and 2, JC1 and SC2 coal samples are from the same coal zone, that the major B and C coal zone underlies most of the Tertiary coal bearing basin to the north, and that the two thick coals in the south part of the field (URC1 and URC3) and (UC9 and UC10), are more continuous than apparent from discontinuous outcrops. These assumptions, although not well established, are based on field and laboratory observations. Additional drilling is necessary to substantiate these estimates, and could result in the discovery of even more mineable coal.

Coal Quality

Previous to the present study, little information was available on the quality of the Jarvis Creek coal.

TABLE 5

Coal reserve estimates in short tons for the Jarvis Creek Coalfield. Numbers in parentheses mark the number of coal seams used in that particular reserve calculation.

	*Aggregate Coal Seam Thickness	Measured Reserves	Indicated Reserves	Inferred Reserves	Hypothetical Reserves
Upper Unit	86.3	12,220,080 (18)	27,718,200 (9)	149,529,600 (7)	421,401,600
Middle Unit	28.0	3,964,800 (7)	7,009,200 (2)	77,880,000 (2)	112,147,700
Lower Unit	8.0	1,132,800 (1)	2,265,600 (1)	—	—
Totals	122.3	17,317,680	36,993,000	227,409,600	533,548,800

* denotes total cummulative thickness of coals in each unit greater than 2.5 feet.

Most older investigations (Moffit, 1942; Thomas,1943; and Toenges and Jolley, 1949), generally listed proximate analyses of one or two samples with no further discussion of coal quality. Wahrhaftig and Hickcox (1955), whose report provided the first substantial information on the area, listed only four analyses and labeled the coal as subbituminous C. Recent drill hole data by Warfield (1973) included several analyses, but only on the Ober Creek mine seam and associated subordinate seams. They revealed an average ash for the mine seam of around 12 percent, a generally low total sulfur content and a heating value between 7500 and 8500 Btu/lb, on an as-received basis. The mine seam was classed as subbituminous C in rank. Although there are only a few analyses on a small number of seams for the Jarvis Creek basin, previous authors generally concur that the coal is generally low in ash and of good quality. Wahrhaftig and Hickcox (1955) were perhaps the most critical of coal quality, reporting that although numerous coals were observed, many were bony, either fully or in part, thus reducing the potential for development. Wahrhafitig, however, was apparently looking only for large reserves, like those seen farther west in the Nenana Coalfield, and therefore emphasized only thicker coals. This may have biased his opinion.

In the present investigation, coal quality determinations were based on extensive analytical, petrologic and geochemical data on 69 coals from throughout the coalfield, including every coal bed greater than 2.0 feet. These analyses support the view that some coals contain bony partings, but such coals are mainly lower in the section where mining may not be feasible because of depth. Most of the coals, however, are close to the surface and are massive, blocky and contain few partings. Ash levels, which average 9 percent for the coalfield as a whole, reflect this lack of partings. Moisture averages 20 percent (as-received) and is comparable with the Healy coals to the west. Heating values show vertical variability, ranging from an average of 9,500 Btu/lb (as-received) in the lower unit to 8,300 Btu/lb in the upper unit; or in apparent rank, from subbituminous A to C from older to younger coals. Most of the coals and reserves at Jarvis Creek, though, are subbituminous C.

Petrologic and geochemical studies of the coals reveal what may be the most negative aspects of Jarvis Creek coal quality. Volcanogenic sulfide deposits near the coalfield apparently were the source of significant amounts of major and minor elements, especially trace metals. These are particularly enriched in coals of the upper unit, and suggest potential environmental problems with their development. Although most major and trace elements show highest levels in the upper unit, where coal development would probably take place, only some of these elements are of environmental concern. These include As, B, Cd, Pb, Hg, Mo, Se, F, Be and sulfur (Hatch and Swanson, 1977; Harvey and Ruch, 1986; Orheim, 1978). Of these, only Cd, Pb, Be and S were analyzed and little or no concentration of Pb, Cd and Be was found. Warfield (1973) analyzed for mercury (Hg) on the Ober Creek drill hole samples but found no detectable quantities. The high but not environmentally dangerous Zn concentrations at Jarvis Creek are probably in the form of ZnS; if so, it can easily be washed out in the heavy fraction (Hatch and Swanson, 1977).

Sulfur concentrations in the upper unit reach 3%, however, and are high relative to other Alaskan coals. Although most of the sulfur at Jarvis Creek is organic, a considerable proportion of it is framboidal pyrite, especially in the potentially mineable upper unit. This is readily apparent in microscopic examination of these coals. Caruccio and Geidel (1978) state that iron and sulfate, the main sources of acidity in mine drainage, are related to the occurrence and decomposition of such framboidal pyrite. In the higher sulfur coals of the upper unit, those in excess of 1 percent, slightly less than one half of the sulfur is in the form of pyrite. In the lower and middle unit coals the sulfur is almost totally organic. Approximately one-third of the sulfur at the Ober Creek mine seam is pyritic (0.54% of 1.47%), and it is especially concentrated near the base, according to a 1986 U.S. Geological Survey analysis (G. Stricker, 1986, written communication). Coal seams with framboidal pyrite concentrations of over 0.3 percent have been known to cause acid mine drainage (R. D. Merritt, 1987, personal communication). Although pyritic sulfur here is high for an Alaskan coal, compared to other high sulfur coals in the midwest and eastern parts of the Lower 48, it is still relatively low. In addition, the upper unit coals at Jarvis Creek also contain the highest proportion of CaO of all three units; this should at least partly offset the effect of framboidal pyrite on acid mine drainage by acting as a buffer or neutralization medium (Caruccio and Geidel, 1978; Parks, 1983). This high calcium concentration was also found by R. D. Merritt (1986, personal communication).

In summary, the only potential drawback to the otherwise excellent quality coals at Jarvis Creek is framboidal pyrite. The highly calcic natural water system should mitigate problems associated with coal mining. There may be other problems related to coal composition, but they lie beyond the scope of the present investigation.

Overburden: Implications for Mining and Reclamation

In the mining of coal, characteristics of the strata adjacent to the mineable seams are critical in all aspects of the mining operation. These rocks must be studied in detail to predict spoil quality and determine a practical reclamation plan (Merritt, 1983). The nature, thickness, and characteristics of the overburden are also important in predicting the economic feasability of the operation by determining the stripping ratios and equipment required.

At Jarvis Creek, most of the coal reserves lie close to the surface. In fact, all the Jarvis Creeks coals, starting with "A" seam, are overlain by less than 1500 feet of overburden. The thick B/C seam coal zone at the base of the middle unit, although laterally continuous, dips into the base of high bluffs and is not favorably disposed for open pit mining (Wahrhaftig and Hickcox, 1955). All of the thick coals in the upper unit, however, lie within 100 feet of the top of the plateau, giving very favorable stripping ratios. Metz and others (1981), for example, predicted a 2:1 stripping ratio at the beginning and a 5:1 ratio at the termination of a mine proposed for the mine seam on Ober Creek, but he did not include reserve estimations at these ratios.

Overburden rocks in the upper unit consist of fine grained to pebbly, gray, lithic-rich sandstones, gray carbonaceous siltstones and claystones, and black carbonaceous shales. Although the upper unit contains a greater proportion of finer-grained rocks than lower two units, fine-grained rocks still are only a small part of the total overburden. The minor amount of fine-grained rocks, along with the observation that they contain most of the potentially unfavorable trace elements (Hinkley and others,1982), should minimize environmental impacts. Elements of particular environmental concern here, namely Cd, Pb and Be, are present in negligible concentrations. However, a study by Massey and Barnhisel (1972), indicated that Cu, Ni and Zn, not usually considered of environmental concern, can create problems in the revegetation of spoil banks. At concentrations of 145, 85, and 122 ppm, respectively, these elements caused toxicity in eastern Kentucky coal mine spoils. In the upper unit, Cu, Ni, and Zn show average concentrations of 97, 50 and 486 ppm, respectively. These values suggest that toxicity from Cu and Ni in spoils is not likely at Jarvis Creek but Zn may be a problem. Massey (1972) demonstrated that liming the spoils to increase the pH was quite successful in reducing toxic levels of copper and zinc, but not nickel. Such treatment, therefore, might be effective at Jarvis Creek because Ni concentrations are negligible.

Iron concentrations in the overburden exhibited low levels (Table 4). The lowest amounts were in the coarser rocks (i.e., sandstones), while the siltstones showed the highest. In fact, when iron levels in overburden rocks of all grain sizes are compared, the Jarvis Creek samples are significantly lower than other western U.S. overburdens. This suggests that elemental iron in the form of pyrite is minimal in the overburden of the upper unit and was preferentially enriched in the reducing environment of the peat swamp.

Reclamation of mined land at Jarvis Creek should proceed without unusual expense or adverse effects on the environment. The subdued topography with well drained coarse glacial outwash gravels mantling the surface coals should easily be returned to approximate original contour. The potential toxicity of the framboidal pyrite in the coals should be offset by the natural calcic water systems of the Jarvis Creek area. High zinc concentrations in coals and overburden should be correctable, if necessary, by artificial liming.

Geologic Implications

The interpretation and discussion of the geology of the Jarvis Creek area will be summarized in terms of clastic provenance, depositional environments, and correlation with rocks of similar age near Healy.

Clastic Provenance

Determination of the provenance for Jarvis Creek Tertiary basin sediments requires the separate study of each individual stratigraphic unit. These units are lithologically dissimilar and were derived from different areas or source rocks.

Lower Unit - The Healy Creek Formation is texturally immature. The detrital grains are angular to subangular, include low percentages of heavy minerals, and are predominantly quartz-rich (Wahrhaftig and others, 1969). Quartz-mica schist fragments and flakes of sericite are common. At Jarvis Creek, similar lithologic components occur in the lower unit. Conglomerates here contain almost exclusively milky-white angular quartz pebbles with minor schist fragments and flakes of silvery sericite. Microscopic appearance of the sands in this unit reflects what is seen macroscopically. In thin section, quartz is the dominant detrital grain with minor quartz-mica schist fragments and sericite. These monocrystalline quartz grains are generally undulose, angular and exhibit an unusual shattered appearance (Fig. 43). Angular polycrystalline quartz grains are also common and are coarser grained than chert grains. This lower unit unconformably overlies a quartz-sericite schist basement rock (Birch Creek Schist) that is highly contorted, folded and contains abundant quartz lenses, pods and stringers. The quartz in this schist is also milky white in color, similar to that observed in the Tertiary detritus. Where the schist is in direct contact with the overlying Tertiary sediments, it is highly weathered, friable, and is often oxidized to such an extent as to appear brown, green and even purple. This intense weathering of the exposed schist probably explains the lack of feldspars in the lower unit. White sericitic clay with quartz fragments is also observed in this zone. Wahrhaftig and Hickcox (1955), interpreted this as a weathered or soil zone that formed just prior to the deposition of the Tertiary rocks.

Sandstones with large quantities of undulose monocrystalline quartz in conjunction with large percentages of polycrystalline quartz indicate a metamorphic provenance (Basu and others, 1975). Milky white, angular quartz fragments in the associated conglomerates are similar to those in the Birch Creek Schist quartz veins, and were probably derived from this source. Wahrhaftig and Hickcox (1955) stated that the predominant direction of streamflow during deposition of the lower unit was to the north. The planar crossbed measurements (Fig. 17) taken by the author suggest a more north-northwest direction in the Jarvis Creek area. The two directional measurements from pebble imbrications in conglomerates support such an interpretation. In summary, it seems that lower unit clastics were derived locally from the surrounding and underlying Birch Creek Schist and were transported from the south-southeast.

Middle Unit - Middle unit sands alternate between tan to milky white, coarse-grained, quartzarenite and brown to buff, medium- to coarse-grained, arkose. Both sandstones are laterally continuous. The quartzarenite is generally the thicker of the two sand-

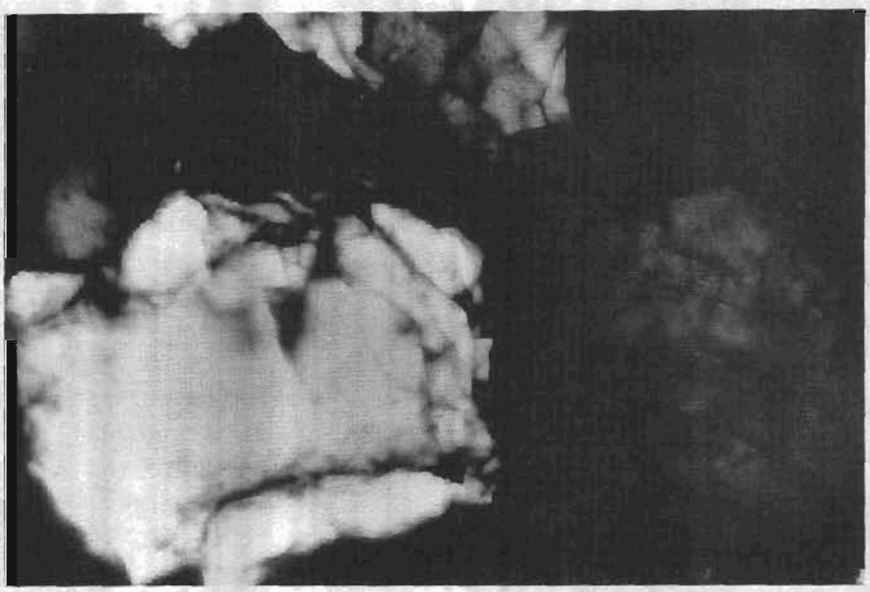


Figure 43. Photomicrograph of shattered monocrystalline quartz from lower unit sandstone. Photomicrograph taken in transmitted light, width of field is .43 mm.

stone types, ranging to 48 feet thick but averaging about 25 feet. The arkosic sandstones are thinner, ranging to 27 feet (8.5 m) thick with an average thickness of 15 feet. The quartz-rich sandstones typically have angular to subrounded clasts, are locally pebbly and contain mostly quartz with minor chert, metamorphic and plutonic rock fragments and sericite. Conversely, the arkoses average 59 percent quartz, 21 percent feldspar (mainly potassium feldspar), and 20 percent lithic fragments (mostly mica, schist and plutonic rock fragments). The percentage of non-undulose quartz is slightly higher in these arkosic sands, suggesting derivation from a plutonic source (Basu and others, 1975). Blatt and Christie (1963) suggest that an increase in non-undulose detrital grains is not related to provenance but to maturity. If so, this suggests slightly more mature sands in the middle unit compared to the lower unit. The decrease in monocrystalline quartz in the middle unit arkose, coupled with a marked increase in potassium feldspar, gives clear indication of a change in provenance for these sands. The slightly more rounded nature of the white quartzose sands suggests that they are second cycle sands derived from exposed lower unit white quartz conglomerates and sandstones.

The original source for the arkosic sands was probably the stock of Cretaceous granitic rocks directly northeast of the coalfield at Granite Mountain or possibly the Totatlanika schist (Wahrhaftig and Hickcox, 1955; Wahrhaftig, 1968). Granite Mountain is generally composed of quartz diorite, granodiorite, biotite granite and granite (Zehner and others, 1985), which locally intruded muscovite-chlorite schist and biotite-garnet gneiss basement rock (D. Warner, 1987, personal communication). Capps (1912) described the Totatlanika schist as a quartz-feldspar schist and gneiss. This schist is suspected to be buried beneath the Tertiary and Quaternary deposits in the Tanana Valley to the north (Wahrhaftig and Hickcox, 1955). Paleocurrent studies of these arkosic sands, although limited, indicate a transport direction toward the southwest, in agreement with Wahrhaftig and Hickcox's suggestion. Although crossbedding was not recognized in the friable quartzose sands, and thus no paleocurrent measurements are available, a general transport direction toward the north similar to the lower unit is postulated because the sands are identical petrologically. Since both the middle and lower stratigraphic units contain the characteristic white quartzose sands and seem to be locally derived, these units together are probably the lithologic correlative of the Healy Creek Formation.

Upper Unit - Upper unit sandstones are strikingly different from the lower two units. The sands attain thicknesses of up to 82 feet, but average about 25 feet, and are lenticular to such a degree that they sometimes pinch out within a single outcrop. No white quartzose sands are present. These upper unit sands are characteristically light-gray to gray, fine- to medium-grained and are lithic-rich. Microscopic examination reveals 50 percent quartz, 8 percent feldspar and 42 percent lithic fragments, mostly sedimentary. Chert and polycrystalline quartz are abundant and comprise approximately one-third of the detrital grains. The sands are often pebbly and contain the most and best preserved crossbedding of any of the units. Detrital grains are generally subangular to subrounded. Although the sands are lithic-rich, they are generally more texturally mature than the lower units, suggesting longer transport distances or reworking.

