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David R. Kleesattel
University of North Dakota

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PETROLOGY OF THE BEULAH-ZAP LIGNITE BED,
SENTINEL BUTTE FORMATION (PALEOCENE)
MERCER COUNTY, NORTH DAKOTA

by

David R. Kleesattel

Bachelor of Science, Edinboro State College, 1982

A Thesis

Submitted to the Graduate Faculty

of the

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in partial fulfillment of the requirements

for the degree of

Master of Arts

Grand Forks, North Dakota

August

1985

This thesis submitted by David R. Kleesattel in partial fulfillment of the requirements for the degree of Master of Arts from the University of North Dakota is hereby approved by the Faculty Advisory Committee under whom the work has been done.

Frank R. Karner
(Chairman)

Richard D. LeFever

Harold H. Schobert

This thesis meets the standards for appearance and conforms to the style and format requirements of the Graduate School of the University of North Dakota, and is hereby approved.

Dean of the Graduate School

Permission

Title Petrology of the Beulah-Zap lignite bed, Sentinel Butte Formation (Paleocene) in Mercer County, North Dakota

Department Geology

Degree Master of Arts

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ABSTRACT

The Beulah-Zap lignite bed is one of several economically important lignites in the Sentinel Butte Formation (Paleocene). This lignite occurs as a subsurface unit in the Knife River Basin of Mercer and Oliver counties of North Dakota. The Beulah-Zap lignite is a heterogeneous carbonaceous rock unit composed of megascopic and microscopic components, which are lithotypes and macerals, respectively. Relationships between the maceral contents of the lithotypes follow patterns similar to those of bituminous coals. Coal petrology, the study of maceral and lithotype occurrence and distribution, was applied to determine: 1) mode of coalification, and 2) depositional environment of the Beulah-Zap lignite.

The lignite seams were divided into lithologic units (lithobodies) on the basis of petrographic features within the layers. These lithobodies range in thickness from 5 to 85 cm. Lithotypes, the petrographic units within the lithobodies, were separated for various analyses and their relative abundances were estimated. Three distinct lithotypes in the Beulah-Zap lignite have been identified and average abundances estimated as: vitrain (50%), fusain (5%), and attritus (45%).

Macerals were identified by reflected light microscopy. Maceral groups were classified into three major groups on the basis of their relative reflectances. Individual maceral types within the same group were differentiated by morphology. The morphology is related to the maceral precursor and mode of coalification. The lithotype fusain is rich in inertinite macerals such as fusinite and semifusinite. The attritus lithotype is composed of all three maceral groups in variable

percentages: huminite (41-82%), inertinite (10-65%), and liptinite (4-13%). The identified liptinite macerals include sporinite, resinite, cutinite, and suberinite. The huminite maceral group, consisting mainly of ulminite, is the major constituent of vitrain.

The lithotype and maceral occurrence and distribution suggests that the depositional environment of the Beulah-Zap lignite was a lacustrine-marsh complex with a steady rate of subsidence and peat accumulation. The initial peat deposition occurred in water 1.5 to 2.0 m deep. Later stages of deposition occurred in shallow water (<0.6 m deep) with occasional subaerial exposure.

Three processes are responsible for the coalification of the Beulah-Zap lignite. These processes are: 1) humification, 2) gelification, and 3) fusinitization. The principal mode of coalification was humification. This process was the dominant type of diagenetic alteration in the middle of the seams. Gelification, the complete biochemical maceration, has also altered portions of the Beulah-Zap lignite. The gelification process is most pronounced immediately above the clay partings. Fusinitization, indicative of oxidizing conditions, was more frequent towards the uppermost part of the seams. Several local fusinized horizons are present in the middle section of the Beulah- Zap lignite.

INTRODUCTION

Purpose

Lignites are heterogeneous, carbonaceous rocks composed of intimately associated megascopically observable components (lithotypes). The lithotypes are in turn composed of crystalline inorganic and non-crystalline organic constituents, which are the minerals and macerals, respectively. Past geologic studies of the Paleocene lignitic sedimentary sequences in North Dakota have focused largely on the characteristics of the inorganic sediments associated with the lignite beds. In many reports, field descriptions of the lignite characteristics, other than noting the occurrence, are ignored, or at best, brief.

The purpose of this study is to investigate the petrologic and basic chemical characteristics of the Beulah-Zap lignite bed of North Dakota, a major bed in the Sentinel Butte Formation (Paleocene). Petrographic characterization of the lignite based on maceral distribution and abundance combined with detailed descriptions of the lithotypes can be used to: 1) determine environmental conditions at the time of deposition, 2) aid in the understanding of utilization potentials, and 3) identify and aid in the correlation of the lignite beds and seams in North Dakota.

This study demonstrates the relationships between the various occurrences of lithotypes and macerals. Distribution patterns of macerals show that individual maceral groups are more commonly associated with certain lithotypes. For example, huminite and inertinite macerals are more abundant in the vitrain and fusain lithotypes, respectively. Liptinite macerals have no distinct abundance distribution with respect to a particular lithotype, but are closely associated with the macerals of the huminite group. Similar associations between macerals and lithotypes have been noted in some bituminous coals in the United States (Cameron, 1976) and Europe (Stach et al., 1982).

Traditionally coal beds have been classified, on the basis of basic chemical properties, using a scale with peat and anthracite as end members. The basic chemical properties most often used are ash, moisture, carbon, hydrogen, oxygen contents, and heating value reported as British Thermal Units (BTU). These properties aid in the assessment of the utilization potential of a given coal. Currently the basic chemical properties are determined for the average bulk composition of the coal at discrete sampling locations. Analyses of bulk composition at best reflect only the horizontal variation of chemical properties within a coal bed. This study investigates vertical as well as the horizontal chemical variability of the Beulah-Zap lignite. The relationships between the chemical properties and the different lithotypes are also examined. Preliminary results of the vertical distribution of coal components may suggest the possibility of preferential mining techniques in order to utilize the lignite in the most efficient manner.

Study Area Selection

The Beulah-Zap lignite bed was chosen for this study on the basis of three major criteria. First, the Beulah-Zap lignite bed occurs as a laterally extensive, thick lignite unit traceable in the subsurface with the use of electric logs. The traceability assures the proper correlation of the three seams in the different sampling locations. Knowing the stratigraphic positions of the seams aids in the assessment of coal petrography as a method for identification and correlation of coal beds.

The second reason for choosing the Beulah-Zap is because the University of North Dakota Energy Research Center (UNDERC) is currently establishing a large data base using this lignite. Routine analyses performed by UNDERC include x-ray fluoresence (XRF) for major and minor elements, and proximate and ultimate analyses for the basic chemical properties. UNDERC has previously performed this suite of analyses on lignite samples from three measured sections of the Beulah-Zap. Petrography of these samples has been included in this thesis for the purpose of better lithotype and maceral characterization with respect to the elemental and chemical composition of this particular low-rank coal.

The commercial importance of this coal is the third reason for studying the Beulah-Zap. This lignite has been used as a source for heating fuel by private land owners since the late 1800's (Leonard et al., 1925). During the past 40 years, the Beulah-Zap lignite has been developed into a commercial fuel resource for electricity generation. The Great Plains Gasification facility is using Beulah-Zap lignite for its conversion processes and electrical power requirements. At their planned peak production schedules, the Coteau Properties' Freedom Mine will process the nearly 14 million tons of lignite annually required to meet the needs of the gasification and power plants. Due to the rapidly increasing importance of the Beulah-Zap lignite, a better understanding the of basic characteristics of this resource is needed. It is for these reasons that this petrographic study has been performed.

Previous Work

Coal Petrology and Petrography

Coal petrology has been developing for the past 150 years as a method for studying the origins, history, occurrence, and characteristics of coal. The main interest of coal petrology is in the microscopic components. Coal petrography is the systematic classification and description of these components. A few of the major contributors in the field of coal petrography during the early 1900's include M.C. Stopes, M. Teichmuller, D. White, and R. Thiessen. Through the work of White and Thiessen (1913), petrographic analyses of coal were made possible by the development of thin-sectioning techniques. In 1927, E. Stach of Germany introduced an oil immersion petrographic technique which aided in the characterization of coal based on the microscopically observable components (van Krevelen, 1961).

Stopes (1919, 1935) introduced nomenclature for the megascopic and microscopic components of coal that later in 1935 became the basis for international classification. In 1935, the Congress on Coal Nomenclature established a widely accepted classification (referred to as the Stopes-Heerlen System) for both megascopic and microscopic components, lithotypes and macerals, respectively. Workers in the Soviet Union were not in agreement with the Stopes-Heerlen System. The Academy of Sciences of the USSR developed their own nomenclature (referred to as the IGM System) based on the genetic characteristics of the components. The IGM System is still in current usage today in the USSR (ICCP, 1975). Thiessen (1929), working for the United States Bureau of Mines, introduced a classification system which was in partial agreement with the Stopes-Heerlen System. The Thiessen system has not been totally abandoned, but the Stopes-Heerlen System is currently the most widely accepted system. A comparison of the different nomenclature systems will be made in the section on lithotype terminology.

North Dakota Lignite

Petrography of North Dakota lignites has been performed on a very limited basis. David White and Reinhardt Thiessen (1913) studied two lignites, the Lehigh and Wilton (Hagel?) beds, in North Dakota. White describes the prevailing megascopic characteristic of these lignites as being predominately xyloid (woody). He states that approximately 80% of the lignite is composed of woody fragments visible with the unaided eye, many of which are flattened logs and branches. The important feature of the coal beds that White noted was the presence of naturally occurring layers. This type of layering may prove to be an important consideration when characterizing a lignite bed. Similar layering has been observed in the Beulah-Zap lignite. White attributed this phenomenon to the changes in vegetation type and depth of water in the peat-forming environment.

The petrographic portion of White's 1913 study was performed by R.

Thiessen. According to his terminology, the microscopic components he studied represented wood fragments and attrital debris. Thiessen concluded that the Tertiary lignites of North Dakota were formed from peat bogs similar to the present day wooded swamps found in Wisconsin and Michigan.

The U.S. Bureau of Mines, in the 1950's, completed an overview of the petrographic characteristics of the Fort Union lignites (McCabe, 1954). The report suggested the importance of detailed petrographic analyses for: 1) knowledge of the coal origin, 2) stratigraphic identification and correlation of lignite beds and seams, and 3) utilization of lignite. McCabe agreed with White's and Thiessen's (1913) observations of the high percentage of anthraxylon (woody) material. McCabe suggested that the low relative percentage of attrital coal in North Dakota lignites is responsible for the poor liquefaction yields.

Roe (1950) examined the lignite sequences of western North Dakota, in particular the Beulah-Zap. He suggested the possibility of distinction and identification of the different lignite beds on the basis of weathering characteristics as seen at outcrops. Roe states that low-ash (inorganic content) lignites weather to a glossy black, whereas the high-ash variety becomes dull black. The elemental composition of the Tertiary lignites was found to be similar to coals of that age in other parts of the world. The ash contains high percentages of calcium and magnesium. Roe attributed the ash composition to original plants of the coal-forming environment. Modern conifers have been determined to contain large amounts of lime and magnesia (Roe, 1950).

In the early 1970's, Francis Ting of the University of North Dakota performed preliminary investigations of the chemical and botanical characteristics of coal components. Ting (1972a) identified the first known occurrence of a silicified peat deposit (Paleocene) in North Dakota. He suggested the botanical origins of the silicified peat were analogous to modern peat deposition in the Okefenokee swamp, Georgia. From this investigation, Ting was also able to determine the compaction ratio for the peat to lignite transition. The compaction ratio 1.52:1.00, peat to lignite, was calculated for the Tertiary lignites in western North Dakota. Ting (1972b) suggested the importance in chemical variation in the different macerals, but did not complete the study of North Dakota lignites.

Depositional Environment of the Sentinel Butte Formation

The depositional conditions of the Paleocene of North Dakota have been the focus of several geologic investigations in the past. Major contributions to the reconstruction of the paleoenvironmental conditions include Royse (1967), Hickey (1972), and Clayton (1977).

The depositional environment of the Sentinel Butte Formation, including the Beulah-Zap lignite, has been described by a range of conditions including middle to upper deltaic, lacustrine, and fluvially dominated systems. Three different fluvial facies for the Sentinel Butte Formation have been described by Royse (1967) as backswamp, floodplain, and channel dominated. Descriptions of the geologic formations in the study area are presented below.

Recent studies of modern peat deposition (Cohen, 1984) suggest that the presence of a thick, vertically and laterally extensive lignite bed indicates that the depositional environment was quiescent with a steady rate of subsidence. Thick peat deposits, which are presumed to be precursors of lignites such as the Beulah-Zap, are known to be occurring in the Okefenokee swamp of Georgia and Florida.

Study Area Location

The study area is located in the Knife River Basin, a sub-basin of the Williston Basin (Figure 1). The Beulah-Zap lignite occurs as a subsurface unit in Mercer and Oliver counties of North Dakota (Fig. 2). Beulah-Zap lignite underlies the Townships 143 N., 144 N., 145 N., and 146 N.,and Ranges 86 W., 87 W., and 89 W. The study area is restricted to mining exposures, encompassing a much smaller area than noted above. Beulah, North Dakota is located near the center of the study area at the confluence of the Knife River and the Spring Creek. The study area is bounded to the south by the Knife River Coal Company's South Beulah Mine, to the west by the North American Coal Corporation's Indianhead Mine, near the town of Zap, and to the north by the Coteau Properties Company's Freedom Mine. All field work was performed within the mines noted above.

Figure 1. Location of the Williston and Knife River Basins. (after Groenewold et al., 1979).

