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# COAL GEOLOGY AND RESOURCES OF THE SUSITNA LOWLAND, ALASKA

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## ABSTRACT

The Susitna lowland of south-central Alaska contains major reserves of subbituminous and lignite coals within the Kenai Group of Tertiary age, predominantly within the Tyonek Formation. The region encompasses the second largest coal-resource base in Alaska, and is surpassed only by the deposits of the North Slope. Measured coal resources of the Susitna lowland (including the Beluga and Yentna basins) are at least 3 billion short tons, identified resources are 10 billion short tons, and hypothetical resources are estimated at 30 billion short tons. Most of the known resources occur in a crescent-shaped belt along the western and southern margin of the Susitna lowland.

Coals of the Kenai Group formed in paleoenvironments associated with continental fluvial depositional systems. Rapid lateral and vertical changes in lithology often make the correlation of coal beds difficult over distances of even a thousand meters. Coal petrologic studies indicate that most Susitna lowland coals originated in forest-moor-swamp environments during a relatively temperate (warm and moist) climatic period. Peat-forming episodes, which occurred during lulls in regional tectonism (quiescent times), were interrupted by the rejuvenation of adjacent uplands of low to moderate relief and the shedding of clastics into backswamps.

The coals of the Susitna lowland are comparable in overall quality to those of the Powder River Basin of the western United States. The sulfur content in the Susitna lowland coals is extremely low---nominally 0.3 percent---and ash content is variable but averages about 15 percent; mean heating values are about 8200 Btu per pound (all on as-received basis). Most of the trace elements that could become volatilized during combustion are relatively low.

Coal overburdens of the region are also low in pyrite and sulfur (less 0.5 percent); the sulfur occurs mainly in the organic species, as it does in the coals. Minor quantities of framboidal pyrite, present as pyritic sulfur, were documented in certain overburden samples. The overburdens in some cases also show relatively high trace-element contents of boron, lead, zinc, molybdenum, nickel, cobalt, and cadmium. However, the serious acid conditions commonly associated with eastern and midwestern U.S. coal mines and the high levels of soluble salts and adsorbed sodium found in the western U.S. coal fields are unlikely to be significant problems.

Large-scale surface mining in the Susitna lowland will probably begin within the next five to ten years. At that time, material textures in mine spoils, particularly with regard to clays and weathered gleys, may become a significant problem (for proper drainage and revegetation) on certain tracts. In addition, siltation of streams may be problematic locally, and in areas of perched groundwater or springs, dewatering of trenches and pits will be necessary.


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## INTRODUCTION

The Susitna lowland occupies a broad region of south-central Alaska that is drained by the Susitna River and its tributaries (Figure 1). Subbituminous coal beds exposed along the major drain-

Figure 1---NEAR HERE

ages of the lowland and along the southern foothills of the Alaska Range indicate there are abundant, relatively shallow, subsurface coal deposits. Exploratory drilling by leaseholders in the southwestern and west-central Susitna lowland has already proven major coal reserves suitable for surface mining.

The strategic location near tidewater, the thickness, extent, and quality of the numerous coal seams, and overburden characteristics combine to make the deposits of the Susitna lowland---particularly the southern area---the most economically attractive for near-term new mine development in Alaska.

## LOCATION AND SETTLEMENTS

The entire Cook Inlet-Susitna lowland Tertiary province is about 515 km long by 130 km wide (Figure 1). The Susitna lowland encompasses about 13,000 $km^2$ and is covered by the Anchorage, Talkeetna, Talkeetna Mountains, and Tyonek 1:250,000-scale topographic maps. The lowland is bounded by the arcuate Alaska Range on the north and west, the Talkeetna Mountains on the east, and Cook Inlet on the south. Surface elevations of the lowlands increase from sea level at Cook Inlet northward to about 300 m. Isolated uplands of intrusive and pre-Tertiary rocks rise to 1,200 m above the surrounding lowlands.

The Susitna lowland includes northern Cook Inlet. Some workers (Miller and others, 1959, p. 47) consider the Susitna lowland the northwestern extension of the Cook Inlet Tertiary basin. Barnes (1966) terms the area the Beluga-Yentna region. The Castle Mountain fault, a major northeast-trending discontinuity separates upper Cook Inlet (on the south) and the Susitna lowland (on the north; Figure 2). Most stratigraphic studies in the Cook Inlet petroleum province terminate at the fault; however, important coal leases in the Beluga area lie on both sides of the fault zone.

Figure 2---NEAR HERE

The upper Cook Inlet region, site of metropolitan Anchorage and nearby settlements in Matanuska Valley and on the Kenai Peninsula, is the most densely populated region in Alaska. The State's principal agricultural region is located in the lower Matanuska Valley and the State has made additional lands available for agricultural development near Mackenzie Point, across Knik Arm from Anchorage. Except for small settlements along the Parks Highway and the Alaska Railroad, the Susitna lowland is essentially uninhabited. Activity in the summer months includes placer mining in the Petersville-Cache Creek area in the northern part of the lowland and continuing exploration and pre-mine investigations in the southwestern lowland.

## ACCESS

The Parks Highway and the Alaska Railroad transect the Susitna lowland in a north-south direction, roughly paralleling the Susitna River, connecting ports at Seward and Anchorage with Fairbanks in the Interior, and passing through the Susitna, Matanuska, and Broad Pass coal fields. Because of its accessibility to rail and ocean transportation, the Susitna lowland has been the chief coal exploration target in the state by industry. Most of the lowland is accessible only by aircraft or river boats; helicopters are generally used for geological field investigations. Surface conditions and environmental concerns limit the use of off-road vehicles.

## PHYSIOGRAPHY

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

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

## PREVIOUS WORK

Geologic investigations and reports of coal in the Susitna lowland were made by the U.S. Geological Survey as early as 1900 (Barnes, 1966). The 1957 discovery of oil and gas in the Cook Inlet basin at Swanson River and the increasing interest thereafter in the coal and agricultural potential of the region have resulted in a number of reports on the environment and resources of the region. Although now somewhat outdated, the report of Barnes (1966) is still the most thorough work on coal in the region.

## STRUCTURAL GEOLOGY AND REGIONAL TECTONISM

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

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

According to Hackett (1976a), the Tertiary basins of the upper Cook Inlet region represent a system of tilted horsts and grabens produced by extensional fragmentation of a pre-Tertiary basement (Figure 3). He postulated (p. 13) substantial translational and rotational block movements in south-central Alaska during Late Cretaceous and Early Tertiary times, caused by a change from normal to oblique subduction between major plate boundaries. Continued oblique rifting during the Middle and Late Tertiary further accentuated these coal-bearing basins. Hackett recognized several subbasins within the region and interpreted the Cook Inlet, Beluga and Yentna basins as rhombochasms, parallel-sided gaps in the crust caused by dilation (in dextral rhombochasms the crustal blocks are moved apart with a right-hand lateral component). He interpreted the Susitna basin and Matanuska Valley as sphenochasms, or triangular gaps separating two crustal blocks with fault margins converging to a point. Carey (1958) concluded that this structure originates by rotation of one of the blocks.

Figure 3---NEAR HERE

Hackett (1977) also produced a simple Bouguer gravity map of the Cook Inlet region that includes the southern Susitna lowland

(Figure 4). On this map, gravity highs correlate with exposures of pre-Tertiary basement rocks, whereas gravity lows indicate areas underlain by Tertiary sediments. The Beluga, Susitna, and Yentna basins are characterized by steep gravity gradients and low Bouguer anomalies indicating the presence of large basement discontinuities forming deep tectonic basins. The regional gravity gradient over the upper Cook Inlet region infers a gradual westward thickening of the earth's crust (Barnes, 1976; Hackett, 1977). Relief on the pre-Tertiary basement surface generates the larger anomalies over the region (Hackett, 1977).

Figure 4---NEAR HERE

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

The Castle Mountain fault bends or splays into the Bruin Bay fault to the south of the Lake Clark fault (Figure 2). The Beluga Mountain fault trends northwest along the Beluga Mountain-Mount Susitna front and Susitna lowland boundary; it has been interpreted as a high angle reverse fault dipping 60°-75°, upthrown on the southwest, and with a vertical displacement over 3,000 m (Hackett, 1977). In some areas the Castle Mountain fault shows evidence suggesting dextral-strike-slip movement or right-lateral drag. This is supported by the direction of offset of stream drainages such as the Susitna River. The fault is clearly visible as a surface lineament crossing the Susitna Flats (Kirschner and Lyon, 1973). Kelly (1963) inferred a minimum lateral displacement of 450 to 600 m along the fault as it transects the Susitna lowland.

These major high-angle reverse faults and small-scale high-angle block faults within the Susitna lowland have definitely offset the coal deposits. The ultimate effect of these on future coal exploration and development has not been fully ascertained. Downthrown blocks commonly localize channeling and result in the erosion of coal seams. However, the faulting in this case has localized certain blocks favorable for coal mining, as in the Chuitna River area, which occurs near the surface in an upthrown block of the Tyonek Formation.

The major faults of the Cook Inlet region have acted to control the development and general configuration of basinal depocenters. In addition to coal, these thick sedimentary rock sequences may hold some potential for oil and gas resources as well (Hackett, 1976b).

The Susitna lowland contains several subbasins within the main basin, all of which have a similar tectonic and sedimentologic history. However, each contains a variable number and thickness of coal beds.

## TERTIARY LITHOSTRATIGRAPHY

The current stratigraphic nomenclature for the Tertiary coal-bearing strata of the Susitna lowland was first proposed by Calderwood and Fackler (1972) for the Cook Inlet basin (Figure 5). Because of the thickness and complexity of the Tertiary sedimentary succession, they changed the 'Kenai Formation' originally adopted by Dall and Harris (1892) to the Kenai Group, and recognized that it contains five distinct formations: West Foreland, Hemlock Conglomerate, Tyonek, Beluga and Sterling Formations (Figure 5). Their divisions were based in part on five lithologic zones distinguished by Kelly (1963) from subsurface well data in the central part of the Cook Inlet basin (from top to bottom):

- Zone 1---Massive sand beds (5,000 ft; 1525 m thick)
- Zone 2---Sandstone, shale, and lignite (several thousand feet thick)
- Zone 3---Siltstone, shale, and low rank coal (several thousand feet thick)
- Zone 4---Sandstone and conglomerate ('Hemlock producing

zone,' 700 ft; 215 m thick)

- Zone 5---Siltstone and shale (several hundred feet thick).

Most of the major oil fields of the Cook Inlet region produce from the Hemlock Conglomerate (Magoon and Claypool, 1981), and past petroleum exploration in the region has yielded valuable stratigraphic information. Oil or gas has been produced from all the formations of the Kenai Group (Calderwood and Fackler, 1972).

Figure 5---NEAR HERE

Magoon and others (1976) and Boss and others (1978) have separated the West Foreland Formation from the Kenai Group because of the major unconformity separating it from the overlying Hemlock Conglomerate (Figure 6). They regard the Hemlock Conglomerate as the basal formation of the Kenai Group. Boss and others (1978) considered the Hemlock Conglomerate to be a member of the Tyonek Formation, and Magoon and others (1976) included it with the Tyonek Formation in their regional compilation.

Figure 6---NEAR HERE

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

Nonmarine coal-bearing rocks of the Kenai Group possess many dissimilar characteristics from marine and brackish water systems. The chief characteristics common to coal-bearing strata of the Kenai Group of the Susitna lowland include:

- Highly variable ash contents in coals. The ash mainly represents influxes of terrigenous silts and typically has abundant silica (quartz) and kaolinite.
- Locally thick coals but discontinuous laterally.
- Low sulfur content of both coals and overburdens.
- Lack of diagnostic marine fossils. Absence of faunal elements and burrowing (biogenic structures; bioturbation).
- High sand:mud ratios in overburdens.
- Abundant organic matter and plant detritus. Common coalified roots and in-place stumps.
- Rare dark-gray to grayish-black claystones.
- Coals often have rooted, slickensided, refractory underclays.
- Illitic-kaolinitic clay associations.
- Siderite nodules and bands present in some coals and associated strata but not common or diagnostic. Their presence is simply a reflection of poor drainage conditions.

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

## WEST FORELAND FORMATION

The West Foreland Formation crops out in the southern foothills of the Alaska Range. In the Beluga area, exposures occur northwest of the Lake Clark and Castle Mountain faults. In the Capps field area, Adkison and others (1975) measured 630 m of the West Foreland Formation strata in exposed sections. The type section for the West Foreland Formation is a drill hole 60 km to the south of the Capps Glacier area; at the type locality, the unit is 270 m thick. The formation is composed of interbedded siltstones, tuffaceous claystones, graywackes, and poorly sorted polymictic conglomerates with a few thin lignitic coal beds (Schmoll and others, 1981).

The West Foreland Formation was formerly regarded as early Eocene, characteristic of the Franklinian biostratigraphic (floral) stage of Wolfe (1966), but was later refined (Wolfe and others, 1980) and is now thought to be latest Paleocene as well. The West Foreland Formation is the lone representative of the early Cenozoic tectonic cycle. It was deposited on an erosional surface of Mesozoic and Early Tertiary rocks (Schmoll and others, 1981). The West Foreland Formation contains no significant coal deposits.

## HEMLOCK CONGLOMERATE

The Hemlock Conglomerate has been mapped to the northwest of the Castle Mountain fault (Detterman and others, 1976), but Magoon and others (1976) restricted it to the southeast side of the Bruin Bay fault. Calderwood and Fackler (1972) found it in the subsurface in the Beluga area. The unit is predominantly pebbly sandstone and conglomerate with minor siltstone. The conglomerates contain white quartz and black chert clasts (Conwell and others, 1982). The Hemlock Conglomerate is thought to be early Oligocene and has been assigned to the Angoonian stage (Wolfe, 1977). It forms the basal unit of the late Cenozoic tectonic cycle in the refined classification of the Kenai Group (Boss and others, 1978; Schmoll and others, 1981). The Hemlock Conglomerate contains no significant coal deposits.

## TYONEK FORMATION

The type section of the Tyonek Formation is in a well south of the village of Tyonek (Figure 7); this section includes numerous significant coal bed sequences and penetrates 2,333 m of the Tyonek Formation. The well (Pan American Petroleum State 2) intersected 42 significantly thick coal beds in this interval (Sanders, 1981). Adkison and others (1975) described exposures of the lower Tyonek Formation south of Capps Glacier, including the Capps and Waterfall coal beds (Figure 8). They assigned the coal-bearing exposures along the Chuitna River to the upper part of the Tyonek Formation. The formation underlies most of the Beluga area southeast of the Lake Clark and Castle Mountain faults. Outcrops around Capps Glacier and along the Chuitna River serve as the type section for the Seldovian stage (Wolfe and others, 1966; Wolfe, 1977).

Figures 7 and 8---NEAR HERE

The Tyonek Formation is finer-grained overall than the West Foreland Formation and Hemlock Conglomerate. The Tyonek Formation contains the thickest coal beds of the Kenai Group. Other lithologies present include massively bedded sandstones, siltstones, claystones, and conglomerates. Adkison and others (1975) divide the

Tyonek Formation in the Chuitna River field into a basal conglomerate (the Middle Ground Shoals Member) and a finer-grained upper coal-bearing unit, the Chuitna Member, which corresponds to the upper part of the lower 'Kenai Formation' of Barnes (1966). The stratigraphically highest coal bed in the type section well probably corresponds to the Chuitna bed of Barnes (1966; Figure 9). This bed, now known as the Brown Seam (Ramsey, 1981) is underlain by five other beds, which are, from highest to lowest, the Yellow, Green, Blue, Red, and Purple Seams (Figure 10).

Figures 9 and 10---NEAR HERE

Reed and Nelson (1980) divided the Tyonek Formation in the Talkeetna Quadrangle, which includes the Yentna basin, into sandstone and conglomerate members. The sandstone member is either conformable with the underlying conglomerate member or interfingers with it. The Tyonek Formation is separated from Mesozoic rocks by an angular unconformity. The Sterling Formation, stratigraphically the highest unit of the Kenai Group, unconformably overlies the Tyonek Formation as suggested by the presence within the Sterling Formation of coal fragments derived from the Tyonek Formation. The beds of both the sandstone and conglomerate members consistently dip either gently or moderately to the southeast.

The Tyonek Formation is late Oligocene to middle Miocene in age. Triplehorn and others (1977) and Turner and others (1980) obtained a 15.8-m.y. date from a volcanic ash parting in a coal bed of the upper Seldovian section along the Chuitna River. The rocks of the Tyonek Formation are products of channel and flood-plain sedimentation for the most part. Certain of the coarse-grained components indicate a near-source lithotype. Lacustrine deposits are also in evidence locally.

The Tyonek Formation is by magnitudes the most important coal-bearing unit of the Kenai Group; it contains the bulk of the coal resources of the Susitna lowland. The formation is widely distributed over the region, and its coals in general are thicker, laterally more continuous, and of better quality (for example, lower ash and higher heating values) than those of the Beluga and Sterling Formations of the Susitna lowland.

## BELUGA FORMATION

The Beluga Formation crops out along the lower Beluga and Chuitna Rivers and along Beshta Bay east of Granite Point. The total thickness cannot be determined from outcrops but it is over 1,200 m thick in the type section, a well near Beluga (Schmoll and others, 1981). The coal-bearing strata of the Beluga Formation dip synclinally eastward beneath Cook Inlet and extend into the subsurface of the Kenai Peninsula (Sanders, 1981). The formation consists of thin-bedded sandstones, claystones, and lignitic coals locally with bentonitic claystone interbeds; near basin margins it grades to predominantly sandy siltstones, claystones, and bony coals. The unit is late Miocene and is assigned to the Homerian stage and lower part of the Clamgulchian stage (Wolfe, 1966).

The large percentage of graywacke and greenstone lithic fragments in pebbly sandstones and conglomerates of the Beluga Formation suggest that these sediments may have been shed from the south and east during uplift of the Chugach Range, although a secondary source area could be from the Alaska Range to the north. The sediments were probably deposited as coalescing alluvial fans on fluvial plains (Clardy, 1978) from source areas of moderate to low relief.

The coals of the Beluga Formation are significantly less important than those of the Tyonek Formation. In the Susitna lowland, the unit covers much less area and contains magnitudes less coal resources of lower quality.

## STERLING FORMATION

Sterling Formation strata were mapped by Reed and Nelson (1980) in the northern Yentna basin. At Fairview Mountain it is

770 m thick. In the Beluga well, the unit overlies the Beluga Formation and together with Quaternary deposits makes up the upper 1,100 m of the hole.

The Sterling Formation is predomiantly a sandy, loosely consolidated unit with minor claystones and a few relatively thin (less 2 m) lignitic coals. Reed and Nelson (1980) describe it as orange to light-gray massive coarse-grained clastics, predominantly conglomerate. Clasts range in diameter up to 30 cm but average 5-10 cm. Induration is typically poor to moderate with a clay or iron oxide (ferruginous) matrix. Proportions of clast lithologies differ from those in the Tyonek Formation, but generally contain the same types---quartz, chert, shale, graywacke, and igneous rocks.

The Sterling Formation is late Miocene and Pliocene in age, and falls within the Clamgulchian stage of Wolfe (1966). Triplehorn and others (1977) obtained K-Ar dates of 11 and 6 m.y. from volcanic ash partings within coal beds of the Sterling Formation on the Kenai Peninsula. The Sterling Formation deposits are probably characteristic of braided streams that drained a tectonically active area (Clardy, 1978). Near basin margins it becomes conglomeratic indicating a high energy, near-source environment. Epidote dominates the heavy-mineral suite (Kirschner and Lyon, 1973). An indication of provenance is the easterly to southeasterly current directions displayed in cross-bedded sandstone lenses.

The coal deposits of the Sterling Formation are of minor significance compared to those of the Tyonek Formation. In the Susitna lowland, the coals of the Sterling Formation of the northern Yentna basin are discontinuous laterally and of general low quality. However, one coal at Sunflower Creek is about 17-m thick but clearly of local extent and structurally disturbed (Reed and Nelson, 1980).

## PETROGRAPHY OF TYONEK FORMATION ROCKS

### SANDSTONE COMPOSITION AND CLASSIFICATION

Sandstones of the Tyonek Formation examined during this study are fine- to coarse-grained, but predominantly medium-grained. Colors vary through shades of gray, yellow, tan, and brown, and locally may be slightly tinted by green or blue. Gradded bedding is common in the sandstones, and fining-upward sequences grade from coarse-grained sandstone at the base into fine-grained sandstone and siltstone. The sandstones consist predominantly of quartz and rock fragments. Feldspars, mica, and heavy minerals are generally minor accessory components. The sandstones typically have an argillaceous matrix or silica cement.

<u>Quartz</u>

Quartz grains grade from silt to pebble size entities in the sandstones. Plutonic quartz (with vacuoles and exhibiting strain shadows) and vein quartz (exhibiting slight to strong undulose extinction) types are most abundant. A minor subcomponent probably originated from metamorphic rocks; a few of the polycrystalline or mosaic type grains were also observed.

<u>Lithic Components</u>

Rock fragments are usually of low abundance (less 5 percent) but occasionally range to 25 percent, and one coarse-grained sandstone sample examined had over 50 percent. Most of the fragments are of sedimentary origin with secondary metamorphic types. Shale fragments (carbonaceous or bituminous) are a usual sedimentary component with disseminated and finely divided coal detritus; others are chert and cherty sandstone, argillaceous sandstone, and argillite (sometimes silicified). Metamorphic fragments include quartzite, slate, chlorite, and muscovite.

<u>Feldspars</u>

Feldspar (predominantly plagioclase and typically less than 3 percent) occurs in twinned (albite and Carlsbad) and untwinned varieties. Microcline (with diagnostic crosshatched twinning) was observed in a few samples. Almost all of the feldspar grains are highly altered---to sericite, chlorite, and other clays, and some have limonite rims. Relatively fresh grains of possible pyroclastic origin were not observed in the sandstones.

### Micaceous Minerals

Biotite is the most abundant mica (to 7 percent), usually deformed by compaction and often swollen and altering to clay---kaolinized. Sericite, intimately intermixed with chlorite, prochlorite, and clay, typically composes less than 2 percent, and muscovite makes up less 1 percent.

### Opaque and Heavy Minerals

These minerals are almost always estimated at less than 5 percent in modal analyses, but in an occasional sample range up to 15 percent. Usually the heavy minerals occur as isolated grains, but in some samples are concentrated in defined laminae. Among the heavy minerals identified are tourmaline, apatite, rutile, zircon, garnet, epidote (to 1 percent), clinozoisite (to 5 percent), and hornblende. In general, anywhere from 10 to 50 percent of the heavy mineral fraction is opaque.

### Matrix and Cement

The matrix of most Tyonek Formation sandstones examined is either siliceous or argillaceous. Often silica and clay occur in a mixture. Cryptocrystalline silica is common as a matrix material (including void-filling chalcedony) and cementing agent in most samples, as is ferruginous and sometimes silty clay. Illite and kaolinite are most abundant, and these are usually stained by iron oxides and hydroxides, and intimately intermixed with sericite, chlorite, and chloromphacite. A small proportion of the clay minerals have formed authigenically. In finer-grained sandstones, clay composes up to 20 to 30 percent of the matrix.