The presence of abundant chert, rounded grains and only minor detrital mica suggests that these sands were not derived locally, in contrast to the lower stratigraphic units. The large percentage and types of lithic grains in this upper unit suggest that they are recycled detritus of sedimentary or metasedimentary origin (Dickinson and Suczak, 1979). Such metasedimentary rocks are the main lithology in the southern and eastern Yukon-Tanana Upland and along the northern front of the Eastern Alaska Range (Mertie, 1937; Moffit, 1942; and Churkin, 1973). Wahrhaftig and others (1969) suggested that the abundant chert in the Suntrana Formation at Healy probably originated in the southern Yukon-Tanana Upland, including the area of the Livengood Chert (Mertie, 1937). This is not a likely source for chert in the upper unit of Jarvis Creek because paleocurrent measurements from the abundant crossbedding in this unit show a distinct current direction from the east southeast. Clast composition of the upper unit, moreover, does not resemble the salt and pepper sandstone of the Suntrana Formation. In fact, paleocurrent directions and lithology for the upper unit sands are quite similar to those observed in sandstone of the Lignite Creek Formation in the Nenana coalfields. Sandstones in the coalfields near Tatlanika Creek and Wood River are also similar (Wahrhaftig and others, 1969).

The change in coarseness (from coarse to fine/medium) and general morphology of the sandstone beds from the middle to the upper unit suggest that below this boundary, sandstones were derived locally and deposited by gravelly braided to sandy braided streams as at Healy (Buffler and Triplehorn, 1976), respectively. The upper unit, however, had a more distant source and was deposited by a sandy braided or possibly slightly meandering stream system as is possible in distal alluvial fan deposits (Nilsen, 1982). The dispersion of corrected paleocurrent directions, (Fig. 17), from the upper unit is more diverse than the other units, which is consistent with a minor meandering habit (Cant, 1982). The lower two units seem to be classic braided deposits. Although sand forsets often form at right angles to the stream direction by lateral accretion, especially in meandering deposits (Crowder, 1987, personal communication), most are subparallel (oblique) and parallel to the direction of the average local current vector (Potter and Pettyjohn, 1963). The upper unit displays more braided than meandering characteristics, such as abundant convolute bedding (Fig. 18), poor development of cyclicity, and thin sand units (Cant, 1982). Transport directions for the upper unit are generally toward the west-northwest and not from various directions as would be expected from a meandering stream.

Trace element studies also indicate derivation from eastern source areas where known base-metal sulfide deposits exist. These were weathered and eroded, allowing soluble metal ions to be transported and eventually precipitated in the upper unit, especially the peat swamps.

Depositional Environments

There is abundant evidence indicating a fluvial environment of deposition for the coal-bearing strata at Jarvis Creek. However, variations in composition and geometry of sandstone beds warrant discussion of the three stratigraphic units individually.

Prior to deposition of the lower unit, topography of the north side of the present Alaska Range was rugged with high relief (Wahrhaftig and others, 1969). Intense weathering prior to deposition of the Tertiary rocks had reduced much of the exposed Birch Creek Schist basement rock to angular quartz and schist fragments in a sericite clay soil matrix (Fig. 44a). Steep-gradient north flowing streams eroded this soil and concentrated sediment in valleys during the Late Oligocene to Early Miocene. These valleys formed as a result of local deformation from differential block faulting, and occurred at various times during the Tertiary (Churkin, 1973). Rapid subsidence of these structural basins along the north side of the ancestral Alaska Range, including the Jarvis Creek basin, seems to be indicated (Stevens, 1971).

The extreme lenticularity of the lower unit at Jarvis Creek attests to this valley filling, as this unit of approximately 500 feet of sediments thins rapidly to only 13 feet, one mile to the west and pinches out entirely within 2 miles. The coarseness of this unit (coarse pebble conglomerate with minor medium- to coarse sandstone) suggests that it was deposited by steep-gradient gravelly braided streams (Fig. 44b). Braided streams characteristically produce high sand to shale ratios, lack cyclicity, and contain thinner, more widespread sheet sands in contrast to the thicker shoestring sands of meandering streams (Nilsen, 1982; Hayes and others, 1975; Miall, 1980; and Beaumont, 1979). Other braided stream features in the lower unit include minor fine-grained overbank deposits, clasts to four inches long, lack of ripple marks, and abundant low-angle planar cross stratification (Nilsen, 1982). The absence of trough cross stratification and the presence of unidirectional tabular crossbedding (in this case from the south-southwest) generally describe deposition near the distal part of alluvial fans (R.K. Crowder, 1985, personal communication). Nilsen (1982) however, suggests that this cross stratification style occurs at the mid-fan/distal facies boundary.

The presence of isolated angular quartz pebbles in many fine-grained carbonaceous shales underlying lower unit and basal middle unit coals implies steep relief relatively close to the developing peat swamps. This is more evidence for the early valley filling episode at Jarvis Creek. Such relatively common lenticular carbonaceous shales are irregularly distributed throughout the lower unit, but are more frequent in the upper part. They demonstrate that organic buildups occurred between braided stream channels. However, the lack of substantial coal seams, with the exception of the eight-foot "A" seam, suggests that such phases were usually short-lived or had low preservation potential in this setting of shifting channels.

Braided rivers are laterally unstable with thin, easily erodible banks resulting in frequent lateral migrations (Nilsen, 1982; Cant, 1982; Hayes and others, 1975; Miall, 1980; and Beaumont, 1979). Sheet-like clastic detritus from these migrations was constantly choking off any organic buildup or contaminating it so that only bony coal or carbonaceous shale was formed. The presence of the eight-foot thick "A" seam indicates that a peat swamp did persist for

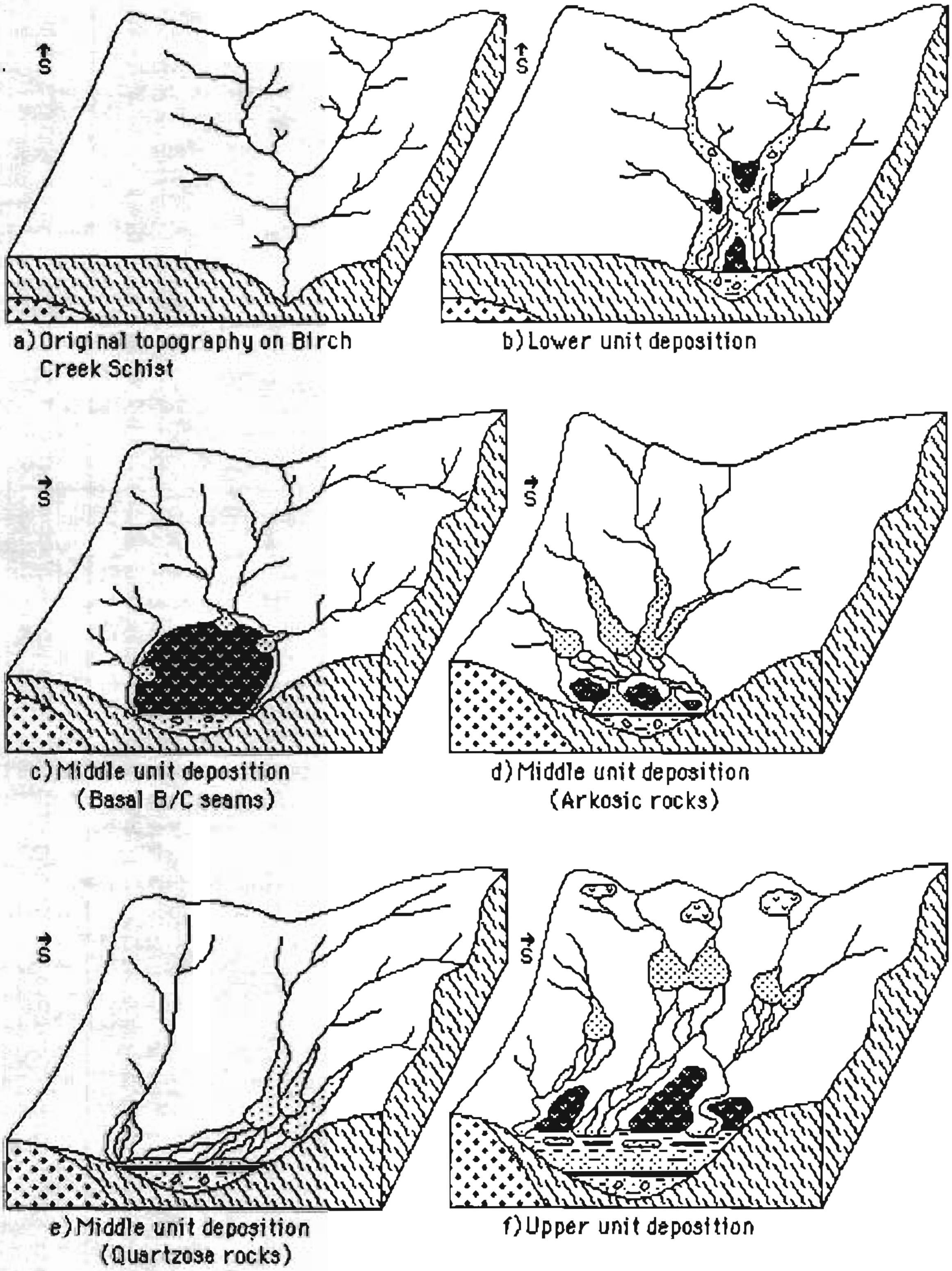


Figure 44. Block diagrams showing hypothetical stages in development of the Tertiary stratigraphy at Jarvis Creek.

some time during the early stages of deposition of the lower unit. Its lenticularity suggests that it formed between two separate stream channels, a common occurrence in some Appalachian upper delta plain coals (Horne and others, 1978) or that it was flanked by two prograding alluvial fan complexes (Fig. 44b).

Tectonic activity seems to have played an important role in controlling deposition of the middle unit at Jarvis Creek. The alternation of quartzose sands and arkosic sands suggests that streams emptied into the basin from two different directions (Fig. 44d,e) but not at the same time during the early Miocene.

Uplift of either the Cretaceous granitic complex at Granite Mountain or the feldspathic Totatlanika Schist beneath the present Tanana Valley probably resulted in the shifting of drainages into the Jarvis Creek basin. These drainages flowed from the north-northeast in contrast to the north-flowing trends of the lower unit and supplied the arkosic sands (Fig. 44d). Return to greater subsidence rates and subdued tectonic activity would then have brought about a change back to stream flow to the north and a corresponding influx of white quartzose sands (Fig. 44e). Sporadic uplifts of these feldspathic terrains throughout the deposition of the middle unit resulted in the alternating composition of the sands. The coarseness of both sand types in conjunction with high sand/shale ratios, suggests that they both were deposited by braided streams. Increased textural maturity of both sand types, compared to the lower unit, suggests reworking of the lower unit quartz conglomerate to produce the white quartzose sands and/or derivation from a more distant source in the case of the arkosic sands. The white quartzose sandstone was probably a sheet sand from the upper distal facies of an alluvial fan. The gradual thickening of the arkosic sandstone that splits the B and C coal seams at the base of the middle unit toward the east suggests that it is a crevasse splay. It probably came from a braided stream channel on the upper distal part of an alluvial fan system flowing in a southwesterly direction just east of the present coalfield (Fig. 44d). Lateral coarsening of this arkosic sandstone towards the east and a distinctive vertical coarsening followed by fining upwards at any given place, attests to such an interpretation (Horne and others, 1978; R.K. Crowder, 1985, personal communication). The thinness of the arkosic sands compared to the quartzose sands suggests that the former were produced by shorter duration depositional events while the main stream flow direction was to the north. The sporadic uplifts that caused pulses of arkosic detritus into the Jarvis Creek basin often caused stream blockages, diverting them away from the coalfield and allowing organic material to accumulate in the absence of fluvial sediment. Stream blockages in the Nenana field to the west were combined with a rate of subsidence exceeding sediment influx. This resulted in "ponding" of the sediments which was the cause of the lacustrine Sanctuary Formation (Wahrhaftig and others, 1969; Stevens. 1971). Such ponding did not occur at Jarvis Creek as no thick shales were observed. A rather long-lived blockage did occur at Jarvis Creek but here it resulted in the deposition of the B and C seams (Fig. 44c). In the middle unit, coal beds, carbonaceous shales or other fine-grained sediments generally underlie arkosic sand bodies. This signifies blockage followed by crevasse splay deposition.

The strong contrast between the upper unit sediments and the lower two units can be interpreted in many ways. The distinct lithic-rich character of the upper unit sands along with their greater textural maturity and finer grain size suggest derivation from a different and distant provenance area. The extreme lenticularity of the sand bodies and the presence of both trough and planar cross stratification, in conjunction with the decrease in the sand/shale ratio, as well as the abundance of coal seams (over 30), are evidence for a change in depositional setting. And finally, the presence of high concentrations of major and minor elements in the coals and finer-grained clastic overburden rocks of the upper unit indicate that some of the streams emptying into the subsiding Jarvis Creek basin drained areas rich in base metal sulfides.

Paleocurrent studies, although limited, also show a contrast between the upper and two lower stratigraphic units. There is a greater diversity of current directions in the upper unit as compared to the lower two units. In the upper unit, the general flow direction, based mainly on planar foresets, is to the west-northwest (Fig. 44f). Trough cross stratification measurements down trough axes also show a current to the northwest. Some sandstones in the upper unit also show crude fining-upward sequences with scouring, and most show differing combinations of trough, planar and rippled bedding (Fig. 45). Such bedding was formed either by meandering streams which deposited them in point bar sequences, or by braided streams which deposited them in longitudinal and transverse bars.

The upper unit at Jarvis Creek displays both braided and meandering stream depositional habits. Braided characteristics include a high sand/shale ratio

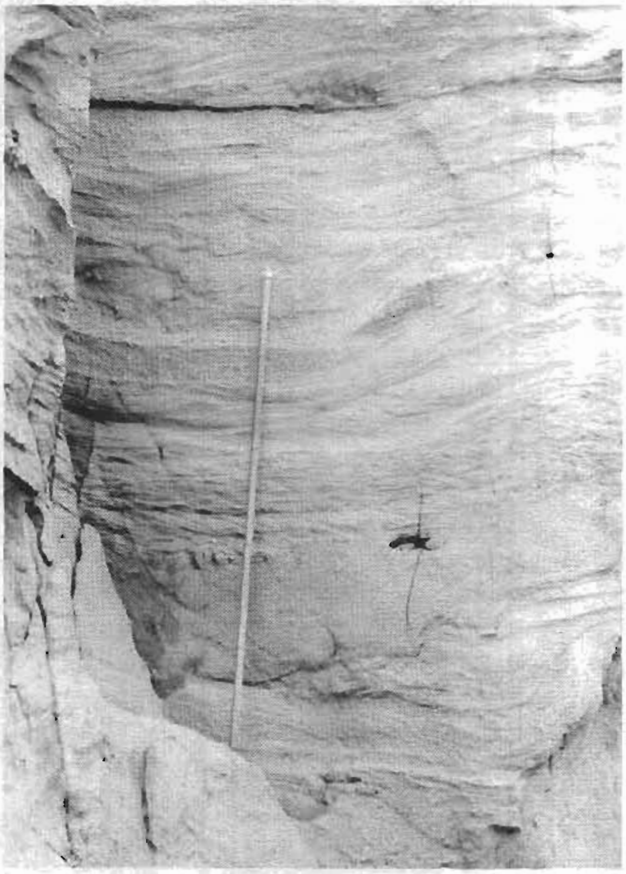


Figure 45. Photograph of trough, planar and rippled bedding in an upper unit sandstone near Jarvis Creek.

(although lower than the two lower units), and a general lack of cyclicity with finer-horizons and organic beds occurring randomly in the sequence. The frequent occurrences of soft sediment deformation in the sands is also diagnostic of braided environments (R.K. Crowder, 1985, personal communication).

Meandering stream characteristics at Jarvis Creek include an abundance of finer-grained overbank deposits and thick, lenticular sandstone bodies occasionally showing en echelon stacking (Fig. 46). Flores (1983) saw similar sandstone geometry in the Tertiary sandstones of the Northern Powder River Basin of Wyoming. The high diversity of paleocurrent directions also suggest a meandering stream environment (Hayes and others, 1975).