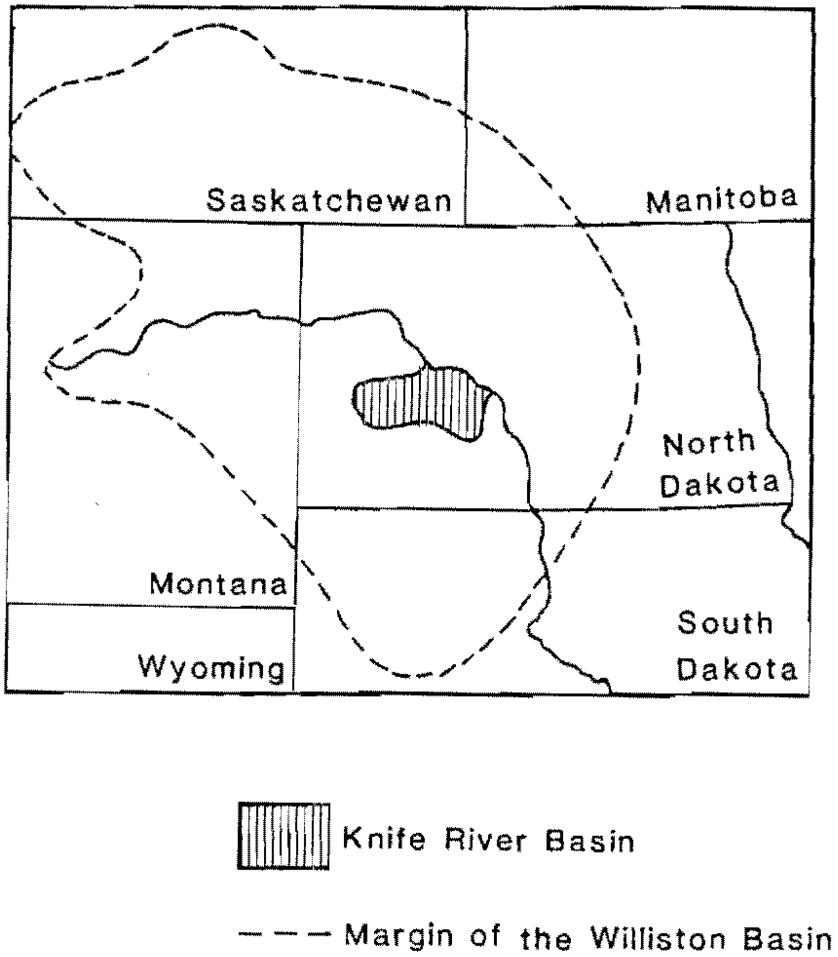
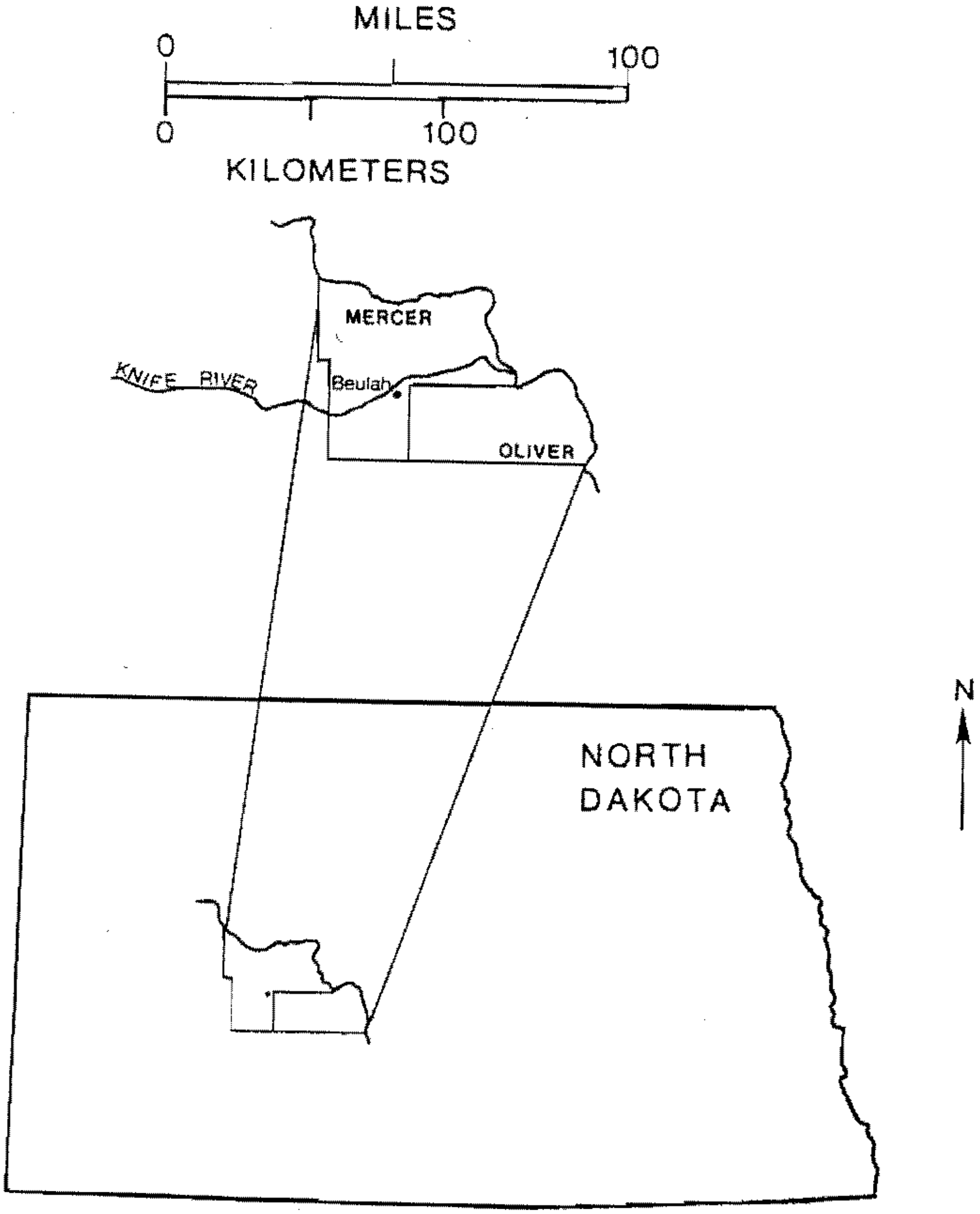

Saskatchewan
Manitoba
N
Montana
North Dakota
Wyoming
South Dakota
Knife River Basin
Margin of the Williston Basin

Figure 2. Generalized map of study area location.


MILES
0
100
0
100
KILOMETERS
MERCER
KNIFE RIVER
Beulah
OLIVER
NORTH DAKOTA
N

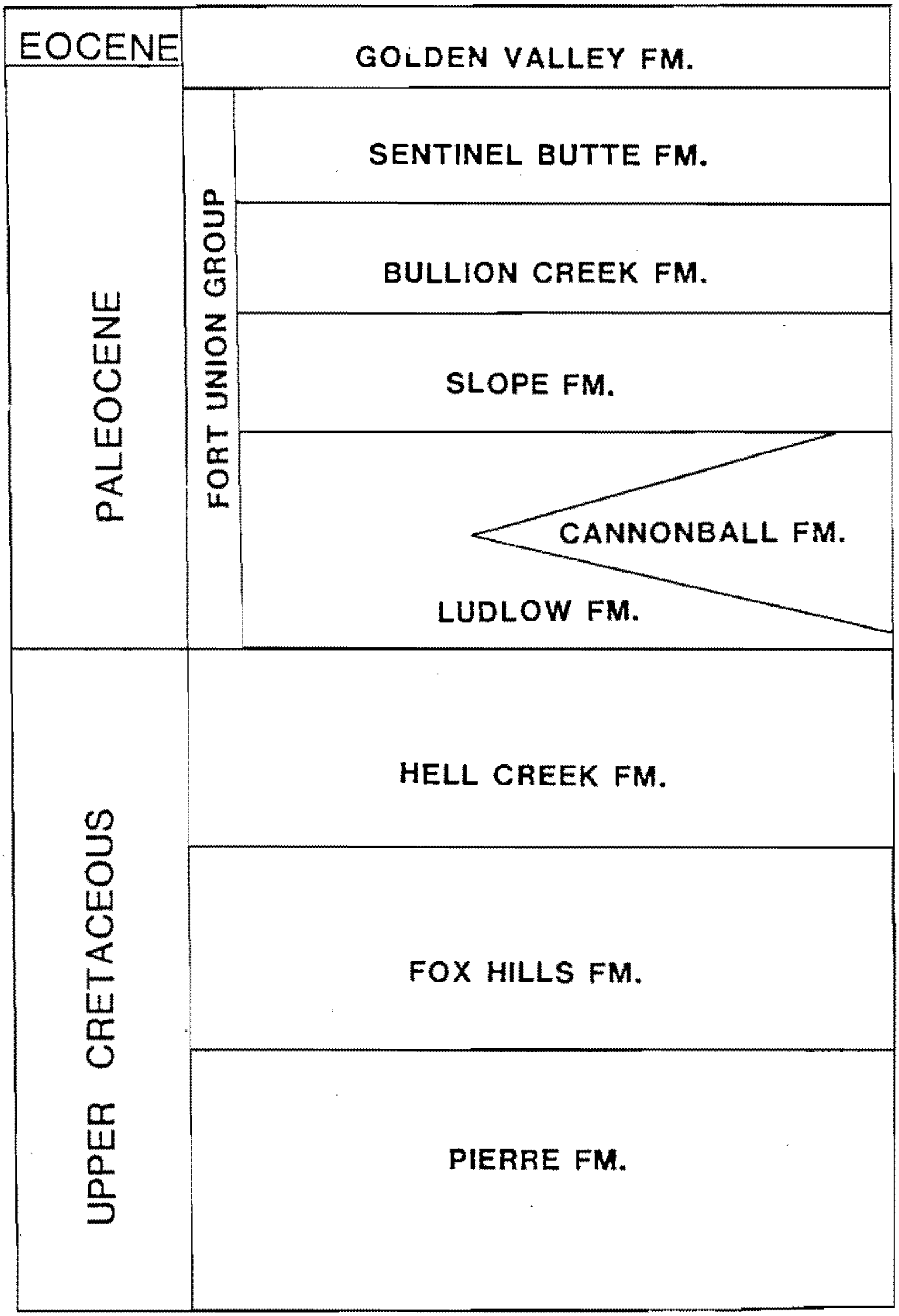
General Geology

The Beulah-Zap lignite bed, named by Leonard (1925), is one of the several laterally extensive, thick lignites occurring in the Sentinel Butte Formation, Paleocene, in North Dakota (Figure 3). The Sentinel Butte Formation is a non-marine unit of the Fort Union Group consisting of alternating beds of clay, silt, sand, and lignite. Nine major lignite beds can be traced throughout the study area (Groenewold et al., 1979). The Sentinel Butte Formation is, in general, gray and brown in color. These same general color characteristics often make it difficult to distinguish from the underlying Bullion Creek Formation. The Bullion Creek Formation weathers to a slightly more yellowish color (Royse, 1967). The Golden Valley Formation, Paleocene-Eocene in age, conformably overlies the Sentinel Butte Formation in the Knife River Basin. The Golden Valley Formation occurs only in a few scattered locations in the Knife River Basin as erosional remnants (Hickey, 1972).

The topography of the area can be considered as gently rolling uplands. The study area is dissected by the Knife River, and the Antelope and Spring Creeks. A veneer of glacially deposited sediment covers the Sentinel Butte Formation in much of the area, except where it has been eroded by stream activity (Royse, 1967). The most unusual topographic features of the area are the subsidence craters located to the east and north of the town of Beulah. These craters are the result of roof failure in abandoned underground mine shafts (Groenewold et al., 1979).

The Beulah-Zap lignite has an average overburden thickness of 12 m, and ranges from 3 to 27 m throughout the area. The Beulah-Zap lignite

Figure 3. Stratigraphic nomenclature of upper Cretaceous, Paleocene, and lower Eocene strata in western North Dakota (from Steadman, 1985).

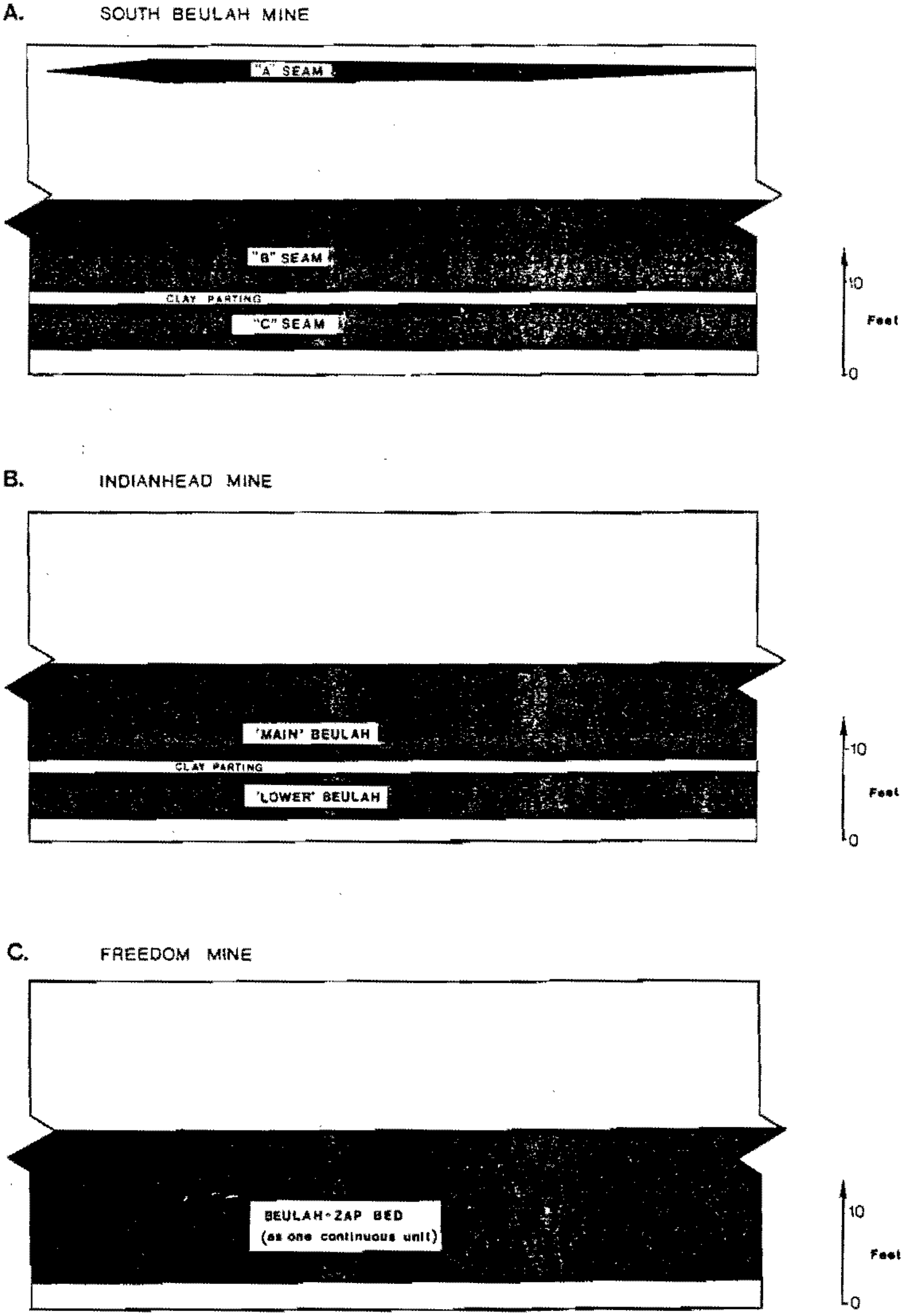

EOCENE
GOLDEN VALLEY FM.
PALEOCENE
FORT UNION GROUP
SENTINEL BUTTE FM.
BULLION CREEK FM.
SLOPE FM.
CANNONBALL FM.
LUDLOW FM.
UPPER CRETACEOUS
HELL CREEK FM.
FOX HILLS FM.
PIERRE FM.