### Classification of the Sandstones

The sandstones are predominantly lithic or sublithic rocks---arenites or graywackes. Protoquartzites or orthoquartzites were not examined in the Tyonek Formation rocks studied.

### Roundness, Sorting, and Textural Maturity

Most quartz grains are subangular to subrounded in shape with rarer angular and rounded grains. A few well-rounded grains are undoubtedly recycled, and some show abraded overgrowths. Some clay-coated grains are also present, either recycled or with the coat formed authigenically by alteration. Chert clasts are typically more angular than quartz, easily observable in the coarser-grained sandstones. Sorting is generally poor to moderate, and most sandstones would be classified as submature to immature.

CLAYSTONES

Claystones are common in Tyonek Formation coal-bearing strata of the Susitna lowland. They may be silty or sandy locally, and often are carbonaceous (with shreds of organic matter, coaly streaks, and carbonized plant fragments), ferruginous (iron oxide and hydroxide mottles, irregular patches, encrustations, rims, and fracture coats), and with highly altered slate, quartzite, and graphitic or phyllitic schist rock fragments. They are crypto-crystalline with included flakes typically oriented parallel to bedding and they they may have discontinuous very fine laminations. They are sometimes banded with light and dark lenses of finer- and coarser-grained material (the lighter lamellae siltier, containing significantly more quartz than the darker lamellae of clay). Seat-rocks that are underclays are commonly rooted, and sometimes contain regular black, cryptogranular spheres which could be pollen grains. Colors of the claystones range through shades of gray and brown, sometimes with tints of red, yellow, and green. Root casts are sometimes observed, and syneresis or shrinkage cracks are also present in some samples.

X-ray diffraction analysis reveals that illite-kaolinite associations are most common in claystone samples from this region, with secondary abundances of mixed-layer minerals (as chlorite) and montmorillonite. Mixed-layer mineral and illite compete for the same sites, and resultantly the illite peaks appear relatively broad and asymmetric on diffractograms. The illite may also be poorly ordered because of surficial weathering. Chlorite (and clinochlore) and sericite occur as alteration products of hornblende or other ferromagnesian silicates and are intimately intermixed with other clays. Kaolinite in the samples exhibited a general lower birefringence than illite and sericite.

Cryptocrystalline quartz occurs in most claystone thin sections as scattered minute fragments, as small and irregular silicic veins and veinlets, and as cavity fillings. Both chalcedony and opal (isotropic and amorphous) are common. Quartz typically composes less than 10 percent in most modal analyses but is usually the second main constituent.

Minor or accessory minerals are present in the claystones in numerous forms. Carbonaceous (organic) matter is less than 7 percent on a modal basis. Opaque minerals are usually less than 5 percent. Biotite is the predominant mica (less 5 percent) with little muscovite (less 1 percent), both highly altered. Clinozoisite (often from 2 to 7 percent) is more abundant than epidote (usually less 1 percent). Other occurrences include anatase ($TiO_2$, diagnostic deep blue color and high relief), garnet, spinel, tourmaline, laumontite (zeolite in slate and schist rock fragments), and antigorite (brownish-green, platy serpentine mineral). Calcite, dolomite, siderite, and pyrite are extremely rare in these fine-textured sediments.

## CARBONACEOUS SHALES

These rocks are relatively rare in Tyonek Formation coal-bearing strata of the Susitna lowland. They are typically very thin (less 0.5 m) and occur adjacent to coal seams. They are reddish to dark brown or black. Irregular, silicic veinlets and cavity fillings of cryptocrystalline quartz transect carbonaceous fragments. Minor accessory minerals include iron oxides and hydroxides, clinozoisite, epidote, sericite (in minute shreds), muscovite, cryptogranular chlorite, feldspar (altering to clinozoisite), anatase, and tourmaline.

## CARBONATE AND CONCRETIONS

The carbonate content of the Tyonek Formation rocks studied was generally very low. Differentially calcium-carbonate cemented sandstone lenses and siderite concretions were found locally in the coal-bearing sections. Microscopically, the rocks include a mixture of very fine-grained calcite and siderite with argillaceous matter and silt- to fine sand-sized quartz. Differentially-cemented lenses are most abundant in sandstones, while siderite concretions are found mainly in silty shales. Some of the concretions have weathering rinds of limonite or hematite.

TONSTEINS

Several tonsteins have been identified as thin claystone partings in coal seams of the Tyonek Formation. Ovoids of relatively clear kaolinite are definitive of so-called graupen tonsteins. Major oxide geochemistry for two of these tonsteins is presented in Table 1, and in general is consistent with their interpreted origin as air-fall tuffs. X-ray diffraction of the samples show that the chief constituent is kaolinite (Figure 11); they contain little quartz. The high phosphate content of sample CnC7-12 has tentatively been identified by X-ray diffraction as goyazite $[SrAl_3(PO_4)_2 \cdot (OH)_5 \cdot H_2O]$ or gorceixite $[BaAl_5(PO_4)_2 \cdot (OH)_{11}]$, members of an isostructural group of rhombohedral phosphates of the plumbogummite family (Price and Duff, 1969). Definitive identification of a specific hydrated aluminum phosphate was not possible because of interference with other minerals of the series with similar 2θ and peak intensity. Relatively high titanium (particularly in sample CG4-6) is probably present as anatase, which was identified petrographically.

Table 1 and Figure 11---NEAR HERE

The tonsteins (CG4-6 and CnC7-12) exhibit the textures and general features of a palagonite tuff or recrystallized baked clay. Angular fragments (sometimes as shards) of red and black devitrified (to various stages) volcanic glass are present. The kaolinite is often intimately intermixed with iron oxides and hydroxides (goethite, limonite, and hematite), and shows parallel orientation with aggregate polarization. Chlorite and chloromphacite are scattered throughout the matrix, and occur as cryptogranular alteration products concentrated along silicic (chalcedonic) veinlets; clinozoisite, epidote, and sericite are also present as alterations.

## BAKED ROCKS

Several thermally altered rocks that were baked or burned by the natural combustion of adjacent coal beds were also examined petrographically. The degree of alteration present is directly proportional to its distance from the burning seam. A localized contact aureole is formed surrounding the burned zone caused by metamorphism.

A suite of baked rocks (samples CnC3-1 through CnC3-5) were sampled at an upper Canyon Creek locality of the west-central Susitna lowland (Figure 12). It is probable that the baking was produced by the burning of the adjacent coal seam underground. Table 2 shows certain gradational geochemical trends that occur from relatively unaltered rocks to highly altered rocks: 1) an increase in total iron as $Fe_2O_3$; 2) an increase in $Na_2O$ and $K_2O$; and 3) an expected decrease in $H_2O$· and LOI (loss on ignition). No additional trends were noted in the other major oxides.

Figure 12 and Table 2---NEAR HERE

The baked claystones have a very fine-grained matrix that extinguishes in two principal directions. Vesicles (pores and voids) and veinlets are commonly filled with cryptocrystalline quartz. Identification of individual minerals becomes more difficult with increased alteration. The minerals, of course, have been recrystallized and show indefinite boundaries with flow banding and glass sometimes observable in thin section.

## SUMMARY OF PETROGRAPHY

The petrographic characteristics of the Tyonek Formation rocks examined during this study are consistent with the hypothesized origin of these continental coal-bearing sequences as alluvial plain deposits, that is, the sandstones as channel or near-channel sediments and the finer-grained claystones and shales in interfluvial and lacustrine areas. The results of this petrographic analysis show that these rocks are in general poorly sorted, submature to immature, and suggest a multisource provenance.

## PALEOBOTANY AND PALEOCLIMATES

The ages of Tertiary coal-bearing stratigraphic units in south-central Alaska were essentially established by the paleobotanical and palynological work of Wolfe and others (1966), who proposed three new provincial time-stratigraphic units---the Seldovian, Homerian, and Clamgulchian stages. Plant megafossils and microfossils (spores and pollens) were used as criteria for age assignments. No megafossil or microfossil plants of the Clamgulchain stage were found in the Susitna lowland. Adkison and others (1975) measured numerous sections on the south side of Capps Glacier and at two localities along the Chuitna River and reported detailed lithologic descriptions and lists of palynomorph assemblages identified.

From his study of leaf floras of southwestern British Columbia and other parts of northwestern North America, Wolfe (1978) concluded that middle Eocene time was characterized by widespread, equitable climates. The warm and temperate broad-leaved forest trees lose their dominance after mid-Miocene, and cool temperate families (as Betulaceae or birch) proliferate (Wolfe, 1972, 1977; Wolfe and others, 1980). Williams and Ross (1979), based on their studies of Eocene coal-bearing strata in the Tulameen coal field of south-central British Columbia, also postulate a period of widespread equitable climates. This type of climate is inferred by most Tertiary models (Kirschner and Lyon, 1973) and probably was characteristic of the period of deposition of the coal-bearing Tyonek Formation of the Kenai Group. Relatively lush plant plant growth in a lowland plain paleoenvironment is envisioned to account for the abundant vegetation needed to form the thick peats and ultimately the thick coals of the Tyonek Formation.

## DEPOSITIONAL ENVIRONMENTS OF KENAI GROUP COALS

Source areas adjacent to the basins of the Susitna lowland were rejuvenated during Late Cretaceous and Early Tertiary. Periodic or gradual uplift converted areas of the basinal flood plains into widespread coal-forming environments by late Oligocene to middle Miocene time when the Tyonek Formation was deposited. Vegetal and woody materials accumulated and thick peats formed in stagnant depositional areas.

The depositional environments proposed by Dickinson and Campbell (1978) for Tyonek Formation sedimentary rocks in the Peters Hills and Fairview Mountain areas of the northern Susitna lowland are generally representative of those envisioned for other parts of the region. They conclude that some of the conglomerates and sandstones of the area indicate near-source deposition in mudflows and proximal braided-stream systems on alluvial fans, whereas other conglomerates and sandstones are characteristic of distal-braided-channel and flood-plain deposits. Carbonaceous mudstones, claystones, and coal formed in interchannel lacustrine and paludal areas. A generalized model representing typical paleoenvironments for the Tyonek Formation, Cook Inlet basin has been developed by Hite (1976; Figure 13).

Figure 13---NEAR HERE

A small synclinal basin with a thick coal seam east of Beluga Lake in the Susitna lowland may represent a lacustrine coal (Figure 14). A similar model is the basin-center coal and fringing marginal-shale-facies lacustrine model proposed by Hacquebard and Donaldson (1969) for basins in Nova Scotia.

Figure 14---NEAR HERE

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

These cycles result from shifts of channels and sediment deposition across an alluvial plain as indicated by lithologic relationships. The coarser basal units represent lateral-accretion deposits that commonly are cross-bedded. The upper finer-grained units represent overbank and lake or swamp deposits. As proposed, the flow-regime intensity progressively decreases upward through the section.

Cyclicity in the Susitna lowland was best observed at Fairview Mountain. A statistical Markov-chain analysis was applied to the section at that site (Figure 15) based on the repetition of the five major rock types (conglomerate, sandstone, shale, claystone, and coal). The analysis followed the stepwise procedure outlined by Gingerich (1969) for Paleocene fluvial sedimentary rocks in the northern Bighorn Basin of Wyoming.

Figure 15---NEAR HERE

The general frequency of occurrence of the five rock types is:

| | | |
|---|---|---|
| Shale (SH) | 5 | beds |
| Coal (CO) | 7 | |
| Claystone (CL) | 12 | $= f_i$ |
| Sandstone (SS) | 8 | |
| Conglomerate (CG) | 4 | |
| total = | 36 | |

The independent-trials matrix calculated is:

| | SH | CO | CL | SS | CG |
|---|---|---|---|---|---|
| SH | 0.00 | 0.22 | 0.39 | 0.26 | 0.13 |
| CO | 0.17 | 0.00 | 0.41 | 0.28 | 0.14 |
| CL | 0.21 | 0.29 | 0.00 | 0.33 | 0.17 |
| SS | 0.18 | 0.25 | 0.43 | 0.00 | 0.14 |
| CG | 0.16 | 0.22 | 0.38 | 0.25 | 0.00 |

$= e_{ij}$

The transition count matrix is:

| | SH | CO | CL | SS | CG |
|---|---|---|---|---|---|
| SH | 0 | 0 | 3 | 0 | 2 |
| CO | 4 | 0 | 2 | 0 | 0 |
| CL | 1 | 6 | 0 | 4 | 1 |
| SS | 0 | 1 | 6 | 0 | 0 |
| CG | 0 | 0 | 0 | 4 | 0 |

$= f_{ij}$

The transition probability matrix is:

| | SH | CO | CL | SS | CG |
|---|---|---|---|---|---|
| SH | 0.00 | 0.00 | 0.60 | 0.00 | 0.40 |
| CO | 0.67 | 0.00 | 0.33 | 0.00 | 0.00 |
| CL | 0.08 | 0.50 | 0.00 | 0.33 | 0.08 |
| SS | 0.00 | 0.14 | 0.86 | 0.00 | 0.00 |
| CG | 0.00 | 0.00 | 0.00 | 1.00 | 0.00 |

$= p_{ij}$

The $\chi^2$ statistic is calculated from the following:

$$\chi_v^2 = \sum_{ij} (f_{ij} - f_i e_{ij})^2 / f_i e_{ij}$$

The number of positive elements in $e_{ij}$ is 20. The rank of $e_{ij}$ is 5. The rank of a matrix is the maximum number of independent row vectors or column vectors, and is determined by converting the matrix to row-echelon form and finding the number of non-zero rows or columns (Hawkins, personal commun., 1982).

The echelon form of the matrix is:

| | SH | CO | CL | SS | CG |
|---|---|---|---|---|---|
| SH | 1 | 0 | 2.59 | 1.65 | 0.82 |
| CO | 0 | 1 | 1.77 | 1.18 | 0.59 |
| CL | 0 | 0 | 1 | 0.34 | 0.16 |
| SS | 0 | 0 | 0 | 1 | 0.18 |
| CG | 0 | 0 | 0 | 0 | 1 |

The degrees of freedom are 15. This is determined by subtracting the rank of $e_{ij}$ from the total number of positive entries:

$$v = 20 - 5 = 15$$

Solving for the equation yields a $\chi^2$ of 35.9.
The difference matrix that applies here is as follows:

$$\begin{array}{c} \\ SH \\ CO \\ CL \\ SS \\ CG \end{array} \begin{array}{c} \begin{array}{ccccc} SH & CO & CL & SS & CG \end{array} \\ \begin{bmatrix} 0.00 & -0.22 & 0.21 & -0.26 & 0.27 \\ 0.50 & 0.00 & -0.08 & -0.28 & -0.14 \\ -0.13 & 0.21 & 0.00 & 0.00 & -0.09 \\ -0.18 & -0.11 & 0.43 & 0.00 & -0.14 \\ -0.16 & -0.22 & -0.38 & 0.75 & 0.00 \end{bmatrix} \end{array} = p_{ij} - e_{ij}$$

The positive elements in the difference matrix represent those transitions that have a higher than random probability of occurring.

With a $\chi^2$ of 35.9 and 15 degrees of freedom, it is highly improbable that the Fairview Mountain sequence was deposited by an independent or non-Markovian mechanism. The section represents cyclic sedimentation in an alluvial environment. The fully developed cycle may be diagrammed as in Figure 16.

Figure 16---NEAR HERE

These cycles lend evidence for relative quiescent periods (tectonic lulls) during the Tertiary when large areas of the basinal flood plains were coal-forming swamps that alternated with periods of uplift in source regions, relative rapid basin subsidence, and the influx of clastics. In general, the Tertiary was a time of widespread but discontinuous coal formation in the Susitna lowland. Conditions conducive for coal formation were most favorable during the late Oligocene to middle Miocene during the deposition of the Tyonek Formation.

## PALEOSALINITY

Various workers (Couch, 1971; Bohor and Gluskoter, 1973; Spears, 1973, 1974; and Berner and others, 1979) have related the paleosalinity of strata to paleoenvironmental interpretation, for example, to decipher marine transgressions and regressions. Couch (1971) calculated paleosalinities from boron and clay mineral data. Bohor and Gluskoter (1973) used boron in illite as an indicator of paleosalinity in Illinois coals. Spears (1973, 1974) used exchangeable cations and water-soluble cations, and Berner and others (1979) used authigenic iron sulfides as paleosalinity indicators.

Spears (1973) found that the concentration of exchangeable magnesium is higher in marine shales, whereas the concentrations of exchangeable calcium, sodium, and potassium are lower than in nonmarine and brackish shales. He correlated the changes in exchangeable cations (p. 79, 81) to paleosalinity throughout the sequence, and postulated that these changes more likely occurred during halmyrolysis (submarine weathering) than diagenesis. Spears (1974) proposed that high concentrations of water-soluble calcium and magnesium cations reflect marine-influenced environments, whereas low concentrations are diagnostic of fresh and brackish water paleoenvironments; sodium and potassium have reverse trends.

Figure 17 shows considerable variation of ammonium acetate extractable cations and total cation-exchange capacity (CEC), expressed as milliequivalents per 100 g, for a Tyonek Formation coal-bearing section near Peters Hills. Increases in extractable $Mg^{++}$, $Ca^{++}$, and $K^{+}$ are mirrored by an increase in total CEC. Spears (1973) found a corresponding decrease in total CEC with increasing exchangeable magnesium. Changes in CEC are also directly related to changes in mineralogy; as in this example, a reduction in CEC simply reflects a decrease in the amount of clay, and is most likely related to provenance. The Peters Hills section is believed to have been deposited entirely in continental fluvial environments, and hence the variations are not related to transitions with marine environments.

Figure 17---NEAR HERE

# COAL PETROLOGY

## MACERAL COMPOSITION

Maceral composition for Susitna lowland coal samples analyzed during this study is summarized in Table 3 and Figure 18. The petrology of the raw coals is commonly similar based on maceral group proportions. However, the relative contents of individual macerals and maceral types vary considerably both within a seam and among different seams. Representative photomicrographs of coals from the region show the variety, morphology, and associations of various macerals (Figure 19).

Table 3, Figures 18 and 19---NEAR HERE

The huminite group of macerals is by far the most abundant in coals of the Susitna lowland; typically, this group contains over 90 percent of all macerals, and is always over 75 percent (Table 3). Ulminite, the main huminite maceral present, usually appears fairly uniform in structure and reflectance, and is medium to light gray, and sometimes has desiccation cracks or microfractures. Texto-ulminite is partially gelified, whereas eu-ulminite is completely gelified. The corpohuminites occur as both phlobaphinite (primary cell infillings) and pseudophlobaphinite (secondary cell infillings). Pseudovitrinite is extremely rare.

Mean-maximum reflectance values for all Susitna lowland coals as measured from ulminite macerals are summarized in Figure 20. Reflectance values range from 0.23 to 0.45 percent, and confirm that most of the coals are subbituminous to lignitic. Little variation occurs in the reflectance values of ulminite within a seam or among all the seam samples analyzed.

Figure 20---NEAR HERE

Inertinites commonly occur as minor constituents in the coals of the Susitna lowland; however, several seams, particularly those of the northern Yentna field at Fairview Mountain and in the Peters Hills area, have inertinite contents ranging up to over 18 percent by volume on a mineral-matter-free basis. The inertinites are typically white or very light gray and bright in normal incident light; they exhibit the highest reflectances of all macerals. The most predominant inertinite macerals are macrinite, fusinite, and semifusinite. Inertodetrinite (dispersed clastic fragments of inertinite) and sclerotinite (hard fungal remains found mainly in younger coals such as those of the Tertiary period) were also observed. The sclerotia may be rounded or elliptical; its lumens or cavities may contain resinite, pyrite, or other mineral matter. Micrinite (fine granular debris) was not identified in the coals of the region.

The liptinites occur as minor constituents in the coals of the Susitna lowland; liptinites range up to about 12 percent by volume on a mineral-matter-free basis. The most abundant liptinites are resinite and suberinite. The liptinites have the lowest reflectances of all macerals. They are black to dark gray in normal incident (reflected) light but are fluorescent under blue-light irradiation. Resinite occurs as cell fillings (of lumens) or secretions and may be found as isolated, elongate or spherical bodies; it typically displays an orange fluorescence. Exsudatinite was not counted separately but was included with resinite. Exsudatinite commonly fills cracks in vitrinite, the cell lumina of fusinite, or the chambers of sclerotinite (Spackman and others, 1976). Suberinite is commonly found in Tertiary coals; it originates from cork cell walls mainly in barks and root tissues. Sporinite occurs as squashed elongate bodies with slitted centers. Yellow stringers (in fluorescent light) of cutinite typically are crenulated or toothed on one side, may be thin-walled or thick-walled, and sometimes are folded. Alginites---preserved algal remains---are rare in the coals of the Susitna lowland; they fluoresce yellow under blue-light irradiation.

PALEOENVIRONMENTAL INTERPRETATION FROM MACERAL COMPOSITIONS AND ASSOCIATIONS

Coal petrology provides evidence for the depositional environments of coals. Maceral composition establishes the predominant types of vegetation and indicates conditions of the ancient peat swamp. The depositional system is integrative in that everything in this regime is interdependent and related. For example, tectonic factors determine relative subsidence rates, which influence coalification, peat diagenesis, coal categenesis, and ultimately coal petrology.

Cohen (1973), in relating precursor peat types to eventual coal composition, differentiated two major groups of peats: a) herbaceous peats, which produce a massive (unlaminated) dull coal, and b) tree-vegetation peats, which result in a brighter, laminated coal. He found that the herbaceous peats were low in preresinites (cell fillings and secretions), presclerotinites (fungal remains), and fusinite (charcoal) but higher in premicrinites (fine granular debris). However, tree-vegetation peats have a higher percentage of preresinites, presclerotinites, and fusinite but a low amount of premicrinitic materials. Based on this subdivision, most Susitna lowland coals formed from tree-vegetation peats.

Paleoenvironmental interpretation from coal petrology begins with an understanding of the concept of microlithotypes, which are associations of macerals of the same group or with those from other maceral groups. They can be monomaceralic (microlithotypes containing macerals of only one group), bimaceralic (with macerals of two groups), or trimaceralic (all three groups). Microlithotypes compose the macroscopic lithotypes---vitrain, clarain, durain and fusain.

The coal samples from the Susitna lowland were not collected close enough---either vertically or laterally---to permit detailed interpretation of facies changes from the petrographic variations within the coal seams. However, the main microlithotypes present can very generally be determined by selectively counting the maceral associations on the polished pellets and from the extensive maceral composition data collected. The different groups of microlithotypes can be subdivided into individual microlithotypes by taking account of these maceral associations (Stach and others, 1982). Vitrite is the dominant microlithotype, with clarite containing minor interbands of vitrinertite and trimacerite (duroclarite). Williams and Ross (1979) found similar maceral compositions and microlithotypes in Tertiary (Eocene) bituminous coals in the Tulameen coal field of south-central British Columbia. They also found vitrite to be the dominant microlithotype, with clarite containing minor interbands of trimacerite (clarodurite) and durite. From their maceral determinations, they proposed that the coal-forming peats there developed in a forest-moor-swamp environment in a poorly drained low-lying basin that was adjacent to an eroding upland during a warm, moist climatic period.