Although both braided and meandering characteristics occur in this upper unit, thick sequences of both are not seen. They seem to grade into each other both vertically and horizontally within short distances. Meandering streams are known to become braided with increased bedload and vice versa (Nilsen, 1982). In the extreme distal parts of alluvial fans, small changes in bedload and gradient can make a big change in depositional systems (Nilsen, 1982), and this is where upper unit deposition took place (Fig. 44e). Distance from the sediment source here was also the greatest, accounting for the greater textural maturity and smaller grain size of the sands. The relatively great abundance and thickness of finer-grained overbank

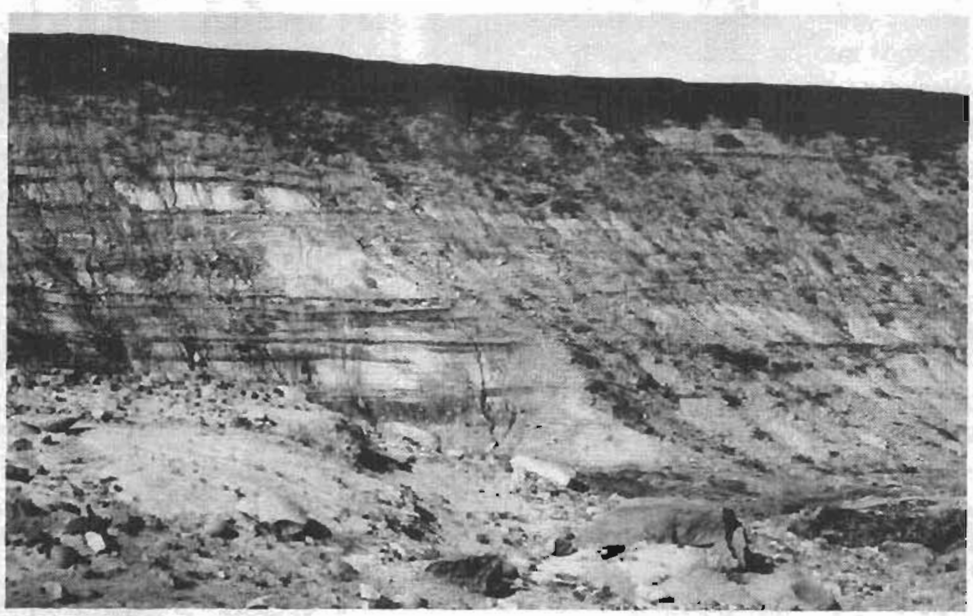


Figure 46. Photograph of an echelon stacking of sandstones in an upper unit exposure near Jarvis Creek.

deposits suggest long periods of time between stream avulsion events, allowing frequent flooding and enhanced preservation of these sediments in the floodplain. The high frequency of coals in the upper unit suggests that developing peat swamps were common between active channels as well as over abandoned channels. However, quiescent periods were not long enough for accumulation of thick coals except in a few cases, and mainly thin coals developed.

Periodic uplifts of the Yukon-Tanana metasediments to the east and the elevated highlands of plutonics to the northeast during the late Miocene to early Pliocene supplied the combination of metaclastic fragments and feldspar observed in the upper unit sands. Streams originating in these highlands flowed in a general westerly direction into the Jarvis Creek basin (Figure 44f), bringing the diverse mineral assemblages previously described. During periods of uplift, streams tended to be braided due to high gradients. As uplift ceased streams became meandering. Switching between braided and meandering environments occurred throughout the upper unit deposition.

Deposition of Tertiary coal-bearing sequences were first deposited in the Jarvis Creek basin during the later Oligocene to early Miocene by north-flowing, gravelly braided streams on coalescing alluvial fans. These alluvial fans just filled the valleys, leaving part of the high-relief country rock exposed, thus giving a distinct lenticularity to the lower unit. Subsequent local uplift of feldspathic schist and granite to the north and northeast during the early Miocene diverted these northflowing braided streams to the west-southwest, bringing arkosic sands into the basin. This original diversion lasted a considerable time as demonstrated by the persistence of peat swamps and the resultant thick B and C coal zone. Later periodic uplifts and diversions were of shorter duration and thus the amount of arkosic detritus and organics interrupting the southerly derived quartzose sediments was less. For some time the basin was filled by alternating southerly derived quartzose and northeasterly derived arkosic sandstones, all deposited by braided streams in the upper distal part of large alluvial fans. This produced the middle unit, which onlapped across the exposed basement rock, producing the unconformity seen in the southwestern part of the coalfield. During later Miocene, the Yukon-Tanana Uplands to the north and east of the Jarvis Creek basin were uplifted. They became the dominant sediment source, thereby terminating the alternating sources. Sandy braided to meandering streams on the extreme distal part of alluvial fans flowed westerly into the Jarvis Creek basin. Periodic flooding by some of these streams into the numerous well-developed upper unit backswamps, supplied metal ions in high concentrations to the accumulating organic beds. These streams evidently drained areas rich in base-metal sulfides.

Overall there is a progressively fining-upward trend in the Jarvis Creek coal-bearing units. A mid fan alluvial origin is proposed for the lower unit composed of conglomeratic material. Medium- to coarse-grained arkosic and quartzose sands of the middle unit were deposited as an upper distal facies of an alluvial fan system. Finally, topping the sequence is the lithic-rich, texturally mature, fine- to medium-grained sandstones from the upper unit. These are interpreted as lower distal facies of an alluvial fan system.

This generally fining-upward system was probably related not only to the change from dominantly gravelly braided to sandy braided and meandering fluvial systems, but also to the proximity of the sources. The provenance of the lower unit was local, while sediments upsection were derived from progressively more distant sources.

Correlation with Healy coal bearing strata

Coal-bearing strata in the Jarvis Creek basin have been tentatively correlated with the Healy Creek Formation (Wahrhaftig and Hickcox, 1955). My study of the strata in the coal-bearing units of Jarvis Creek suggest that this interpretation may be partially incorrect. The lower and middle units at Jarvis Creek both contain the distinctive white angular quartzose sandstone with quartz-sericite schist fragments that is observed in the Healy Creek Formation furthur west. Both localities show quartz with a distinctly shattered appearance and an abundance of clay matrix, although there is less clay matrix at Jarvis Creek. Bony coals are common in the Healy Creek Formation (Wahrhaftig and others, 1969), and this applies also to the lower two units at Jarvis Creek. The arkosic member of the middle unit is related to local sediment sources and can still be considered part of the Healy Creek Formation.

The distinctive brown-weathering shale of the Sanctuary Formation and the cyclic "salt and pepper" sandstone of the Suntrana Formation (Wahrhaftig and others, 1969) are not present at Jarvis Creek. Because there is no evidence of extensive erosion it seems likely that such lithologies were never deposited.

The upper stratigraphic unit at Jarvis Creek exhibits too many differences from both the lower two units and the Healy Creek Formation at the type section to be considered their lithologic equivalents. From gross bedding characteristics, physical appearance and detailed sandstone petrology, the upper unit highly resembles the Lignite Creek Formation at the type section. For example , there are very similar percentages of detrital grains and pebbles (Figures 20a,b; 21a,b; and Appendix 1). The grains at both localities are subrounded and show better sorting than subjacent units. Quartz grains are unlike the shattered grains in the Healy Creek Formation. Feldspathic grains are somewhat more abundant in the Lignite Creek Formation than in lower units and include more plagioclase (Wahrhaftig and others, 1969). The latter may be caused by close proximity of the Tertiary Teklanika and Mount Galen volcanics (Gilbert and others, 1976; Decker and Gilbert, 1978). The Lignite Creek Formation and Jarvis Creek upper unit are both lithic-rich and low in clay matrix. Larger scale similarities include thick fine-grained horizons (e.g. siltstone and claystone beds) with numerous concretions as well as numerous thin and lenticular coal beds and thick, lenticular sandstone bodies. All of these are distinguishing characteristics of the Lignite Creek Formation according to Wahrhaftig and others (1969). The existence of the Nenana Gravels directly northeast of the Jarvis Creek coalfield at Macumber Creek and the Gerstle River (Moffit, 1942) suggests a similarity to the Nenana basin where Pliocene gravels overly the upper part of the Coal-bearing Group. At Jarvis Creek this contact is not present due to structural deformation and erosion discussed earlier.

The sharp drop in vitrinite reflectance observed between the middle and upper units at Jarvis Creek as well as the change in paleoflora suggest an age difference between these units. Such an age difference can be explained as a result of a hiatus, perhaps the time during which the Sanctuary and Suntrana Formations were deposited in the Nenana Basin. A disconformity between the Healy Creek Formation equivalents (lower and middle units) and Lignite Creek Formation equivalents (upper unit) at Jarvis Creek would then be required, although it is not apparent from field relationships. Finally, if one subtracts the 900 foot thick upper unit from the total thickness of the coal-bearing strata, the lower and middle units would then total 1100 feet, which is very close to the maximum reported Healy Creek Formation thickness of 1150 feet (Wahrhaftig and others, 1969).

This suggested correlation of the upper unit at Jarvis Creek with the Lignite Creek Formation should be regarded as speculative. Additional study of the stratigraphic units at both localities, including more sampling of the Lignite Creek sands and age control, is required to confirm or deny this correlation.

SUMMARY AND CONCLUSIONS

The investigation of the Jarvis Creek coalfield resulted in a greater understanding of the Tertiary stratigraphy of this part of Alaska as well as coal quality and quantity. This new knowledge provides the basis for plausible answers to the four basic questions raised in the Introduction. They are again: (1) Is the stratigraphy at Jarvis Creek similar to or different from that observed in the commercially important Nenana Field to the west; (2) How do coal and overburden properties change with respect to stratigraphic position; (3) What is the lateral continuity of the coal seams and which analyses are most appropriate for correlation in determining this; and (4) why is the reported sulfur content of the Jarvis Creek coals so much higher than most other Alaskan coals and is this related to the environment of deposition?

The Tertiary lithologies exposed in the Jarvis Creek coal field resemble those of the Healy Creek and Lignite Creek formations of the Nenana field. Equivalents of the Sanctuary and Suntrana formations are not present and presumably were never deposited. The absence of the Suntrana Formation equivalent coupled with the limited extent of the Healy Creek Formation equivalent at Jarvis Creek resulted in the lack of substantial coal reserves that these formations contained farther west.

Properties of the coals and overburden obtained from the limited stratigraphic interval at Jarvis Creek show significant changes, mainly vertically, within the three stratigraphic units represented. Coals tended to increase in moisture, oxygen, sulfur and vitrinite content upsection while decreasing in volatile matter, carbon, hydrogen, liptinite and inertinite content, heating values and associated rank. Overburden shows an upsection increase in number and thickness of beds with a corresponding decrease in grain size. Both coals and overburden show an increase in major and minor elements, especially trace metals, toward younger strata.

Few coal seams at Jarvis Creek, with the exception of B and C, the "sandwich" seams, and the mine seam, show lateral continuity beyond 1/2 mile. These seams, along with a few lenticular seams close to the surface, contain the bulk of the estimated coal reserves of the basin. Correlation of these seams was made possible through analytical techniques that exhibited little lateral variation and thus show promise for correlation. These are maceral and microlithotype analysis, major oxide and trace element geochemistry, moisture and sulfur analysis, and vitrinite reflectance.

The elevated sulfur contents of the Jarvis Creek coals, which are somewhat anomalous in Alaska, appear to be a result of secondary enrichment. This enriched sulfur, mainly organic but containing a large percentage of framboidal pyrite, is exclusively observed within coals of the upper stratigraphic unit. This suggests a change in the depositional regime of this unit compared to the subjacent units. The reported existance of numerous volcanogenic sulfide deposits in the vicinity of the coalfield, coupled with increases in associated trace metals in upper unit coals, strongly suggest that sulfur ions originated in and were transported as sulfates from these deposits. Paleocurrent studies of upper unit sands support this. Adverse environmental effects of this sulfur enrichment, should be mitigated by the natural calcic water system of the area.

The Jarvis Creek coalfield is a small basin and data trends shown in this report may be exaggerated by local influences. This study, however, was more detailed than most coal basin studies in Alaska in terms of efforts to correlate seams, identify and estimate resources, as well as determine coal quality and environments of coal deposition. Future studies of this type may yield similar principles that are applicable to a broad spectrum of coalfields in Alaska and elsewhere.

REFERENCES

Anonymous, 1985, American Society for Testing and Materials: Annual Book of ASTM Standards, Philadelphia, Pa, 992 p.

Basu, A., Young, S.W., Suttner, L.J., James, W.C. and Mack, G.H., 1975, Re-evaluation of the use of undulatory extinction and polycrystallinity in detrital quartz for provenance interpretation: Journal of Sedimentary Petrology, v. 45, no. 4, pp. 873-882.

Beaumont, E.A., 1979, Depositional environments of Fort Union sediments (Tertiary, Northwest Colorado) and their relation to coal: American Associations of Petroleum Geologists Bulletin, v. 63, no. 2 ,(Feb), pp. 194-217.

Blatt, H. and Christie, J.M., 1963, Undulatory extinction in quartz of igneous and metamorphic rocks and its significance in provenance studies of sedimentary rocks: Journal of Sedimentary Petrology, v. 33, no. 3, pp. 559-579.

__________, Middleton, G., and Murray, R., 1980, Origin of Sedimentary Rocks: New Jersey, Prentice-Hall, Inc., 782 p.

Buffler, R.T., and Triplehorn, D.M., 1976, Depositional environments of the Tertiary Coal-Bearing Group, Central Alaska, in Miller, T.P. ed., Symposium Proceedings: Recent and Sedimentary Environments in Alaska: Alaska Geological Society, Anchorage, 10 p.

Cant, D.J., 1982, Fluvial facies models and their applications, in Sandstone Depositional Environments: American Association of Petroleum Geologists Memoir 31, pp. 115-137.

Capps, S.R., 1912, The Bonnifield Region, Alaska: U.S. Geological Survey Bulletin 501, 64 p.

Caruccio, F.T., and Geidel, G., 1978, Geochemical factors affecting coal mine drainage quality: in Reclamation of Drastically Disturbed Lands, presented at Symposium, August, 1976, Ohio Agricultural Research and Experiment Station, pp. 129-147.

Chesterman, C.W., 1978, The Audubon Society Field Guide to North American Rocks and Minerals: Alfred A. Knopf, Inc., New York, 850 p.

Chou, K.T., 1987, Oxygen application to chloride leaching of complex sulfide ores: University of Alaska Fairbanks Mineral Industry Research Laboratory Report 77, 27 p.

Churkin, M. Jr., 1973, Paleozoic and Precambrian rocks of Alaska and their role in its structural evolution: U.S. Geological Survey Professional Paper 740, 64 p.

Csejtey, B. Jr., Cox, D.P., Evarts, R.C., Stricker, G.D., and Foster, H.L., 1982, The Cenozoic Denali fault system and the Cretaceous accretionary development of Southern Alaska: Journal of Geophysical Research, v. 87, no. B5, pp. 3741-3753.

Decker, J.E., and Gilbert, W.G., 1978, The Mount Galen Volcanics - A new Middle Tertiary volcanic formation in the central Alaska Range: Alaska Division of Geological and Geophysical Surveys Geologic Report 59, 11 p.

Dickinson, W. R., 1985, Interpreting provenance relations from detrital modes of sandstone, in Zuffa, G. G. ed., Provenance of Arenites: Proceedings of the NATO Advanced Study Institute on Reading Provenance from Arenites, Italy, June 1984, pp. 333-361.

Dickinson, W.R., and Suczek, C.A., 1979, Plate tectonics and sandstone compositions: American Association of Petroleum Geologists Bulletin, v. 63, no. 12, pp. 2164-2182.

Flores, R.M., 1983, Basin Facies Analysis of coal-rich Tertiary fluvial deposits, northern Powder River Basin, Montana and Wyoming, in Modern and Ancient Fluvial Systems, J.D. Collinson, J. Lewin eds.: Special Publication, No. 6, of the Internation Association of Sedimentologists, London, pp. 501-517.

Foley, J.Y., 1985, Petrology, geochemistry, and geochronology of Alkaline dikes and associated plutons in the eastern Mount Hayes and western Tanacross Quadrangles, Alaska: University of Alaska- Fairbanks, M.S. Thesis, 95 p.