bed is locally continuous and splits into as many as five lignite and carbonaceous clay seams (Groenewold et al., 1979) The Beulah-Zap lignite is the major coal bed commercially mined in the study area. It ranges in thickness from 13 to 24 feet (3.9 to 7.3 m) in the area, with an average thickness probably near 17 feet (5.2 m). Leonard (1925) describes the structure of the Beulah-Zap lignite as a broad, westwardly plunging anticline with minor undulations of less than 10 feet (3.0 m).

The Beulah-Zap bed occurs as three distinct seams separated by carbonaceous shale and clay partings in the South Beulah Mine (Figure 4). At several locations in the mine, the uppermost seam, seam "A", has been removed by erosion or occurs as an inorganic rich, highly oxidized unit. For these reasons the uppermost seam is not always economically useful. Seam "B", the middle seam, is the thickest and most economically important. The middle seam varies in thickness but averages 12 feet (3.6 m). A local clay/silt parting occurs near the base of seam "B". This parting reaches a maximum thickness of four inches. The lowest seam, seam "C", is separated from seam "B" by a continuous clay parting ranging in thickness from 20 cm up to approximately 90 cm in some locations. The lowest seam is often saturated with water causing drainage problems in the mine pits.

In the Indianhead mine, the Beulah-Zap lignite occurs as two separate seams (Figure 4). The upper of the two, named the "Main Beulah" by the mine, is stratigraphically correlatable to the middle seam (seam "B")in the South Beulah Mine. The "Main Beulah" is the most economically important seam in the Indianhead Mine. The lower seam is separated from the "Main Beulah" seam by a clay parting of variable thickness. The two seams found in the Indianhead Mine are reported to

Figure 4. Generalized cross-section of the: A) South Beulah Mine, B) Indianhead Mine, and C) Freedom Mine showing the thickness and seam designation of the Beulah-Zap lignite.



A. SOUTH BEULAH MINE

B. INDIANHEAD MINE

C. FREEDOM MINE

merge into one vertically continuous bed in the northeastern portion of the mine property. At the time of this study, the merging of these seams was not yet exposed by mining operations. The "Main Beulah" seam ranges in thickness from 11 to 13 feet (3.3 to 3.9 m) with an average of 12 feet (3.6 m). The lower seam has an average thickness of about 5 feet (1.5 m).

The Freedom Mine exposes the Beulah-Zap lignite as a vertically continuous bed with a range in thickness from 17 to 22 feet (5.1 to 6.7 m) (Figure 4). At the two sampling locations, no clay partings were observed. An inorganic rich horizon was noted approximately 7 feet (2.1 m) above the base of the coal bed. This horizon was demarcated by an occurrence of "rocks" which are actually silt and clay lenses. These lenses have the dimensions of 7 to 12 cm in length, and 1.0 to 2.5 cm in thickness. All of the clay lenses are oriented with the long axes within the bedding planes of the coal.

Coalification

A brief synopsis of coalification is presented here to introduce and define terminology important in the discussion of the origin of the different coal components. The emphasis of this project was not to examine the degree or cause of the coalification processes. For detailed information involving the evolutionary paths of the organic various functional groups, the following references should be examined: van Krevelen, (1961); Francis, (1961); ICCP, (1963, 1971, 1975); Stach et al., (1982); and Given, (1984).

Coalification is the process by which the organic materials of the peat deposits are converted to coal (ICCP, 1963). Both geochemical and biochemical alteration are important in coalification. The most important factors in these processes are: 1) temperature, from the geothermal gradient or intrusive origins; 2) pressure (depth of burial or tectonic activity); 3) time; and 4) an oxygen-deficient environment, not completely anaerobic (ICCP, 1963, 1975).

Coalification occurs by two types of mechanisms. Diagenesis, the initial stage of coalification, occurs at normal temperatures and pressures at or near the Earth's surface. Biochemical alteration, decomposition by bacteria and fungi, is the principal diagenetic process (Stach et al., 1982). Coalification from peat through the lignite stage is caused by diagenesis. A slight increase in carbon and a significant decrease in the moisture content are characteristic diagenetic alterations. The effectiveness of microbiological decomposition decreases with depth. Biochemical alteration beyond the lignite stage is doubtful (van Krevelen, 1961). The amount of biochemical degradation in the formation of various coal types is not agreed upon, but it is known to contribute significantly to the coalification process.

Coalification from sub-bituminous coal (bright lignite) through the anthracite stages is considered metamorphism (ICCP, 1963). The principal mode of metamorphism is geochemical reactions between the coal components. The major chemical transformations during metamorphism are: 1) increase in carbon content; 2) decrease in volatile matter; and 3) increase in calorific value (ICCP, 1963). Temperature affects the chemical properties of the coal. The increased pressure necessary for metamorphism mainly affects the physical properties of the coal, e.g., porosity and optical anisotropy (van Krevelen, 1961).

In diagenesis two principal processes act upon the organic materials at and soon after the time of deposition: humification and gelification. Humification is generally the most important process in the formation of peat. The humification process, by means of bacteria and fungi, hydrolyzes the starches, celluloses, and proteins of the plant structure to form humic acids (Given, 1984). Some oxygen is needed for humification to take place. The oxygen is supplied by occasional desiccation of the peat by subaerial exposure and by flowing oxygenated groundwater. Most cellulose is decomposed by the lignite stage (Francis, 1961). The lignins of the plant structure are more resistant than cellulose during humification. Excessive oxidation will decompose the lignin.

Gelification is the dominant diagenetic process as the humic acids become weaker. It is responsible for the conversion of lignite to subbituminous coal. Gelification involves the conversion of the humic matter into a colloidal gel (ICCP, 1963). The gel, which is more plastic than fluid, is precipitated through desiccation processes to form a solid material. A range of gelification can occur within the same coal depending on the type of original material. Gelified cell wall material may either retain the original morphology, or become amorphous. The degree of gelification determines which macerals are formed (Stach et al., 1982 and ICCP, 1975). The distinction between these macerals is presented later in the discussion of the huminite macerals.

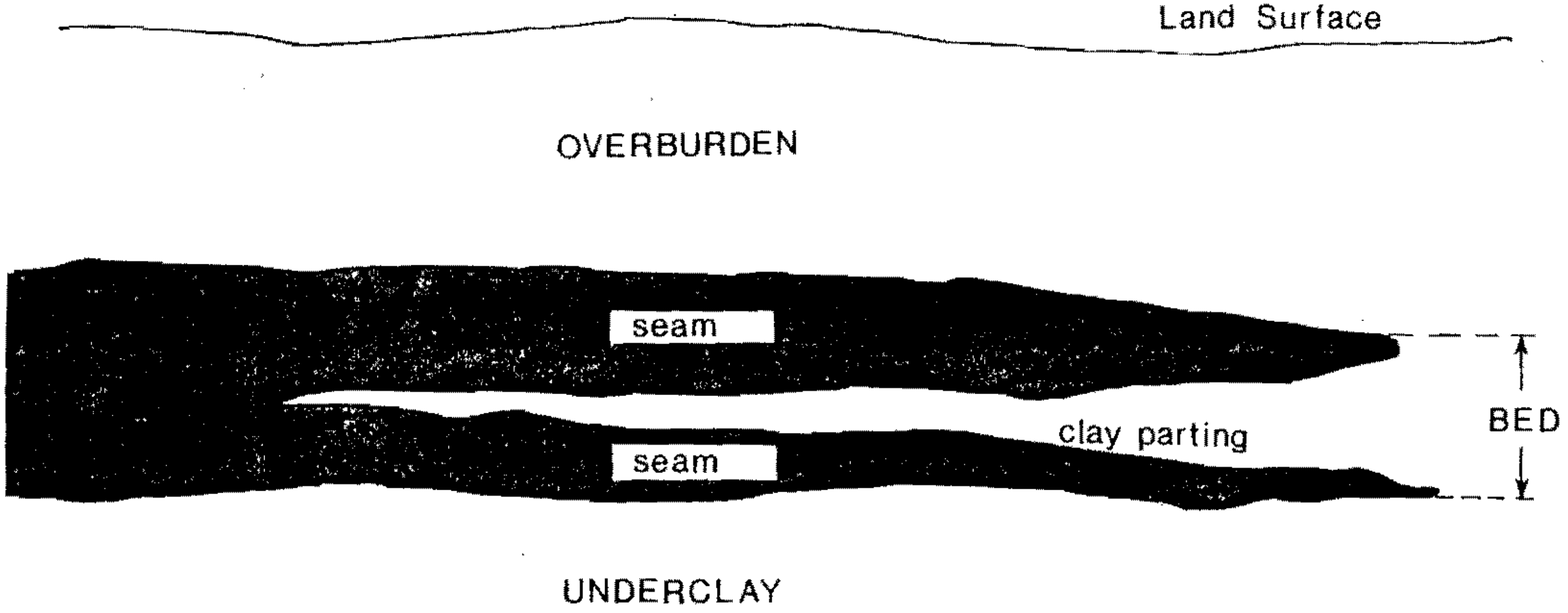
METHODS

Sampling Strategy

For the purpose of this report, the term "bed" refers to the entire lignite depositional sequence; therefore a lignite bed is composed of clay partings and individual lignite seams (Figure 5). One of the major objectives of this project was to investigate the possibility of petrographically characterizing an individual lignite seam, and then by using those characteristics, identify that same interval where the lignite bed occurs as one vertically continuous unit. The Beulah-Zap mining exposures are situated perfectly for this type of experiment. In two of the three mines, the South Beulah and Indianhead Mines, the Beulah-Zap bed occurs as two or three seams separated by distinct clay partings of variable thickness. The Freedom Mine, located to the north of the previously mentioned mines, exposes the Beulah-Zap as one vertically continuous lignite bed with no observable clay partings.

All three of the seams were sampled in the Knife River Coal Company's South Beulah Mine. The lowest seam is commonly high in inorganic content or saturated with water. For these reasons the lowest seam, where it occurs as a discrete unit, is not easily accessible for sampling. Only one complete measured section of the lowest seam was collected. The major emphasis was placed on the middle seam. This seam is the most economically important due to its good quality and thickness. A total of eight measured sections were sampled: three from

Figure 5. Comparison between bed and seam nomenclature used in this study.


Land Surface
OVERBURDEN
seam
seam
clay parting
BED
UNDERCLAY

the uppermost seam, four from the middle seam, and one from the lowest seam. Included in these sections are five sections previously collected by UNDERC.

One measured section of the uppermost seam was collected in the Indianhead Mine, located to the northwest of the South Beulah Mine. Due to the mining operations and the timing of the sampling trip, only one pit was available for sampling. The lower seam in the available pit had not yet been mined, therefore no exposure was accessible.

The measured sections sampled at the Freedom Mine represent the entire thickness of the Beulah-Zap lignite bed. No major clay partings or carbonaceous shales occur within the bed at these sampling sites. Two complete measured sections were collected, each from a different pit in the mine. Detailed sampling procedures and techniques are discussed below.

Sampling Procedures and Techniques

Site Selection

Site selection of the locations for the measured sections was based on several factors. The most important consideration in site selection was the overall safety conditions in that area. The highwalls in strip mines are notoriously unstable. Large slides and slumping caused by the unconsolidated overburden are common. The lignite tends to fracture and become unstable as the coal dries and weathers. Before any work was performed on the coal face, the overburden was carefully inspected to assure that no overhangs or previously slumped areas occurred directly above the proposed sampling site.

After the site passed the safety inspections, the next factor considered was accessibility. Both the top and bottom contacts with the overburden and underclays needed to be readily available for sampling. One major problem often encountered was the ponding of the water draining from the lignite. This produced extremely slippery conditions and poor footing for placing a ladder against the highwall.

The last, but equally important, factor in determining a good sampling location was the freshness of the exposed face. The intention was to collect coal as close to a pristine state as possible. Prolonged exposure will cause excessive moisture loss and oxidation. In most cases the samples used in this project were collected within three weeks of exposure.