The determination of the paleoenvironment in which a coal-forming peat developed extends back to a classic paper by Hacquebard and Donaldson (1969), who described how flood-plain and limnic environments in Nova Scotia could be related to Carboniferous coal deposition. They emphasized that coal-forming materials can either essentially form in situ and be indigenous (autochthonous coals) or can be transported to another region where these materials accumulate (allochthonous coals). Hypautochthonous coals refer to those that originated mainly from plant debris transported within the general area of its growth, whereas allochthonous coal seams form from peats that were deposited as drifted vegetation---more specifically, plant accumulations that drifted or were rafted into regions that do not correspond to those in which the plants originally grew.

Evidence indicates that most Susitna lowland coals undoubtedly formed essentially in situ, but some coals exhibit characteristics of each group. Upright and rooted fossil trees occur locally. Most leaf impressions are complete and intact, which indicate no transport. Some coals have classic underclays while others do not.

Hacquebard and Donaldson (1969) subdivided the seam profile at each sample location into petrographic intervals that they considered represented time-rock units. Each interval is bounded on top and bottom by clastic partings or distinctive dull layers, which have both a relative widespread continuity and a characteristic microscopic composition. They expressed the aggregate thickness of individual microlithotypes as a percentage of the total thickness of an interval and plotted these percentages in a four-component 'facies' diagram (Figure 21). The vertices of the triangles represent those microlithotypes (or combinations of microlithotypes) that are characteristic of specific environments in the peat bog:

- ·Spore-clarite + duroclarite---characterized by a high content of spore exines
- ·Fusito-clarite---has distinct lenses of fusite in a matrix of clarite
- ·Vitro-clarite + cuticle clarite---has high vitrinite content, is low in sporinite
- ·Clarodurite + durite + carbargilite

Figure 21---NEAR HERE

Hacquebard and Donaldson (1969) recognized four diagnostic vegetation zones that characterize the different types of swamp environments, following the procedure of von Karmasin (1952; Figure 21). They recognized the forest-moor as the environment for the deposition of vitrite and vitro-clarite, and the open-moor for the deposition of largely subaquatic coals as cannel and boghead and for certain types of spore-rich clarite. They concluded that fusito-clarite formation occurs in a forested moor (designated FtM) of the terrestrial zone where relatively dry conditions prevail. The forest-moor and reed-moor facies of the bright-coal upper triangle formed in the telmatic zone between high and low water levels (Osvald, 1937). The subaquatic deposits of the lowermost sector of the dull-coal triangle (Figure 21) formed in the limnic zone whereas the two remaining sectors of this lower triangle represent limnotelmatic deposits.

The microlithotypes that are most clearly related to coals of the Susitna lowland are those of the lower-left sector (C) of the upper bright-coal triangle, which has a high content of vitrinite (or huminite) and is low in sporinite. However, there are differences in the microlithotypes present in the two regions. The forest-moor-swamp environment, where predominantly vitrite and vitro-clarite are deposited, is typical of most Susitna lowland (particularly Tyonek Formation) coals, as it is for coals of the Tulameen field. The types of vegetation and conditions of preservation of the plant materials in this environment indicate that most of the coals of this region formed in the telmatic zone.

## PYRITES IN SUSITNA LOWLAND COALS

Four major morphological species of sedimentary pyrite or marcasite occur in coals and their associated sediments: 1) framboidal pyrite; 2) euhedral grains; 3) coarse-grained masses (over 25 micron diameter) that replace original plant material; and 4) coarse-grained platy masses or cleats that occupy joints. Disseminated euhedral grains (usually 1-10 microns in diameter) and framboids (less 25 microns in diameter) are primary pyrite varieties, and the coarse-grained, massive, and replacement forms are secondary. 'Framboidal' refers to a unique 'raspberry-like' microtexture that forms clusters of spherical agglomerates; the diameter of each microsphere varies from 0.25 to 1 micron. Groups of framboidal spheres are termed polyframboids (Caruccio and others, 1977).

Framboidal pyrite occurs in the continental-fluvial low-sulfur coals of the Kenai Group. It has been documented petrographically in coal samples from several areas in the Susitna lowland (Figure 22). Until recently, the origin of framboidal pyrite seemed to involve sulfur-reducing marine or brackish-water microbial organisms, particularly bacteria. However, fine-grained pyrites have recently been identified in till (Stene, 1979), unconsolidated mud and ancient shale (Czurda and others, 1973), and freshwater sediments (Dell, 1975). Organic matter and a reducing environment are prerequisites for framboidal-pyrite formation. Contrary to previous theory, sulfur-reducing bacteria such as Desulfovibrio desulfuricans (Berner, 1969; Sweeney and Kaplan, 1973), which are restricted to marine and brackish waters, are probably not required.

Williams and Keith (1963) found that roof rock of marine or brackish-water origin contains more sulfur than that of freshwater origin. Indeed, pyrite morphology and grain size are controlled to some degree by the geochemical regime in ancient peat-swamp environments. However, because of the recent discovery of framboidal pyrite in a variety of sediments, paleoenvironmental interpretations should not be based on their presence; new theories as to their origin must incorporate the diverse physical and geochemical conditions of these paleoenvironments.

Figure 22---NEAR HERE

Most Susitna lowland coals contain less than 0.4 percent sulfur (Table 4), and all contain less than 0.75 percent sulfur. Thus, coal cleaning (washing for sulfur) is generally not required. The organically-combined variety of sulfur most abundant in these coals is difficult to remove or reduce substantially. A high sulfate-sulfur content in a coal commonly indicates a weathered sample (for example, WC1-3 of Table 4).

Table 4---NEAR HERE

Primary sedimentary sulfides rapidly oxidize to iron oxides and to ferrous and ferric sulfates when exposed to air, but secondary pyrite (Figure 23) is stable and leaches very slowly (Caruccio and others, 1977). Although framboidal pyrite is responsible for most acid-mine drainage in coal-mining regions (Caruccio, 1970), problems are not expected in the Susitna lowland because of the minor amount of pyritic sulfur and disseminated reactive framboidal pyrite. In addition, the contamination of surface waters and ground water by the solution and release of chemically bound trace elements in the primary sulfide fraction should not occur because of the small quantity of this disseminated pyrite in the coals of south-central Alaska.

Figure 23---NEAR HERE

## COAL QUALITY

The major coal deposits of the Susitna lowland are predominantly subbituminous B, subbituminous C, or lignite. Other seams locally show apparent ranks of high-volatile B bituminous and subbituminous A.

Almost all coal-quality data published to date for the Susitna lowland (except for summaries developed by industry from core samples) have been derived from analyses of weathered outcrop samples. Readers are alerted to view coal quality data during the present study as measurements of 'apparent rank.'

The chief attraction of most Alaskan coals is their extremely low sulfur content. Coals of the Susitna lowland nominally have only 0.3 percent total sulfur (Figure 24). Ash content is quite variable, but is low to moderate in some of the higher quality coals of the Tyonek Formation.

Figure 24---NEAR HERE

The range of trace element contents in coal ash of Susitna lowland samples are compared with the general contents found in coal ashes from other regions in Figure 25. Elements that might tend to become volatilized during combustion are generally low. In almost all cases, the contents of elements in the Susitna lowland samples fall within the ranges commonly found in other coals. However, barium, manganese, and chromium were higher in certain samples, while the contents of arsenic, zinc, boron, lead, and molybdenum were lower in the ashes of certain samples.

Figure 25---NEAR HERE

During the present investigation, 66 coal samples from the Susitna lowland were analyzed (Table 5; Figures 26 through 28). A factor analysis based on proximate coal quality data and heating values derived two significant factors. Factor 1 is explained by fixed carbon, heating value, and ash; it shows that the coals with high fixed carbon have accompanying high heating values and relatively low ash (and vice versa). Factor 2 is explained by volatile matter and ash, and shows that coals with high volatile matter contents are accompanied by low ash (and vice versa). Moisture and sulfur contents were insignificant as factors explaining the variance.

Table 5; Figures 26-28---NEAR HERE

Scatter plots of paired proximate variables and heating values reveal similar trends as in the factor analysis (Figure 27). The high positive correlation in Figure 27A supports a direct relationship between heating value and fixed carbon content; that is, as the fixed carbon content increases, so does the rank (as reflected in heating value) of the coal. The high positive correlation in Figure 27B shows that the heating values also vary directly with the volatile-matter content of the coals. The high negative correlation in Figure 27C illustrates the inverse relationship of the ash content and fixed carbon; that is, coals with a higher fixed carbon content (higher rank) tend to have lower ash. The trend displayed by the high negative correlation in Figure 27D is that coals with higher volatile matter contents show lower ash (as in factor 2 explained above). These relationships are expected for a group of coal samples exhibiting a narrow range in rank variance, that is, most Susitna lowland coals being of subbituminous rank.

A cluster analysis based on proximate data, total sulfur, and heating value of the Susitna lowland coals analyzed is depicted in Figure 28. Distinct clusters represent those coals with similar characteristics. Often many coals from a given locality form a fairly close cluster, while in other instances they appear to vary significantly in quality.

Ultimate analysis results of selected coals from scattered localities of the Susitna lowland are presented in Table 6, and in general are typical for subbituminous and lignite coals. The carbon contents are relatively low, while the oxygen contents are relatively high but indicative of low-rank coals. Lignites, subbituminous, and low-rank bituminous coals generally have hydrogen contents around 5 or 6 percent; in high-rank bituminous and anthracite coals, it decreases to 3 or 4 percent. Sulfur and nitrogen contents are usually highest in bituminous coals and decrease both in lower- and higher-rank coals.

Table 6---NEAR HERE

Considering the broad spectrum of coal rank, ash contents are typically independent of the various rank indicators, and reflect variations in the quantity of mineral matter initially deposited in a peat swamp. Most of the inorganic matter in Susitna lowland coals is accounted for by silica, alumina, and calcium oxides with lesser abundances of iron and magnesium oxides (Figure 29). Silica is highest in Fairview Mountain coal ash and lowest in some Chuitna River coal ashes. Alumina oxide is higher in certain Canyon Creek coal ashes, and Chuitna River and Saturday Creek coal ashes tend to have higher calcium oxides. Saturday Creek coals also exhibit higher $SO_3$ contents. The other major oxides are fairly consistent at all sites.

In summary, coals of the Tyonek Formation are generally of higher quality than those of the younger Beluga and Sterling formations in the Susitna lowland. This conclusion is supported by the results of coal characterization research to date. However, coals from all the formations are primarily subbituminous, with moderate to high moisture, extremely low sulfur, and variable ash contents.

Figure 29---NEAR HERE

## COAL RESOURCES AND RESERVES

The Cook Inlet-Susitna lowland province represents the second largest coal-resource base in Alaska, surpassed only by the deposits on the North Slope. Large areas of the Susitna lowland hold relatively shallow, surface-minable coal deposits. Many areas judged to have a high potential for future coal development have already been leased. There are other large tracts on which the coal resources have been poorly defined.

The total identified coal resources of the Susitna lowland are 10 billion short tons. Hypothetical resources are estimated to be 30 billion short tons. Measured resources are at least 3 billion short tons. The latter estimate includes 1.5 billion tons on Diamond Alaska Coal Company leases, 1.0 billion tons on Beluga Coal Company leases, and 0.5 billion tons on leases of Mobil Resources. Minor additional measured resources have been defined on other leases in the region.

The coal deposits of the Susitna lowland have been delineated by private drilling programs since 1967, but most of the data are still proprietary. The three deposits with the highest potential for minability in the immediate future are in the Beluga coal field; these are Chuitna River, Capps basin, and Threemile Creek. The Capps deposits, which occupy a localized coal basin 11 to 13 $km^2$ in area has two major minable coal beds, the Capps and Waterfall seams. These beds have maximum thicknesses of 17 and 7.6 m, respectively. The stripping ratio is estimated at 4:1 to 5:1 (Patsch, 1976). Six seams constitute most of the minable resources of the Chuitna River area (Figure 10). Cumulative stripping ratios over the estimated mine life in this area are about 4.5:1 (Ramsey, 1981).

The most favorable mining prospects within the Susitna lowland occur where thick beds of the Tyonek Formation are within 100 m of the surface. Most of the coals of the region over 6-m thick are restricted to the Tyonek Formation, where over 100 separate beds have been distinguished in a single well log. The West Foreland, Hemlock Conglomerate, and Beluga Formations have several thick coal beds at depth as indicated in oil well logs. Coal beds of the Sterling Formation, which crops out to the northern part of the Yentna basin, are generally less than 2.5-m thick.

Although individual estimates of resources and reserves vary significantly, the coal deposits of the Susitna lowland are enormous by all accounts. Total minable reserves, as currently defined, amount to several billion tons.

## OVERBURDEN CHARACTER

The character of overburden strata of Kenai Group coals in the Susitna lowland has received very little attention, mainly because of the lack of active coal-mining operations. However, surface mining in the region cannot be conducted without detailed studies of both consolidated and unconsolidated overburden materials.

A broad spectrum of overburden characterization analyses were performed on Susitna lowland samples during the present study (Table 7). Some of the most important characteristics of overburden materials relate to their texture, acidity and saline-sodic conditions, cation exchange capacity, organic matter, trace element, macronutrient and micronutrient contents. Although guideline criteria used in evaluating the character and quality of overburden materials have been developed in several other states, including Wyoming and Montana, none have been established yet in Alaska.

Table 7---NEAR HERE

### TEXTURE

A plot of particle sizes and resultant textures for Susitna lowland overburden samples show that several fall in poor texture zones (Figure 30). In general, these poor-texture zones relate to a regraded spoil medium being derived from high sand (greater 70 percent) or high clay (greater 40 percent) content overburden.

Figure 30---NEAR HERE

Based on unconfined compressive strength tests of Capps coal field core samples, Chleborad and others (1982) conclude that the materials range from soft soil to soft rock.

### ACIDITY

The overburden strata at Fairview Mountain, northwest Yentna basin, exhibit both low pH values (to 4.1; Figure 31) and, in at least two samples, deficiencies of ameliorating capacity over 5 tons $CaCO_3$ equivalent per 1000 tons of material. However, the pyritic sulfur content of the roof and floor beds of coal seams C-F was less than 0.1 percent and the total sulfur content was less than 0.48 percent in all cases. The acidity here is believed to have resulted from the biochemical breakdown of organic matter, which ranged from 1.27 to 11.89 percent in those samples analyzed from the site.

Figure 31---NEAR HERE

Because of the near-normal pHs and very low sulfur contents in overburden materials (Figure 32), acidity should not be a significant problem in most areas of south-central Alaska.

Figure 32---NEAR HERE

SALINE-SODIC SPOIL

Results of analyses during the present study support the conclusion that saline and sodic spoil should not be a major problem in the Susitna lowland. No zones of salt accumulation or sodium adsorption levels that would be detrimental to the establishment of plant growth were found in the overburden materials analyzed. Electrical conductivities range from 0.1 to 0.9 mmhos/cm at 25°C, and the mean sodium adsorption ratio is less than 1.0. Although a few samples exhibit anomalously high exchangeable sodium percentages, the mean value is 16.5 percent.

CATION-EXCHANGE CAPACITY

The range in 54 overburden samples analyzed from the Susitna lowland (three sites) is 1.3 to 88.4 meq/100 g with a mean of 20.0 meq/100 g. Generally, shales and mudstones have relatively high cation-exchange capacities (CEC). The CEC in sandstones rarely exceeds 5 meq/100 g unless they are argillaceous.

TRACE ELEMENTS

Little baseline data exist for acceptable trace-element contents for overburden materials, particularly in Alaska. Hinckley and others (1982) concluded that considerable variation occurs in rock chemistry and depositional environments over short distances in the Beluga area, and that fine-grained rocks (claystones) typically contained higher abundances (by a factor of two or more) of most trace elements than coarse-grained rocks (sandstones; Table 8). Certain trace elements (for example, lead, zinc, nickel, cobalt, and cadmium) in samples of overburden materials at several localities in the Susitna lowland---Beluga River, Capps Glacier, Fairview Mountain, Peters Hills area, Saturday Creek, and Wolverine Creek---appear to be at levels significantly higher than recommended for substitution of these materials as prime topsoil or subsoil media (Figure 33).

Table 8, Figure 33---NEAR HERE

The maximum content of selenium (Table 7) found in the 20 samples analyzed (two sites) from the Susitna lowland was 0.05 ppm, well below the probable toxicity threshold level of 2 ppm. The total boron content of the 20 samples analyzed ranged up to 100 ppm with a mean value of about 34 ppm, indicating that excess boron concentrations (greater than 5 ppm) in mine spoil material could be a problem. Molybdenum was less than 15 ppm in all Susitna lowland overburden samples analyzed; at this level, molybdenum could concentrate in plant tissues consumed by grazing ruminants and result in the condition known as molybdenosis. Lead contents in the overburden samples ranged up to about 50 ppm; in general, materials with lead levels higher than 10 ppm should be selectively handled.

MACRONUTRIENTS AND MICRONUTRIENTS

Extractable nutrient levels were analyzed in 43 overburden samples from six sites across the Susitna lowland (Table 7). The range and mean values for nitrate nitrogen are 2.1-13.8 and 4.0 ppm, respectively; for phosphorous 6.85-38.54 and 15.44 ppm; and for potassium 47.6-280.4 and 136.4. These results indicate that the samples are deficient in the major plant nutrients nitrogen and phosphorous and sometimes potassium, and that amendments with these compounds should aid revegetation if the materials are used as a subsoil medium. Of the common micronutrients (iron, manganese, zinc, boron, molybdenum, and copper), none appear to be deficient. Zinc, boron, molybdenum, and manganese levels in some samples may indicate a potential problem with metal phytotoxicity. Iron and copper appear to be at levels sufficient for normal plant growth.

SUMMARY OF OVERBURDEN CHARACTER

In summary, evaluations of coal overburden character from Susitna lowland samples indicate that 1) poor texture zones could result in regraded soil materials causing problems for proper drainage and revegetation; 2) acidity problems should be minor and localized; 3) there is little potential for the development of saline-sodic conditions; 4) toxic levels of certain trace elements, including boron, molybdenum, and lead in spoil materials could result locally; 5) positive growth response can be expected with additions of the macronutrients nitrogen and phosphorous; and 6) certain micronutrients, including zinc, boron, molybdenum, and manganese are not deficient but could actually cause problems of metal phytotoxicity locally.

## CONCLUSIONS

The Tertiary Kenai Group of the Susitna lowland of south-central Alaska contains substantial reserves of subbituminous and lignite coals suitable for surface mining. Most of the coal resources occupy a crescent-shaped belt along the western and southern margin of the Susitna lowland. Although individual estimates of resources and reserves vary significantly in the region, total minable reserves undoubtedly amount to several billion tons. The chief attractions of these coals are their extremely low sulfur content and favorable location relative to prospective Pacific-rim markets.

The coals are generally comparable in quality with those of the Powder River Basin of the western United States. Calorific and mean-maximum reflectance values indicate that most coals are of subbituminous rank. Although the coals are laterally discontinuous and sometimes high in ash, the large number of seams---particularly within the Tyonek Formation---and the geochemical and physical character of the enclosing strata result in economically attractive deposits within several fields. However, subsurface information is scant and the true extent of these deposits is unknown.

Petrologic studies indicate that most Susitna lowland coals probably originated in forest-moor-swamp environments within the telmatic zone. A drier paleoenvironment (perhaps in the terrestrial zone) and an origin from tree-vegetation peats is interpreted for coal seams of the northern Yentna basin (upper Tyonek and Sterling Formations). Most of the coals formed on alluvial flood plains within poorly drained low-lying basins adjacent to eroding uplands during a warm, moist climatic period.

Coal overburdens are low in sulfur (less 0.5 percent), which mainly occurs in the organic form as it does in the coals. Serious acid conditions and high levels of soluble salts and adsorbed sodium should not be a significant problem in the Susitna lowland. However, isolated acid conditions could develop, and the levels of certain trace elements in overburden materials, regraded spoils, and in surface and ground waters should be monitored. Material textures in the regraded spoil profile could pose challenging problems for proper drainage and revegetation.

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## FIGURE CAPTIONS

Figure 1...General location and physiographic setting for the Susitna lowland of south-central Alaska. Modified from Miller and Dobrovolny, 1959. Vertical exaggeration about 4X.

2...Mesozoic and Cenozoic tectonic elements, major faults, basins, and highland exposures of pre-Tertiary basement rocks (shaded) in the Cook Inlet region of south-central Alaska. Modified from Payne, 1955 and Hackett, 1977.

3...Structural sections based on geophysical profiles across the Beluga basin and adjacent areas, southern Susitna lowland. Modified slightly from Hackett, 1977.

4...Simple Bouguer gravity map of the Beluga basin and adjacent areas of the Cook Inlet region, south-central Alaska. Modified from Hackett, 1977.

5...General stratigraphic nomenclature for the Tertiary Kenai Group of southcentral Alaska. After Calderwood and Fackler, 1972.

6...Surface and subsurface Tertiary stratigraphic correlation chart. (a) from Wolfe and others, 1966; (b) from Magoon and others, 1976.

7...Lithologic column for the Tyonek Formation at the type section in the Pan American Petroleum Corporation Tyonek State 17587 No. 2 well. From Calderwood and Fackler, 1972.

8...Typical cross section of the Capps area of the Beluga coal field showing the thickness of the Capps and Waterfall seams, and of overburden and interburden zones. Adapted from Conwell, 1977.

Figure 19...(A-F) Photomicrographs of various macerals from Susitna lowland coal samples, oil immersion.

A. Pseudophlobaphinites and ulminite, 400X.

B. Fusinite, 315X.

C. Semifusinite, ulminite, and sclerotinite, 315X.

D. Phlobaphinite and porigelinite, 400X.

E. Phlobaphinite and suberinite, 400X.

F. Sclerotinite, ulminite, and porigelinite, 315X.

20...Vitrinite reflectance frequency histogram for coal samples from the Susitna lowland. Number in brackets indicates the total number of vitrinites measured at the given reflectance interval.

21...Four-component 'facies' diagram used to express the aggregate thickness of individual microlithotypes as a percentage of the total thickness of a coal interval. The vertices of the diamond-shaped diagram are occupied by those microlithotypes or combinations of microlithotypes representing specific environments in a peat bog. Adapted from Hacquebard and Donaldson, 1969.

22...Photomicrograph of framboidal pyrite in a Susitna lowland coal seam (Tertiary, Tyonek Formation).

23...Photomicrograph of coarse-grained, striated, massive, secondary pyrite in a Susitna lowland coal seam (Tertiary, Tyonek Formation).

24...Histogram showing the maximum and arithmetic mean values for the percent total sulfur and sulfur species of analyzed Susitna lowland coal samples (as received basis). [ ]= number of samples.