Foster, H.L., Weber, F.R., Forbes, R.B., and Brabb, E.E., 1973, Regional geology of the Yukon-Tanana Upland, Alaska, in Arctic Geology: American Association of Petroleum Geology Memoir 19, pp. 388-395.

Gilbert, W.G., Ferrell, V.M., and Turner, D.L., 1976, The Teklanika Formation - A new Paleocene volcanic formation in the central Alaska Range: Alaska Division of Geological and Geophysical Surveys Geologic Report 47, 16 p.

Gluskoter, H.J., 1975, Mineral matter and trace elements in coal, in Babu, S. P. ed., Trace Elements in Fuel: Washington D.C. American Chemical Society Advances in Chemistry Series, no. 141, p.1-27.

_______________, Ruch, R.R., Miller, W.G., Cahill, R.A., Dreher, G.B., and Kuhn, J.K., 1977, Trace elements in coal; occurrence and distribution: Illinois State Geological Survey Circular 499, 154 p.

Harvey, R.D., and Ruch, R.R., 1986, Mineral matter in Illinois and other U.S. coals: Rock and Mineral Analysis - second edition, New York, Wiley and Sons, eds., pp. 11-52.

Hatch, J.R., and Swanson, V.E., 1977, Trace elements in Rocky Mountain coals: in 1976 Symposium on the geology of Rocky Mountain coal, Ed. D. Keith Murrey, pp. 143-163.

Hayes, J.B., Harmes, J.C., and Wilson, T. Jr., 1975, Contrasts between braided and meandering stream deposits, Beluga and Sterling Formations (Tertiary), Cook Inlet, Alaska, in Recent and Ancient Sedimentary Environments: Alaska Geological Society Proceedings, Miller T.P. ed., pp. J1-J27.

Hickman, R.G., Craddock, C., and Sherwood, K.W., 1977, Strucural geology of the Nenana River segment if the Denali fault system, central Alaska Range: Geological Society of America Bulletin, v. 88, pp. 1217-1230.

Hinkley, T.K., Smith, K.S., Peard, J.L., and Tompkins, M.L., 1982, Whole-rock chemical composition of same samples from two drill hole cores in the Capps coal field, Beluga coal area, south-central Alaska: U.S. Geological Survey Open-File Report 82-672, 50 p.

Holmes, G.W., and Foster, H.L., 1968, Geology of the Johnson River area, Alaska: U.S. Geological Survey Bulletin 1249, 49 p.

Horne, J.C., Ferm, J.C., Caruccio, F.T., and Baganz, B.P., 1978, Depositional models in coal exploration and mine planning in the Appalachian Region: American Association of Petroleum Geologists Bulletin, v. 62, pp. 2379-2411.

Johnson, W. M. and Maxwell, J.A., 1981, Rock and Mineral Analysis: Second Edition, Wiley and Sons, eds., New York, pp. 135-136.

Lange, I.M., Nokleberg, W.J., Aleinikoff, J.N., and Church, S.E., 1987, Genesis and tectonic setting of volcanogenic massive sulfide deposits, eastern Alaska Range, Alaska: U.S. Geological Survey Circular 995, pp. 39-40.

Levinson, A.A., 1974, Introduction to Exploration Geochemistry: Applied Pub. Co., Calgary, 612 p.

Massey, H.F., 1972, pH and soluble copper, nickel, and zinc in eastern Kentucky coal mine spoil materials: Soil Science, v. 114, no. 3, pp. 217-221.

_________, and Barnhisel, R.I., 1972, Copper, nickel, and zinc released from acid coal mine spoil materials of eastern Kentucky: Soil Science, v. 11, no. 3, pp. 207-212.

Merritt, R.D., 1983, Coal Overburden - Geologic Characterization and Premine Planning: Noyes Data Corporation, New Jersey, 343 p.

___________, and Hawley, C.C., 1986, Map of Alaska's coal resources: Alaska Division of Geological and Geophysical Surveys Special Report 37, scale 1:2,500,000.

Mertie, J.B. Jr., 1937, The Yukon-Tanana region, Alaska: U.S. Geological Survey Bulletin 872, 276 p.

Metz, P.A., Rao, P.D., and Smith, J.E., 1981, Mine plan and preliminary feasibility study for the

Jarvis Creek coalfield - A model for small scale mine development: University of Alaska Mineral Industry Research Laboratory, unpublished report, 70 p.

Miall, A.D., 1980, Cyclicity and the facies model concept in fluvial deposits: Bulletin of Canadian Petroleum Geology, v. 28, no.1 (March 1980), pp. 59-80.

Moffit, F.H., 1942, Geology of the Gerstle River district, Alaska: U.S. Geological Survey Bulletin 926-B, pp. 107-159.

__________, 1954, Geology of the eastern part of the Alaska Range and adjacent area: U.S. Geological Survey Bulletin 989-D, pp. 136-141.

Moore, P.D., Webb, J.A., 1978, An Illustrated guide to Pollen Analysis: Hodder and Stoughton, eds. London, 133p.

Nilsen, T.H., 1982, Alluvial fan deposits, in Sandstone Depositional Environments: American Association of Petroleum Geologists Memoir 31, pp. 49-86.

Nockleberg, W.T., and Lange, I.M., 1983, Volcanogenic massive sulfide occurrences, Jarvis Creek Glacier Terrane, western Mount Hayes quadrangle, eastern Alaska Range: U.S. Geological Survey Circular 945, pp. 77-80.

Orheim, A., 1978, Geochemical affinities as exploration and classification tools: Proceedings of the Second International Coal Exploration Symposium, Denver, Colorado, USA, in Coal Exploration, p. 328-345.

Parks, B., 1983, Trace metals in surface water and stream sediments of Healy and Lignite Creek basins, Alaska: U.S. Geological Survey Water Resources Investigation Report 83-4173, 26 p.

Pewe, T.L., and Holmes, G.W., 1964, Geology of the Mount Hayes D-4 quadrangle, Alaska: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-394, scale 1:63,360.

Potter, P.E. and Pettijohn, F.J., 1963, Paleocurrents and Basin Analysis: Berlin; Springer-Verlag, 296 p.

Rao, P.D. and Smith, J.E., 1983, Petrology of Cretaceous coals from northern Alaska: University of Alaska-Fairbanks Mineral Industry Research Laboratory Report No. 64, 141 p.

__________ and Smith, J.E., 1986, Characterization of Chuitna coal from deep drill core with possible applications to seam correlation: Focus on Alaska's Coal '86, University of Alaska Fairbanks-Mineral Industry Research Laboratory Report 72, p. 157-182.

Reed, B.L., and Lanphere, M.A., 1973, Alaska-Aleutian Range batholith geochronology, chemistry, and relation to circum-Pacific plutonism: Geological Society of America Bulletin, v. 84 (August, 1973), no. 8, pp. 2583-2610.

Richter, D.H., and Jones, D. I., 1973, Structure and stratigraphy of the eastern Alaska Range, Alaska: American Association of Petroleum Geologists Memoir 19, pp. 408-420.

Rimmer, S.M., 1984, Lateral variability in mineralogy and petrology of the lower Kittanning Seam, western Pennsylvania and eastern Ohio: Final Report - Part II; Fossil Energy, Coal Research Section, Pennsylvania State University, 247 p.

Royse, C.A. Jr., 1970, Heavy mineral analysis and evaluation of directional data, in an Introduction to Sediment Analysis: Arizona State University, pp. 93-96 and pp. 137-149.

Schmidt, R.A., 1979, Origin and properties of coal, in Coal in America: Coal Week, McGraw-Hill, 57 p.

Sholes, M.A., and Cole, G.A., 1981, Depositional history and correlation problems of the Anderson-Dietz coal zone, southeastern Montana: The Mountain Geologist, v. 18, no. 2 (April, 1981), pp. 35-45.

Stach, E., Mackowsky, M.-Th., Teichmuller, M., Taylor, G.H., Chandra, D., and Teichmuller, R., 1982, Stach's textbook of coal petrology: Gebruder Borntraeger, Berlin, 535 pp.

Stevens, C.C., 1971, A provenance study of the Tertiary sandstones in the Healy Creek and Lignite Creek coal basins, Nenana coal field, Alaska: University of Alaska-Fairbanks unpub. M.S. thesis, 122 p.

Suhr, N.H., and Gong, H., 1983, Some procedures for the chemical and mineralogical analysis of coals: Final Report - Part 3 of A Data Base for the Analysis of Compositional Characteristics of Coal Seams and Macerals, Coal Research Section, Pennsylvania State University, 38 p.

Thomas, B., 1943, Donnelly coal field ("Big Delta" coal field): Alaska (Ter.) Department of Mines, unpublished report, 4 p.

Toenges, A.L., and Jolley, T.R., 1949, Investigations of coal deposits in south-central Alaska and the Kenai Peninsula: U.S. Bureau of Mines Report of Investigations 4520, 37 p.

Wahrhaftig, C., 1968, Schists of the central Alaska Range: U.S. Geological Survey Bulletin 1254-E, 22 p.

______________, and Hickcox, C.A., 1955, Geology and coal deposits, Jarvis Creek Coal Field, Alaska: U.S. Geological Survey Bulletin 989-G, pp. 353-367.

______________, Wolfe, J.A., Leopold, E.B., and Lanphere, M.A., 1969, The coal-bearing group in the Nenana coal foeld, Alaska: U.S. Geological Survey Bulletin 1274-D, 30 p.

Warfield, R.S., 1973, Rotary drilling for strippable coal in the Jarvis Creek coalfield, Alaska: U.S. Bureau of Mines Open-File Report 7-73, 35 p.

Wolfe, J.A., Hopkins, D.M., and Leopold, E.B., 1966, Tertiary stratigraphy and paleobotany of the Cook Inlet region, Alaska: U.S. Geological Survey Professional Paper 398-A, pp. A1-A29.

Wood, G.H. Jr., Kehn, T.M., Carter, M.D., and Culbertson, W.C., 1983, Coal resource classification system of the U.S. Geological Survey: U.S. Geological Survey Circular 891, 65 p.

Zehner, R.E., O'Leary, R.M., Day, G.W., Sutley, S.J., Nokleberg, W.J., and Koch, R.D., 1985, Emission spectrographic and atomic absorption analysis of rock, mineral occurrence, prospect, and deposit samples from the Mount Hayes quadrangle, eastern Alaska Range, Alaska: U.S. Geological Survey Open-File Report 84-774, 138 p. one plate, scale 1:250,000.

APPENDIX 1

SANDSTONE POINT COUNT DATA, VOL %

	URC6-3S	RGD1-1S	UC2-1S	UC7-1S	RC1-1S	RC1-3S	URC2-4S	RGD1-2S	UC7-2S	RC2b-2S	URC1-1S	RGD1-3S	LGC3-3S	SC1-1S
UNIT	L	L	L	L	M	M	M	M	M	U	U	U	U	U
DETRITAL GRAINS														
Undulose Qtz	65.5	53.5	42.8	45.0	36.8	25.8	21.0	25.5	37.3	7.3	17.0	15.8	13.8	13.3
Straight Qtz	10.8	6.0	6.8	6.0	4.5	3.8	13.8	6.8	8.8	2.3	2.3	3.0	1.8	5.0
Poly Qtz	17.0	24.8	19.3	27.8	15.8	25.5	21.3	26.5	17.3	36.5	22.0	32.3	23.0	28.8
K-Feldspar	---	0.3	---	---	26.5	17.8	19.3	13.5	22.8	4.3	4.5	4.0	5.8	3.5
Plagioclase	---	---	---	---	0.3	1.8	1.0	0.3	0.3	0.5	2.0	0.5	3.0	0.5
Plutonic RF (K)	---	---	---	---	4.0	6.0	6.3	2.5	3.5	1.8	0.8	1.0	1.5	1.0
Plutonic RF (Q)	---	---	---	---	1.8	3.0	3.3	3.3	1.5	1.5	1.5	0.8	2.5	1.0
Alkali Feld (Tri)	---	---	---	---	0.3	1.0	0.8	---	---	---	0.3	---	0.3	---
Altered Feldspar	---	---	---	---	2.0	3.0	3.8	1.5	1.3	0.8	2.3	1.5	2.0	0.5
Chert	---	---	0.3	---	2.8	0.8	1.5	3.3	1.0	6.8	8.0	10.8	5.5	7.5
Cherty argillite	---	---	---	---	1.5	1.8	1.8	4.8	0.8	7.8	9.0	4.5	7.8	7.0
Argillite	---	---	---	---	---	0.5	0.3	5.0	---	1.5	4.3	1.8	1.5	2.8
Siltstone	---	---	---	---	---	---	---	---	---	1.8	3.0	2.0	2.0	2.8
Sandstone	---	---	---	---	---	1.8	---	1.5	---	2.0	0.8	1.5	1.0	1.8
Slate/shale	---	---	---	---	---	---	---	---	---	3.3	1.5	2.5	1.3	1.5
Coal/organics	1.5	1.3	4.0	4.8	1.5	1.3	1.0	0.5	3.3	3.0	3.5	3.0	3.8	1.0
Volcanic rock frag	---	---	---	---	---	0.5	---	---	---	---	0.5	---	---	0.3
Qtz-mica sch/gn	3.0	10.0	13.5	14.0	1.5	3.5	2.5	2.0	1.5	6.8	3.8	8.3	6.0	5.0
Qtz-mica phyllite	---	---	---	0.3	---	---	---	---	---	10.3	12.0	6.8	16.3	16.5
Sericite/muscov	2.0	4.3	13.3	2.3	1.0	2.5	2.8	3.0	1.0	2.3	1.0	0.3	1.5	0.5
Zircon	0.3	---	---	---	---	---	---	---	---	---	---	---	---	---
Carbonate	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Chlorite	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Pyroxene	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Amphibole	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Biotite	---	---	0.3	---	---	---	---	---	---	---	---	---	---	---

APPENDIX 1 (con't)

SANDSTONE POINT COUNT DATA, VOL %

	URC6-1S	DC1-1S	DD1-2S	HCF1	SF1	LCF2	JCM2S*	URC3-2S*	LGC1-2S	HCF2*	SF2*	LCF1*	LCF3*
UNIT	BCS	M?	U?	HC	S	LC	U	U	U	HC	S	LC	LC
DETRITAL GRAINS													
Undulose Qtz	41.5	23.3	16.5	28.3	18.3	19.8	10.5	3.0	3.5	42.3	14.5	21.3	9.0
Straight Qtz	3.3	3.8	3.3	2.5	8.5	8.0	1.5	---	0.5	5.0	2.5	4.3	2.5
Poly Qtz	29.5	47.5	18.5	19.8	16.3	20.0	28.0	27.0	32.0	13.5	31.5	16.8	23.0
K-Feldspar	---	9.5	12.8	7.5	11.8	14.5	2.0	1.0	---	12.5	2.0	9.3	3.0
Plagioclase	---	---	---	---	1.8	3.0	---	---	---	0.3	---	1.3	---
Plutonic RF (K)	---	3.0	1.8	3.0	1.5	2.5	5.0	2.0	1.0	2.0	1.0	1.8	7.0
Plutonic RF (Q)	---	4.0	1.8	2.3	3.0	2.0	8.0	2.0	3.0	4.0	3.0	1.0	6.5
Alkali Feld (Tri)	---	---	---	---	---	---	---	---	---	0.3	---	---	---
Altered Feldspar	---	1.8	0.8	1.0	0.8	1.5	1.5	1.0	1.5	1.5	---	1.0	0.5
Chert	---	1.3	7.5	3.8	5.1	4.0	9.0	16.0	5.5	1.8	18.5	6.3	7.0
Cherty argillite	---	1.0	7.0	7.3	8.8	5.8	3.5	6.0	4.0	3.8	5.5	9.3	8.0
Argillite	---	---	1.3	1.5	1.3	2.8	2.5	4.0	1.0	0.8	2.0	2.8	4.0
Siltstone	---	1.8	1.0	2.0	2.5	2.0	1.5	2.0	4.0	0.8	1.0	4.0	1.5
Sandstone	---	0.8	3.0	2.5	3.3	0.3	10.0	6.0	15.5	1.0	7.5	3.8	13.0
Slate/shale	---	---	3.3	1.8	3.3	0.8	6.5	12.0	4.0	0.3	2.0	2.0	2.5
Coal/organics	5.5	0.3	2.3	1.0	1.5	3.0	---	1.0	2.0	0.8	0.5	1.8	1.0
Volcanic rock frag	---	---	---	---	---	0.3	---	---	0.5	---	0.5	---	0.5
Qtz-mica sch/gn	12.8	1.8	6.3	9.5	4.8	0.5	6.5	9.0	9.5	6.3	5.5	6.5	6.5
Qtz-mica phyllite	---	---	3.5	1.5	5.5	4.0	2.0	8.0	9.0	0.5	2.0	1.0	2.0
Sericite/muscov	7.5	0.5	9.8	4.8	1.0	4.3	1.5	---	---	2.0	0.5	4.3	1.0
Zircon	---	---	---	---	1.3	0.3	---	---	0.5	---	---	1.0	1.5
Carbonate	---	---	---	---	---	---	0.5	---	3.0	---	---	---	---
Chlorite	---	---	---	0.3	---	---	---	---	---	0.3	---	1.3	---
Pyroxene	---	---	---	---	---	0.5	---	---	---	---	---	---	---
Amphibole	---	---	---	---	---	0.5	---	---	---	---	---	---	---
Biotite	---	---	---	---	---	---	---	---	---	---	---	---	---