Bench and Channel Sampling

Samples were collected from various intervals within a cleared channel in the lignite seam. A standard channel (Swanson and Huffman, 1976) was prepared. The channel, approximately 30 cm wide and 10 cm deep, was cleared using a rock pick and chisel. The seam was then cleaned with a small whisk broom to remove all loose, extraneous material. Immediately adjacent underclays, overburden, and clay partings were collected separately as part of the sample series.

After the channel was prepared, the section was measured and divided into intervals on the basis of megascopically observable characteristics. The term lithobody has been introduced by Spackman (1984) for these naturally occurring lithologic intervals. The lithobodies are composed of the megascopic coal components, lithotypes. Beulah-Zap lithobodies ranged in thickness from 5 to 85 cm. The criteria used to distinguish these lithobodies are 1) massiveness (the degree of induration), 2) occurrence of fusain partings, and 3) relative luster. Lithobodies represent the general overall characteristics of that interval usually containing one dominant lithotype, but all lithotypes may be present. Detailed descriptions were made after the lithobodies were demarcated. Characteristics noted other than the criteria used for lithobody classification include mineral occurrences, texture, and fracture patterns.

Samples were collected beginning at the base of the seam. Approximately two kg of coal were collected from each lithobody. Samples were taken from the entire lithobody to obtain as close to a representative sample of the interval as possible. In an attempt to preserve the original moisture content, the samples were sealed in plastic bags. The procedure to preserve the original moisture seemed to be inadequate. The ideal method for preserving the moisture is to core the lignite prior to the removal of the overburden. The cores are placed in sealed plastic bags and kept frozen until analyzed. No cores for the Beulah-Zap were available for this study. By the time the samples were collected, the coal had lost a significant amount of water due to evaporation. When analyzed, the samples contained less than 20% moisture. This value is much less than the 35% considered average for lignite (van Krevelen 1961; ICCP 1971; and The Keystone Manual 1984). Since the moisture content values were suspect, due to loss prior to collecting, no emphasis was placed on that sample characteristic.

Analytical Techniques

All analyses performed on the lignite were funded by the University of North Dakota Energy Research Center. The scanning electron microprobe analyses were performed at the University of North Dakota geology department. Detailed analytical methods used in this study will be discussed immediately preceding the results of each individual technique.

LITHOTYPES AND LITHOBODIES

Terminology

The foundation of lithotype terminology was presented by M.C. Stopes (1919) of Great Britian. The actual term lithotype was introduced by Seyler (1926). Thiessen, working in the United States of America, had concurrently introduced a nomenclature system for the megascopic components. The differences between the two systems are centered around the genetic implications of the terminology. Thiessen (1929) suggested three main megascopic components of coal, those being anthraxylon, fusain and attrital debris. Stopes (1919) cited four "ingredients" of banded coal, vitrain, clarain, durain, and fusain. The fusain lithotype characteristics and occurrence are agreed upon in both systems. The differences between clarain and durain in the Stopes system are based on the relative amounts of dull, granular material and vitreous lenses. Thiessen's term attrital debris essentially is synonymous with clarain and durain, but without the distinction between two separate types. The major point of contention lies in the terminology of vitrain (Stopes) and anthraxylon (Thiessen). Stopes describes vitrain as being black, vitreous, of subconchoidal fracture, and structureless. Anthraxylon, described by Thiessen has similar properties (with the exception of being structureless) to vitrain. Thiessen suggests that all anthraxylon is of woody material origin.

Through the advancements in microscopic petrographic techniques

Stach et al. (1982) have shown that, contrary to Stopes' terminology, vitrain does in fact have structure (fossilized plant growth rings, cell lumens, etc.). These same techniques have also shown that, contrary to Thiessen, not all anthraxylon originates from woody material. Controversy between the two systems still exists. It has been suggested (Spackman, 1984) that the Thiessen system be employed when the emphasis of the study is to be placed on the botanical aspects of the coal, and the Stopes system when describing the overall characteristics of the coal.

Problems arise when applying the previously discussed terminology to the description of lignites. Stopes and Thiessen developed the classical nomenclature based on the characteristics of Paleozoic banded bituminous coals. The terminology is closely related to the degree of coalification of the organic sediments. Since coalification has not progressed as far with lignite as with bituminous coal, description of lignite using the classical terminology can become confusing. A lithotype nomenclature system for low-rank coals has not yet been agreed upon internationally.

For the purpose of this study the lithotypes were classified on the basis of their physical characteristics as described by the International Committee of Coal Petrography (ICCP, 1963). The terminology best suited for the description of the Beulah-Zap lignite includes terms from the two previously discussed systems. Vitrain and fusain terminology was used in accordance to the Stopes-Heerlen system, and attritus from the Thiessen-Bureau of Mines system (ICCP, 1963). The distinction between clarain and durain (Stopes-Heerlen System) was not possible due to the overall dull luster caused by the low degree of coalification. Attritus (Thiessen, 1929; Schopf, 1960) seemed to be the most appropriate term for the dull, granular, finely laminated portions of the seams. The associated clay/silt partings contained within the coal can also be considered lithotypes. Descriptions of the lithotypes present in the Beulah-Zap lignite are given below.

Vitrain

The term vitrain was chosen from the Stopes-Heerlen system because of the easily recognizable macroscopic characteristics. No implications as to the precursors of this lithotype are made by using the Stopes-Heerlen System. The minimum thickness of vitrain lenses noted was approximately five mm.

The distinguishing characteristics of vitrain used for identification purposes include 1) the bright luster, 2) smooth surfaces, 3) and fractures 90 degrees to the bedding planes (cleats). Vitrain occurs as discontinuous lenses, 5 to 30 mm thick, contained within the dull, granular matrix of the coal. Less than one-half of the vitrain contained plant structures such as concentric growth rings. Even though some original plant structure is preserved, the term vitrain is preferred instead of anthraxylon. The latter term is more appropriately applied in quantitative microscopy studies (Schopf, 1960). Two types of vitrain occur in the Beulah-Zap lignite, a bright, glossy type and a dull textured type. The less bright variety of vitrain occurred more frequently in the massive attrital lithobodies. Internal plant structures were better preserved in the dull vitrain variety.

The most typical property of the vitrain was its brittleness. This is caused in part by the tendency to fracture along two perpendicular planes. The perpendicular fracture pattern resulted in the formation of regular, blocky fragments. Since the vitrain is brittle, it is easily separated from the surrounding attrital matrix, and will remain intact when handled. Vitrain does not produce much dust, which makes it clean to the touch.

Fusain

Terminology from the two classification systems agrees on the characteristics and occurrence of fusain; therefore, this term is well suited for field descriptions. The lithotype fusain is composed of fragmental chips and fibers, occurring as fine lenses <2 cm thick on bedding plane surfaces. The thicker fusain lenses were frequently continuous for distances of three meters on either side of the sampling channel. Most occurrences were observed as thin lenses contained wholly within the prepared channel.

The most noticeable and characteristic property was the extreme friability which is responsible for many of the horizontal partings within the lignite seam. Since these partings produce natural breaks or divisions of the seam, demarcation of the various lithobodies was often based on the occurrence of thick fusain lenses. The friability of this lithotype is also responsible for producing more fine particles than the other lithotypes. Fusain has been described as the part of the coal which "dirties" the hands when touched (Stopes, 1919).

Attritus

The term attritus is taken from the Thiessen-Bureau of Mines classification system. The attritus (or attrital coal, Schopf, 1960) is used as a collective term for the layers of dull to moderately bright coal interlaminated with the lenses of vitrain and fusain. Attritus has a granular texture which makes it easy to distinguish from the other lithotypes. The attrital coal flakes easily when scraped with a knife, and behaves with extreme resistance when struck with a hammer or pick. These attritus-dominated lithobodies appeared to show fewer effects of physical weathering, as seen by the absence of desiccation cracks. The lithobodies in which the attritus lithotype is the major constituent reflect the resistant weathering nature by causing noticeable bulges or protrusions on the highwall face.

Field Descriptions

Megascopic descriptions were taken from the freshly exposed coal face within the cleared channel. The lithobodies were designated at each of the sampling sites based on the dominant lithotype characteristics. Physical characteristics such as friability, fracture patterns, and luster were also noted. Inorganic inclusions and discrete minerals (e.g., pyrite and marcasite) were identified and noted in the coal descriptions. Most inorganic inclusions represent concretionary (?) zones or horizons of clay accumulations. The field descriptions and relative locations of the lithobodies at each measured section are listed in Appendix A.

The lithobodies were later classified into six major types. The lithobody classification was made by using a principal component factor analysis combined with a clustering technique. The relative abundances of lithotypes were the main criteria used in the clustering routine. The characteristics of the statistically derived groups were examined to determine whether or not they correlated with the observed lithobodies. The clustering technique results helped justify the lithobody classification on the basis of the previously discussed megascopic characteristics (Figure 6). It must be noted that this classification system was designed strictly for this project. There is no currently accepted terminology for lithobodies. The six different lithobody types were assigned the letters "A" through "F". Characteristics of the lithobodies are given in Table 1.

Lithotype and Lithobody Distribution and Abundance

The approximate average percentages of the three lithotypes are attritus 45%, vitrain 50%, and fusain 5%. The average values from the different measured sections may vary slightly. Due to the poorly indurated nature of this lignite, only approximate lithotype abundances could be determined. The standard method for quantitative analyses is to use core samples which have been split and polished (Chao et al., 1983). The thickness of each lithotype can be accurately measured on a flat, polished surface and reported as a percentage of the total volume. No core samples of the Beulah-Zap lignite were available for this study. Accurate measurements of the individual lithotype thickness

Figure 6. Hierarchical cluster-analysis of lithotype occurrence of the Beulah-Zap lignite samples.

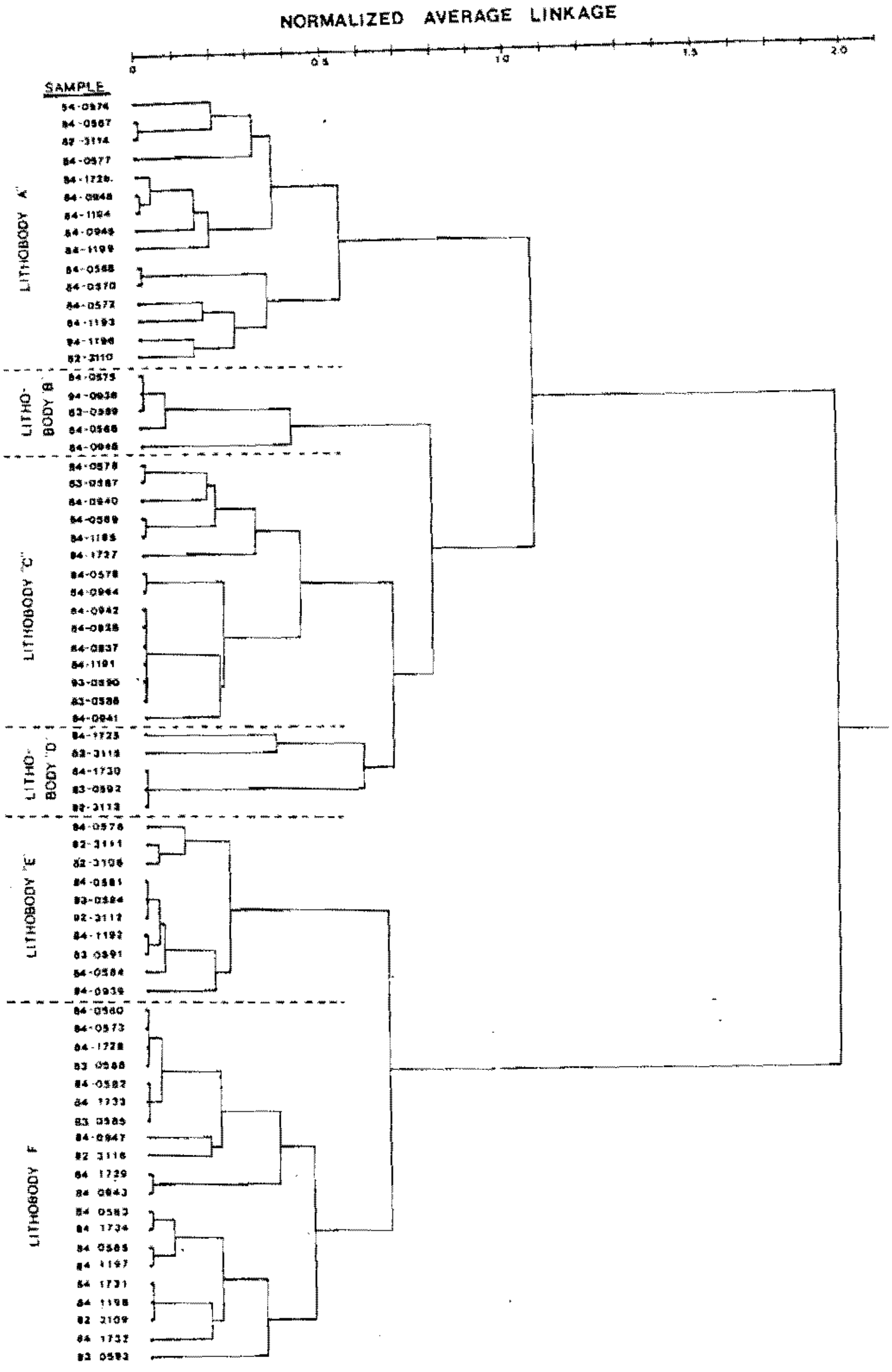

NORMALIZED AVERAGE LINKAGE
0
0.5
1.0
1.5
2.0
SAMPLE
LITHOBODY 'A'
84-0574
84-0567
82-3114
84-0577
84-1726
84-0948
84-1194
84-0949
84-1199
84-0568
84-0570
84-0572
84-1193
84-1196
82-3110
LITHO-BODY 'B'
84-0575
84-0938
83-0589
84-0566
84-0946
LITHOBODY 'C'
84-0571
83-0587
84-0940
84-0589
84-1185
84-1727
84-0579
84-0944
84-0942
84-0936
84-0937
84-1191
83-0590
83-0588
84-0941
LITHO-BODY 'D'
84-1725
82-3118
84-1730
83-0592
82-3113
LITHOBODY 'E'
84-0576
82-3111
82-3106
84-0581
83-0584
82-3112
84-1192
83-0591
84-0584
84-0939
LITHOBODY F
84-0580
84-0573
84-1728
83-0586
84-0582
84-1733
83-0585
84-0947
82-3116
84-1729
84-0943
84-0583
84-1734
84-0585
84-1197
84-1731
84-1198
82-3109
84-1732
83-0593

Table 1. The average lithotype abundance (percent volume) of the Beulah-Zap lithobodies. Compiled from field descriptions (Appendix A).