25...Range of trace element contents in raw coal ashes commonly found in other coals compared with abundances in

Susitna lowland coals. Range in other coals from Mason, 1966, fig. 9.5, p. 242.

Figure 26...Histograms of various coal-quality parameters for Susitna lowland coal samples. The frequency expresses the number of samples exhibiting a particular value.

27...Scatter plots with regression lines of paired-proximate variables for Susitna lowland analyzed coal samples. Note the correlation coefficients in each case. Refer to text for discussion.

28...Cluster analysis based on proximate data, total sulfur, and heating values for Susitna lowland analyzed coal samples. Coals of similar quality form close clusters.

29...Range in concentration of major oxides in raw coal ash of samples from eight localities in the Susitna lowland. 1=Beluga River; 2=Canyon Creek; 3=Capps Glacier; 4=Chuitna River; 5=Fairview Mountain; 6=Peters Hills; 7=Saturday Creek; and 8=Wolverine Creek.

30...Particle sizes and textures for Susitna lowland overburden samples showing those rock materials that would tend to form poor texture zones in spoil material. Poor texture zones (greater 40 percent clay and greater than 70 percent sand) are indicated by unshaded pattern.

31...Overburden/interburden characteristics for a Fairview Mountain coal-bearing section (Tyonek Formation, northwest Yentna basin).

32...Histograms for pH and total sulfur content for Susitna lowland overburden samples. The frequency expresses the number of samples exhibiting a particular value.

Figure 33...Comparison of the range for certain trace element contents in overburden materials at six localities in the Susitna lowland. BR=Beluga River; CG=Capps Glacier; FM=Fairview Mountain; PA=Peters Hills area; SC=Saturday Creek; and WC=Wolverine Creek.

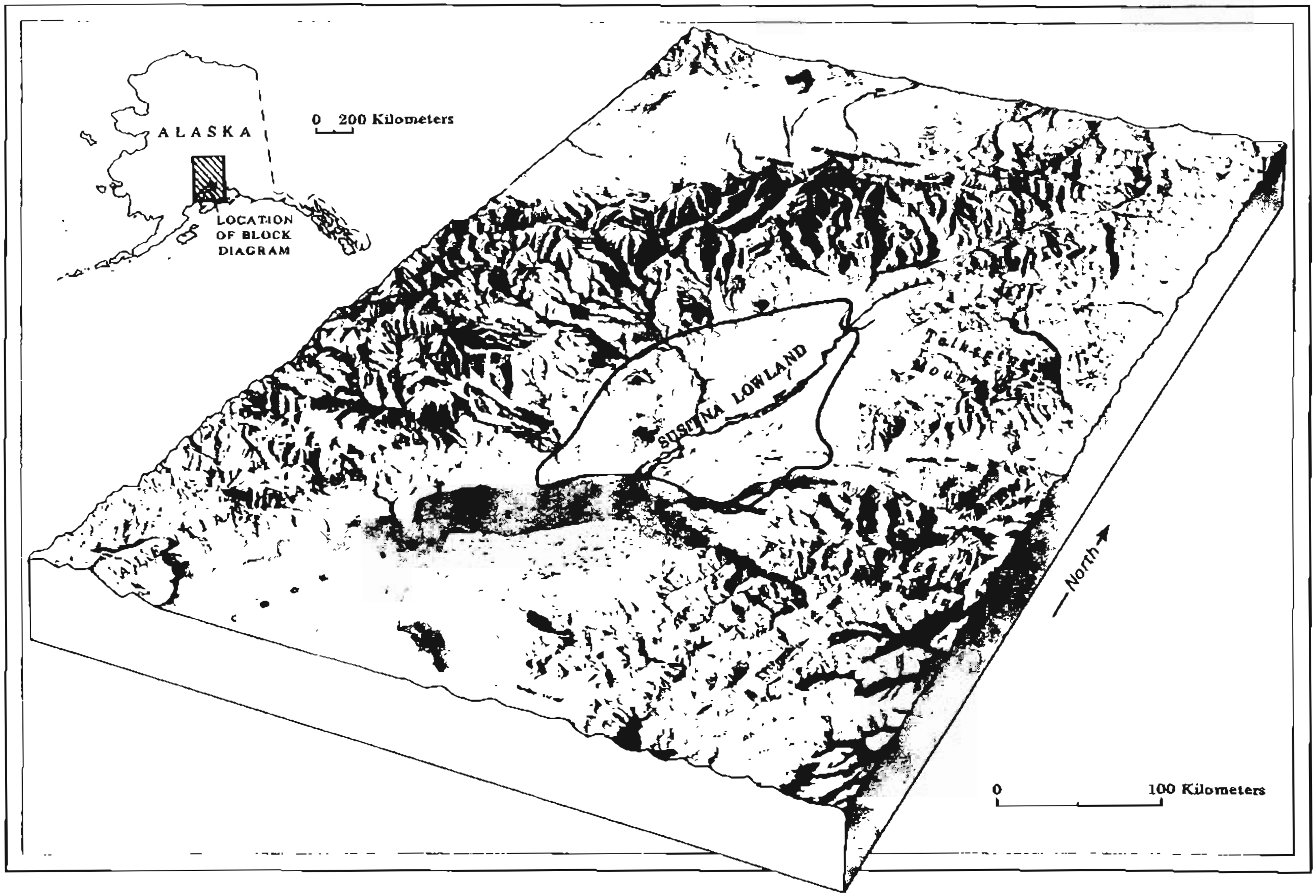

ALASKA
0 200 Kilometers
LOCATION OF BLOCK DIAGRAM
SUSITNA LOWLAND
North
0
100 Kilometers

Figure 1

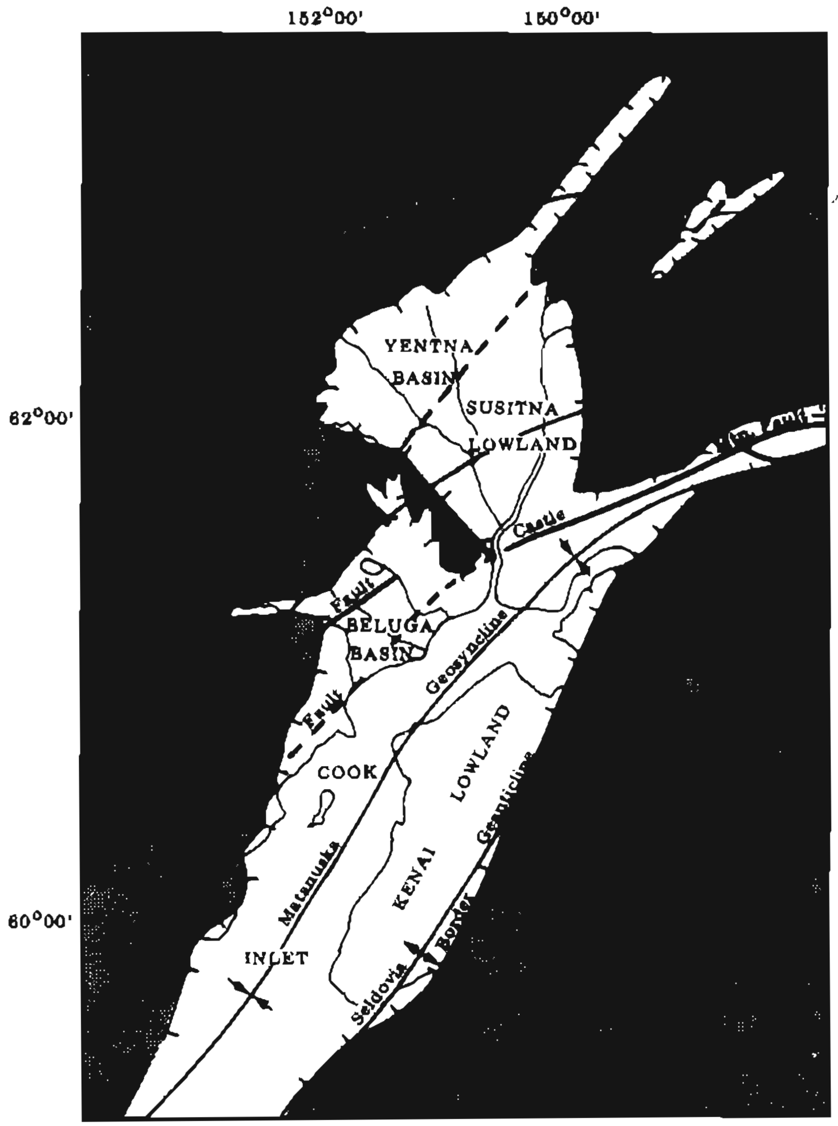

152°00'
150°00'
62°00'
60°00'
YENTNA
BASIN
SUSITNA
LOWLAND
Castle
Fault
BELUGA
BASIN
Fault
Geosyncline
COOK
KENAI
LOWLAND
Geanticline
Matanuska
INLET
Seldovia
Border

Figure 2

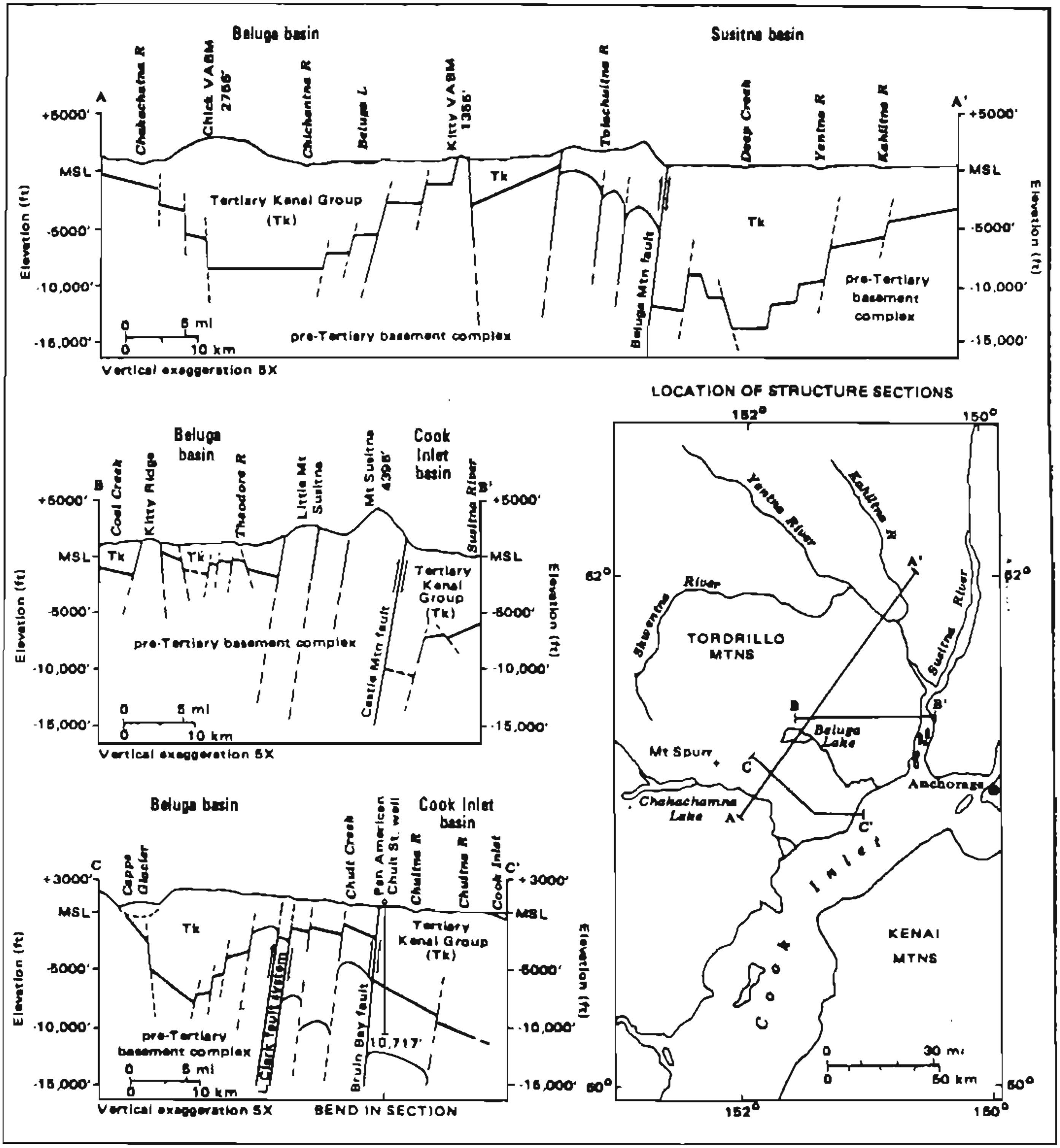
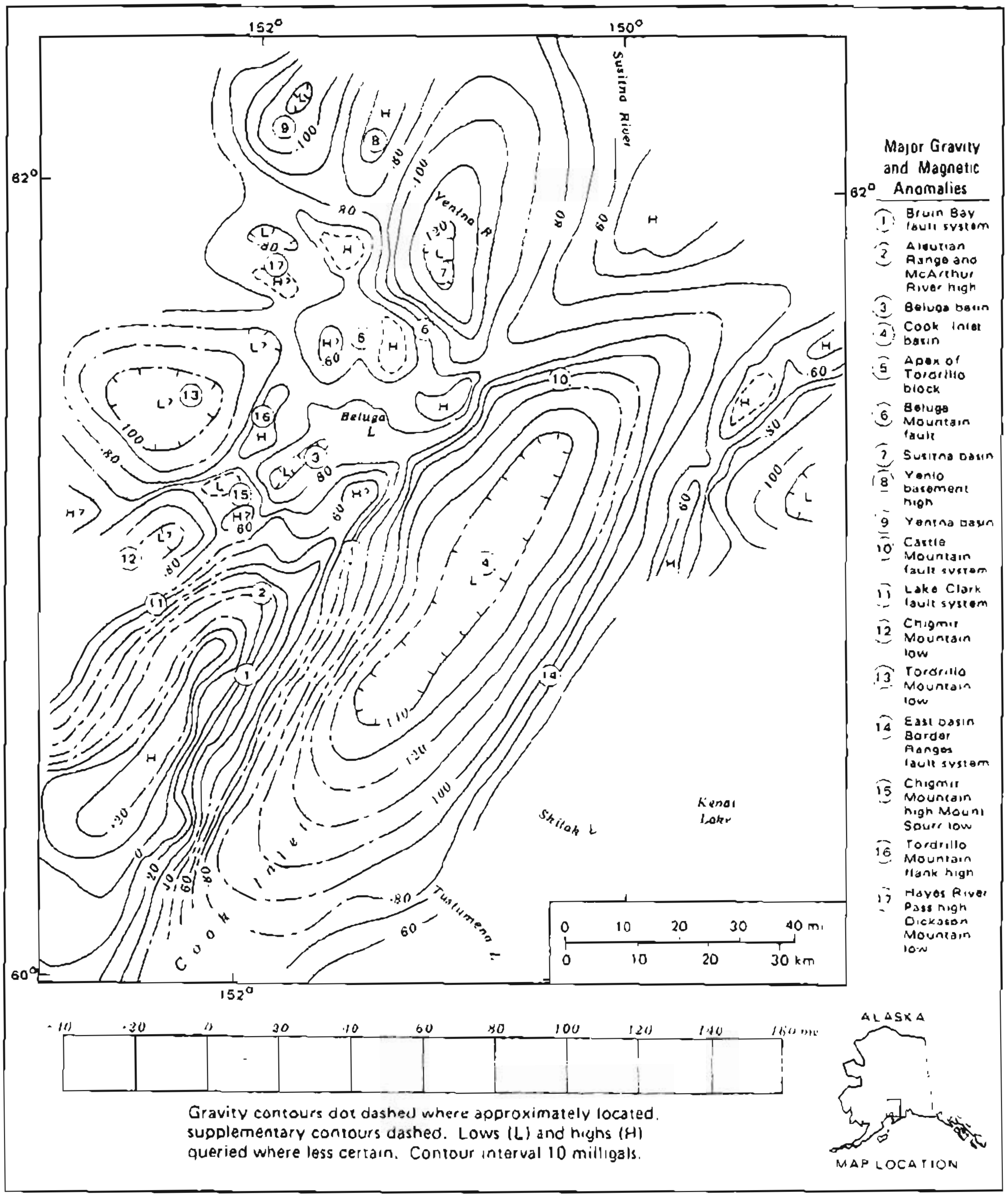

Beluga basin
Susitna basin
A
A'
Chakachatna R
Chick VABM 2756'
Chichantna R
Beluga L
Kitty VABM 1355'
Tolachulitna R
Deep Creek
Yentna R
Kahiltna R
+5000'
MSL
-5000'
-10,000'
-15,000'
Elevation (ft)
Tertiary Kenai Group (Tk)
Tk
pre-Tertiary basement complex
Beluga Mtn fault
pre-Tertiary basement complex
0 5 mi
0 10 km
Vertical exaggeration 5X
Beluga basin
Cook Inlet basin
B
B'
Coal Creek
Kitty Ridge
Theodore R
Little Mt Susitna
Mt Susitna 4396'
Susitna River
Tertiary Kenai Group (Tk)
Castle Mtn fault
pre-Tertiary basement complex
Vertical exaggeration 5X
Beluga basin
Cook Inlet basin
C
C'
+3000'
Capps Glacier
Chuit Creek
Pan American Chuit St. well
Chuitna R
Chulitna R
Cook Inlet
Tertiary Kenai Group (Tk)
Clark fault system
Bruin Bay fault
10,717'
pre-Tertiary basement complex
Vertical exaggeration 5X
BEND IN SECTION
LOCATION OF STRUCTURE SECTIONS
152°
150°
62°
60°
Yentna River
Kahiltna R
Skwentna River
Susitna River
TORDRILLO MTNS
Beluga Lake
Mt Spurr
Chakachamna Lake
Anchorage
Cook Inlet
KENAI MTNS
0 30 mi
0 50 km

Figure 3



Major Gravity and Magnetic Anomalies
1 Bruin Bay fault system
2 Aleutian Range and McArthur River high
3 Beluga basin
4 Cook Inlet basin
5 Apex of Tordrillo block
6 Beluga Mountain fault
7 Susitna basin
8 Yenlo basement high
9 Yentna basin
10 Castle Mountain fault system
11 Lake Clark fault system
12 Chigmit Mountain low
13 Tordrillo Mountain low
14 East basin Border Ranges fault system
15 Chigmit Mountain high Mount Spurr low
16 Tordrillo Mountain flank high
17 Hayes River Pass high Dickason Mountain low
Susitna River
Yentna R
Beluga L
Cook Inlet
Tustumena L
Skilak L
Kenai Lake
152°
150°
62°
60°
0 10 20 30 40 mi
0 10 20 30 km
ALASKA
MAP LOCATION
Gravity contours dot dashed where approximately located, supplementary contours dashed. Lows (L) and highs (H) queried where less certain. Contour interval 10 milligals.