* Pebble counts

APPENDIX 2
PROXIMATE AND ULTIMATE ANALYSES OF JARVIS CREEK COALS

Sample Number	Basis	Moisture %	Volatile Matter %	Fixed Carbon %	Ash %	Heating Value (Btu/lb)	C %	H %	N %	O %	S(Tot) %	S(Pyr) %	S(Sul) %	S(Org) %
RC1-1	1	23.64	35.44	38.37	2.56	8,641					0.63			
	2	12.73	40.50	43.85	2.93	9,875					0.72			
	3	_	46.41	50.25	3.35	11,316					0.83			
	4	_	48.01	51.99	_	11,707					0.85			
	5					8,897								
RC1-2	1	20.54	35.14	34.35	9.98	8,371	48.23	5.66	.75	34.98	0.40	0.02	0.00	0.38
	2	8.34	40.53	39.62	11.51	9,656	55.63	4.79	.87	26.74	0.46	0.02	0.00	0.44
	3	_	44.22	43.23	12.56	10,535	60.69	4.21	.95	21.09	0.50	0.02	0.00	0.48
	4	_	50.57	49.43	_	12,048	69.43	4.83	1.09	24.08	0.57	0.02	0.00	0.55
	5					9,408								
RC1-3	1	21.17	35.01	35.13	8.70	8,506					0.34			
	2	10.53	39.73	39.87	9.87	9,654					0.39			
	3	_	44.41	44.56	11.03	10,790					0.44			
	4	_	49.90	50.10	_	12,125					0.49			
	5					9,409								
RC2b-1	1	22.09	40.26	31.31	6.34	8,914					0.98			
	2	12.87	45.02	35.02	7.09	9,969					1.10			
	3	_	51.67	40.19	8.14	11,441					1.26			
	4	_	56.25	43.75	_	12,455					1.37			
	5					9592								
RC2b-2	1	26.88	32.96	35.27	4.88	8,066					0.96			
	2	16.59	37.60	40.24	5.57	9,202					1.10			
	3	_	45.08	48.24	6.68	11,032					1.32			
	4	_	48.30	51.70	_	11,822					1.41			
	5					8,533								
RC3-1	1	15.90	40.25	32.39	11.46	9,425					0.37			
	2	8.09	43.99	35.40	12.52	10,301					0.40			
	3	_	47.86	38.52	13.62	11,207					0.44			
	4	_	55.41	44.59	_	12,975					0.50			
	5					10,790								
RC3-2	1	18.04	29.87	25.64	25.64	6,852					0.43			
	2	8.95	33.18	28.48	28.48	7,612					0.48			
	3	_	36.44	31.28	31.28	8,360					0.53			
	4	_	53.03	46.97	_	12,165					0.77			
	5					9,548								
URC1-1	1	22.36	33.36	34.44	9.85	8,180	48.36	4.82	.52	34.28	2.17	1.18	0.14	0.85
	2	14.64	36.67	37.86	10.83	8,993	53.14	4.19	.57	28.88	2.39	1.30	0.15	0.94
	3	_	42.96	44.34	12.69	10,535	62.28	2.98	.67	18.58	2.80	1.52	0.18	1.10
	4	_	49.20	50.80	_	12,066	71.31	3.42	.76	21.30	3.21	1.75	0.20	1.26
	5					9,197								

APPENDIX 2 (continued)

Sample Number	Basis	Moisture %	Volatile Matter %	Fixed Carbon %	Ash %	Heating Value (Btu/lb)	C %	H %	N %	O %	S(Tot) %	S(Pyr) %	S(Sul) %	S(Org) %
URC1-2	1	24.74	34.64	30.94	9.69	8,377					1.04			
	2	11.52	40.72	36.37	11.39	9,848					1.22			
	3	_	46.02	41.11	12.87	11,130					1.38			
	4	_	52.82	47.18	_	12,775					1.58			
	5					9,387								
URC1-3	1	20.91	33.17	35.75	10.17	8,879					1.65			
	2	11.92	36.94	39.81	11.33	9,889					1.84			
	3	_	41.94	45.20	12.86	11,227					2.09			
	4	_	48.13	51.87	_	12,884					2.40			
	5					10,017								
URC1-4	1	21.34	34.74	32.78	11.14	8,437					0.99			
	2	13.18	38.34	36.18	12.30	9,312					1.09			
	3	_	44.16	41.67	14.17	10,726					1.26			
	4	_	51.45	48.55	_	12,496					1.46			
	5					9,626								
URC1-5	1	22.89	33.52	36.63	6.95	8,436					0.83			
	2	14.63	37.11	40.56	7.70	9,340					0.92			
	3	_	43.47	47.51	9.02	10,941					1.08			
	4	_	47.78	52.22	_	12,025					1.18			
	5					9,143								
URC2-1	1	19.42	38.10	39.20	3.29	9,896	54.10	4.39	.95	36.87	0.40			
	2	12.20	41.51	42.71	3.58	10,782	58.55	3.78	1.03	32.62	0.44			
	3	_	47.28	48.65	4.08	12,281	66.69	2.75	1.17	24.81	0.50			
	4	_	49.29	50.71	_	12,803	69.50	2.87	1.22	25.89	0.52			
	5					10,272								
URC2-2	1	18.57	37.92	38.35	5.16	9,668	55.77	6.25	.42	32.68	0.25	0.03	0.00	0.22
	2	10.26	41.79	42.26	5.69	10,655	61.49	5.12	.46	26.96	0.28	0.04	0.00	0.24
	3	_	46.57	46.97	6.34	11,873	68.50	4.41	.51	19.81	0.31	0.04	0.00	0.27
	4	_	49.72	50.28	_	12,676	73.17	4.72	.55	21.23	0.33	0.05	0.00	0.28
	5					10,253								
URC3-1	1	17.60	39.86	36.98	5.56	9,906					0.31			
	2	10.51	43.29	40.16	6.04	10,758					0.34			
	3	_	48.37	44.87	6.75	12,021					0.38			
	4	_	51.87	48.13	_	12,891					0.41			
	5					10,555								
URC3-2	1	25.03	32.24	32.94	9.78	7,671					0.69			
	2	13.65	37.14	37.94	11.27	8,835					0.80			
	3	_	43.01	43.94	13.05	10,232					0.93			
	4	_	49.47	50.53	_	11,767					1.07			
	5					8,603								

APPENDIX 2 (continued)

Sample Number	Basis	Moisture %	Volatile Matter %	Fixed Carbon %	Ash %	Heating Value (Btu/lb)	C %	H %	N %	O %	S(Tot) %	S(Pyr) %	S(Sul) %	S(Org) %
URC3-3	1	21.76	34.71	34.60	8.92	8,280					0.77			
	2	12.50	38.82	38.70	9.98	9,262					0.86			
	3	-	44.36	44.23	11.41	10,585					0.98			
	4	-	50.07	49.93	-	11,947					1.11			
	5					9,189								
URC3-4	1	22.82	36.04	33.08	8.06	8,586					1.10			
	2	13.39	40.44	37.12	9.05	9,635					1.24			
	3	-	46.69	42.86	10.45	11,125					1.43			
	4	-	52.14	47.86	-	12,422					1.60			
	5					9,433								
URC3-6	1	23.78	33.34	36.93	5.96	8,623	52.22	5.24	.65	34.37	1.56	0.35	0.05	1.16
	2	16.22	36.64	40.59	6.55	9,478	57.40	4.66	.71	28.96	1.72	0.39	0.05	1.28
	3	-	43.73	48.45	7.82	11,313	68.54	3.38	.84	17.37	2.05	0.46	0.06	1.53
	4	-	47.44	52.56	-	12,272	74.33	3.66	.92	18.86	2.23	0.51	0.06	1.66
	5					9,244								
URC4-1	1	17.86	39.55	35.17	7.42	9,192					0.87			
	2	11.74	42.50	37.79	7.97	9,876					0.94			
	3	-	48.15	42.82	9.03	11,190					1.07			
	4	-	52.93	47.07	-	12,301					1.17			
	5					10,019								
URC4-2	1	20.70	35.22	30.83	13.26	7,836					0.59			
	2	9.32	40.27	35.25	15.16	8,960					0.68			
	3	-	44.41	38.87	16.72	9,881					0.75			
	4	-	53.32	46.68	-	11,864					0.90			
	5					9,181								
URC5-1	1	21.86	35.45	33.48	9.21	8,309					0.52			
	2	15.15	38.49	36.36	10.00	9,023					0.57			
	3	-	45.36	42.85	11.79	10,635					0.67			
	4	-	51.42	48.58	-	12,055					0.76			
	5					9,251								
URC5-2	1	25.43	34.76	27.35	12.47	7,580	44.15	5.82	.37	36.27	0.92			
	2	12.68	40.70	32.02	14.60	8,876	51.70	4.91	.43	27.29	1.08			
	3	-	46.61	36.67	16.72	10,165	59.20	4.01	.49	18.34	1.24			
	4	-	55.97	44.03	-	12,205	71.09	4.82	.59	22.01	1.49			
	5					8,795								
URC6-1	1	12.35	31.95	23.26	32.44	6,549					0.30			
	2	6.01	34.26	24.94	34.79	7,023					0.32			
	3	-	36.45	26.53	36.17	7,472					0.34			
	4	-	57.87	42.13	-	11,863					0.54			
	5					10,187								

APPENDIX 2 (continued)

Sample Number	Basis	Moisture %	Volatile Matter %	Fixed Carbon %	Ash %	Heating Value (Btu/lb)	C %	H %	N %	O %	S(Tot) %	S(Pyr) %	S(Sul) %	S(Org) %
URC7-1	1	18.79	37.95	36.57	6.69	9,236					0.35			
	2	10.30	41.92	40.39	7.39	10,201					0.39			
	3	_	46.73	45.03	8.24	11,372					0.43			
	4	_	50.93	49.07	_	12,393					0.47			
	5					9,974								
URC8-1	1	15.84	43.15	36.14	4.86	10,094					0.38			
	2	7.45	47.45	39.75	5.35	11,101					0.42			
	3	_	51.27	42.95	5.78	11,995					0.45			
	4	_	54.42	45.58	_	12,731					0.48			
	5					10,669								
RGD1-2	1	21.37	34.24	35.36	9.03	8,518	51.50	5.32	.79	33.06	0.30	0.03	0.00	0.27
	2	12.64	38.04	39.29	10.03	9,464	57.22	4.66	.88	26.88	0.33	0.03	0.00	0.30
	3	_	43.54	44.98	11.48	10,833	65.52	3.71	1.01	17.90	0.38	0.04	0.00	0.34
	4	_	49.19	50.81	_	12,238	73.81	4.19	1.14	20.43	0.43	0.04	0.00	0.39
	5					9,460								
RGD1-4	1	17.87	36.93	30.90	14.30	8,409					0.34			
	2	9.86	40.53	33.91	15.70	9,229					0.37			
	3	_	44.96	37.62	17.42	10,239					0.41			
	4	_	54.45	45.55	_	12,398					0.50			
	5					9,982								
UC1-3	1	15.80	40.49	30.96	12.75	9,683	53.84	5.86	.34	26.23	0.98	0.11	0.00	0.87
	2	7.44	44.51	34.03	14.02	10,644	59.17	5.32	.37	20.04	1.08	0.12	0.00	0.96
	3	_	48.09	36.77	15.15	11,500	63.90	4.85	.40	14.53	1.17	0.13	0.00	1.04
	4	_	56.67	43.33	_	13,552	75.15	5.70	.47	17.30	1.38	0.15	0.00	1.22
	5					11,276								
UC2-1	1	17.28	38.29	37.16	7.27	9,996	59.14	6.13	1.07	25.82	0.57	0.06	0.01	0.50
	2	8.33	42.43	41.18	8.06	11,077	65.57	5.60	1.19	18.95	0.63	0.07	0.01	0.55
	3	_	46.29	44.92	8.79	12,084	71.54	5.09	1.30	12.59	0.69	0.08	0.01	0.60
	4	_	50.52	49.48	_	13,188	78.42	5.60	1.42	13.81	0.75	0.08	0.01	0.66
	5					10,872								
UC3-1	1	19.58	37.35	38.45	4.61	9,914					0.44			
	2	11.60	41.06	42.27	5.07	10,898					0.48			
	3	_	46.45	47.82	5.74	12,328					0.54			
	4	_	49.27	50.73	_	13,078					0.58			
	5					10,448								
UC4-2	1	17.35	38.24	30.27	14.15	8,524	49.09	5.34	.49	30.60	0.33			
	2	10.51	41.40	32.77	15.32	9,229	53.24	4.88	.53	25.67	0.36			
	3	_	46.26	36.62	17.12	10,312	59.52	4.14	.59	18.23	0.40			
	4	_	55.82	44.18	_	12,443	71.82	5.00	.71	21.98	0.49			
	5					10,100								

APPENDIX 2 (continued)

Sample Number	Basis	Moisture %	Volatile Matter %	Fixed Carbon %	Ash %	Heating Value (Btu/lb)	C %	H %	N %	O %	S(Tot) %	S(Pyr) %	S(Sul) %	S(Org) %
UC5-1	1	16.79	41.43	32.03	9.03	9,245					0.31			
	2	6.98	46.32	35.81	10.09	10,335					0.35			
	3	-	49.79	38.50	10.85	11,110					0.38			
	4	-	55.86	44.14	-	12,464					0.42			
	5					10,268								
UC7-2	1	17.99	37.90	35.00	9.11	9,528	55.79	5.72	.47	28.45	0.46			
	2	11.86	40.73	37.62	9.79	10,241	59.99	5.32	.51	23.90	0.49			
	3	-	46.21	42.68	11.11	11,619	68.09	4.51	.58	15.15	0.56			
	4	-	51.98	48.02	-	13,071	76.55	5.11	.65	17.06	0.63			
	5					10,595								
UC7-5	1	18.66	35.44	40.17	5.74	9,578	56.43	5.64	.78	30.92	0.49			
	2	11.40	38.60	43.75	6.25	10,432	61.47	5.15	.85	25.75	0.53			
	3	-	43.57	49.38	7.05	11,775	69.40	4.36	.96	17.63	0.60			
	4	-	46.87	53.13	-	12,668	74.62	4.68	1.17	18.89	0.64			
	5					10,229								
UC8-1	1	19.91	34.77	37.48	7.83	9,344	55.57	5.15	.37	30.64	0.44	0.07	0.02	0.35
	2	15.52	36.68	39.54	8.26	9,857	58.62	4.81	.39	27.46	0.46	0.07	0.02	0.37
	3	-	43.42	46.80	9.78	11,668	69.41	3.62	.46	16.19	0.54	0.08	0.02	0.44
	4	-	48.12	51.88	-	12,932	76.91	4.02	.51	17.96	0.60	0.09	0.03	0.48
	5					10,229								
UC8-2	1	20.22	35.40	34.18	10.19	8,423	52.01	5.59	.38	31.43	0.40			
	2	12.18	38.97	37.63	11.22	9,272	57.28	5.02	.42	25.62	0.44			
	3	-	44.38	42.85	12.78	10,558	65.24	4.21	.48	16.79	0.50			
	4	-	50.86	49.14	-	12,100	74.75	4.83	.55	19.30	0.57			
	5					9,491								
UC8A-1	1	20.51	34.31	40.99	4.20	9,254					0.24			
	2	11.19	38.33	45.79	4.69	10,338					0.27			
	3	-	43.16	51.56	5.28	11,641					0.30			
	4	-	45.57	54.43	-	12,290					0.32			
	5					9,704								
UC9-1	1	27.62	33.70	29.70	8.99	7,420					0.69			
	2	13.20	40.41	35.61	10.78	8,898					0.83			
	3	-	46.56	41.03	12.42	10,251					0.96			
	4	-	53.16	46.84	-	11,704					1.09			
	5					8,241								
UC9-3	1	24.16	33.59	32.81	9.44	8,120	49.43	5.95	.85	33.30	1.03			
	2	17.38	36.59	35.75	10.28	8,846	53.85	4.92	.93	28.40	1.12			
	3	-	44.29	43.27	12.44	10,707	65.16	3.43	1.13	16.48	1.36			
	4	-	50.58	49.42	-	12,229	74.42	3.90	1.29	18.84	1.55			
	5					9,071								