LITHOBODY	FUSAIN	VITRAIN	ATTRITUS	LUSTER
A	19.0	25.0	56.0	Dull
B	1.5	91.5	7.7	Bright
C	3.4	76.0	21.5	Mod. Bright
D	6.3	50.7	43.0	Mod. Bright
E	3.1	32.3	64.7	Dull to Mod. Bright
F	0.6	18.0	81.4	Very Dull

on the irregular surface of the highwall are difficult to obtain.

Vertical distribution patterns of the lithotypes show that the relatively resistant attrital coal was more abundant directly overlying clay partings and at the base. Thick, discrete fusain layers were absent in these locations. Vitrain occurs as thin(<5 mm), discontinuous lenses within the attrital coal. Vitrain- and fusain-dominated lithobodies occur more frequently near the top of the seam. The association of the attrital coal with the clay partings and underclays is similar to some southern Illinois bituminous coals reported by Cameron (1979). The dull clarain and durain lithotypes in Cameron's study are comparable to the attrital coal from the Beulah-Zap lignite. Bituminous seams of southern Illinois show similar vertical distribution patterns of vitrain and fusain as were found in the Beulah-Zap lignite seams.

The lateral extent of the lithotypes varies. Vitrain commonly occurs as lenses with a maximum horizontal length of less than 25 cm. Fusain most often occurs as discontinuous fragments two to five cm in length on bedding plane surfaces. One local fusain horizon is traceable for approximately 30 m. A fusain horizon of this extent is considered uncommon in the study area, and proved to be an excellent stratigaphic marker when attempting to trace lithobodies along the highwall. The attrital coal is the most laterally continuous lithotype. Discrete attrital coal layers 10 cm thick can often be traced for several meters before pinching out or merging with other lithotypes.

Lithobodies, in contrast to lithotypes, are more laterally extensive. Examination of the lithobodies in the Freedom Mine shows that four lithobodies can be traced throughout the mining exposure.

Each of the four lithobodies can be subdivided into locally distinguishable units. Similar laterally extensive lithobodies can be observed in the South Beulah Mine. The exposure at the Indianhead Mine was such that visually tracing lithobodies was impossible. Much of the coal was coated with inorganic sediments washed down from the overburden, which concealed the subtle lithobody boundaries. The lithobodies have characteristic maceral assemblages which aid in identification and correlation. These characteristics will be discussed in the results section pertaining to maceral distribution.

MACERALS

Sample Preparation Techniques

Maceral analyses were performed using standard reflected light microscopy (Stach et al., 1982). A Leitz Ortholux microscope with a 60X oil immersion objective was used to identify the maceral types. The lignite was embedded in epoxy pellets. The preparation of these pellets is discussed below. Quantitative maceral analyses were performed using point counting techniques developed by Stach (1982). Approximately 500 counts on coal were made of each sample. The epoxy component of the plugs was not considered in the point counts.

The samples were prepared for reflected light microscopy by first vacuum-drying approximately 25 grams of lignite. The drying process took 24 hours at a pressure of 10 to 15 microns of mercury. All but about 4% (by weight) of the moisture was removed. Vacuum-drying the samples made the coal easier to crush. This technique is not commonly used for the preparation of other types of biological samples. Extensive drying often causes the destruction of cell morphology of modern biological samples by removing the water from the structure (Goldstein et al., 1981). The removal of water from coalified plant material does not appear to alter the maceral morphology.

After drying the lignite samples were crushed by hand with a mortar and pestle to pass through a 20 mesh screen. Particles of this size are needed to insure complete impregnation of the epoxy embedding medium. The coal was formed into pellets by mixing several drops of premixed epoxy resin and hardener with approximately two grams of sample. The amount of epoxy should only be enough to assure that each coal particle is completely coated. The epoxy and coal mixture was then placed into the bottom of a 2.5 cm diameter mold. Standard pelletization procedures (ASTM, 1980a) at this point require the addition of 5000 psi pressure to the mixture to reduce the amount of air bubbles and impregnate the coal with epoxy. The American Society for Testing and Materials (ASTM) procedures require this pressure to be maintained until the epoxy has cured. After the epoxy has cured, the pressure is to be released. Additional epoxy is then poured onto the cured coal and epoxy pellet to a depth of approximately 2 cm. This procedure produces a final pellet 2.5 cm in diameter and 4.0 cm thick.

The equipment necessary for strictly adhering to ASTM methods was not available at the time of this study. A vacuum impregnation technique was employed. After the epoxy and coal mixture was placed into the mold, approximately two cm of epoxy was poured over the top. The sample molds were placed in a vacuum desiccator. A reduced pressure (approximately 25 mm) was applied for approximately five minutes. This was sufficient to remove the air trapped between the coal particles. The viscosity of the epoxy was low enough to allow it to penetrate the lignite. Complete impregnation of the lignite particles was achieved by using this vacuum method.

The coal/epoxy pellets were polished using a lapidary wheel and various size polishing compounds. Initial grinding was performed using a 400 grit sand paper disk with water lubrication. The samples were cleaned in a ultrasonic bath for approximately five minutes between the different polishing steps. The final polishing procedure used one-micron-diameter diamond paste. The area of the final polished surface is approximately five sq. cm, of which lignite comprises nearly 75%. After the final polishing step, the samples were placed in protective plastic caps. The samples did absorb some moisture from the air. This was evident by the swelling of the lignite particles embedded in the epoxy. The swelling nature of the coal ruined the final polished surface after one month.

Terminology

The terminology for the microscopic components of coal was introduced by Stopes (1935). She derived the term maceral from the Latin macerare, meaning to macerate, because coals originate from macerated plant (vegetable) material. Macerals in coal are analogous to minerals in inorganic rocks. The comparative properties of macerals and minerals can be summarized accordingly; macerals are naturally occurring, solid organic, non-crystalline material with a variable chemical composition. Minerals are naturally occurring, solid inorganic material with distinctive chemical composition and crystalline structure (Stach et al., 1982).

The three major maceral groups are 1) huminite, 2) liptinite, and 3) inertinite (Table 2). Each of these groups contain macerals which in some manner are related to one another. These relationships may include similar origins (maceral precursors), or method of coalification (e.g., gelification or fusinitization). The maceral groups each have a characteristic range of reflectance values. The reflectance is due to the chemical composition (carbon content) of the macerals contained within the group. When maceral groups of the same rank are compared, huminite contains more oxygen relative to the liptinite and inertinite groups. Inertinite and liptinite contain more carbon and hydrogen, respectively, than huminite (Stach et al., 1982).

Macerals of the same group are differentiated from one another on the basis of morphology. The morphology most commonly reflects the type of original plant material. In some cases the mode of preservation determines the morphological properties of the maceral. For example, if woody material is quickly charred by fire prior to deposition, the resulting maceral, fusinite, may have a well preserved cell structure. If the same type of material is subjected to a slower oxidation process, perhaps via bacterial activity, the resulting maceral may be amorphous macrinite (Stach et al., 1982).

For the purpose of this study, all maceral groups were differentiated on the basis of relative reflectance and individual macerals by morphology. Equipment needed for quantitative reflectance was unavailable for this study. The macerals were classified into their respective groupings in accordance to the International Handbook of Coal Petrology (ICCP 2nd Supplement, 1975). Maceral identification was made by using reflected light microscopy. Standard point counting techniques (Stach et al., 1982 and ASTM, 1980b) were employed for the quantitative maceral analyses. Descriptions of the maceral groups and respective macerals found in this investigation are given below.

Huminite Maceral Group

The macerals of the huminite group were divided into three major classifications on the basis of their origins. These classifications include the cell walls and lumens, cell fillings (primary or secondary), and detrital fragments. Most huminite macerals have a characteristic low reflectance value. Ulminite is the dominant maceral of the huminite group. Ulminite accounts for an average of 62% of the huminite macerals in the Beulah-Zap lignite. The origin of ulminite is from the woody (cellulose and lignin) portion of the plant structure. Diagenesis of the plant material, through the brown coal stage, degrades the cellulose and lignin to produce a humic colloidal gel. The gel is solidified into humic materials which are used in the coal formation (ICCP, 1975). The solidification of the gel does not occur in a predictable crystallographic structure. The degree of gelification can produce several ulminite submaceral varieties. Most ulminite found in this study was the submaceral type eu-ulminite (Table 2). Eu-ulminite has been highly gelified and contains few observable original plant stuctures (e.g., cell walls and lumens). Texto-ulminite was present in minor quantities in samples near the top of the seam. The submaceral types were not differentiated in the point count analyses (Table 2).

The humodetrinite maceral subgroup contains the macerals attrinite and desinite. These macerals, of detrital origin, account for 35% of the huminite group and approximately 20% of all macerals occurring in the Beulah-Zap lignite (Table 3). The distinction between attrinite and desinite was based on the size of the maceral. Humodetrinite less than ten microns in diameter was classified as attrinite. Attrinite was the most abundant humodetrinite maceral in the Beulah-Zap lignite.

TABLE 2. Maceral terminology and classification used for the Beulah-Zap lignite (after Stach et al., 1982).

Group Maceral	Maceral Subgroup	Maceral	Origin
Huminite	Humotelinite	Textinite	Cell Lumens
		Ulminite	
	Humodetrinite	Attrinite	Detrital Fragments
		Desinite	
	Humocollinite	Gelinite	Cell and Pore Fillings
		Corpohuminite	
Liptinite		Sporinite	Spores
		Cutinite	Cuticles
		Resinite	Resin and Copal
		Suberinite	Cell Walls
		Alginite	Algae
		Liptodetrinite	Detrital Fragments
		Chlorophyllinite	Chlorophyll
Inertinite		Fusinite	Cell Lumens
		Semifusinite	
		Macrinite	Fusinized Gelinite
		Sclerotinite	Fungal Remains
		Inertodetrinite	Detrital Fragments

Table 3. Average maceral composition of the Beulah-Zap lignite as determined by point counting. Compiled from Appendix C. (percent volume)

MACERAL	MEAN	MAXIMUM	MINIMUM	STD DEV.
Ulminite	40.3	71.0	0.0	14.6
Attrinite	19.4	44.0	0.0	8.2
Desinite	3.8	15.0	0.0	2.6
Gelinite	0.6	3.0	0.0	0.7
Corpohuminite	1.8	12.0	0.0	1.5
Sporinite	1.6	6.0	0.0	1.2
Cutinite	1.2	4.0	0.0	0.8
Resinite	1.1	3.0	0.0	0.8
Suberinite	0.3	2.0	0.0	0.5
Liptodetrinite	4.2	13.0	0.0	2.3
Fusinite	3.8	13.0	0.0	3.1
Semifusinite	7.2	25.0	0.0	5.5
Macrinite	0.2	3.0	0.0	0.5
Sclerotinite	0.5	2.0	0.0	0.5
Inertodetrinite	7.9	29.0	0.0	5.8
Minerals	5.9	70.0	0.0	10.0

Desinite consists of those humodetrinite particles larger than ten microns. The precursors of the humodetrinite macerals are similar to that of ulminite. Woody and herbaceous material is physically degraded and easily gelified. The flocculation of the humic colloids forms attrinite. Attrinite can be further gelified to form larger particles of desinite.

Other huminite macerals of the Beulah-Zap include gelinite and corpohuminite. These macerals account for approximately 2% of the huminites (Table 3). Gelinites occur as either cell excretions formed during coalification or solidification of completely gelified cellulose and lignin (ICCP, 1975). Gelinites are generally amorphous except when influenced by the physical structure of the surrounding material. Corpohuminite macerals are tannin-rich cell excretions formed during plant growth. Corpohuminite typically has a higher than normal reflectance for the huminite group. This is caused in part by an abnormally high hydrogen content (ICCP, 1975). Since the reflectance is more similar to that of the inertinite group macerals, corpohuminite was distinguished by its characteristic bright oval or circular cross-section morphology. Corpohuminite is almost always associated with ulminite. Extensive gelification can cause a loss of reflectance in the corpohuminite. In the Beulah-Zap lignite, the degree of gelification was high enough to cause the corpohuminite to lose some of its reflectivity. Differentiation between ulminite and corpohuminite was difficult in the highly gelified samples.

Inertinite Maceral Group

The term inertinite comes from the characteristically inert behavior of this material during reaction (e.g., liquefaction and coking) The inertinite macerals are the most strongly reflecting of all the macerals within the same coal (ICCP, 1963). All the macerals of this group have been found in the Beulah-Zap lignite. The origin of the inertinite macerals has been disputed for years (Marshall, 1953). The inertinite formation process is called fusinitization which has several modes of occurrence. The currently accepted modes of occurrence include 1) oxidation caused by bacteria, 2) quick charring by fires, 3) fungal attack, and 4) mouldering. The end results of each of these fusinitization processes are macerals which contain a high percentage of carbon.

The two most abundant inertinite macerals found in the Beulah-Zap lignite were fusinite and semifusinite (Table 3). These two macerals comprised approximately 55% of the total inertinites. The plant precursors of these macerals are similar to the precursors of ulminite. Fusinite and semifusinite originate from the cellulose and lignin of the plant cell walls. Fusinite has had a high degree of carbonization, whereas semifusinite has not been completely carbonized (Stach et al., 1982). Semifusinite differs from fusinite by having a relatively lower reflectance and thicker, less distinct cell wall structures. The thicker cell walls are a product of a low degree of gelification similar to the huminite macerals. Both fusinite and semifusinite are extremely brittle and easily degrade into fine detrital fragments.