Figure 4

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

Figure 5

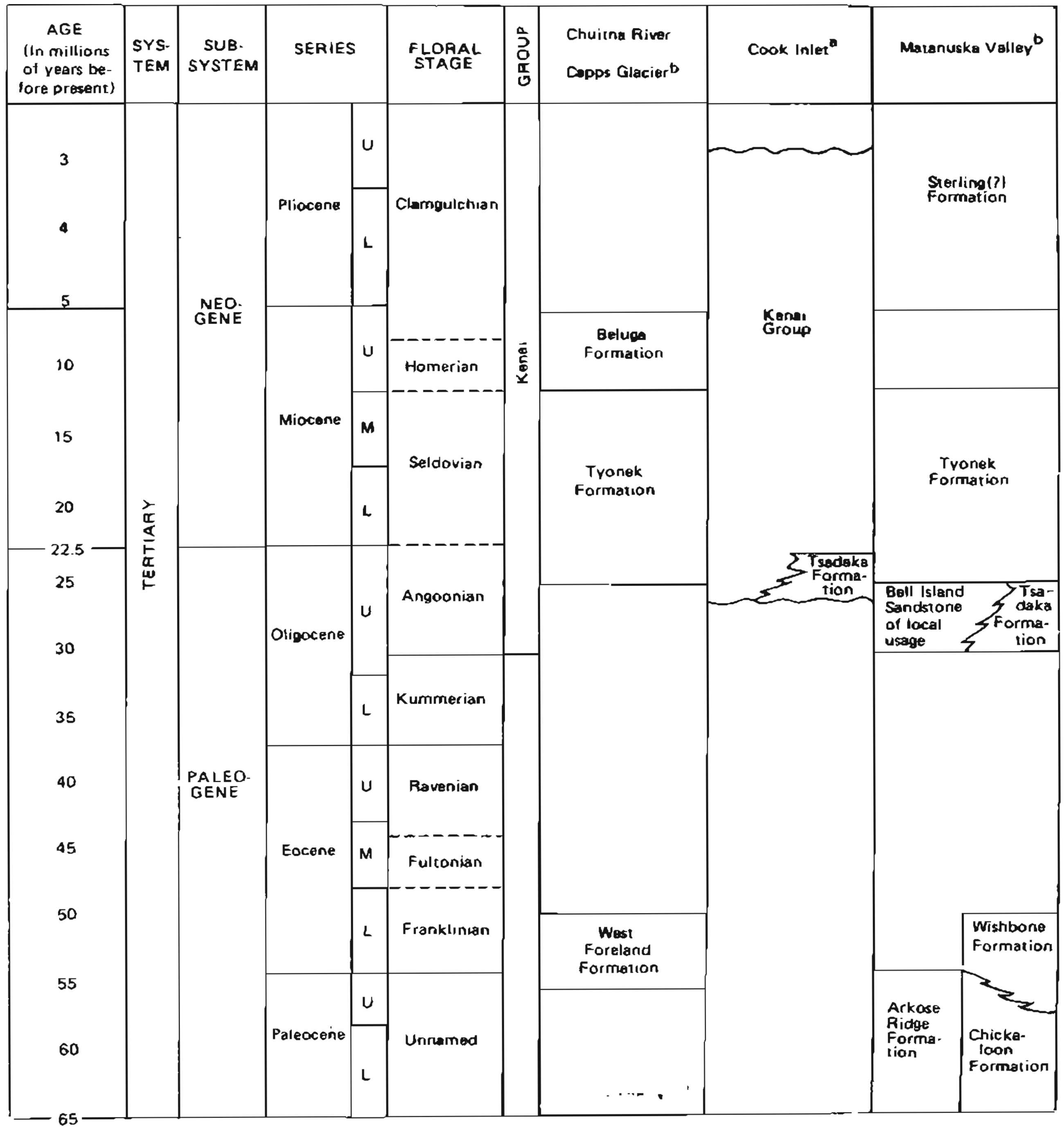
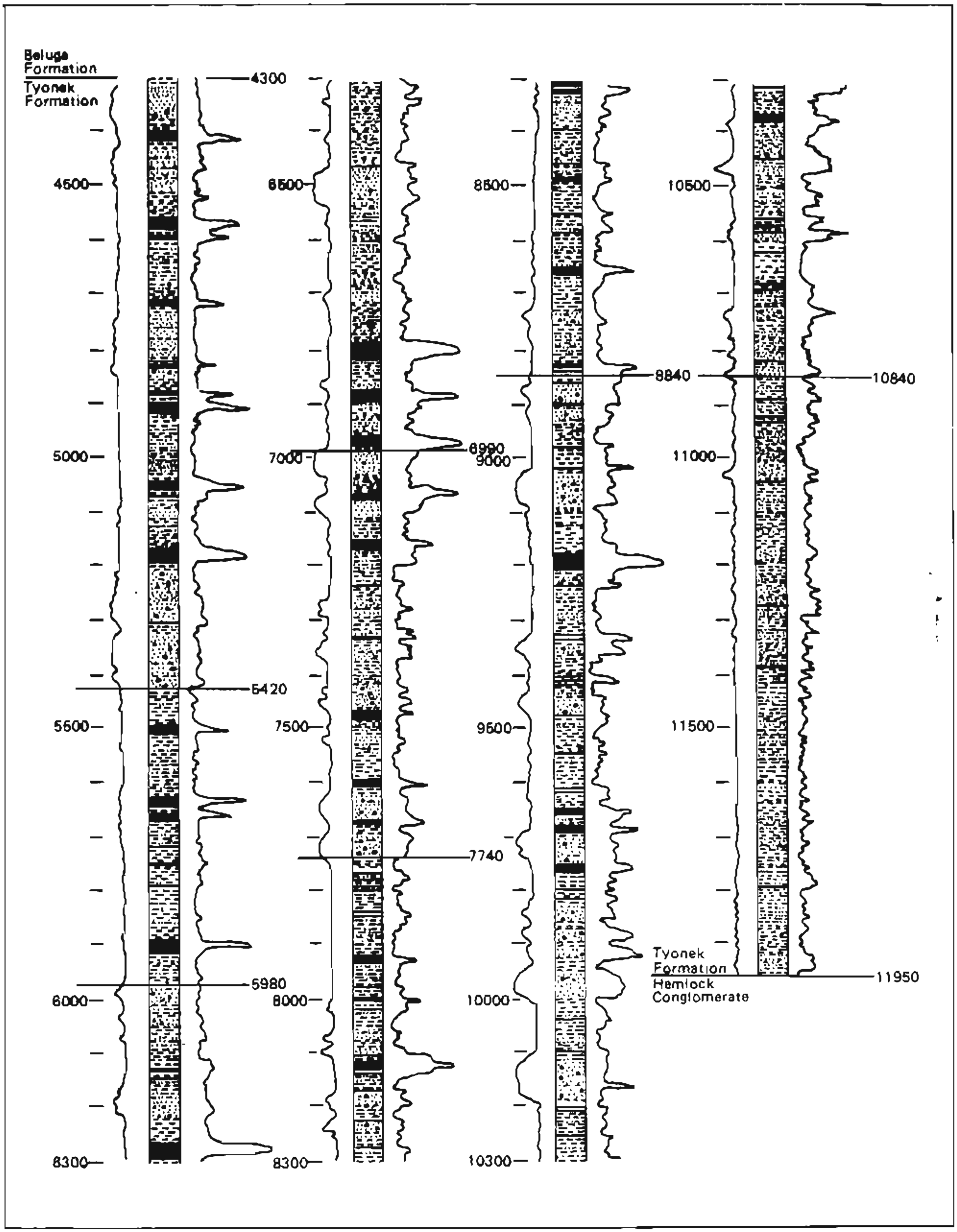
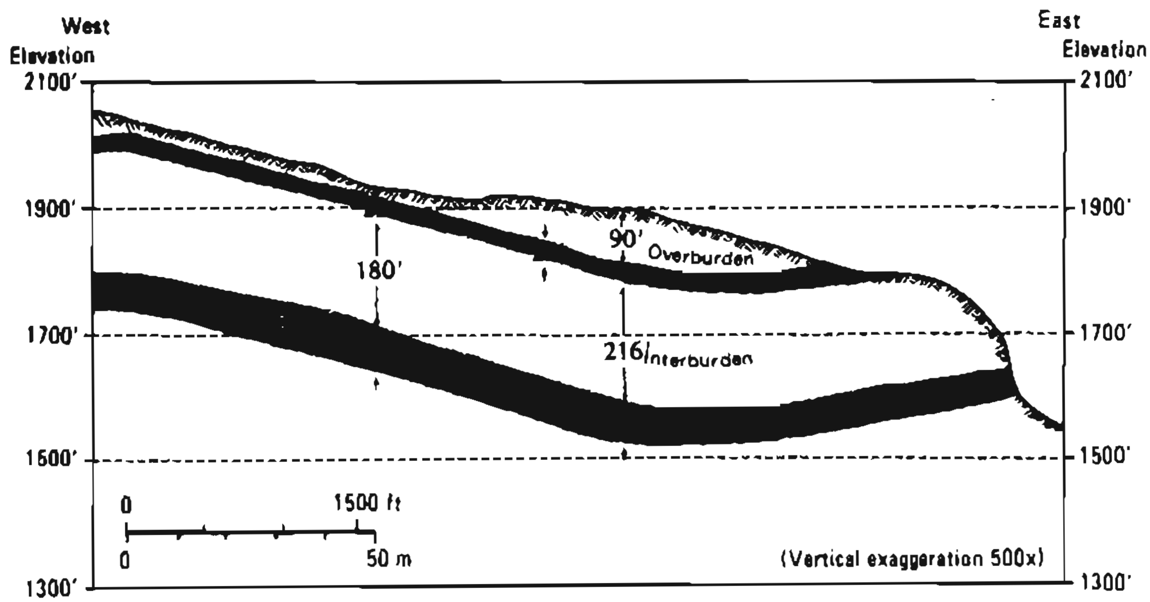

AGE (In millions of years before present)
SYSTEM
SUBSYSTEM
SERIES
FLORAL STAGE
GROUP
Chuitna River
Capps Glacier[b]
Cook Inlet[a]
Matanuska Valley[b]
3
4
5
10
15
20
22.5
25
30
35
40
45
50
55
60
65
TERTIARY
NEOGENE
PALEOGENE
Pliocene
Miocene
Oligocene
Eocene
Paleocene
U
L
M
Clamgulchian
Homerian
Seldovian
Angoonian
Kummerian
Ravenian
Fultonian
Franklinian
Unnamed
Kenai
Beluga Formation
Tyonek Formation
West Foreland Formation
Kenai Group
Tsadaka Formation
Sterling(?) Formation
Tyonek Formation
Bell Island Sandstone of local usage
Tsadaka Formation
Wishbone Formation
Arkose Ridge Formation
Chickaloon Formation

Figure 6



Beluga Formation
Tyonek Formation
4300
4500
5000
5420
5500
5980
6000
6300
6500
6990
7000
7500
7740
8000
8300
8500
8840
9000
9500
10000
10300
10500
10840
11000
11500
Tyonek Formation
Hemlock Conglomerate
11950


Figure 7



West
Elevation
2100'
1900'
1700'
1600'
1300'
East
Elevation
2100'
1900'
1700'
1500'
1300'
180'
90'
Overburden
216
Interburden
0
1500 ft
0
50 m
(Vertical exaggeration 500x)


Figure 8

Figure 9

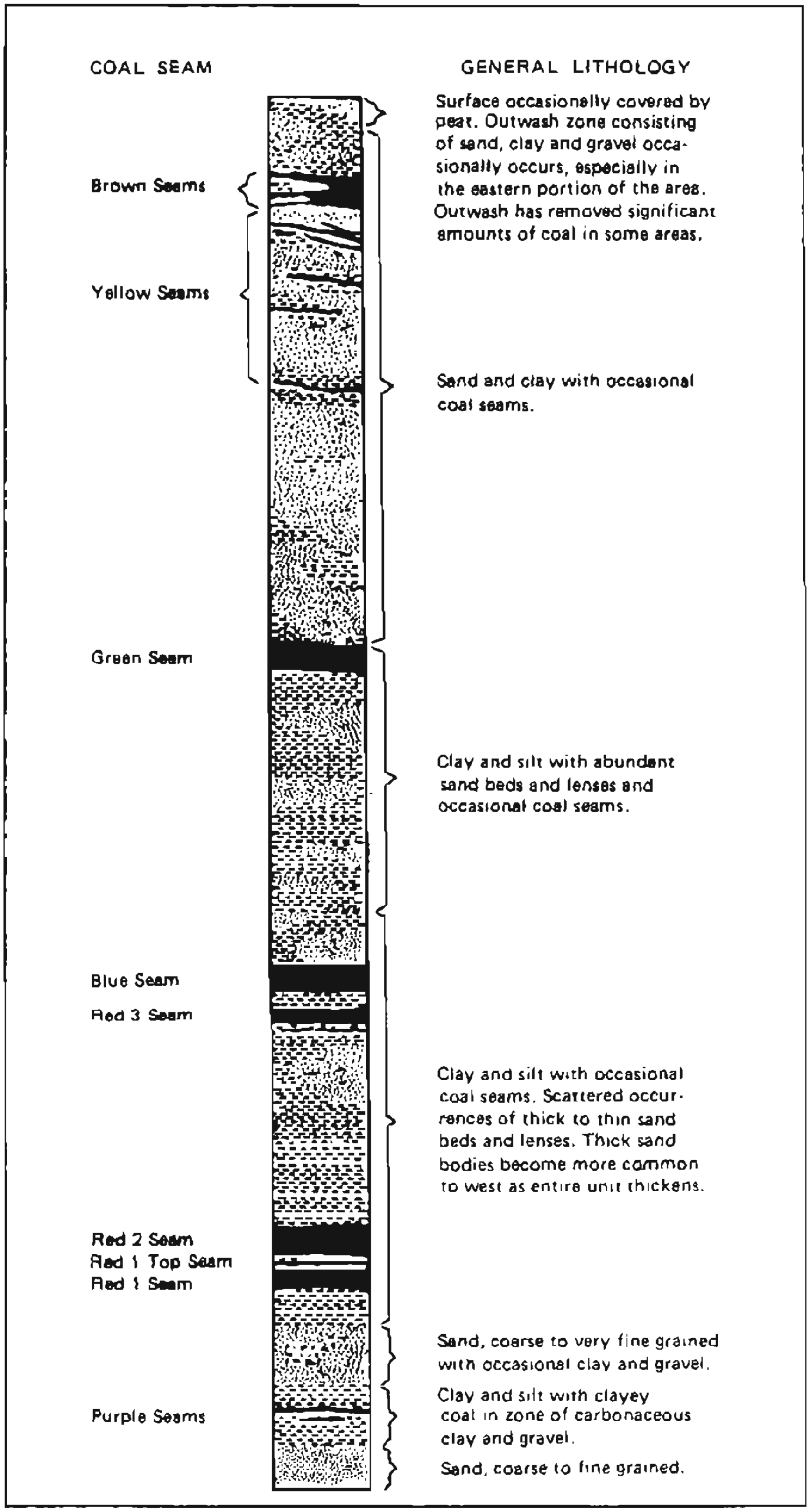

COAL SEAM
GENERAL LITHOLOGY
Surface occasionally covered by peat. Outwash zone consisting of sand, clay and gravel occasionally occurs, especially in the eastern portion of the area. Outwash has removed significant amounts of coal in some areas.
Brown Seams
Yellow Seams
Sand and clay with occasional coal seams.
Green Seam
Clay and silt with abundant sand beds and lenses and occasional coal seams.
Blue Seam
Red 3 Seam
Clay and silt with occasional coal seams. Scattered occurrences of thick to thin sand beds and lenses. Thick sand bodies become more common to west as entire unit thickens.
Red 2 Seam
Red 1 Top Seam
Red 1 Seam
Sand, coarse to very fine grained with occasional clay and gravel.
Purple Seams
Clay and silt with clayey coal in zone of carbonaceous clay and gravel.
Sand, coarse to fine grained.

Figure 10

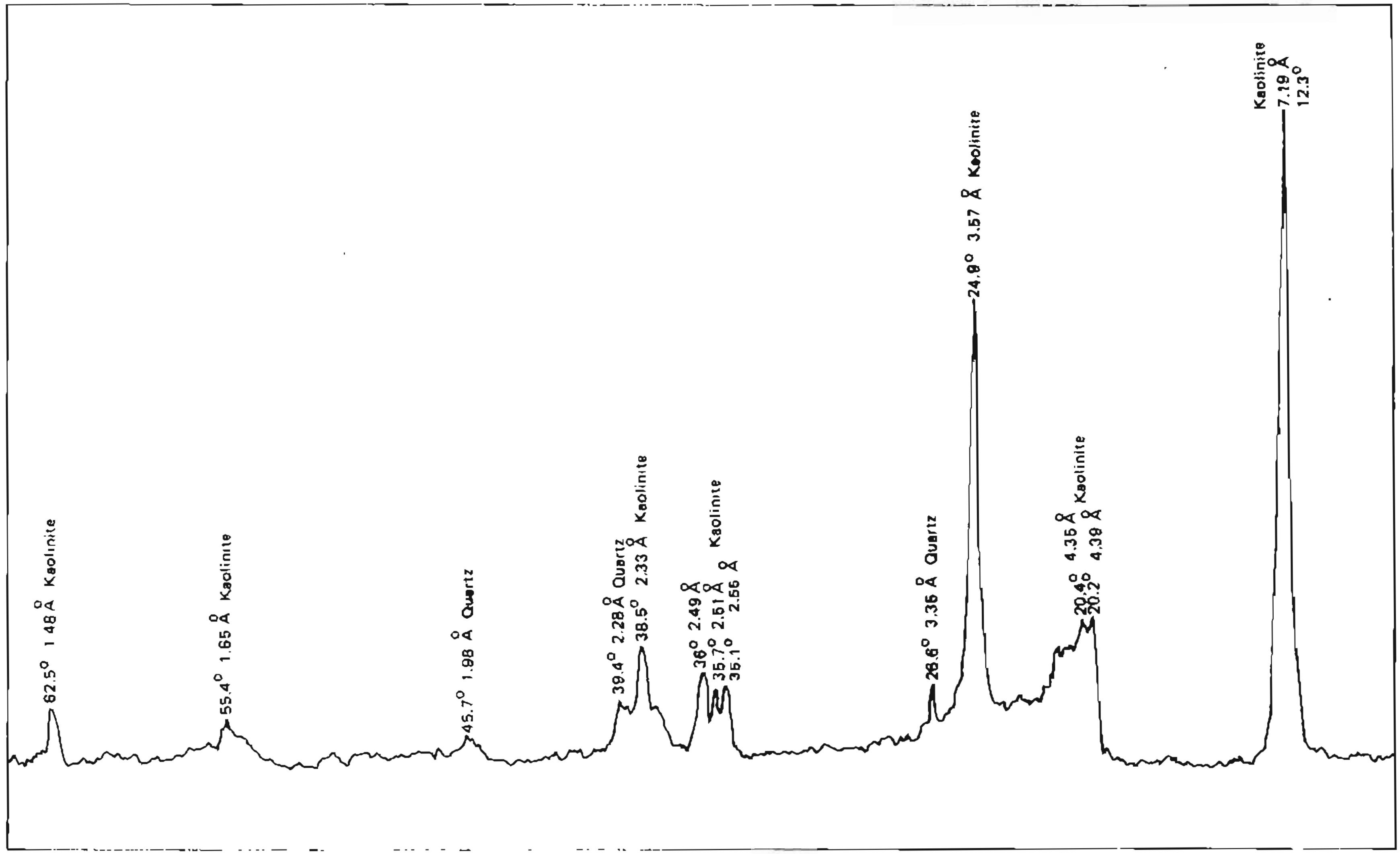

62.5° 1.48 Å Kaolinite
55.4° 1.65 Å Kaolinite
45.7° 1.98 Å Quartz
39.4° 2.28 Å Quartz
38.5° 2.33 Å Kaolinite
36° 2.49 Å
35.7° 2.51 Å Kaolinite
35.1° 2.56 Å
26.6° 3.36 Å Quartz
24.9° 3.57 Å Kaolinite
20.4° 4.35 Å Kaolinite
20.2 4.39 Å
Kaolinite
7.19 Å
12.3°

Figure 11

Figure 12

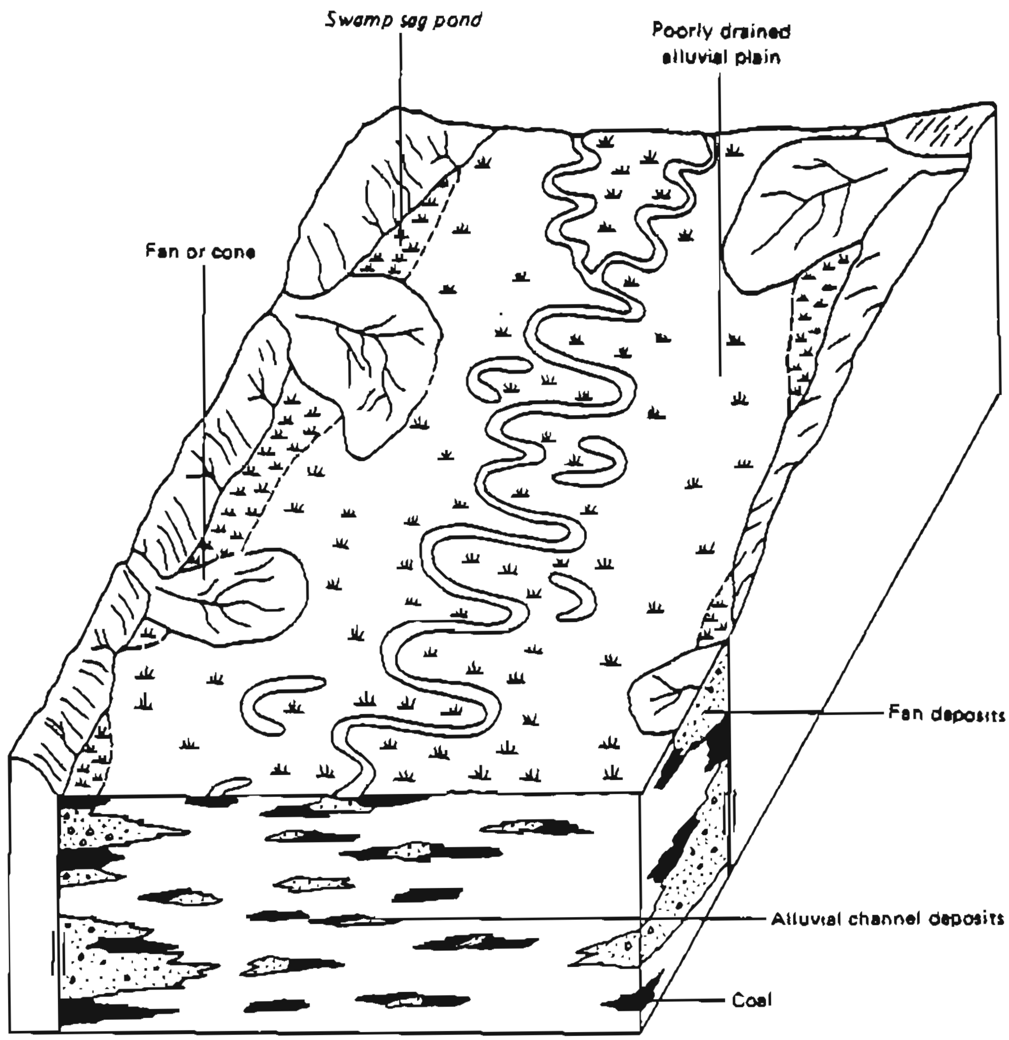

Swamp sag pond
Poorly drained alluvial plain
Fan or cone
Fan deposits
Alluvial channel deposits
Coal

Figure 13

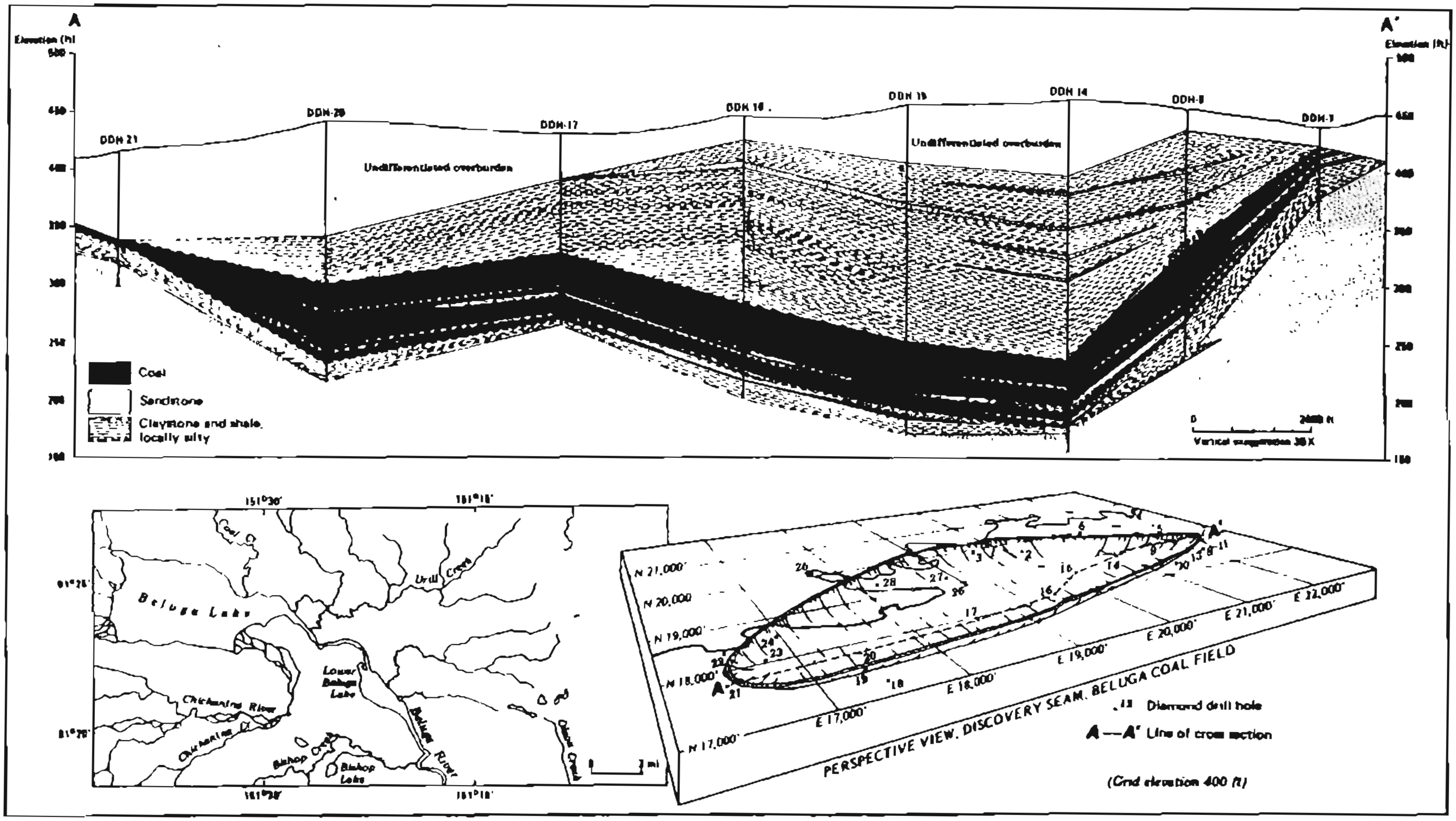

A
A'
Elevation (ft)
DDH 21
DDH-28
DDH-17
DDH 18
DDH 15
DDH 14
DDH-8
DDH-7
Undifferentiated overburden
Undifferentiated overburden
Coal
Sandstone
Claystone and shale, locally silty
Vertical exaggeration 38 X
Beluga Lake
Coal Cr.
Lower Beluga Lake
Beluga River
Chichantna River
Bishop Lake
Bishop Cr.
Olson Creek
Drill Creek
PERSPECTIVE VIEW, DISCOVERY SEAM, BELUGA COAL FIELD
Diamond drill hole
A—A' Line of cross section
(Grid elevation 400 ft)
N 21,000'
N 20,000
N 19,000'
N 18,000'
N 17,000'
E 17,000'
E 18,000'
E 19,000'
E 20,000'
E 21,000'
E 22,000'