APPENDIX 2 (continued)

Sample Number	Basis	Moisture %	Volatile Matter %	Fixed Carbon %	Ash %	Heating Value (Btu/lb)	C %	H %	N %	O %	S(Tot) %	S(Pyr) %	S(Sul) %	S(Org) %
UC9-5	1	21.77	33.22	35.89	9.10	8,397	48.13	4.79	.44	35.07	2.47	1.20	0.16	1.11
	2	13.35	36.80	39.75	10.08	9,301	53.30	4.09	.49	29.30	2.74	1.33	0.18	1.23
	3	_	42.47	45.87	11.63	10,733	61.51	2.99	.57	20.14	3.16	1.53	0.21	1.42
	4	_	48.06	51.94	_	12,147	69.61	3.41	.64	22.76	3.58	1.74	0.23	1.61
	5					9,357								
UC10-1	1	22.43	34.06	33.78	9.73	8,352					1.49			
	2	10.51	39.29	38.97	11.23	9,636					1.72			
	3	_	43.90	43.55	12.55	10,767					1.92			
	4	_	50.20	49.80	_	12,313					2.20			
	5					9,368								
UC10-3	1	24.62	34.24	35.03	6.11	8,364	50.20	5.25	.56	36.30	1.58			
	2	14.90	38.65	39.55	6.90	9,442	56.66	4.48	.63	29.55	1.78			
	3	_	45.42	46.48	8.11	11,095	66.58	3.32	.74	19.16	2.09			
	4	_	49.43	50.57	_	12,074	72.47	3.60	.81	20.84	2.28			
	5					8,982								
UC10-5	1	25.39	32.53	35.35	6.73	7,842					1.47			
	2	18.11	35.70	38.80	7.39	8,607					1.61			
	3	_	43.59	47.37	9.02	10,509					1.97			
	4	_	47.91	52.09	_	11,551					2.16			
	5					8,482								
UC10A-1	1	22.89	33.59	36.11	7.42	8,825					0.80			
	2	15.38	36.86	39.62	8.14	9,684					0.88			
	3	_	43.56	46.82	9.62	11,444					1.04			
	4	_	48.19	51.81	_	12,662					1.15			
	5					9,617								
LGC1-1	1	24.28	32.76	30.68	12.28	8,017					0.99			
	2	18.25	35.37	33.12	13.26	8,656					1.07			
	3	_	43.26	40.51	16.22	10,588					1.31			
	4	_	51.66	48.34	_	12,642					1.56			
	5					9,280								
LGC1-2	1	24.27	32.38	34.80	8.55	8,282					1.10			
	2	16.30	35.79	38.46	9.45	9,153					1.22			
	3	_	42.76	45.95	11.29	10,935					1.46			
	4	_	48.20	51.80	_	12,327					1.64			
	5					9,153								
LGC2-1	1	25.37	33.29	34.08	7.26	8,112					1.14			
	2	17.20	36.94	37.81	8.05	9,000					1.27			
	3	_	44.61	45.66	9.72	10,869					1.53			
	4	_	49.42	50.58	_	12,040					1.70			
	5					8,827								

APPENDIX 2 (continued)

Sample Number	Basis	Moisture %	Volatile Matter %	Fixed Carbon %	Ash %	Heating Value (Btu/lb)	C %	H %	N %	O %	S(Tot) %	S(Pyr) %	S(Sul) %	S(Org) %
LGC2-3	1	23.94	33.90	33.57	8.60	8,310	49.99	5.33	.43	34.78	0.87			
	2	17.92	36.58	36.22	9.28	8,967	53.95	4.86	.46	30.51	0.94			
	3	_	44.57	44.13	11.31	10,924	65.71	3.48	.56	17.79	1.15			
	4	_	50.21	49.79	_	12,307	73.91	3.90	.63	20.27	1.29			
	5					9,187								
LGC2-5	1	21.59	33.81	31.53	13.11	8,348	48.40	5.59	.57	31.24	1.09			
	2	13.05	37.48	34.96	14.53	9,255	53.66	4.98	.63	24.99	1.21			
	3	_	43.10	40.20	16.71	10,643	61.71	4.05	.72	15.42	1.39			
	4	_	51.76	48.24	_	12,781	74.05	4.86	.87	18.55	1.67			
	5					9,767								
LGC2-7	1	23.88	33.34	33.13	9.65	8,004					1.16			
	2	12.92	38.14	37.90	11.04	9,157					1.33			
	3	_	42.75	42.49	12.37	10,263					1.49			
	4	_	50.06	49.94	_	11,712					1.70			
	5					8,967								
LGC3-2	1	25.53	34.32	30.65	9.50	7,874					0.96			
	2	13.29	39.96	35.69	11.06	9,169					1.12			
	3	_	46.09	41.16	12.76	10,575					1.29			
	4	_	52.82	47.18	_	12,121					1.48			
	5					8,803								
LGC3-4	1	24.26	30.94	33.40	11.40	7,758					0.67			
	2	15.89	34.36	37.09	12.66	8,615					0.74			
	3	_	40.85	44.10	15.05	10,242					0.88			
	4	_	48.09	51.91	_	12,058					1.04			
	5					8,877								
JC1-2	1	24.21	35.88	32.71	7.19	8,580	52.90	5.76	1.02	32.31	0.82			
	2	17.90	38.87	35.44	7.79	9,295	57.31	5.32	1.10	27.59	0.89			
	3	_	47.34	43.17	9.49	11,321	69.80	4.05	1.34	14.24	1.08			
	4	_	52.31	47.69	_	12,508	77.14	4.48	1.48	15.70	1.20			
	5					9,325								
JC1-4	1	23.67	32.92	32.89	10.52	8,159	47.34	5.25	.50	34.82	1.57	0.44	0.09	1.04
	2	16.34	36.08	36.05	11.53	8,942	51.91	4.68	.55	29.61	1.72	0.48	0.10	1.14
	3	_	43.13	43.09	13.78	10,688	62.03	3.42	.66	18.05	2.06	0.57	0.12	1.36
	4	_	50.01	49.99	_	12,394	71.95	3.96	.91	20.80	2.38	0.66	0.14	1.58
	5					9,243								
JC1-6	1	22.01	35.23	36.13	6.62	8,586					0.99			
	2	10.41	40.47	41.51	7.61	9,863					1.14			
	3	_	45.17	46.33	8.49	11,009					1.27			
	4	_	49.37	50.63	_	12,031					1.39			
	5					9,270								

APPENDIX 2 (continued)

Sample Number	Basis	Moisture %	Volatile Matter %	Fixed Carbon %	Ash %	Heating Value (Btu/lb)	C %	H %	N %	O %	S(Tot) %	S(Pyr) %	S(Sul) %	S(Org) %
JC2-1	1	26.26	35.03	34.60	4.11	8,281	48.90	6.18	.57	39.25	0.99			
	2	11.80	41.90	41.38	4.92	9,904	58.49	5.18	.68	29.56	1.18			
	3	_	47.51	46.92	5.58	11,229	66.33	4.36	.77	21.62	1.34			
	4	_	50.31	49.69	_	11,893	70.19	4.63	.82	22.84	1.42			
	5					8,682								
JCM2a	1	22.17	33.17	36.55	8.11	8,862	52.37	5.08	.57	32.04	1.83	0.73	0.05	1.05
	2	15.69	35.93	39.59	8.79	9,600	56.74	4.59	.62	27.28	1.98	0.79	0.05	1.14
	3	_	42.62	46.96	10.43	11,387	67.29	3.37	.74	15.82	2.35	0.94	0.06	1.35
	4	_	47.58	52.42	_	12,712	75.12	3.74	.82	17.70	2.62	1.04	0.07	1.51
	5					9,749								
JCM2b	1	21.19	35.14	36.56	7.11	8,764	53.59	5.79	.68	31.88	0.95			
	2	10.78	39.78	41.39	8.05	9,922	60.69	5.10	.77	24.32	1.07			
	3	_	44.59	46.39	9.02	11,121	68.03	4.36	.86	16.53	1.20			
	4	_	49.00	51.00	_	12,223	74.65	4.78	1.06	18.19	1.32			
	5					9,518								
JCM2c	1	22.45	32.73	36.03	8.79	8,368	50.74	5.23	.58	33.76	0.90			
	2	14.85	35.94	39.56	9.65	9,189	55.70	4.65	.64	28.37	0.99			
	3	_	42.21	46.46	11.33	10,792	65.39	3.50	.75	17.87	1.16			
	4	_	47.60	52.40	_	12,171	73.52	3.95	.84	20.38	1.31			
	5					9,273								
JCM4	1	20.07	36.14	35.33	8.47	9,256					0.84			
	2	13.79	38.98	38.10	9.13	9,983					0.91			
	3	_	45.22	44.20	10.60	11,580					1.06			
	4	_	50.57	49.43	_	12,952					1.18			
	5					10,216								
JCM5	1	24.14	30.48	39.59	5.79	8,441					0.79			
	2	13.34	34.82	45.23	6.61	9,643					0.90			
	3	_	40.18	52.19	7.63	11,127					1.04			
	4	_	43.50	56.50	_	12,046					1.12			
	5					9,023								
JCM6	1	20.61	35.30	30.09	13.99	8,400					0.68			
	2	9.89	40.07	34.16	15.88	9,535					0.77			
	3	_	44.47	37.91	17.62	10,582					0.85			
	4	_	53.98	46.02	_	12,845					1.04			
	5					9,936								
SC1-1	1	20.27	34.53	34.65	10.55	8,320	49.12	5.15	.60	31.66	2.92	1.62	0.14	1.16
	2	12.67	37.82	37.95	11.56	9,113	53.80	4.59	.66	26.18	3.20	1.78	0.15	1.27
	3	_	43.30	43.45	13.24	10,434	61.60	3.61	.76	17.13	3.66	2.04	0.17	1.45
	4	_	49.91	50.09	_	12,027	71.02	4.15	.87	19.74	4.22	2.35	0.20	1.67
	5					9,444								

APPENDIX 2 (continued)

Sample Number	Basis	Moisture %	Volatile Matter %	Fixed Carbon %	Ash %	Heating Value (Btu/lb)	C %	H %	N %	O %	S(Tot) %	S(Pyr) %	S(Sul) %	S(Org) %
SC2-2	1	21.60	35.24	35.25	7.91	8,503	51.54	5.78	.94	33.27	0.56			
	2	11.12	39.95	39.96	8.97	9,640	58.43	5.06	1.07	25.84	0.63			
	3	_	44.95	44.96	10.09	10,846	65.73	4.32	1.20	17.97	0.71			
	4	_	49.99	50.01	_	12,063	73.10	4.78	1.34	19.99	0.79			
	5					9,319								
SC3-1	1	23.61	35.65	33.76	6.98	8,240					0.52			
	2	15.23	39.56	37.46	7.75	9,144					0.58			
	3	_	46.66	44.19	9.14	10,786					0.68			
	4	_	51.36	48.64	_	11,872					0.75			
	5					8,930								
SC4-1	1	17.60	35.40	28.15	18.85	7,958					0.53			
	2	9.49	38.88	30.92	20.71	8,741					0.58			
	3	_	42.96	34.16	22.88	9,658					0.64			
	4	_	55.70	44.30	_	12,523					0.83			
	5					10,047								
DD1-1	1	18.75	40.42	30.33	10.59	9,006					0.62			
	2	8.72	45.36	34.04	11.88	10,108					0.70			
	3	_	49.75	37.33	13.03	11,085					0.77			
	4	_	57.20	42.80	_	12,746					0.88			
	5					10,200								
DD1-2	1	23.01	38.74	32.10	6.15	8,779					0.73			
	2	11.45	44.56	36.92	7.07	10,097					0.84			
	3	_	50.32	41.69	7.98	11,403					0.95			
	4	_	54.69	45.31	_	12,392					1.03			
	5					9,424								

Basis:
- (1) As-received
- (2) Air dried
- (3) Moisture free
- (4) Dry ash free
- (5) Moist, Mm-free (Btu-only)

APPENDIX 3a
MACERAL ANALYSIS

SAMPLE	V	PV	GEL	PHL	PPHL	F	SF	MAC	SCL	INERT	SP	RES	EXS	CUT	ALG	LIP	SUB
RC1-1	82.8	0.7	0.7	0.9	1.1	0.2	1.3	0.0	3.2	1.7	3.2	2.0	0.4	0.0	0.0	1.2	0.6
URC1-1	88.8	0.0	0.4	1.1	0.4	0.0	0.9	0.0	0.4	0.4	3.2	2.2	0.0	0.2	0.0	1.4	0.6
URC2-1	75.3	0.3	0.2	1.4	1.4	0.3	2.7	0.0	1.9	1.7	6.4	5.2	0.4	0.4	0.0	2.0	0.4
URC2-2	78.8	0.5	0.7	1.1	1.2	0.0	1.9	0.0	1.9	1.1	4.6	4.6	0.0	1.2	0.0	2.2	0.2
URC3-6	88.5	0.2	0.6	1.8	0.9	0.0	0.6	0.0	0.2	0.6	1.6	3.0	0.2	0.2	0.0	1.2	0.4
URC5-2	77.7	0.9	0.5	3.5	0.5	0.7	2.1	0.2	0.4	1.1	4.2	5.2	0.0	0.6	0.0	1.6	0.8
URC7-1	71.3	0.8	0.8	2.8	1.5	0.0	1.8	0.0	1.1	1.1	7.6	5.8	1.0	0.2	0.0	3.6	0.6
RGD1-2	82.0	0.2	0.5	1.1	1.1	0.0	2.3	0.0	0.9	0.5	3.6	3.8	0.2	0.6	0.0	2.8	0.4
UC1-3	62.0	1.4	0.7	2.7	1.3	0.2	2.9	0.3	2.1	2.2	10.2	7.4	1.0	1.6	0.0	2.8	1.0
UC2-1	74.2	0.5	0.0	1.4	1.9	0.0	4.1	0.0	2.3	1.2	7.2	3.6	0.0	0.2	0.0	2.8	0.6
UC4-2	72.3	0.2	0.3	2.7	1.5	0.0	1.7	0.0	3.2	1.5	8.8	4.2	0.4	0.2	0.0	2.4	0.6
UC7-2	79.1	0.3	0.2	1.2	0.7	0.3	1.8	0.0	1.9	0.5	5.8	4.4	0.2	0.4	0.0	2.6	0.6
UC7-5	84.3	0.0	0.9	2.2	1.3	0.4	1.1	0.0	0.5	0.9	3.0	2.6	0.0	0.6	0.0	1.6	0.6
UC8-1	79.0	0.7	0.7	3.0	1.1	0.4	1.9	0.2	0.5	0.9	3.6	4.4	0.4	0.8	0.0	2.0	0.4
UC8-2	81.6	0.0	0.4	2.0	1.1	0.5	1.6	0.0	0.5	1.1	5.2	3.0	0.0	0.2	0.0	2.0	0.8
UC9-3	83.5	0.5	0.4	0.7	1.1	0.0	1.8	0.2	1.3	0.7	3.0	3.8	0.2	0.0	0.0	2.4	0.4
UC9-5	88.7	0.5	1.3	1.4	1.4	0.2	1.1	0.2	0.4	0.0	1.0	1.8	0.0	0.4	0.0	1.4	0.2
UC10-3	78.4	0.4	1.3	4.9	0.7	0.0	3.1	0.0	1.1	1.3	2.4	4.0	0.0	0.4	0.0	1.4	0.6
LGC2-3	86.2	0.4	0.5	1.9	1.5	0.0	1.1	0.0	0.6	0.4	2.4	2.6	0.0	0.2	0.0	1.0	1.2
LGC2-5	82.7	0.0	0.8	2.4	1.5	0.4	1.5	0.2	0.4	1.1	2.6	3.4	0.0	0.8	0.0	1.4	0.8
JC1-2	86.2	0.0	0.9	2.5	0.8	0.2	0.9	0.0	0.6	1.5	2.2	2.0	0.0	0.2	0.0	1.0	1.0
JC1-4	84.3	0.0	1.3	1.5	0.7	0.0	1.9	0.0	0.6	1.3	2.0	3.0	0.0	0.0	0.0	2.2	1.2
JC2-1	83.5	0.0	2.1	3.9	0.6	0.0	0.9	0.0	0.4	0.6	2.0	3.0	0.0	0.0	0.0	1.2	1.8
JCM2a	84.9	0.0	1.1	1.7	1.3	0.2	0.6	0.2	0.9	0.9	1.6	3.6	0.0	0.0	0.0	1.6	1.4
JCM2b	81.5	0.0	0.6	2.0	1.6	0.0	1.5	0.0	1.8	1.6	3.0	3.6	0.0	0.4	0.0	1.6	0.8
JCM2c	75.0	0.7	2.6	5.5	1.7	0.2	3.9	0.4	1.7	0.9	1.6	3.0	0.0	0.6	0.0	0.8	1.4
SC2-2	85.9	0.0	0.0	1.3	1.4	0.2	1.3	0.0	0.4	0.7	3.2	3.8	0.0	0.6	0.0	1.0	0.2
SC4-1	78.6	0.0	0.2	1.3	0.7	0.7	2.7	0.0	2.1	2.5	4.4	4.4	0.0	0.2	0.0	1.6	0.6
DD1-1	73.4	0.4	0.7	4.7	0.7	1.4	1.0	0.2	1.2	2.1	5.4	5.2	0.0	0.2	0.0	2.0	1.4