The detrital inertinite fragments which are small enough so that the maceral type can not be determined are classified as inertodetrinite. Most inertodetrinite is less than 25 microns in diameter. The morphology varies greatly. Inertodetrinite typically occurs as angular enlongated fragments, but also occurs as rounded, spherical particles. The inertodetrinite comprises approximately 40% of the total inertinites in the Beulah-Zap lignite.

Two other inertinite macerals are found in the Beulah-Zap. These macerals are macrinite and sclerotinite and typically occur in trace amounts (<1%). Macrinite is amorphous and commonly displays desiccation cracks. Bacterial oxidation (biochemical) or subaerial exposure in the early peat stage of coalification produces macrinite (ICCP, 1975).

Sclerotinite is a primary inertinite. Primary inertinites possess characteristic high carbon contents compared to other plant material. Sclerotinite is believed to be preserved fungal spores (Stach et al., 1982) and remains basically unaltered during coalification. Fungal spores found in the Beulah-Zap are commonly multi-chambered. Many of the chambers are filled with liptinitic resin material secreted by the organism prior to deposition.

Liptinite Maceral Group

Liptinite macerals are composed of the hydrogen-rich waxes, fats, and oils as well as the bacteria-generated degradation products of plant proteins and carbohydrates (ICCP, 1975). The macerals of the liptinite group are identified on the basis of their extremely low relative reflectance and strong fluorescence. Liptinite macerals are not easily altered by humification or gelification during diagenesis to the lignite stage (Stach et al., 1982). Low-rank coals, such as the Beulah-Zap, typically contain a high percentage of liptinite macerals due to the low degree of alteration during coalification. Fluorescence microscopy (blue light excitation at 546 nm) is the best method for distinguishing and identifying macerals of this group. The liptinite macerals fluoresce strongly due to the high hydrogen content. Fluorescence microscopy was unavailable for this study. Since this method was not used to distinguish the liptinite group macerals from the epoxy mounting medium, the total abundance was probably underestimated by as much as 50% to 75% (Winans and Crelling, 1983). The liptinite macerals that could be identified on the basis of morphology include sporinite, cutinite, resinite, and suberinite (Table 2). The maceral classification liptodetrinite was used as a collective term for unidentifiable liptinite group macerals. Liptodetrinite is more appropriately used for classifying detrital fragments of all liptinite macerals. Descriptions of the important liptinite macerals are given below.

Sporinite is derived from the exine portion of the spores and pollen. The exine is composed of the long-chained polymer sporopollenin, which is chemically resistant to the reducing depositional environment of the coal swamps. Sporinite is distinguished from other liptinite macerals by its characteristic elongated morphology. Sporinite commonly occurs in the humodetrinite matrix. Sporinite ranges in size from a few to 200 microns in length. Identification of pollen and spore types, palynomorphs, is impossible when examined by this method.

Cutinite is the maceral derived from the waxy coatings on the outer portions of the plants, such as leaves. Cutinite occurs as long, thin layers in the attrital matrix. Physical degradation of the cutinite commonly results in the formation of liptodetrinite. Cutinite was not very abundant in the Beulah-Zap lignite (<2%). Some coals of Europe have a large concentration of cutinite. The cutinite causes planes of weakness in the coal producing a finely laminated, friable "leaf" or "paper" texture (Stach et al., 1982).

Resinite is formed from plant secretions into the cell lumens. Resinite occurs as dark oval to circular bodies usually contained within the recognizable plant cell structures. Resinite is differentiated from corpohuminite by its relatively low reflectance value. Resinite also occurs in the attrital matrix of the coal. Resinite bodies range in size from tens to a few hundred microns in diameter.

Maceral Distribution and Occurrence

Lithotype Association

The maceral ulminite is the major constituent of nearly all the vitrain lithotypes studied. Vitrain of the Beulah-Zap contains up to 70% ulminite and 93% total huminite group macerals (Table 4). Gelinite occurrence was restricted to the thin, vitreous, and nearly structureless vitrain layers commonly associated with the humodetrinite matrix. Corpohuminite was more abundant in the vitrain, due to the close association with ulminite.

The inertinite macerals are the dominant components of the fusain lithotype. Fusinite and semifusinite make up 60% of the total maceral content of fusain (Table 4). Fusinite occurs as discrete, well preserved cell structures. Semifusinite is often associated with ulminite in fusain. The semifusinite is commonly found on the boundaries of ulminite. This produces natural planes of weakness. A majority of the megascopic and microscopic lignite fragments exhibit fusinite and semifusinite at the margins.

The liptinite macerals in the fusain appear to be more intimately associated with huminite than inertinite. Resinite is occasionally found in the fusinitized cell lumens. The porous cell structure of the fusinite frequently contains alumino-silicate clay minerals (Plate 1).

The macerals which represent the organic detrital fragments of each of the maceral groups make up approximately 55% of the attritus lithotype (Table 4). The humodetrinite macerals contribute the majority. The single most abundant maceral found associated with the attritus was ulminite. Gelinite is also a common constituent associated with the thin vitreous lenses of the attritus. The inertodetrinite found in the attritus occurs as elongated angular fragments.

Vertical Distribution

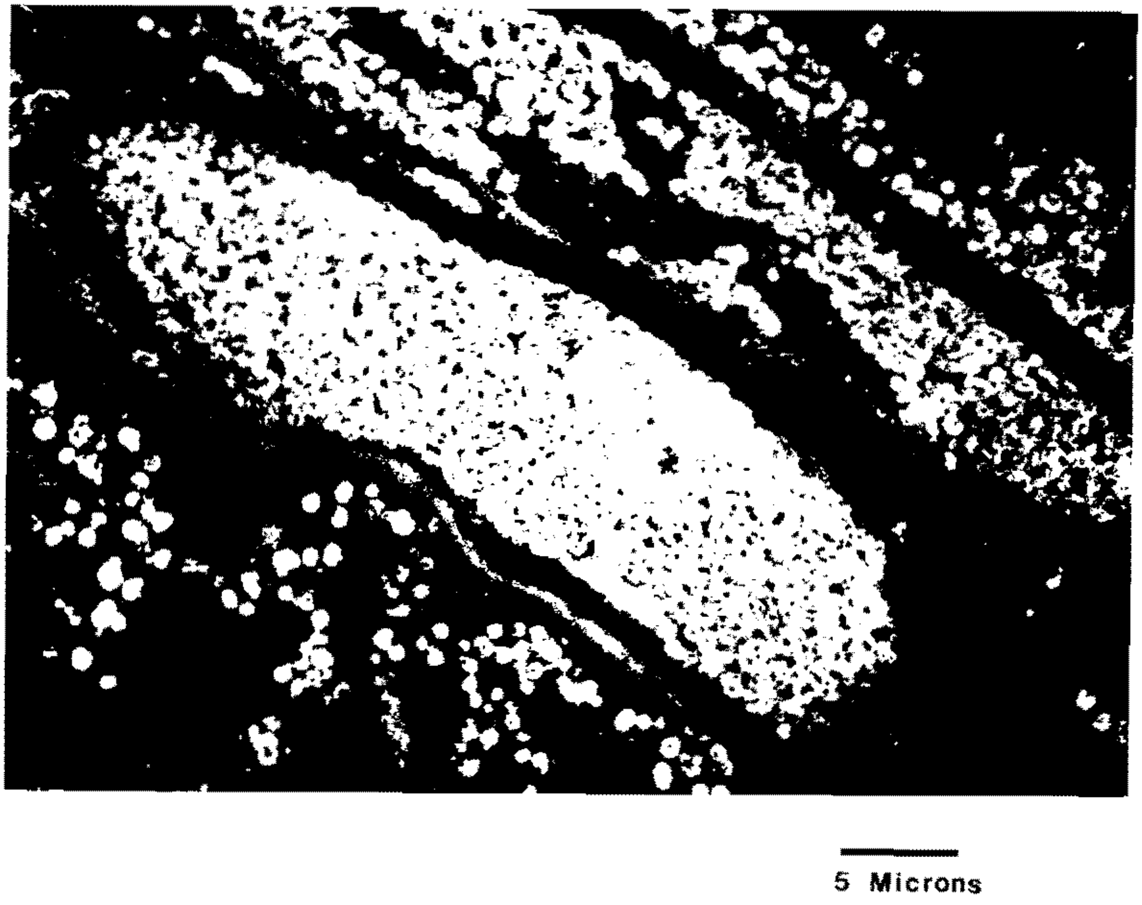
Huminite and inertinite macerals have characteristic vertical distribution patterns. Inertinite tends to be more abundant near the top of each of the seams studied. The exception to this occurs when discrete fusain lenses appear towards the base of the seam. Inertodetrinite is the dominant inertinite maceral found at the top of the seam. Well preserved fusinite and semifusinite occurs in thicker fusain lenses.

In general huminites are dominant throughout the middle and lower portions of the lignite. Ulminite which has not undergone extensive

Table 4. Average maceral content of the separated Beulah-Zap lithotypes. Compiled from Appendix D. (Percent volume)

MACERAL	LITHOTYPE FUSAIN	VITRAIN	ATTRITUS
Ulminite	8.7	62.6	30.4
Attrinite	3.3	5.8	18.3
Desinite	1.2	3.6	15.5
Gelinite	2.5	13.6	5.7
Corpohuminite	0.6	1.6	1.1
Sporinite	0.0	0.8	2.0
Cutinite	0.7	0.9	1.4
Resinite	2.9	0.7	0.9
Suberinite	0.1	0.7	0.5
Liptodetrinite	1.5	3.5	6.7
Fusinite	39.2	1.4	2.3
Semifusinite	16.6	1.2	4.2
Macrinite	0.1	0.0	0.2
Sclerotinite	0.1	0.1	0.6
Inertodetrinite	7.0	2.5	10.0
Minerals	0.4	0.6	0.5

Plate 1. Photomicrograph of kaolinitic mineral in fusinite cell opening.


5 Microns

gelification is associated with the inertinite group macerals near the top of the seam. This ulminite incorporates corpohuminite in the well preserved cell lumens. Huminite macerals which are highly gelified occur more abundantly toward the base of the seam. Gelinite and highly gelified ulminite commonly occurs associated with the attritus lithotype immediately above clay partings and underclays. Attrinite and desinite are more abundant near the base of the seam. The liptinite macerals show very little vertical variation throughout the study area.

Lateral Distribution

The overall bulk maceral composition does not vary significantly between the three mine exposures. The greatest maceral group variance was noted with the inertinites. The average inertinite content ranged from 26% (Freedom Mine) to 16% (South Beulah Mine). The huminite and liptinite maceral content remained nearly constant at all three mine locations (Table 5). Only the middle of the three Beulah-Zap lignite seams could be compared directly from each of the sampling locations. Since macerals are closely associated with lithotypes, and the lithotypes are in turn related to certain lithobodies, macerals are associated with certain lithobodies, which have previously been defined as laterally continuous.

A similar experiment was performed on bulk samples from other North Dakota lignite beds. The purpose of this experiment was to examine the possibility of applying maceral analyses as an identification method for distinguishing lignite beds. Table 6 gives the results of the maceral analyses. The bulk maceral composition of these lignites is very similar (Figure 7). This suggests that North Dakota lignite beds can

Table 5. Bulk maceral content of the Beulah-Zap lithologic intervals from the measured sections. Compiled from Appendix C. (percent volume)

	MEASURED SECTION								
MACERAL	BAB	BPB	BOB	BBA	I32	F72	F64	BEU	BAA
Ulminite	43	38	46	47	43	38	41	40	25
Attrinite	21	26	25	31	18	21	24	23	17
Desinite	3	4	3	2	3	5	3	4	4
Gelinite	1	tr	1	tr	1	1	1	1	tr
Corpohuminite	1	1	1	2	1	1	1	1	tr
Sporinite	2	2	3	2	2	3	1	2	1
Cutinite	1	1	1	1	1	1	1	2	tr
Resinite	2	2	0	1	1	1	1	1	1
Suberinite	tr	tr	0	1	tr	tr	tr	1	0
Liptodetrinite	4	6	5	4	3	4	5	5	2
Fusinite	5	4	3	1	6	4	2	4	5
Semifusinite	4	4	4	1	9	8	5	6	6
Macrinite	0	1	0	0	1	1	0	1	tr
Sclerotinite	tr	1	tr	0	1	tr	tr	1	tr
Inertodetrinite	9	7	6	4	8	9	9	8	14
Minerals	4	5	3	3	4	4	6	4	25

tr = trace amounts (<1%)

BAB = Beulah mine, Alpha pit, "B" seam.
BPB = Beulah mine, Purple pit, "B" seam.
BOB = Beulah mine, Orange pit, "B" seam.
BBA = Beulah mine, Bravo pit, "A" seam.
I32 = Indianhead mine, Pit #3 marker 2, "Main" Beulah seam.
F72 = Freedom mine, Pit #7 marker 2, Entire Beulah-Zap bed.
F64 = Freedom mine, Pit #6 marker 4, Entire Beulah-Zap bed.
BEU = Beulah mine, Orange pit, Entire Beulah-Zap bed.
BAA = Beulah mine, Alpha pit, "A" seam.