Figure 14

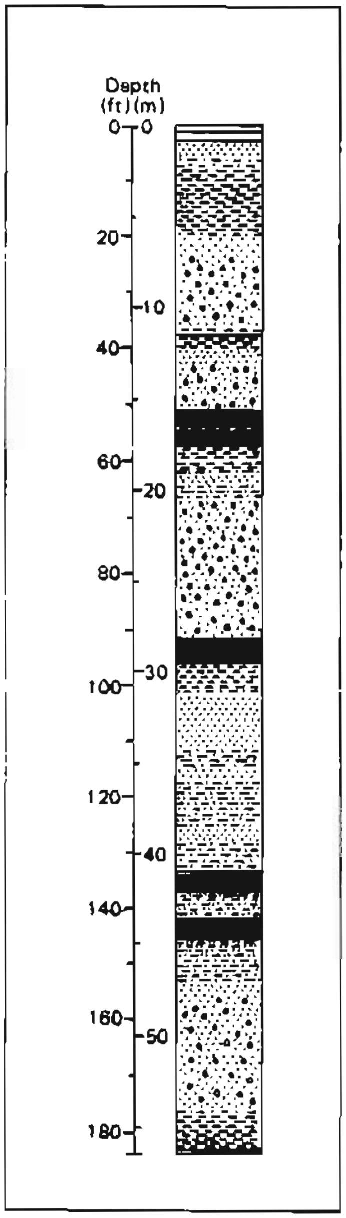



Figure 15

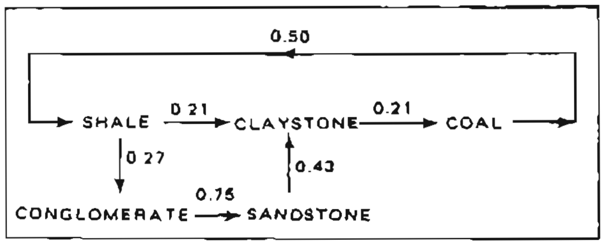
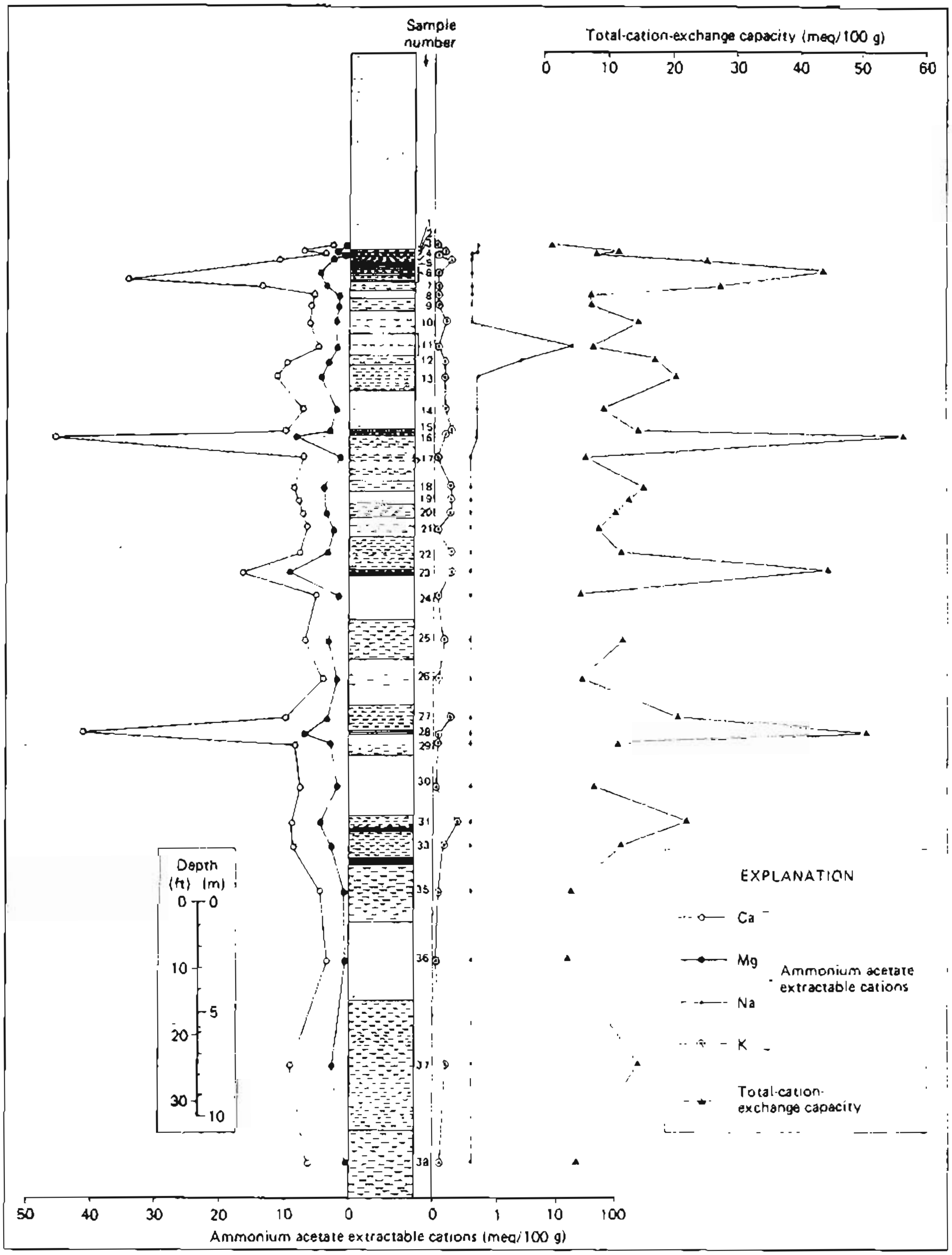

0.50
SHALE
0 21
CLAYSTONE
0.21
COAL
0 27
0.43
CONGLOMERATE
0.75
SANDSTONE

Figure 16



Sample number
Total-cation-exchange capacity (meq/100 g)
0 10 20 30 40 50 60
Depth
(ft) (m)
EXPLANATION
Ca
Mg
Na
K
Ammonium acetate extractable cations
Total-cation-exchange capacity
50 40 30 20 10 0 0 1 10 100
Ammonium acetate extractable cations (meq/100 g)


Figure 17

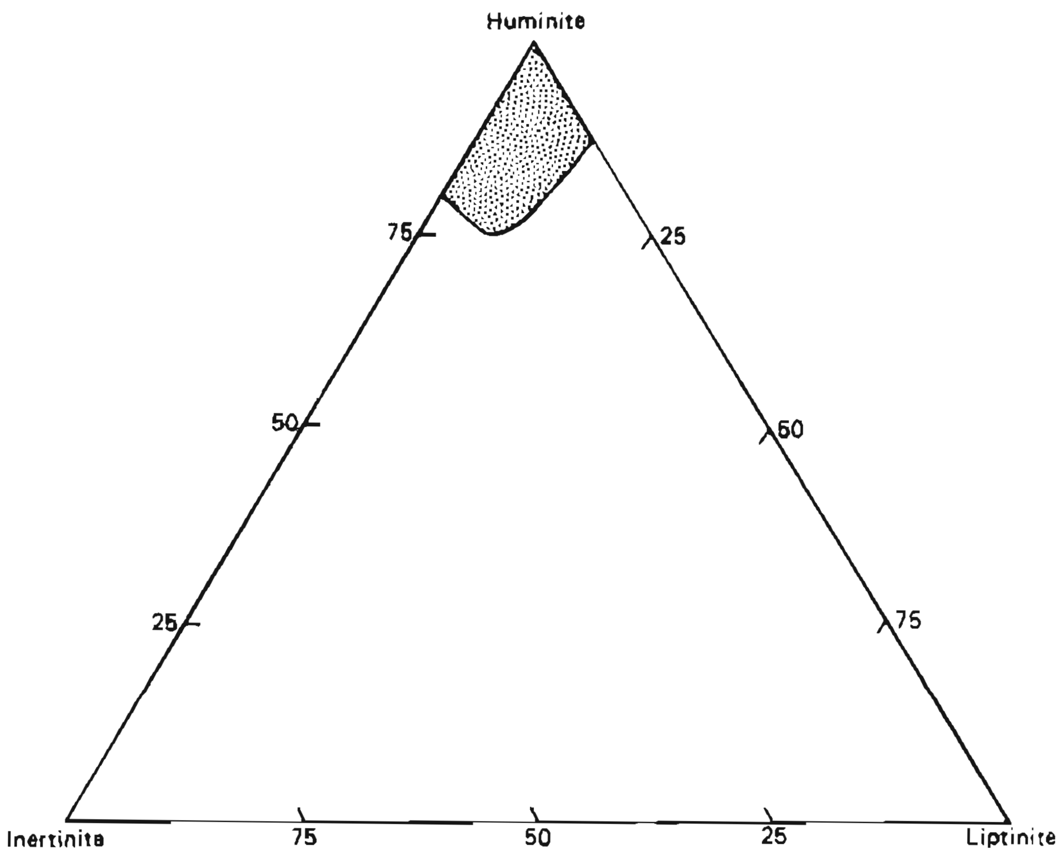



Figure 18

A.

B.

C.

Figure 19

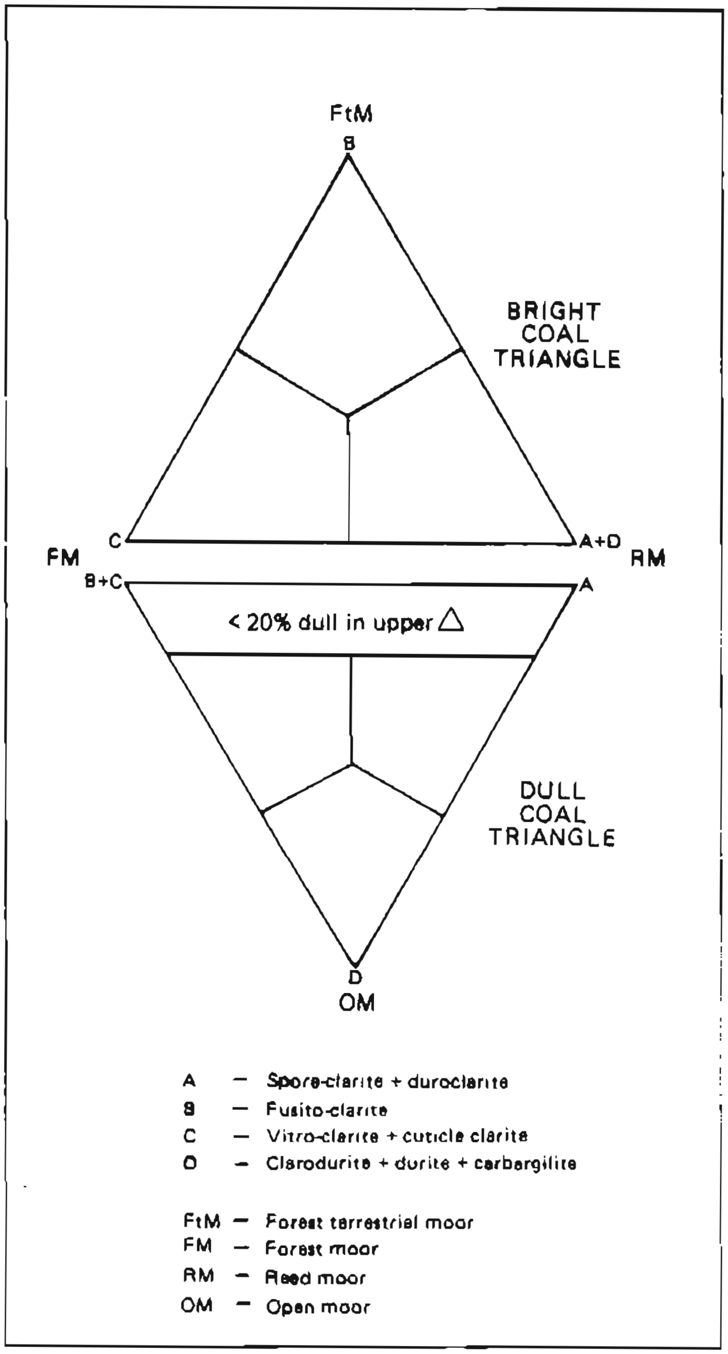

FtM
B
BRIGHT
COAL
TRIANGLE
C
A+D
FM
RM
B+C
A
< 20% dull in upper △
DULL
COAL
TRIANGLE
D
OM
A — Spore-clarite + duroclarite
B — Fusito-clarite
C — Vitro-clarite + cuticle clarite
D — Clarodurite + durite + carbargilite
FtM — Forest terrestrial moor
FM — Forest moor
RM — Reed moor
OM — Open moor

Figure 21

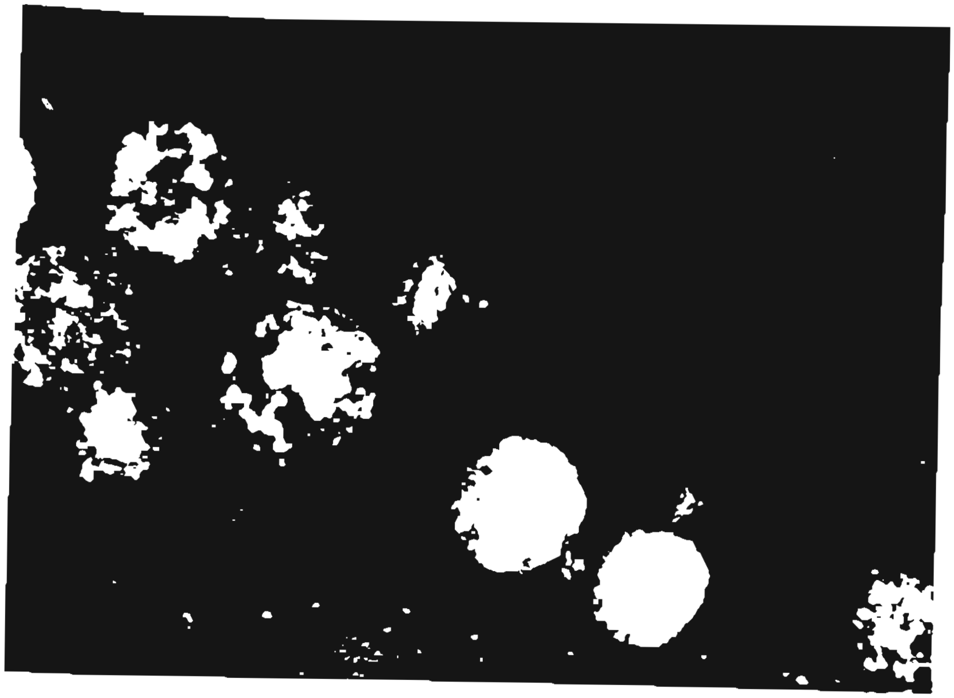
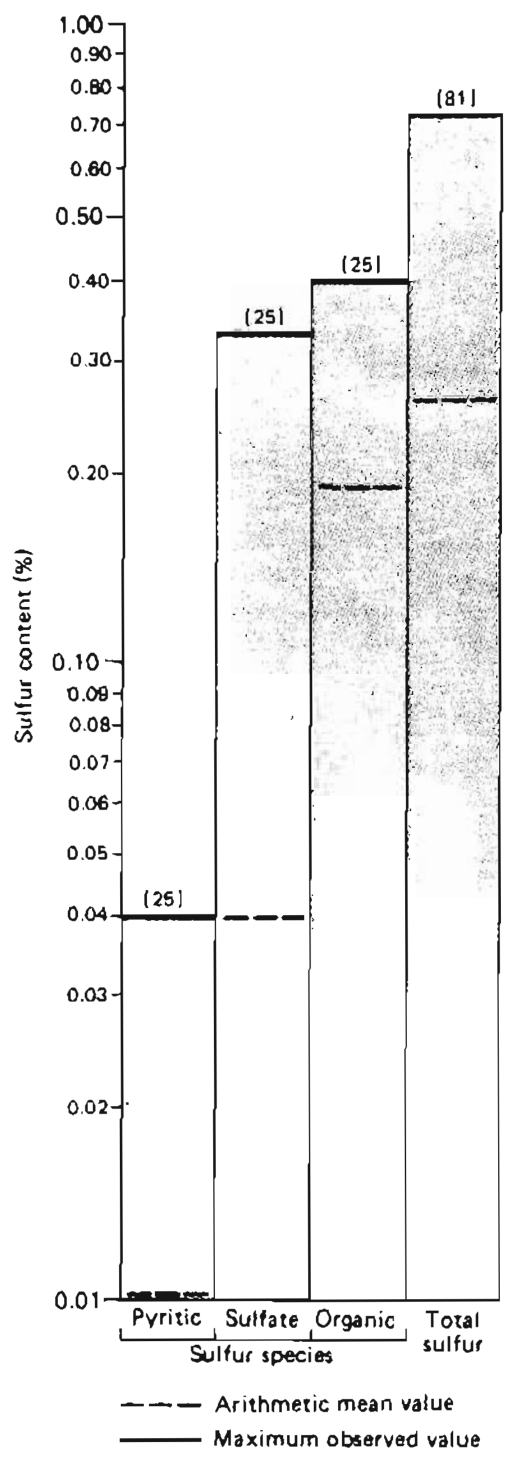


Figure 22

Figure 23



1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
Sulfur content (%)
(81)
(25)
(25)
(25)
Pyritic
Sulfate
Organic
Total sulfur
Sulfur species
Arithmetic mean value
Maximum observed value


Figure 24

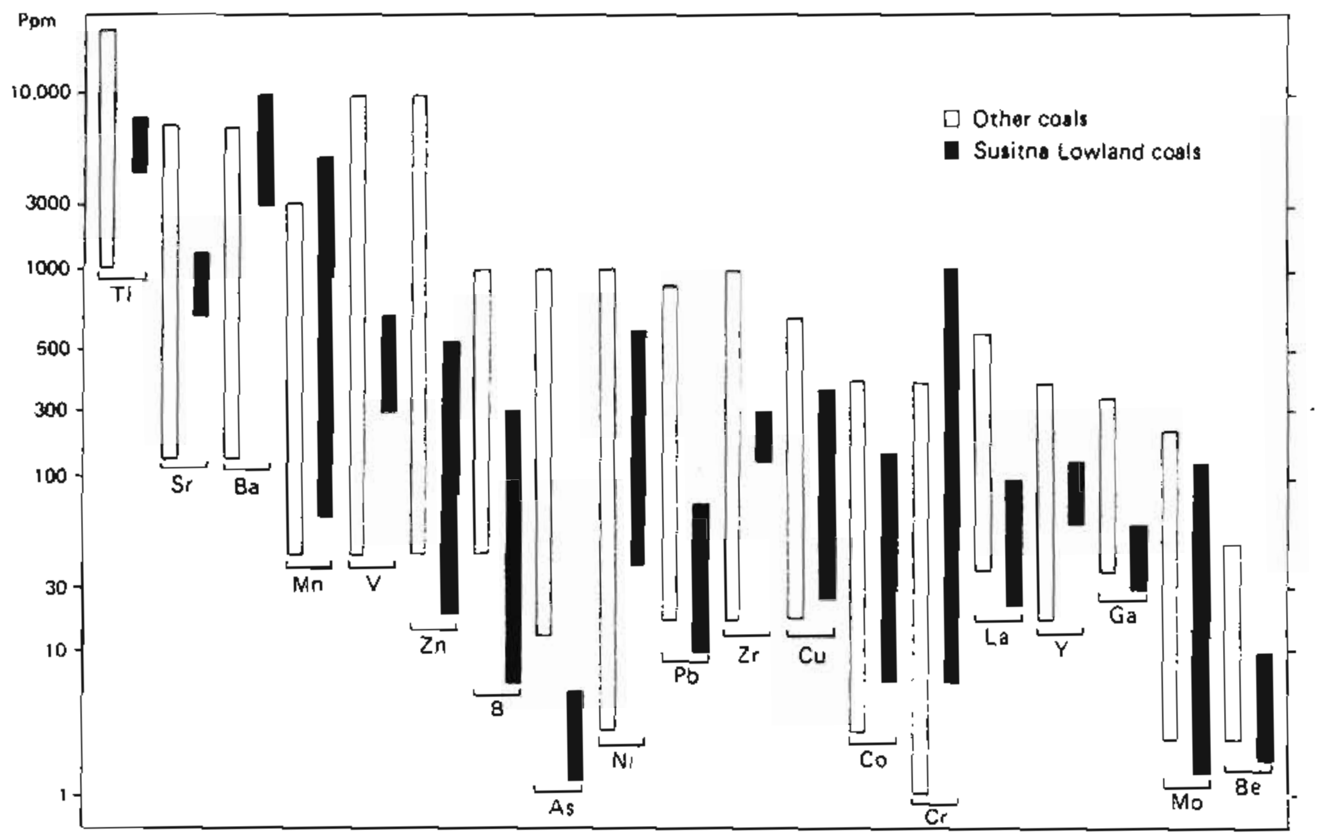

Ppm
10,000
3000
1000
500
300
100
30
10
1
Other coals
Susitna Lowland coals
Ti
Sr
Ba
Mn
V
Zn
B
As
Ni
Pb
Zr
Cu
Co
Cr
La
Y
Ga
Mo
Be