V =	Vitrinite	SF =	Semifusinite	EXS =	Exsudatinite
PV =	Pseudovitrinite	MAC =	Macrinite	CUT =	Cutinite
GEL =	Gelinite	SCL =	Sclerotinite	ALG =	Alginite
PHL =	Phlobaphinite	INERT =	Inertodetrinite	LIP =	Liptodetrinite
PPHL =	Pseudophlobaphinite	SP =	Sporinite	SUB =	Suberinite
F =	Fusinite	RES =	Resinite		

APPENDIX 3b
MICROLITHOTYPE ANALYSIS

SAMPLE	VIT	LIP	INT	DUR	CLAR	VTERT	DURO	CLARO	CARG	CPYR	CS/CA
RC1-1	74.8	0.0	0.0	0.0	16.6	3.0	2.8	0.2	2.2	0.0	0.4
URC1-1	70.0	0.0	0.0	0.0	13.4	0.6	0.8	0.0	2.0	13.2	0.0
URC2-1	56.2	0.0	0.0	0.0	26.0	6.6	7.6	0.2	3.0	0.2	0.2
URC2-2	59.4	0.0	0.0	0.0	24.8	3.6	7.8	1.0	3.2	0.0	0.2
URC3-6	76.4	0.0	0.0	0.0	9.0	1.0	0.8	0.0	5.2	7.2	0.4
URC5-2	62.8	0.0	0.0	0.0	20.0	1.8	2.6	0.2	11.2	1.4	0.0
URC7-1	44.8	0.0	0.0	0.0	39.2	1.4	5.8	0.0	8.8	0.0	0.0
RGD1-1	64.8	0.0	0.2	0.0	25.0	2.2	2.4	0.0	5.2	0.2	0.0
UC1-3	34.4	0.0	0.0	0.0	30.6	8.0	15.4	3.0	8.2	0.2	0.2
UC2-1	44.4	0.0	0.2	0.0	31.8	5.4	11.2	0.6	4.0	0.8	1.6
UC4-2	39.0	0.0	0.2	0.2	29.8	2.8	9.6	1.0	16.4	0.6	0.4
UC7-2	48.8	0.0	0.0	0.0	30.8	3.2	6.2	0.8	8.6	1.2	0.4
UC7-5	70.6	0.0	0.2	0.0	19.4	2.6	2.8	0.0	2.8	0.6	1.0
UC8-1	61.0	0.0	0.0	0.0	25.2	3.0	5.0	0.2	4.6	0.6	0.4
UC8-2	57.6	0.0	0.0	0.0	27.0	1.6	2.8	0.2	10.2	0.4	0.2
UC9-3	54.0	0.0	0.0	0.0	22.8	5.6	4.8	0.2	5.0	7.0	0.6
UC9-5	58.6	0.0	0.0	0.0	15.0	1.0	1.4	0.0	5.4	18.6	0.0
UC10-3	73.6	0.0	0.0	0.0	10.4	1.8	1.0	0.0	4.6	8.0	0.6
LGC2-3	73.6	0.0	0.0	0.0	11.8	2.0	1.2	0.0	9.2	1.4	0.8
LGC2-5	61.8	0.0	0.0	0.0	14.4	2.8	3.4	0.0	16.4	1.2	0.0
JC1-2	60.6	0.0	0.0	0.0	22.2	4.8	3.8	0.2	5.4	2.6	0.4
JC1-4	61.2	0.0	0.0	0.0	14.2	3.0	3.0	0.0	10.0	8.6	0.0
JC2-1	83.4	0.0	0.0	0.0	8.4	0.8	0.6	0.0	3.4	3.4	0.0
JCM2a	72.2	0.0	0.0	0.0	10.2	1.6	0.6	0.0	4.0	10.8	0.6
JCM2b	79.4	0.0	0.0	0.0	10.4	4.0	0.8	0.0	1.4	3.8	0.2
JCM2c	78.0	0.0	0.2	0.0	11.6	3.0	2.0	0.0	1.8	3.0	0.4
SC2-2	72.4	0.0	0.0	0.0	15.6	4.2	4.4	0.0	2.4	0.2	0.8
SC4-1	59.8	0.0	0.2	0.0	17.6	4.6	5.4	0.0	12.2	0.0	0.2
DD1-1	51.8	0.0	0.2	0.0	27.4	2.0	5.6	0.6	11.6	0.2	0.6

VIT = Vitrite
LIP = Liptite
INT = Inertite
DUR = Durite
CLAR = Clarite
VTERT = Vitrinertite
DURO = Duroclarite
CLARO = Clarodurite
CARG = Carbargillite
CPYR = Carbopyrite
CS/CA = Carbosilicate / Carbankerite

APPENDIX 4
VITRINITE REFLECTANCE

SAMPLE	1	2	3	4	5	6	7
RC1	.436	.409	.430				
RC2b	.405	.406					
RC3	.372	.381					
URC1	.418	.400	.383	.375	.386		
URC2	.396	.395					
URC3	.412	.360	.402	.357		.389	
URC4	.376	.380					
URC5	.391	.393					
URC6	.427						
URC7	.422						
URC8	.374						
RGD1		.438		.367			
UC1			.423				
UC2	.370						
UC3	.400						
UC4		.380					
UC5	.419						
UC7		.407			.393		
UC8	.413	.409					
UC8A	.438						
UC9	.377		.360		.324		
UC10	.404		.343		.351		
UC10A	.360						
LGC1	.375	.314					
LGC2	.381		.363		.346		.323
LGC3		.378		.347			
JC1		.329		.358		.347	
JC2	.335						
JCM	.359	.376	.385	.382	.367	.356	
SCI	.386						
SC2		.SC3	.382				
SC4	.380						
DD1	.371	.358					

Horizontal axis at top indicates actual sample numbers (e.g. RC1-3 = .430 R_om). Decreasing sample numbers correspond to increasing depth.

APPENDIX 5a

CONCENTRATION OF MAJOR OXIDES IN OVERBURDEN
(Percent)

Sample	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	TiO_2	MnO	LOI	Lith
URC3-5S	38.59	14.24	3.80	2.98	1.65	0.08	1.60	0.69	0.03	30.23	cs
URC3-7R	39.53	12.90	2.79	2.16	1.53	0.08	1.49	0.74	0.02	31.55	cs
RGD1-1S	16.65	10.18	0.34	0.83	0.96	0.06	0.99	0.42	0.00	59.35	cs
RGD1-3R	48.59	33.03	0.77	0.55	1.10	0.03	1.55	0.62	0.02	12.41	c
UC1-2S	75.98	12.98	0.26	0.38	0.88	0.12	1.80	0.95	0.01	3.40	c
UC1-4R	21.30	14.51	0.92	0.32	0.69	0.08	1.08	0.43	0.00	51.53	cs
UC4-1S	33.60	25.45	0.62	0.76	1.17	0.14	1.92	0.75	0.01	32.34	cs
UC4-3R	31.23	10.84	0.29	0.46	0.86	0.08	1.26	0.53	0.00	45.86	cs
UC7-1S	46.25	24.86	0.69	0.86	0.85	0.16	3.34	0.96	0.01	17.33	cs
UC7-3R	53.02	28.91	0.80	0.42	0.85	0.06	1.76	0.75	0.01	11.64	s
UC7-4S	37.16	21.60	0.70	0.83	1.05	0.09	1.99	0.94	0.01	30.69	cs
UC7-6R	67.76	17.23	1.19	0.30	0.96	0.10	2.39	0.61	0.02	6.92	ss
UC9-2S	72.49	9.03	1.41	1.62	2.35	0.49	1.23	0.84	0.03	5.00	ss
UC9-4R	81.85	8.50	0.60	0.45	1.05	0.47	2.37	0.29	0.01	1.65	ss
UC10-2I	55.24	12.37	2.33	2.43	2.88	0.42	1.35	1.04	0.04	18.05	cs/ss
LGC2-2S	60.08	15.59	3.07	3.44	2.67	0.86	1.71	1.25	0.05	5.80	s
LGC2-4I	57.12	12.94	2.06	2.43	2.61	0.52	1.49	0.97	0.03	14.99	ss/cs
LGC2-6R	55.09	18.43	3.69	3.76	2.27	0.37	2.16	1.01	0.05	7.65	s
LGC3-1S	54.54	16.35	3.35	3.98	2.88	0.07	1.82	1.07	0.06	9.75	c
LGC3-3R	54.13	16.54	2.31	2.69	2.56	0.07	1.83	1.01	0.04	13.77	c
JC1-1S	67.20	13.00	2.66	2.69	3.61	0.87	1.67	1.11	0.06	4.49	ss
JC1-3I	58.59	13.57	2.36	2.51	2.72	0.44	1.58	1.05	0.04	12.71	ss
JC1-5R	48.51	23.06	1.64	1.36	1.74	0.19	1.45	0.97	0.02	17.19	cs/s
JCM1S	65.13	13.46	2.87	2.89	2.90	0.47	1.60	1.15	0.05	4.66	c
JCM3R	49.42	26.76	1.57	1.04	1.63	0.09	1.80	0.90	0.02	15.43	ss
SC2-1S	61.16	18.57	1.33	0.95	1.46	0.29	2.31	0.77	0.03	9.96	ss
SC2-3R	64.93	17.61	1.38	0.99	1.44	0.17	2.29	0.79	0.03	8.40	ss

<u>Sample Description</u>

S = seat rock
I = interburden
R = roof rock

<u>Lithology Description</u>

c = claystone
cs = carbonaceous shale
s = siltstone
ss = sandstone

APPENDIX 5b

CONCENTRATION OF TRACE ELEMENTS IN OVERBURDEN
(Parts per million)

Sample	Cr	Ni	Co	V	Cu	Ba	Zr	Sr	Be	Cd	Zn	Lith
URC3-5S	174	75	30	299	130	2620	106	63	2.3	2	685	cs
URC3-7R	187	49	23	374	204	3590	118	79	2.5	1	650	cs
RGD1-1S	36	--	17	60	30	1310	81	110	4.2	--	505	cs
RGD1-3R	51	25	27	80	47	430	45	993	4.2	1	100	c
UC1-2S	58	7	35	65	--	640	282	53	1.6	--	35	c
UC1-4R	59	5	9	48	33	740	116	66	2.6	1	455	cs
UC4-1S	101	20	17	128	48	2510	125	141	3.6	1	515	cs
UC4-3R	45	9	18	63	27	1130	156	108	3.1	--	50	cs
UC7-1S	95	30	22	112	33	4060	291	244	3.7	--	60	cs
UC7-3R	36	13	14	52	42	330	172	35	3.2	--	525	s
UC7-4S	84	4	19	118	39	1710	141	72	4.3	--	530	cs
UC7-6R	31	18	28	61	26	730	126	69	1.5	--	645	ss
UC9-2S	79	30	40	168	47	110	125	92	1.1	1	362	ss
UC9-4R	24	11	51	21	13	630	97	80	1.1	1	20	ss
UC10-2I	163	46	35	269	137	2080	156	89	1.7	--	635	cs/ss
LGC2-2S	183	68	38	289	94	2200	165	100	1.8	2	180	s
LGC2-4I	163	63	35	304	136	1740	167	107	1.8	--	225	ss/cs
LGC2-6R	230	98	44	357	117	3520	155	91	2.2	2	325	s
LGC3-1S	192	84	45	309	156	2440	166	81	1.8	2	640	c
LGC3-3R	132	52	28	236	97	2020	148	59	2.2	1	660	c
JC1-1S	140	47	49	238	72	2610	164	109	1.4	1	625	ss
JC1-3I	167	48	29	308	154	7820	183	96	1.7	5	720	ss
JC1-5R	1161	59	31	208	116	1440	187	59	3.1	3	690	cs/s
JCM1S	142	49	38	293	81	3660	208	85	1.5	1	625	c
JCM3R	63	21	26	111	61	1280	171	76	3.4	1	655	ss
SC2-1S	71	29	26	81	13	880	285	64	2.4	--	95	ss
SC2-3R	43	26	27	50	22	510	539	31	2.4	1	575	ss

Sample Description

S = seat rock
I = interburden
R = roof rock

Lithology Description

c = claystone
cs = carbonaceous shale
s = siltstone
ss = sandstone

APPENDIX 5c
Concentration of MAJOR OXIDES in coal ash
%

Elements	RC1-2	URC1-1	URC2-1	URC2-2	URC3-6	URC5-2	RGD1-2
SiO_2	45.31	31.62	33.32	37.83	17.65	41.03	41.61
Fe_2O_3	2.95	12.21	2.27	4.93	9.10	3.82	3.83
CaO	5.17	6.38	12.50	8.66	18.10	15.21	8.10
MgO	3.32	2.37	3.15	2.85	2.39	3.61	6.72
MnO	0.02	0.02	0.04	0.08	0.07	0.02	0.03
Na_2O	0.43	0.10	0.11	0.38	0.33	0.21	0.37
TiO_2	0.9	0.80	1.09	2.03	0.48	0.85	1.11
Al_2O_3	32.39	14.15	28.54	30.51	14.05	16.06	29.94
K_2O	1.36	1.41	1.38	1.24	0.75	1.49	1.53
SO_3	4.03	9.21	12.31	4.93	23.61	10.15	4.73
P_2O_5	ND	ND	ND	0.10	ND	ND	ND
TOTAL	96.27	79.37	95.39	94.27	87.82	93.28	98.83

Elements	UC1-3	UC2-1	UC4-2	UC7-2	UC7-5	UC8-1	UC8-2
SiO_2	49.03	39.49	43.38	40.44	39.72	40.32	46.63
Fe_2O_3	1.26	1.61	3.58	1.68	1.33	0.98	1.06
CaO	5.10	11.51	5.40	7.91	7.63	8.52	5.95
MgO	0.94	1.83	1.32	1.86	3.28	3.15	1.95
MnO	0.03	0.01	0.03	0.02	0.01	0.01	0.02
Na_2O	0.35	0.26	0.46	0.22	0.55	0.20	0.15
TiO_2	1.15	1.08	0.75	0.80	1.45	0.76	1.00
Al_2O_3	33.11	29.97	36.77	32.15	30.47	30.24	33.22
K_2O	2.15	1.55	2.14	1.60	1.81	1.65	1.81
SO_3	3.29	9.44	1.58	3.14	6.40	5.85	3.17
P_2O_5	ND	ND	0.16	0.18	0.02	0.13	0.08
TOTAL	96.75	97.38	96.80	90.81	93.39	93.04	95.79