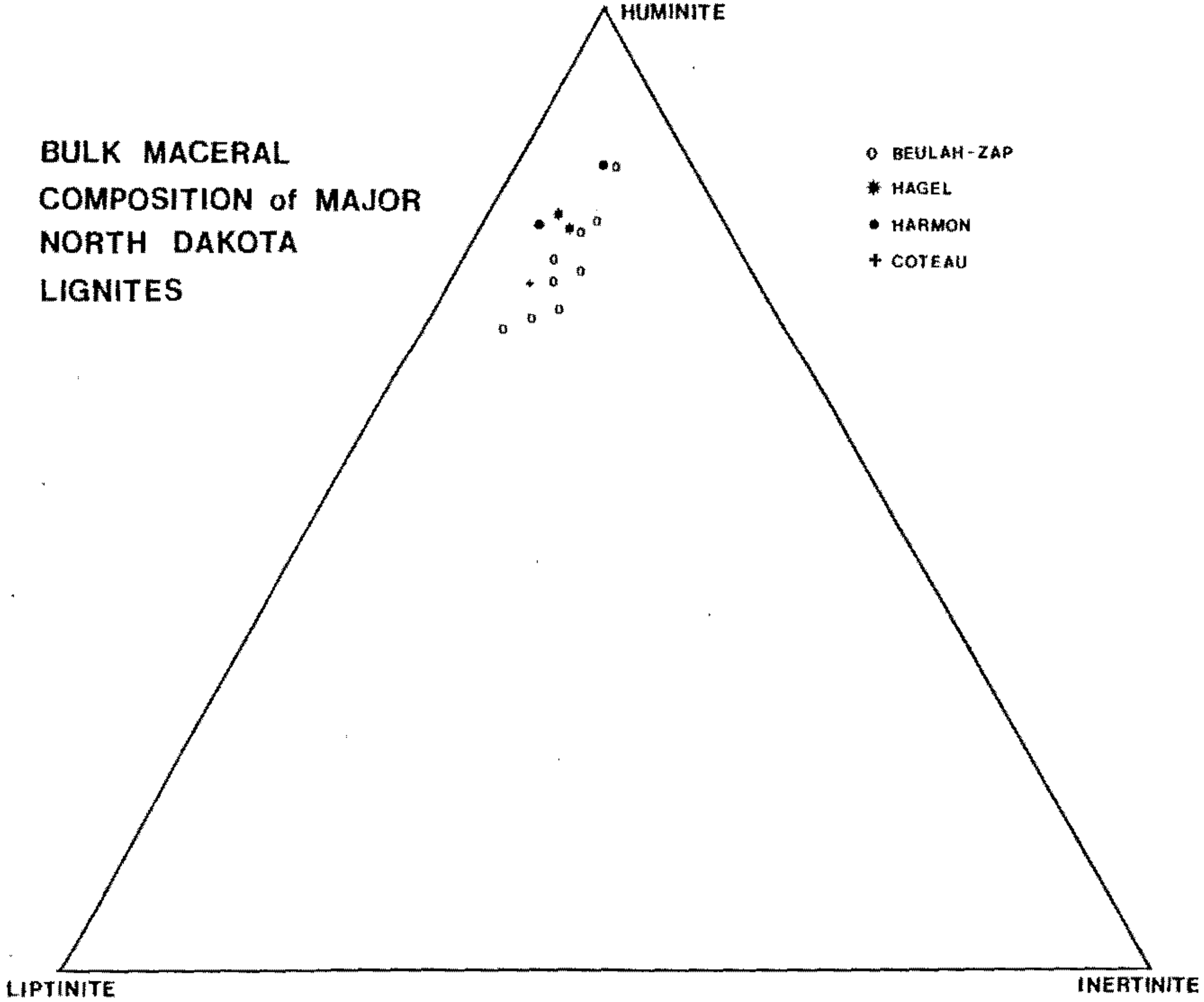
TABLE 6. Bulk maceral analysis of four major North Dakota lignites. (percent volume)

	MINE						
Maceral	Gas. R.	Gas. B.	Vel.	Cen.	Falk.	Free.	Ind.
Ulminite	44	42	39	52	41	37	38
Attrinite	23	22	27	24	29	25	35
Desinite	3	3	3	tr	2	3	2
Gelinite	1	1	1	tr	1	1	1
Corpohuminite	1	1	2	1	2	1	1
Sporinite	1	1	tr	1	3	2	2
Cutinite	tr	1	1	1	1	1	1
Resinite	1	1	2	1	1	1	1
Suberinite	0	0	tr	0	0	0	tr
Liptodetrinite	2	4	4	3	3	7	6
Fusinite	3	1	7	1	1	3	3
Semifusinite	4	2	5	10	6	4	2
Macrinite	0	0	tr	0	0	0	0
Sclerotinite	0	tr	tr	tr	0	tr	tr
Inertodetrinite	10	4	8	3	7	10	7
Minerals	6	3	tr	3	3	3	2

tr = trace amount present.
Gas. R. = Gascoyne Mine, Red Pit.
Gas. B. = Gascoyne Mine, Blue Pit.
Vel. = Velva Mine.
Cen. = Center Mine.
Falk. = Falkirk Mine.
Free. = Freedom Mine, Pit #7.
Ind. = Indianhead Mine, Pit #3.

not be positively identified by bulk maceral analysis alone.

Figure 7. Comparison of the bulk maceral analyses for four North Dakota lignites (Table 6).



BULK MACERAL COMPOSITION of MAJOR NORTH DAKOTA LIGNITES

CHEMICAL ANALYSIS

General

The basic chemical components are commonly used to predict coal utilization potentials and characteristics (ICCP, 1963). The components examined in this study include the ash, volatile matter, fixed carbon, hydrogen, total carbon, nitrogen, sulfur, and oxygen contents. It has been established that most of these chemical constituents follow predictable evolutionary paths during diagenesis and metamorphism (van Krevelen, 1961, Francis, 1961 and Stach et al., 1982). Coal rank determination (the degree of coalification) is often based on several components such as the ratios of hydrogen to carbon, and carbon to oxygen. The analytical methods for determining the basic chemical components of the Beulah-Zap lignite are described below.

Proximate and Ultimate Analyses

The principal method for determining the basic chemical components of the Beulah-Zap lignite was by proximate and ultimate analyses. The analyses were performed at the University of North Dakota Energy Research Center (UNDERC). Techniques comparable to American Society for Testing and Materials (ASTM) procedures were followed. A Fisher Coal Analyzer was used for the proximate analyses (ASTM, 1983a) and a Perkin-Elmer 240 Elemental Microanalyzer for the ultimate analyses (ASTM, 1983b). All lignite samples were dried, then crushed to pass through a 60 mesh sieve prior to analyzing. The moisture content of the samples was not determined on an "as-received" basis because a significant amount of moisture (15-20%) was lost between collecting and analyzing. All reported moisture contents are reported on the "as-run" basis (ASTM, 1983a).

The proximate analysis determines the moisture, ash, volatile matter, and fixed carbon content. These components are expressed as a percentage, by weight, of the total sample. The moisture is determined by the weight difference after drying the coal in an oven at 110 degrees Celcius. Oven drying is complete when the weight remains constant.

The volatile matter is determined by heating a weighed sample to 950 degrees Celcius. in an inert atmosphere, such as nitrogen. At low temperatures the carboxylic acids decompose to form carbon dioxide. As the temperature increases, the tightly bound ether groups decompose to form carbon monoxide (Francis, 1961). The solid carbonaceous material remaining after devolatilization is composed of fixed carbon and ash. This residue is heated in the presence of oxygen removing all fixed carbon and leaving only the ash. The ash content is measured directly by weighing. The percentage of fixed carbon is determined by the sum of ash content, moisture (as-run), and volatile matter subtracted from 100.

Ash content is determined by heating one gram of coal to 700-750 degrees C. in a contained vessel. This process removes all the organic material. It is important to note that not all of the ash was originally bound in mineral phases, and therefore the ash percentage does not necessarily reflect the mineral abundance in the sample. Also the term ash is not meant to suggest the presence of a true ash (e.g., volcanic ash) in the coal. The term is derived from the analytical determination method.

Ultimate analysis (ASTM, 1983b) determines the total carbon (fixed carbon and carbon in volatile forms), hydrogen, sulfur, nitrogen, ash, and oxygen contents. The ash content is determined with the same method as described above in the proximate analysis. The percentage of carbon and hydrogen is determined by burning a known amount of coal in a closed system and trapping the products in an absorption train. The absorption train is weighed before and after the analysis to the nearest 0.1 milligram. This method includes carbon from carbonates and hydrogen occurring as water of hydration of silicates (ASTM, 1983b).

Sulfur content is determined by burning the coal sample and Eschka mixture to form barium sulfate. The percentage of sulfur is calculated from the amount of sulfate precipitated after ignition. The sulfur content is a combination of inorganically and organically bound phases. The nitrogen percentage is determined by the formation of ammonium salts during destructive digestion of the sample. A mixture of hot, concentrated sulfuric acid and potassium sulfate is used. The precipitated ammonium salts are dissolved and the ammonia separated by distillation. Ammonia, from which the nitrogen content is calculated, is determined by acidimetric titration. The oxygen percentage is calculated as the total ash, carbon, hydrogen, sulfur, and nitrogen contents subtracted from 100.

The heating value, reported in British Thermal Units (BTU), was determined according to ASTM method D 2015-77 (ASTM, 1980c). The BTU value was determined for all lignite and several carbonaceous shale samples used in this study. Heating value determination involves burning a weighed sample in an adiabatic oxygen bomb calorimeter. The calorific value is calculated from the temperature difference before and after combustion. The conversion from calories to BTU value is 1 cal/g. = 1.8 BTU/lb. All reported BTU values are on a moisture-free basis, except where noted.

Proximate and ultimate analyses were performed on a total of 133 samples. These samples were from the previously described locations within the Beulah-Zap lignite (Appendix A). The analyses include samples from the lithobodies occurring in the lignite. Individual lithotypes from several lithobodies were separated and analyzed. Chemical analyses on the maceral level were performed using the scanning electron microprobe. Reported values from the proximate and ultimate analyses are given in Appendix B.

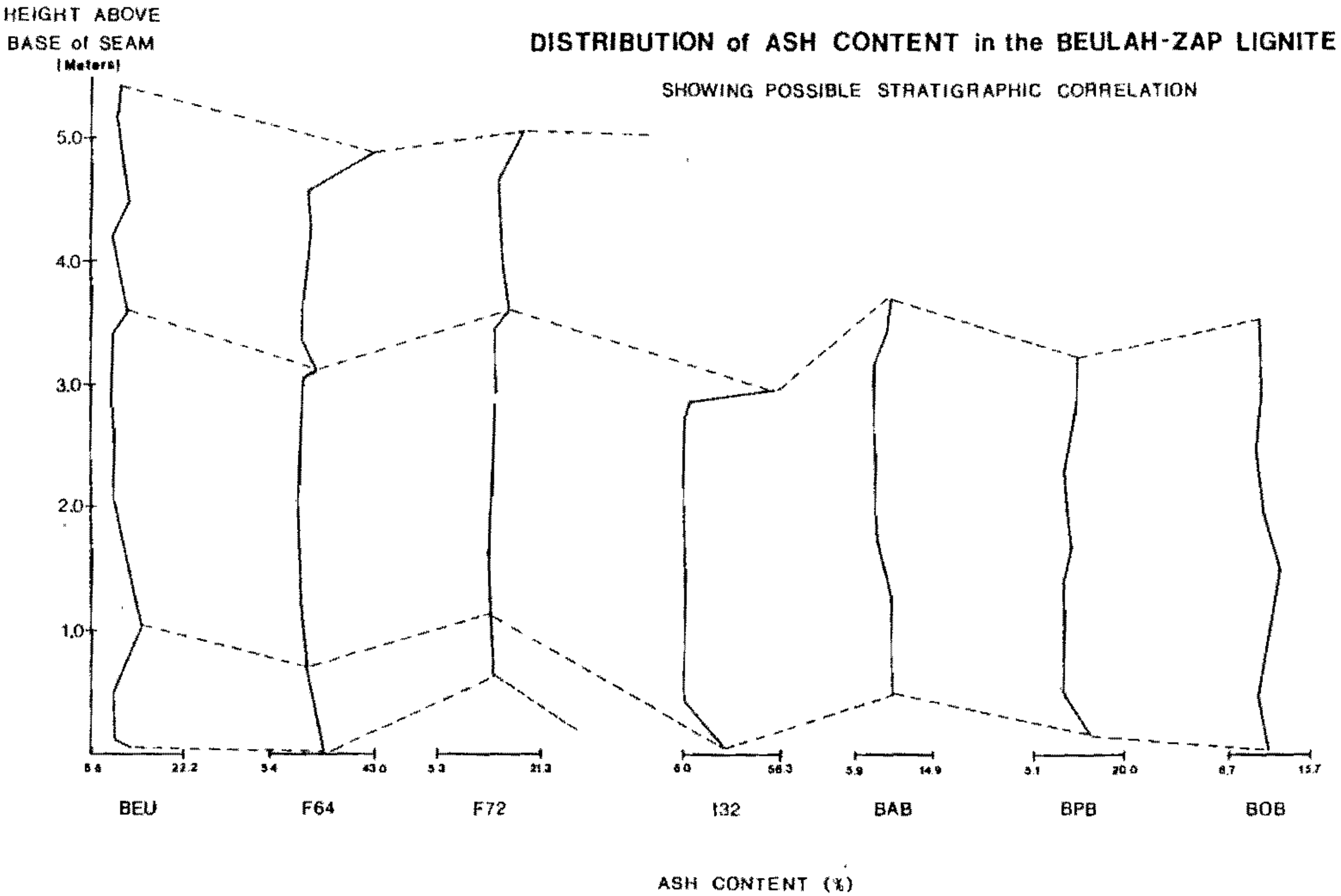
Vertical and Lateral Chemical Distribution

Ash and BTU

The Beulah-Zap lignite bed typically has a higher ash content at the margins (Figure 8). This relationship is persistent throughout the study area. The ash content ranges from 80% to 5% with 13.4% as the mean value for all samples. The middle Beulah-Zap seam has a local clay/silt parting in the southeast portion of the South Beulah Mine. This parting thins to the northwest, where it becomes an inorganic-rich (high-ash) horizon. Discrete mineral grains are difficult to distinguish megascopically in the high-ash horizon. This zone commonly can be distinguished only through chemical analysis (ash content determination) and microscopic examination.