Figure 25

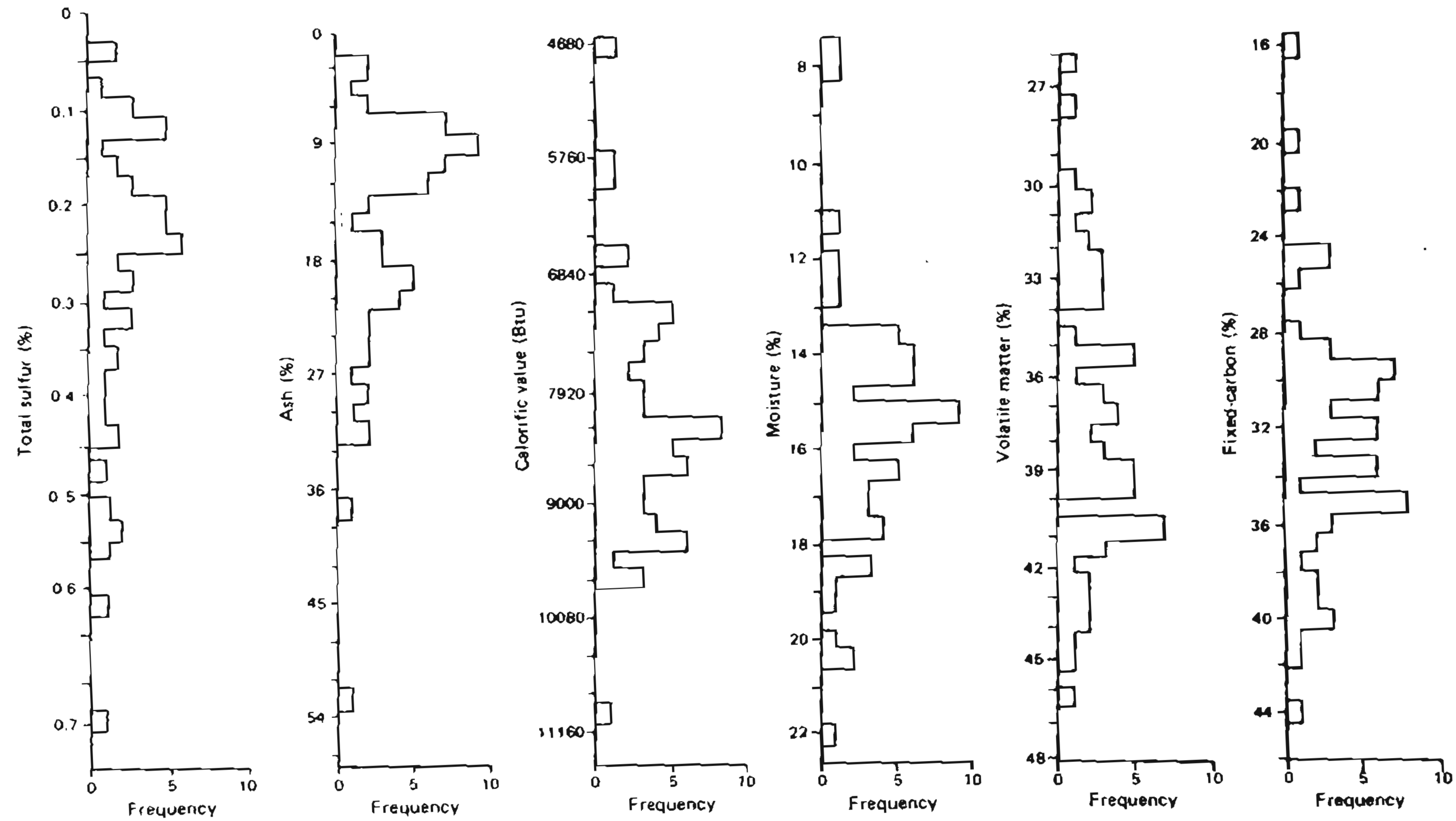

Total sulfur (%)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
Ash (%)
0
9
18
27
36
45
54
Calorific value (Btu)
4680
5760
6840
7920
9000
10080
11160
Moisture (%)
8
10
12
14
16
18
20
22
Volatile matter (%)
27
30
33
36
39
42
45
48
Fixed-carbon (%)
16
20
24
28
32
36
40
44
0
5
10
Frequency

Figure 26.

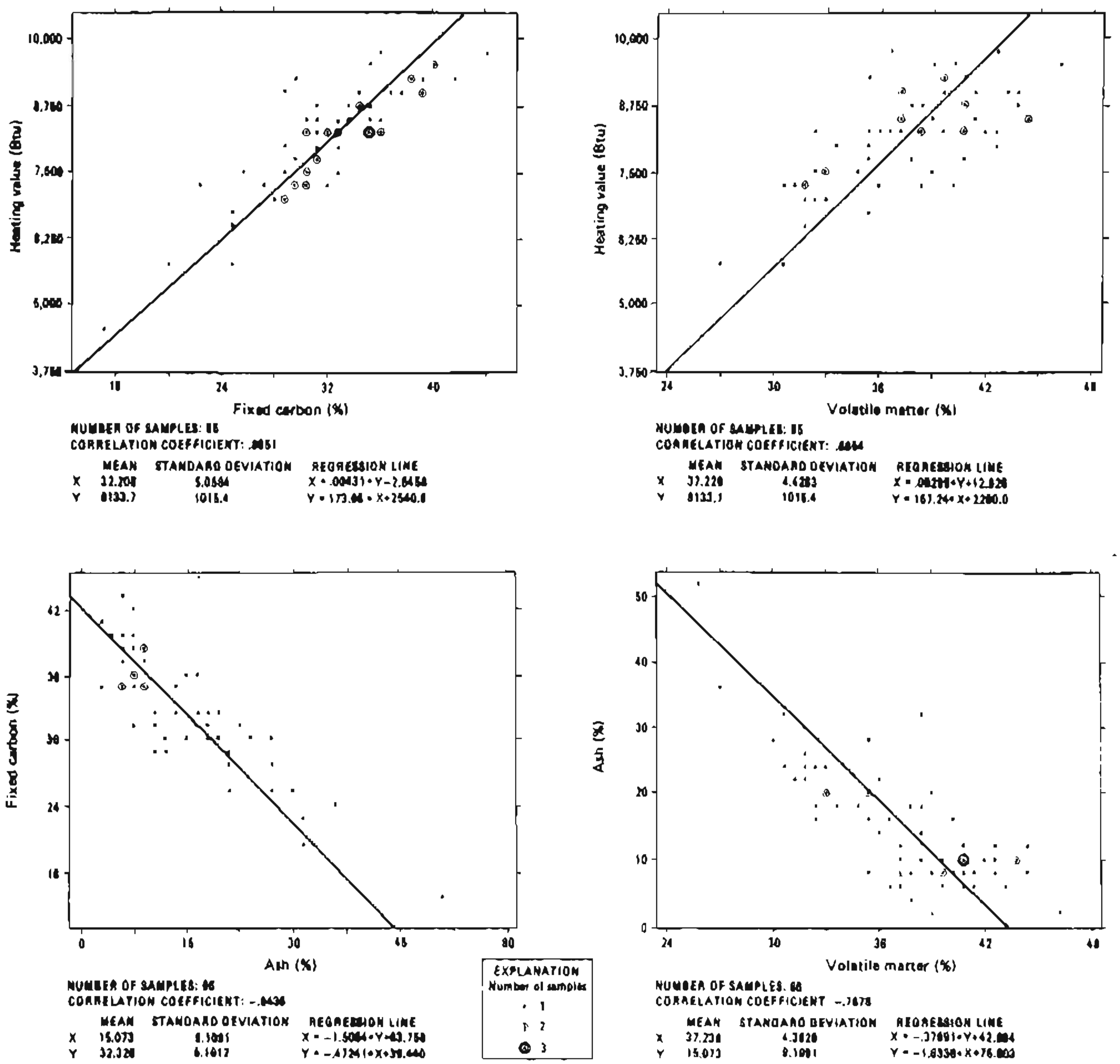

Heating value (Btu)
Fixed carbon (%)
NUMBER OF SAMPLES:
CORRELATION COEFFICIENT:
MEAN STANDARD DEVIATION REGRESSION LINE
X 5.0684
Y 1015.4
Heating value (Btu)
Volatile matter (%)
NUMBER OF SAMPLES:
CORRELATION COEFFICIENT:
MEAN STANDARD DEVIATION REGRESSION LINE
X 37.220
Y 1015.4 Y = 167.24 • X + 2200.0
Fixed carbon (%)
Ash (%)
NUMBER OF SAMPLES:
CORRELATION COEFFICIENT:
MEAN STANDARD DEVIATION REGRESSION LINE
X 15.073
Y 6.1017
EXPLANATION
Number of samples
1
2
3
Ash (%)
Volatile matter (%)
NUMBER OF SAMPLES:
CORRELATION COEFFICIENT
MEAN STANDARD DEVIATION REGRESSION LINE
X
Y

Figure 27

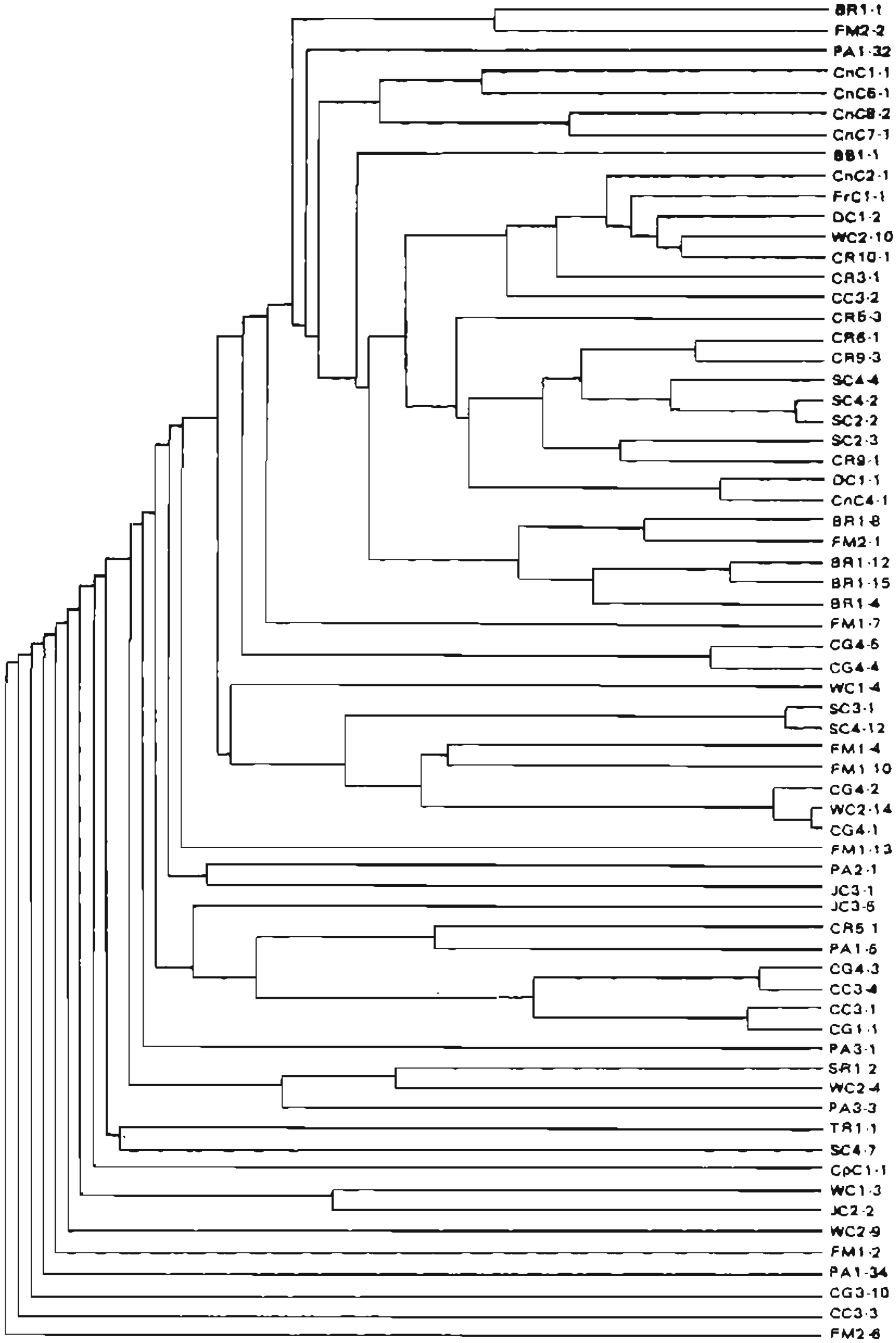

BR1-1
FM2-2
PA1-32
CnC1-1
CnC6-1
CnC8-2
CnC7-1
BB1-1
CnC2-1
FrC1-1
DC1-2
WC2-10
CR10-1
CR3-1
CC3-2
CR5-3
CR6-1
CR9-3
SC4-4
SC4-2
SC2-2
SC2-3
CR9-1
DC1-1
CnC4-1
BR1-8
FM2-1
BR1-12
BR1-15
BR1-4
FM1-7
CG4-5
CG4-4
WC1-4
SC3-1
SC4-12
FM1-4
FM1-10
CG4-2
WC2-14
CG4-1
FM1-13
PA2-1
JC3-1
JC3-6
CR5-1
PA1-6
CG4-3
CC3-4
CC3-1
CG1-1
PA3-1
SR1-2
WC2-4
PA3-3
TR1-1
SC4-7
CpC1-1
WC1-3
JC2-2
WC2-9
FM1-2
PA1-34
CG3-10
CC3-3
FM2-6

Figure 28

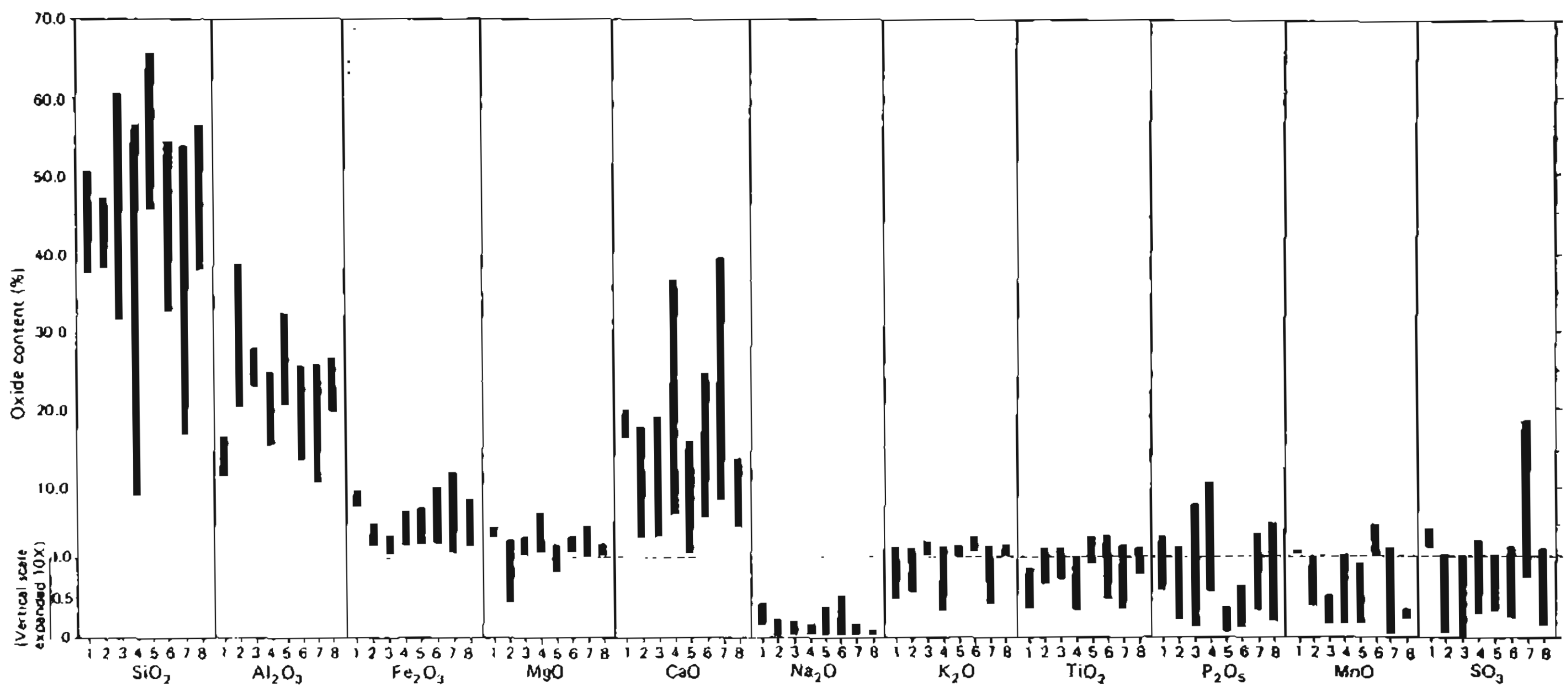

Oxide content (%)
70.0
60.0
50.0
40.0
30.0
20.0
10.0
(Vertical scale expanded 10X)
1.0
0.5
0
1 2 3 4 5 6 7 8
SiO2
Al2O3
Fe2O3
MgO
CaO
Na2O
K2O
TiO2
P2O5
MnO
SO3

Figure 29

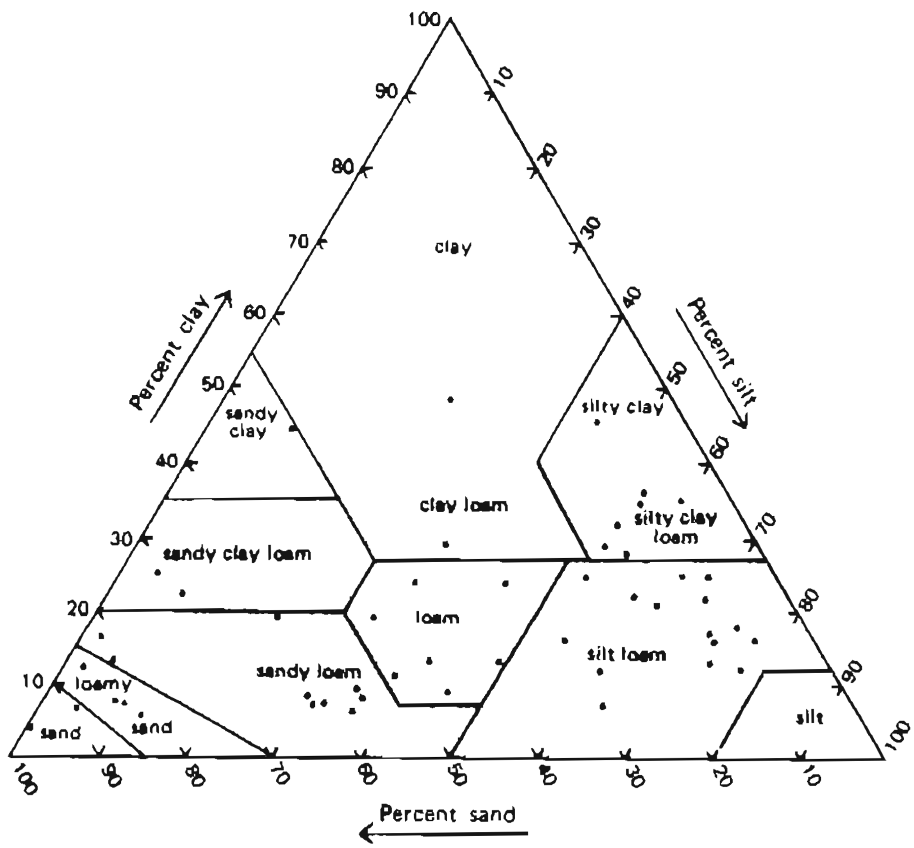
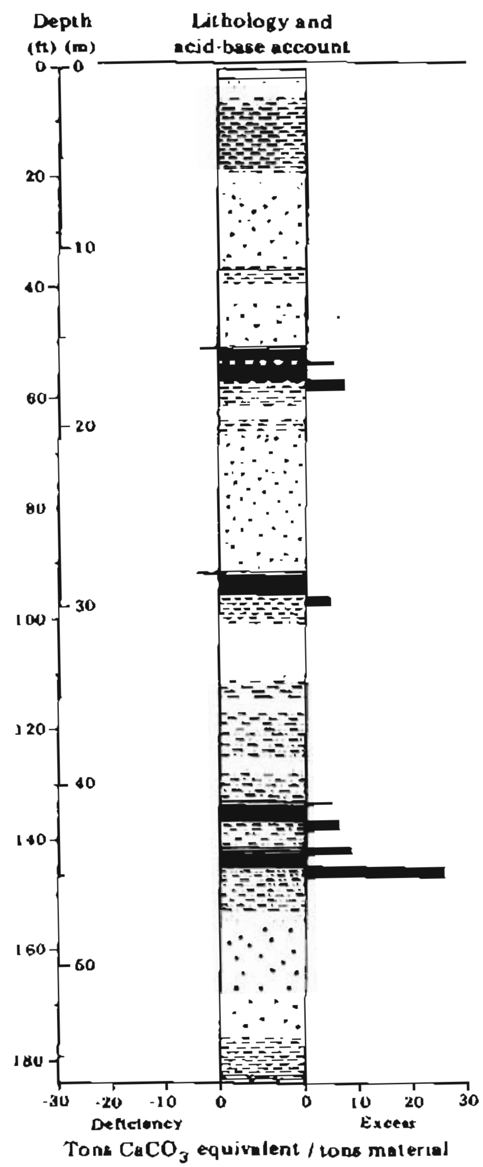

100
90
80
70
60
50
40
30
20
10
Percent clay
10
20
30
40
50
60
70
80
90
100
Percent silt
100
90
80
70
60
50
40
30
20
10
Percent sand
clay
sandy clay
silty clay
clay loam
silty clay loam
sandy clay loam
loam
silt loam
sandy loam
loamy sand
sand
silt

Figure 30




| Sample number | Coal-seam designation | Description | Paste pH | Sulfur (%) Pyritic total | Lime (%) | Organic matter (%) |
|---|---|---|---|---|---|---|
| FM1-1 | F Seam | Roof: carbonaceous shale | 4.1 | 0.06 / 0.30 | 10.0 | 9.46 |
| FM1-3 | | Parting: carbonaceous claystone | 4.8 | 0.02 / 0.06 | 9.8 | 6.10 |
| FM1-5 | | Seatrock: claystone | 6.1 | 0.01 / 0.02 | 9.9 | 1.59 |
| FM1-6 | E Seam | Roof: carbonaceous shale | 4.2 | 0.01 / 0.48 | 9.0 | 8.63 |
| FM1-8 | | Seatrock: claystone | 4.7 | 0.02 / 0.02 | 10.0 | 2.32 |
| FM1-9 | D Seam | Roof: carbonaceous shale | 4.6 | 0.01 / 0.14 | 9.3 | 11.89 |
| FM1-11 | | Seatrock: claystone | 5.1 | 0.01 / 0.01 | 9.9 | 1.27 |
| FM1-12 | C Seam | Roof: carbonaceous shale | 4.8 | 0.04 / 0.32 | 8.2 | 9.56 |
| FM1-14 | | Seatrock: sandy claystone | 7.2 | 0.04 / 0.04 | 10.1 | 1.94 |