Elements	UC9-3	UC9-5	UClO-3	LGC2-3	LGC2-5	JCl-2	JCl-4
SiO_2	32.91	30.37	23.60	29.77	42.15	26.57	37.97
Fe_2O_3	5.38	17.23	13.50	5.84	5.51	7.07	6.43
CaO	13.50	10.61	13.46	21.04	13.33	20.42	9.43
MgO	3.08	2.21	2.18	4.34	3.13	4.02	2 42
MnO	0.02	0.06	0.06	0.04	0.04	0.04	0.04
Na_2O	0.11	0.45	0.76	0.30	0.59	0.54	0.31
TiO_2	0.86	0.72	0.67	0.68	0.94	0.57	1.01
Al_2O_3	16.07	14.88	14.22	14.83	16.86	15.74	17.93
K_2O	1.23	1.37	0.91	0.79	1.36	0.78	1.33
SO_3	17.06	10.8	16.63	14.08	10.37	14.16	10.82
P_2O_5	ND	ND	ND	ND	ND	0.11	0.01
TOTAL	91.44	89.42	81.72	94.47	95.26	91.19	91.74

Elements	JC2-1	JCM2a	JCM2b	JC-M2c	SCl-1	SC2-2
SiO_2	18.40	19.09	18.39	29.17	22.74	33.11
Fe_2O_3	8.78	11.43	7.74	7.22	16.86	6.41
CaO	15.95	17.87	23.05	16.35	10.84	14.22
MgO	2.03	2.02	2.18	1.82	1.50	1.27
MnO	0.05	0.10	0.07	0.06	0.11	0.13
Na_2O	0.34	0.44	0.34	0.46	0.37	0.60
TiO_2	0.58	0.48	1.00	1.10	0.42	0.75
Al_2O_3	23.58	12.00	15.88	24.06	12.68	25.08
K_2O	0.81	1.07	0.63	0.67	1.41	1.07
SO_3	17.30	23.61	19.60	12.45	13.32	9.97
P_2O_5	ND	ND	0.07	0.01	ND	0.01
TOTAL	88.12	89.40	90.31	93.81	81.72	93.64

APPENDIX 5d
Concentration of TRACE ELEMENTS in coal ash (whole coal basis)
(ppm)

Sample	Cr	Ni	Co	V	Cu	Ba	Zr	Sr	Be	Cd	Zn
RCl-2	9	8	9	20	57	376	16	28	2	1	1093
URCl-1	34	46	20	59	59	885	12	79	0.6	ND	38
URC2-1	7	8	4	5	8	182	11	32	0.5	ND	6
URC2-2	6	7	11	11	38	237	20	129	0.5	1	658
URC3-6	15	42	20	36	73	616	6	74	0.4	0	210
URC5-2	36	27	8	68	52	959	18	93	0.6	ND	35
RGDl-2	10	7	11	19	65	490	13	223	0.8	1	1051
UCl-3	18	8	8	23	16	298	50	100	1	0	17
UC2-1	5	3	5	8	8	217	35	228	1	ND	4
UC4-2	23	15	8	30	95	1303	15	347	0.6	2	1445
UC7-2	15	7	11	22	35	987	11	251	0.7	0	7
UC7-5	15	18	12	19	23	332	12	68	0.7	ND	3
UC8-1	9	5	10	15	20	543	9	342	1	ND	4
UC8-2	13	8	5	22	30	487	16	243	0.7	ND	8
UC9-3	20	38	13	49	43	1020	11	83	0.5	ND	41
UC9-5	25	41	25	51	82	590	10	51	0.6	1	950
UC1O-3	16	17	14	32	52	520	8	60	0.3	1	716
LGC2-3	19	14	11	37	65	622	22	89	0.6	1	1153
LGC2-5	33	20	10	58	55	1183	28	87	0.6	2	1480
JCl-2	19	20	13	35	46	706	12	104	0.5	1	759
JCl-4	28	47	24	53	70	1000	25	53	0.6	2	1145
JC2-1	24	20	13	8	63	81	12	48	1	1	652
JCM2a	23	59	13	41	65	914	9	78	0.5	1	1145
JCM2b	4	8	2	10	39	844	17	112	0.2	1	798
JCM2c	4	9	9	16	48	284	25	80	0.4	2	1102
SCl-1	18	64	15	27	67	1420	11	85	0.5	1	1210
SC2-2	17	8	16	38	95	733	11	73	2	1	845

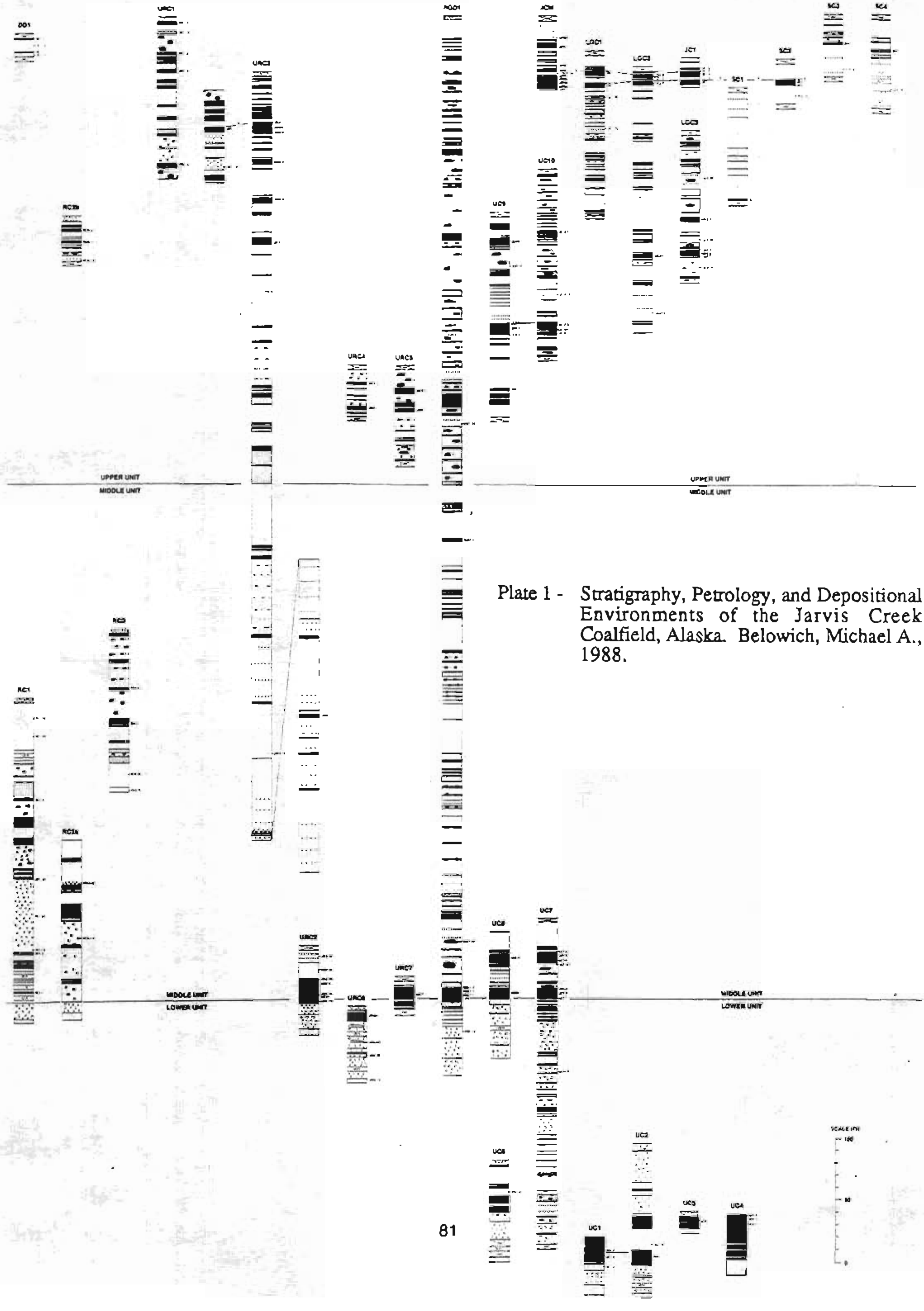
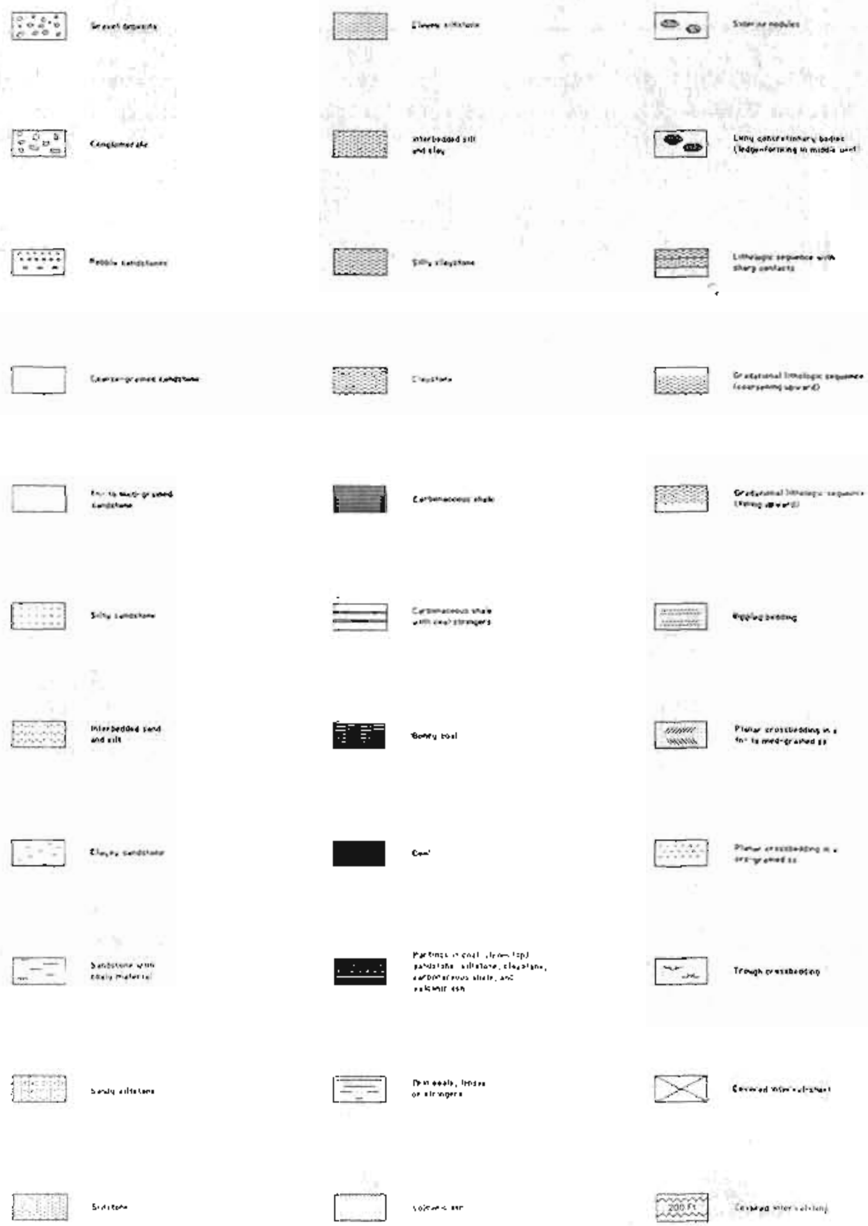


Plate 1 - Stratigraphy, Petrology, and Depositional Environments of the Jarvis Creek Coalfield, Alaska. Belowich, Michael A., 1988.

Plate 2 - Stratigraphy, Petrology and Depositional Environments of the Jarvis Creek Coalfield, Alaska. Belowich, Michael A., 1988.

LITHOLOGIC SYMBOLS USED IN PLATE 1



DESCRIPTION OF STRATIGRAPHIC UNITS

UPPER UNIT

The upper stratigraphic unit is characterized by thick, yet lenticular, highly crossbedded, lithic-rich sandstone bodies. Compared to the lower units there is a pronounced increase in thickness and number of finer-grained siltstones, claystones and coals, and a change from sideritized siltstones and sandstones to limy concretions of the same.

Sandstones are dark gray to gray, greenish-brown, fine- to medium- grained, locally pebbly, lithic-rich, slightly micaceous, carbonaceous, generally friable, moderately well sorted, and contain subangular to rounded grains. Lithics and pebbles include include chert, argillite, shale, plutonic rock fragments and phyllites. Crossbedding (both planar and trough) is common in the sands which are locally concretionary and weather grayish-brown to light brown.

Siltstones are gray to grayish-brown to brown, carbonaceous, mildly micaceous, firm, often containing coal stringers and lenses, and weathers grayish-brown to orange from iron staining. Concretions are common and these contain well preserved plant fragments. Concretions often form ledges to four feet thick.

Claystones are gray to grayish-brown to black, often silty, firm to soft, and is locally carbonaceous. They weather gray to brownish-orange due to iron-staining and occasionally contain plant fragments.

Carbonaceous shale is brownish-black to black, fissile to platy, and often contain coaly stringers and veinlets.

Coals are subbituminous, blocky, with dull and bright bands and are generally lenticular with the exception of the "sandwich" seams and the mine seam. Numerous coals occur in this unit, ranging to ten feet thick.

MIDDLE UNIT

The middle stratigraphic unit is characterized by alternating white quartz-rich and brown arkosic sandstones in laterally continuous beds, a thick coal zone near its base, and the extremely low proportion of finer-grained siltstones, claystones, carbonaceous shales and coal above this zone.

White quartz-rich sandstones are medium to coarse-grained, subangular to subrounded, moderately well sorted, mildly carbonaceous and micaceous, often pebbly, friable, and locally weather brown due to iron-oxide staining. Pebbles are generally quartz and schist fragments and crossbedding was not observed. The other middle unit sandstones are light to dark brown, fine to coarse grained, feldspathic, mildly carbonaceous and micaceous, moderately well sorted with subangular to subrounded grains. This arkosic sandstone is indurated when calcite cemented, forming ledges, weathers orange-brown to purplish-brown due to iron staining, is locally pebbly and occasionally planar crossbedded. Pebbles are comprised of quartz, feldspar, and minor lithic fragments, notably chert, argillite and plutonic rock fragments. Siderite nodules to two feet in diameter are locally present in both sandstone types.

Siltstones are brown to brownish-black, carbonaceous, slightly micaceous, firm, and commonly contain siderite nodules to four feet in diameter, locally containing plant fragments.

Claystones are grayish-brown to brown, carbonaceous, mildly micaceous, soft and weather purplish-brown to brown.

Carbonaceous shale is brownish-black to black, weathers gray, fissile to platy, micaceous, and often contains coaly stringers and veinlets.

Coals are subbituminous, blocky, with dull and bright bands, are laterally continuous, and tend to grade to bone in upper and lower parts. Coals are usually thin with the exception of the thick B and C seam coal zone at its base.

LOWER UNIT

The distinctly lenticular lower stratigraphic unit is characterized by its dominantly conglomeratic nature, white color, and angular detrital grains. Compared to the upper units it has a low proportion of finer-grained sediments such as sandstones, siltstones, claystones, carbonaceous shales and coal.

Conglomerates are comprised of white angular to subrounded quartz fragments to four inches in diameter (1/2 to 1 inch average), and minor quartz-mica schist fragments and sericite flakes. It is mildly indurated, poorly sorted, locally carbonaceous and occasionally planar crossbedded. Sandstones associated with these conglomerates are also white, fine- to coarse-grained, well sorted, micaceous, contain mostly angular to subangular (usually shattered) detrital quartz, and are friable, locally carbonaceous, and mildly planar crossbedded.

Siltstones are brown to brownish black, highly carbonaceous, micaceous, firm, locally contain white, angular quartz pebbles to three inches in diameter, especially in laminated coal seat rocks, and often contain siderite nodules to three feet in diameter as well as and plant fragments.

Claystones are grayish-brown to brown, carbonaceous, micaceous, firm to soft, are locally white when enriched in sericite flakes and quartz, and often contain coaly fragments.

Carbonaceous shale is brownish-black to black, fissile to platy, micaceous, and often contain coaly stringers and veinlets. Such shales are usually found adjacent to coal seams and attain thicknesses to 16 feet.

Coals are subbituminous, lenticular, blocky, with dull and bright bands and tend to grade to bone in upper and lower parts. Coals are usually thin, with the exception of the "A" seam near the base of the unit.