Figure 31

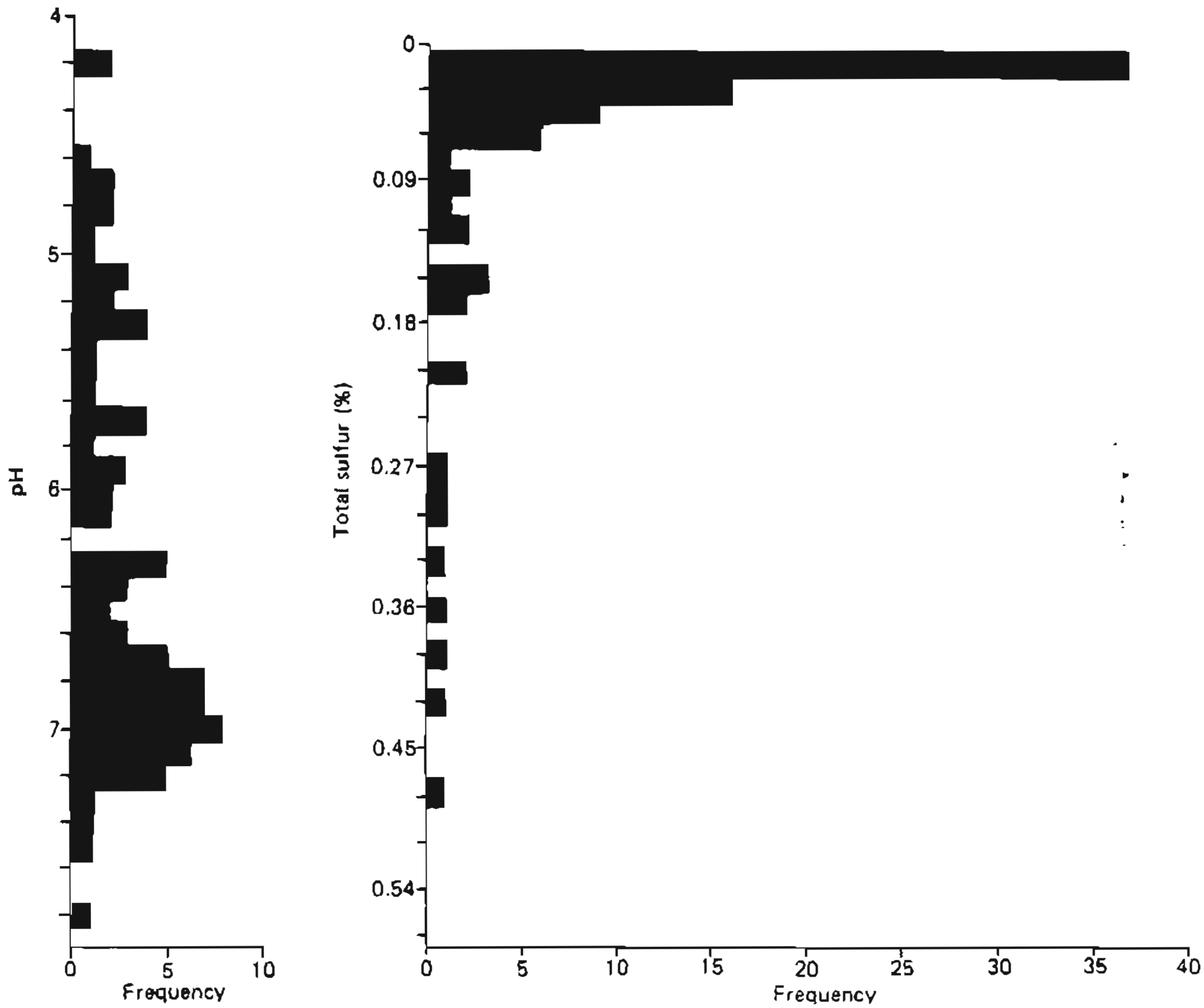

pH
4
5
6
7
0
5
10
Frequency
Total sulfur (%)
0
0.09
0.18
0.27
0.36
0.45
0.54
0
5
10
15
20
25
30
35
40
Frequency

Figure 32

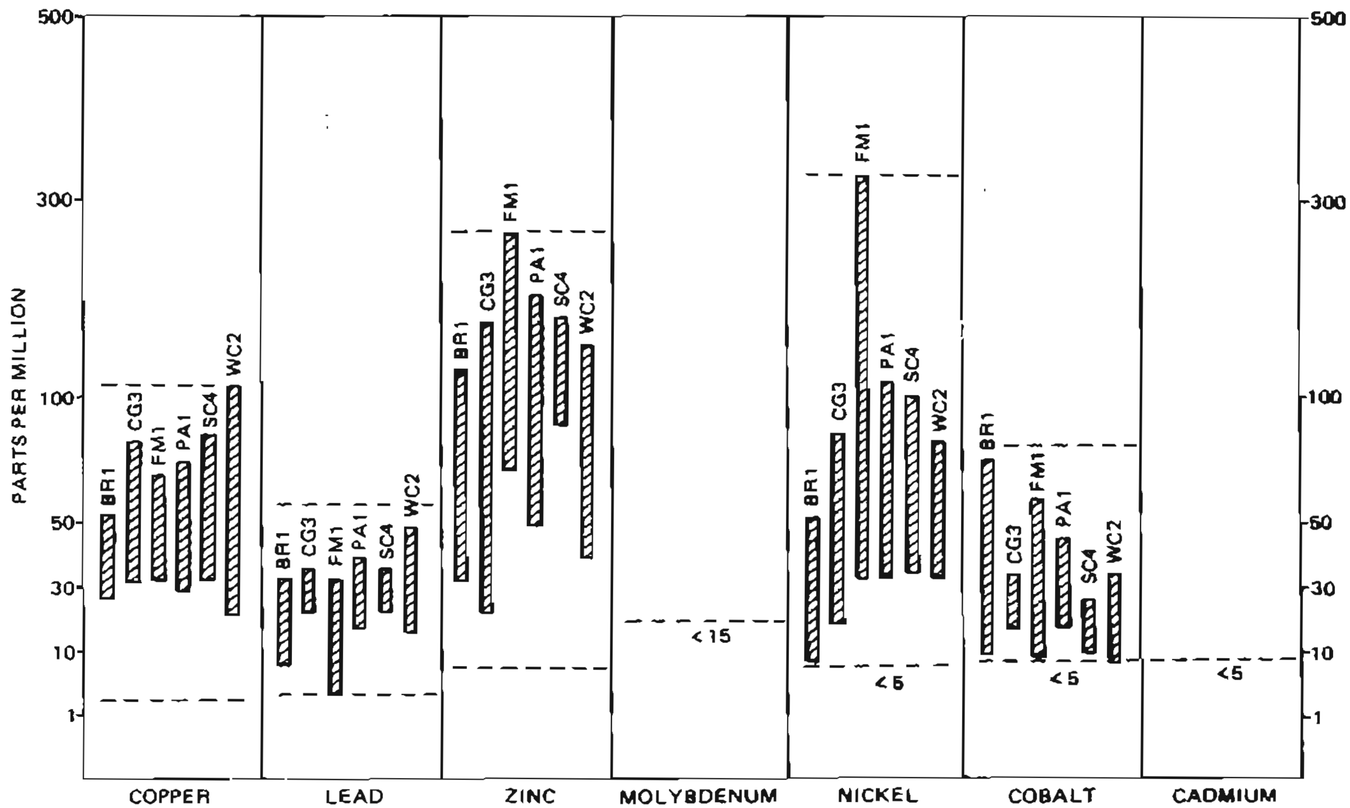

PARTS PER MILLION
500
300
100
50
30
10
1
COPPER
LEAD
ZINC
MOLYBDENUM
NICKEL
COBALT
CADMIUM
BR1
CG3
FM1
PA1
SC4
WC2
<15
<5

Figure 33

Table 1. Major oxide geochemistry of two coal tonsteins from the Susitna lowland.

| Oxide | CnC7-12 | CG4-6 |
|---|---|---|
| $SiO_2$ | 26.37 | 40.63 |
| $Al_2O_3$ | 24.02 | 31.31 |
| $Fe_2O_3$ | 1.22 | 0.42 |
| MnO | 0.00 | 0.01 |
| MgO | 0.15 | 0.09 |
| CaO | 3.28 | 0.62 |
| $Na_2O$ | 0.00 | 0.13 |
| $K_2O$ | 0.39 | 0.20 |
| $TiO_2$ | 0.61 | 1.67 |
| $P_2O_5$ | 8.64 | 0.13 |
| LOI | 20.94 | 20.00 |
| $H_2O$· | 88.86 | 96.43 |

Table 2. Major oxide geochemistry of a gradational series of baked rocks from an upper Canyon Creek locality.

| MAJOR OXIDE / SAMPLE | CnC3-1[a] | CnC3-2[b] | CnC3-3[c] | CnC3-4[d] | CnC3-5[e] |
|---|---|---|---|---|---|
| $SiO_2$ | 49.32 | 69.60 | 49.03 | 46.06 | 67.56 |
| $Al_2O_3$ | 29.26 | 18.22 | 36.50 | 34.96 | 15.06 |
| $Fe_2O_3$ | 1.93 | 1.02 | 2.17 | 4.36 | 4.20 |
| MnO | 0.01 | 0.01 | 0.02 | 0.15 | 0.07 |
| MgO | 0.21 | 0.04 | 0.25 | 0.56 | 0.20 |
| CaO | 0.70 | 0.55 | 1.00 | 2.34 | 0.47 |
| $Na_2O$ | 0.22 | 0.24 | 0.26 | 0.66 | 4.71 |
| $K_2O$ | 0.46 | 0.48 | 0.56 | 1.12 | 3.50 |
| $TiO_2$ | 0.62 | 0.96 | 0.67 | 0.74 | 0.41 |
| $P_2O_5$ | 0.18 | 0.17 | 0.27 | 0.44 | 0.14 |
| LOI | 9.97 | 3.88 | 2.91 | 2.65 | 1.07 |
| $H_2O$ | 6.37 | 2.54 | 2.44 | 2.25 | 0.68 |
| SUM | 96.25 | 97.71 | 96.08 | 96.29 | 97.97 |

a-Shale, carbonaceous, relatively unaltered

b-Light gray baked claystone with abundant plant fossils

c-Cream-colored (beige) baked claystone

d-Pink to light red scoriaceous clinker, abundant hematite

e-Dark red to maroon burn, high hematite

Table 3. Maceral composition summary for 180 coal samples from the Susitna lowland reported on a volume percent, moisture- and ash-free basis.

| MACERAL GROUP | MACERAL/ MACERAL TYPE | RANGE IN CONTENTS | MEAN CONTENT |
|---|---|---|---|
| | Ulminite | 15.8 - 99.0 | 65.0 |
| | Porigelinite | 0.0 - 35.4 | 9.0 |
| HUMINITE | Phlobaphinite | 0.0 - 18.2 | 2.7 |
| | Pseudophlobaphinite | 0.0 - 21.6 | 3.9 |
| | Humodetrinite | 0.2 - 63.2 | 15.7 |
| | Total | 76.6 -100.0 | |
| | Fusinite | 0.0 - 9.6 | 0.6 |
| | Semifusinite | 0.0 - 5.2 | 0.3 |
| INERTINITE | Sclerotinite | 0.0 - 1.4 | 0.1 |
| | Macrinite | 0.0 - 2.0 | 0.9 |
| | Inertodetrinite | 0.0 - 5.2 | 0.2 |
| | Total | 0.0 - 18.6 | |
| | Cutinite | 0.0 - 3.4 | 0.4 |
| | Sporinite | 0.0 - 5.6 | 0.4 |
| LIPTINITE | Resinite | 0.0 - 9.2 | 1.0 |
| | Suberinite | 0.0 - 3.8 | 0.5 |
| | Alginite | 0.0 - 2.0 | 0.05 |
| | Total | 0.0 - 11.8 | |

Table 4. Total sulfur and sulfur species of selected coal seams from the Susitna lowland of south-central Alaska.

| LOCALITY | SAMPLE NUMBER AND SEAM DESIGNATION | SULFUR SPECIES (%) ORGANIC | PYRITIC | SULFATE | TOTAL SULFUR (%) |
|---|---|---|---|---|---|
| Capps Glacier Area | CG4-1 | 0.23 | 0.01 | 0.04 | 0.28 |
| | CG4-3 | | | | 0.38 |
| | CG4-4 | | | | 0.01 |
| | CG4-5 | | | | 0.01 |
| Fairview Mountain | FM1-2 | 0.14 | 0.01 | 0.06 | 0.21 |
| | FM1-4 | 0.24 | 0.01 | 0.02 | 0.27 |
| | FM1-7 | 0.16 | 0.02 | 0.05 | 0.23 |
| | FM1-10 | 0.19 | 0.01 | 0.01 | 0.20 |
| | FM1-13 | 0.23 | 0.01 | 0.01 | 0.24 |
| Peters Hills | PA2-1 | | | | 0.35 |
| | PA3-1 | | | | 0.50 |
| | PA3-3 | | | | 0.64 |
| Wolverine Creek | WC1-3 | 0.22 | 0.05 | 0.39 | 0.66 |
| | WC1-4 | | | | 0.67 |
| | WC2-4 | | | | 0.70 |
| | WC2-9 | | | | 0.48 |
| | WC2-10 | 0.17 | 0.01 | 0.01 | 0.19 |
| | WC2-14 | | | | 0.42 |

Table 5. Range and mean values for coal quality parameters in 66 raw coal samples from the Susitna lowland.

| | BASIS* | MOISTURE | VOLATILE MATTER | FIXED CARBON | SULFUR | ASH | HEATING VALUE |
|---|---|---|---|---|---|---|---|
| | 1 | 7.3-21.9 | 25.9-46.1 | 15.1-43.7 | 0.01-0.73 | 2.4-51.7 | 4570-10960 |
| RANGE | 2 | ---- | 27.9-55.1 | 16.4-50.9 | 0.01-0.91 | 2.8-55.7 | 4930-13400 |
| | 3 | ---- | 45.6-63.2 | 36.8-54.4 | 0.01-1.03 | ---- | 10480-15540 |
| | 1 | 15.4 | 37.2 | 32.3 | 0.26 | 15.1 | 8163 |
| MEAN | 2 | ---- | 44.1 | 38.3 | 0.31 | 17.7 | 9680 |
| | 3 | ---- | 53.7 | 46.3 | 0.39 | ---- | 11766 |

*1-As received; 2-Moisture-free; and 3-Moisture- and ash-free.

Table 6. Ultimate analysis results for selected coals from the Susitna lowland.

| SAMPLE NUMBER | HYDROGEN | | | CARBON | | | NITROGEN | | | OXYGEN | | | SULFUR | | | ASH | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BASIS* | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 |
| BR1-1 | 6.94 | 6.24 | 7.18 | 49.31 | 57.46 | 66.10 | 0.55 | 0.65 | 0.74 | 31.84 | 22.41 | 25.80 | 0.14 | 0.16 | 0.18 | 11.22 | 13.08 | --- |
| CnC7-1 | 6.65 | 5.93 | 6.41 | 55.23 | 64.01 | 69.24 | 0.82 | 0.95 | 1.02 | 30.43 | 21.15 | 22.89 | 0.35 | 0.41 | 0.44 | 6.52 | 7.55 | --- |
| CnC8-2 | 6.69 | 5.98 | 6.64 | 54.44 | 63.03 | 70.04 | 0.91 | 1.05 | 1.17 | 29.10 | 19.69 | 21.89 | 0.21 | 0.24 | 0.26 | 8.65 | 10.01 | --- |
| CG3-10 | 6.08 | 4.92 | 7.96 | 34.48 | 42.31 | 68.41 | 0.53 | 0.65 | 1.04 | 27.62 | 13.72 | 22.21 | 0.19 | 0.24 | 0.38 | 31.10 | 38.16 | --- |
| CG4-1 | 6.32 | 5.43 | 7.37 | 42.89 | 50.71 | 68.87 | 0.52 | 0.62 | 0.84 | 27.73 | 16.59 | 22.54 | 0.24 | 0.28 | 0.38 | 22.30 | 26.37 | --- |
| CR9-3 | 6.42 | 5.63 | 6.41 | 52.30 | 60.92 | 69.26 | 0.80 | 0.93 | 1.06 | 29.88 | 20.18 | 22.94 | 0.25 | 0.29 | 0.33 | 10.35 | 12.05 | --- |
| CR10-1 | 6.43 | 5.66 | 7.29 | 47.16 | 54.78 | 70.62 | 0.73 | 0.84 | 1.09 | 26.28 | 16.18 | 20.85 | 0.10 | 0.11 | 0.15 | 19.30 | 22.43 | --- |
| FM1-7 | 6.57 | 5.86 | 7.07 | 48.90 | 56.48 | 68.17 | 0.50 | 0.58 | 0.70 | 28.99 | 19.70 | 23.79 | 0.20 | 0.23 | 0.27 | 14.84 | 17.15 | --- |
| JC3-1 | 6.70 | 5.92 | 7.22 | 45.25 | 53.15 | 64.83 | 0.49 | 0.57 | 0.70 | 31.97 | 22.04 | 26.89 | 0.25 | 0.30 | 0.36 | 15.34 | 18.02 | --- |
| SC3-1 | 6.58 | 5.61 | 7.34 | 43.52 | 52.69 | 68.94 | 0.56 | 0.67 | 0.88 | 29.66 | 17.20 | 22.48 | 0.22 | 0.27 | 0.36 | 19.46 | 23.56 | --- |

*1-As received; 2-Moisture-free; and 3-Moisture- and ash-free

Table 7. Summary results of coal overburden characterization analyses of Susitna lowland samples.

| PARAMETER | | NUMBER OF SAMPLES | NUMBER OF LOCALES | RANGE IN CONTENTS | MEAN CONTENT | UNITS |
|---|---|---|---|---|---|---|
| paste pH | | 88 | 8 | 4.1 - 7.8 | 6.4 | pH |
| Electrical conductivity | | 88 | 8 | 0.1 - 0.9 | 0.3 | mmhos/cm @ 25°C |
| Saturation percentage | | 88 | 8 | 24.2 -94.1 | 52.8 | % |
| Saturation extract cations | Ca | 28 | 3 | 0.1 - 6.3 | 1.9 | meq/liter |
| | Mg | | | <0.1 - 4.4 | 1.3 | |
| | Na | | | 0.4 - 0.8 | 0.6 | |
| Sodium adsorption ratio | | 28 | 3 | 0.3 - 2.2 | 0.6 | ratio |
| Exchangeable sodium percentage | | 54 | 3 | 0.7 - 506.4 | 16.5 | % |
| Particle size | | 54 | 3 | Variable | --- | --- |
| Texture | | 54 | 3 | Variable | --- | --- |
| Organic matter | | 36 | 4 | 0.82-11.89 | 4.7 | % |
| Lime percentage | | 36 | 4 | 7.7 - 10.1 | 9.9 | % |
| Boron (total) | | 20 | 2 | 1.3 -100.0 | 33.8 | ppm |
| Selenium (total) | | 20 | 2 | <0.01 - 0.05 | --- | ppm |
| Extractable nutrients | $NO_3$-N | 43 | 6 | 2.1 - 13.8 | 4.0 | ppm |
| | P | | | 6.85 - 38.54 | 15.44 | |
| | K | | | <47.6 -280.4 | 136.4 | |
| Ammonium acetate extractable cations | Ca | 54 | 3 | 2.5 - 45.4 | 10.3 | meq/100 g |
| | Mg | | | 0.3 - 9.0 | 3.3 | |
| | Na | | | 0.6 - 39.5 | 1.4 | |
| | K | | | <0.1 - 0.7 | 0.2 | |
| Cation exchange capacity | | 54 | 3 | 1.3 - 88.4 | 20.0 | meq/100 g |
| Base saturation | | 54 | 3 | 16.7 -100.0 | 83.4 | % |
| Sulfur | Sulfate | 28 | 3 | <0.1 | --- | % |
| | Pyritic | | | <0.01 -0.09 | --- | |
| | Total | | | 0.00 -0.48 | 0.07 | |
| Acid potential | | 88 | 8 | 0.0 - 30.0 | 4.1 | meq $H^+$/100 g |
| Neutralization potential | | 88 | 8 | 3.85 - +213.84 | +24.2 | tons $CaCO_3$ equivalent/ 1000 tons |
| Potential acidity* | | 88 | 8 | -5.55 - +212.89 | +22.3 | tons $CaCO_3$ equivalent/ 1000 tons |

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

Table 8. Geometric means (ppm) for certain trace element contents in Susitna lowland overburden samples (present study), Capps coal field and overburden suites from other areas in the conterminous United States (Hinckley and others, 1982).

| Trace Element | Rock Type* | Susitna Lowland overburden | Capps coal field overburden, Beluga area, 1979 | Capps coal field overburden, Beluga area, 1980 | Ft. Union Formation overburden | Kimbeto, New Mexico overburden | Cretaceous overburden suite | San Juan Basin Topsoils | San Juan Basin Minesoils |
|---|---|---|---|---|---|---|---|---|---|
| Boron | 1 | 22 | 17 | -- | 42 | 13 | 14 | 7 | 13 |
| | 2 | 37 | 26 | -- | 59 | 19 | 28 | | |
| Chromium | 1 | -- | 35 | 39 | 46 | 19 | 16 | 22 | 14 |
| | 2 | -- | 61 | 70 | 72 | 30 | 43 | | |
| Cobalt | 1 | 12 | 7 | 6 | 11 | 8 | 4 | 6 | 9 |
| | 2 | 16 | 9 | 8 | 9 | 12 | 9 | | |
| Copper | 1 | 28 | 11 | 23 | 14 | 14 | 7 | 10 | 18 |
| | 2 | 51 | 40 | 43 | 38 | 39 | 30 | | |
| Lead | 1 | 15 | 11 | 22 | 12 | 10 | 6 | 11 | 11 |
| | 2 | 26 | 20 | 37 | 11 | 16 | 13 | | |
| Manganese | 1 | 761 | 167 | 412 | 233 | 183 | 75 | 260 | 340 |
| | 2 | 804 | 302 | 303 | 300 | 105 | 209 | | |
| Molybdenum | 1 | <10 | 2 | -- | 2 | 2 | 2 | 2 | 3 |
| | 2 | <10 | 2 | -- | 6 | 3 | 2 | | |
| Nickel | 1 | 26 | 23 | 24 | 26 | 12 | 10 | 9 | 12 |
| | 2 | 52 | 36 | 38 | 30 | 23 | 27 | | |
| Vanadium | 1 | -- | 60 | 71 | 75 | 60 | 37 | 45 | 56 |
| | 2 | -- | 119 | 117 | 86 | 90 | 91 | | |
| Yttrium | 1 | -- | 17 | 15 | 30 | 26 | 19 | 27 | 32 |
| | 2 | -- | 28 | 21 | 19 | 33 | 30 | | |
| Zinc | 1 | 60 | 61 | 102 | 62 | 61 | 35 | 48 | 56 |
| | 2 | 100 | 108 | 143 | 59 | 80 | 103 | | |

* 1--Coarse-grained rocks (sandstones)
2--Fine-grained rocks (claystones)