The ash content and BTU value are inversely related, therefore BTU values are typically low at the margins and higher in the middle

Figure 8. Distribution pattern of the ash content for the measured sections located at the South Beulah and Freedom Mines (as determined by proximate and ultimate analyses, moisture free). Compiled from Appendix B.



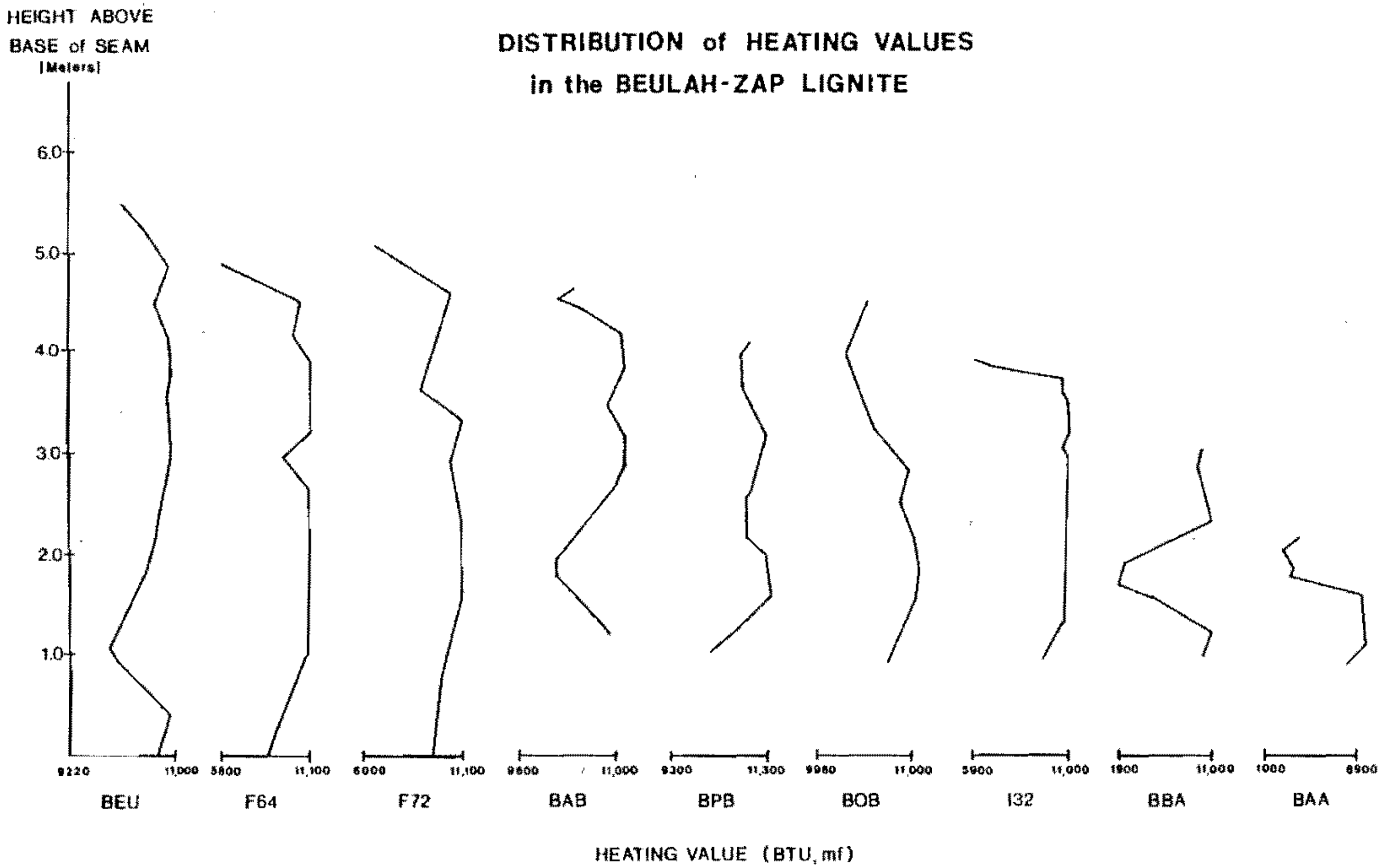
DISTRIBUTION of ASH CONTENT in the BEULAH-ZAP LIGNITE

SHOWING POSSIBLE STRATIGRAPHIC CORRELATION portions of the lignite (Figure 9). The mean BTU value of the Beulah-Zap lignite is approximately 10,000 (on a moisture-free basis). This average value places the Beulah-Zap lignite in the sub-bituminous rank according to ASTM classification (Stach et al., 1982). The discrepancy in the rank classification is probably due to the inability to accurately determine the moisture content. The BTU value and the moisture content have a strong inverse relationship.

Fixed Carbon and Total Carbon Fixed and total carbon have similar vertical and lateral distribution patterns as the BTU value (Figures 10 & 11). A strong relationship between the carbon content and the BTU value can be shown by a Pearson Product-moment correlation analysis. The calculated positive correlation value is r=0.988 (Figure 12). The total carbon content ranges in value from 7% to 68% (moisture-free basis) with the average of 61%. The extremely low value is from a horizon which contains up to 80% inorganic material.

Volatile Matter, Oxygen, and Hydrogen These three components have similar and possibly related distribution characteristics. The distribution patterns show that these components are more closely related to the carbon-rich (fixed and total carbon) portions. This relationship is typical throughout the study area (Figure 13). The volatile matter and hydrogen contents are commonly used to determine the degree of coalification (Stach et al., 1982). The abundance of both these components decreases as the degree of coalification increases. Neither of these components decreases significantly until the coal reaches the rank of medium volatile bituminous coal. The application of volatile matter and hydrogen content for the distinction between coal of ranks lower than bituminous is somewhat subjective (Stach et al.,

Figure 9. Distribution pattern of the heating value for the Beulah-Zap (reported as moisture free, in BTU). Compiled from Appendix B.



DISTRIBUTION of HEATING VALUES in the BEULAH-ZAP LIGNITE

Figure 10. Distribution pattern of the fixed carbon content for the Beulah-Zap lignite (moisture free). Compiled from Appendix B.

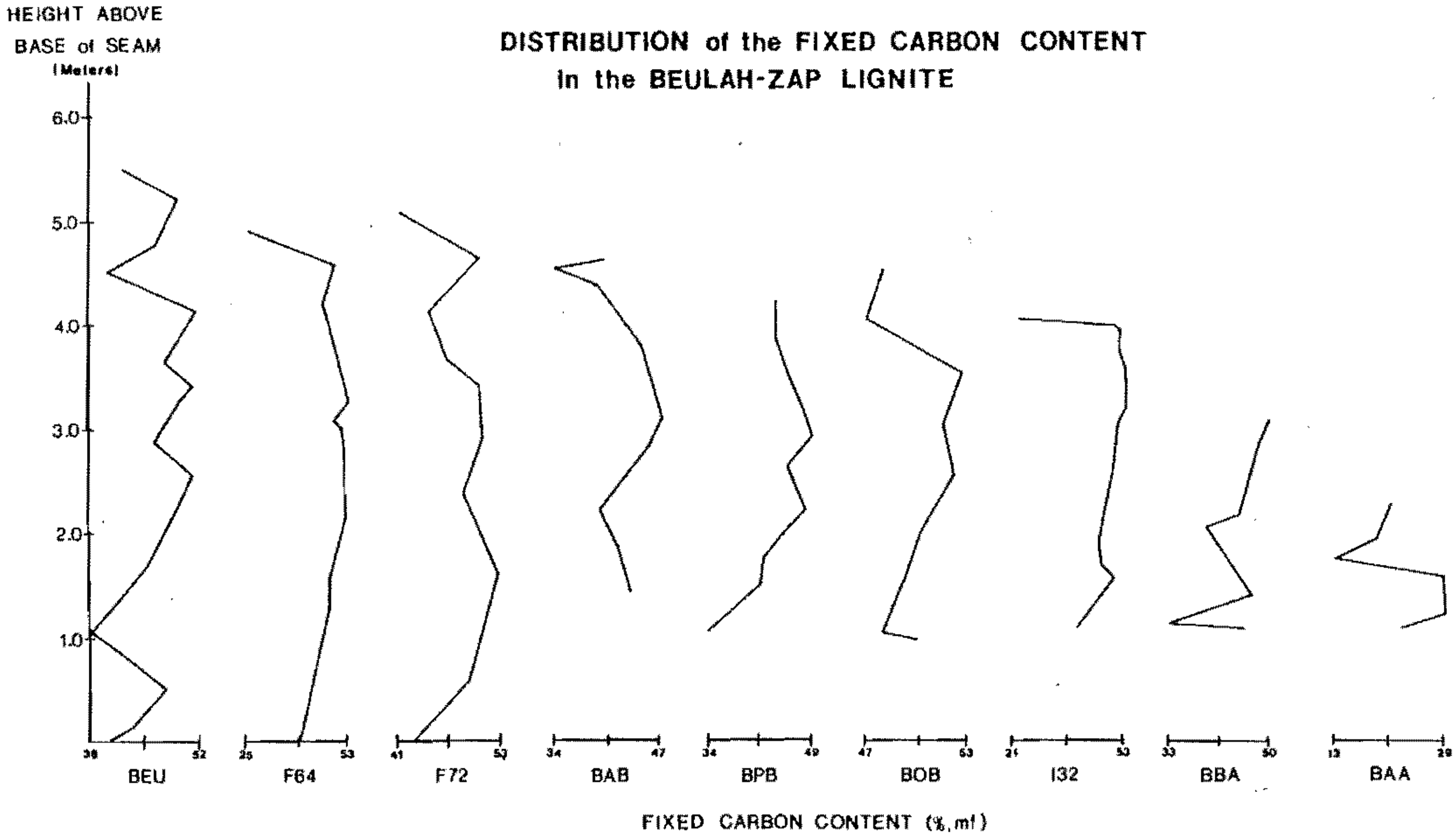
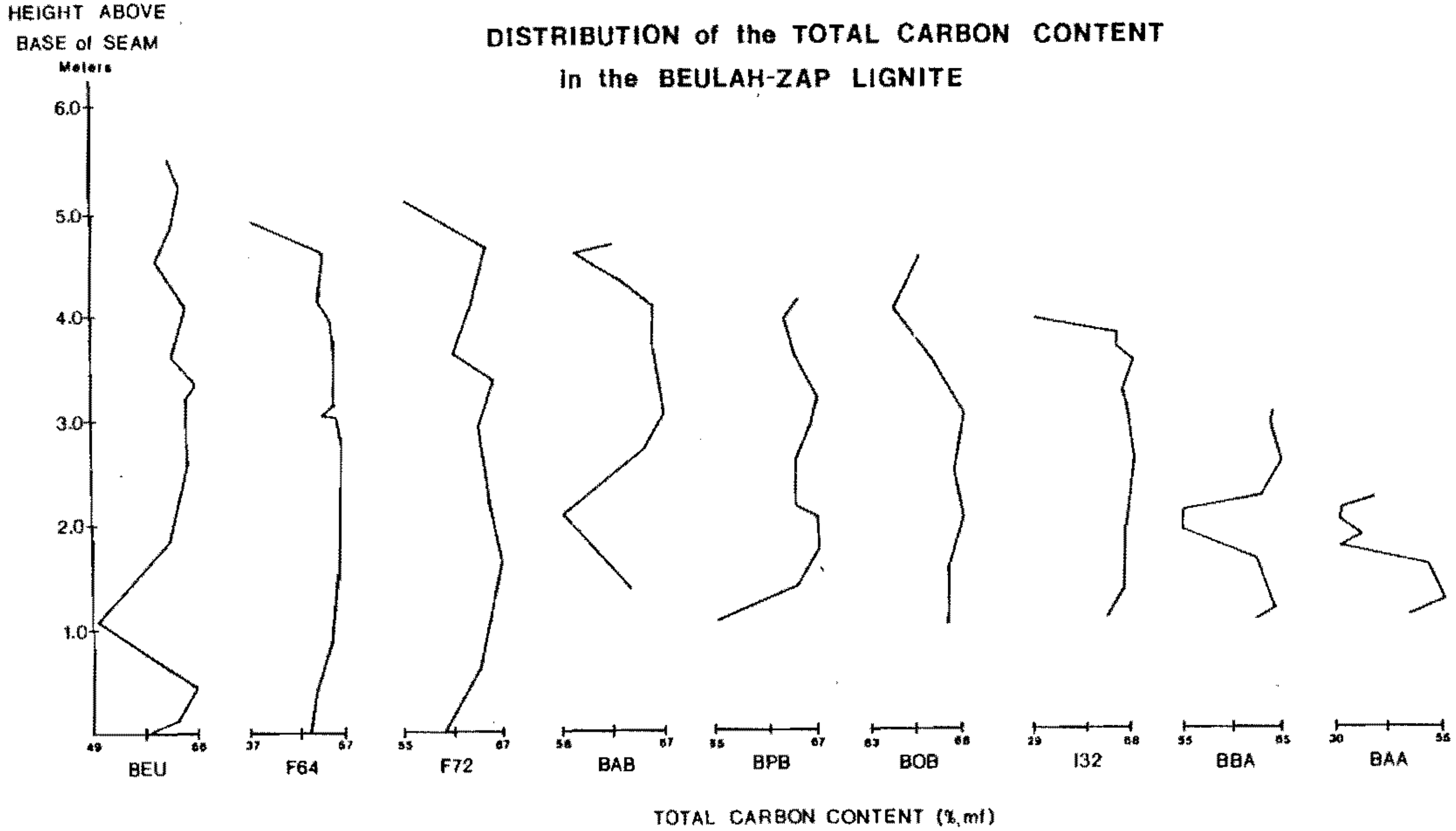


Figure 11. Distribution pattern of the total carbon content for the Beulah-Zap lignite (as determined by proximate and ultimate analyses, moisture free). Compiled from Appendix B.



DISTRIBUTION of the TOTAL CARBON CONTENT in the BEULAH-ZAP LIGNITE

Figure 12. Scatter diagram showing the Relationship between the total carbon content and heating value. Compiled from Appendix B.

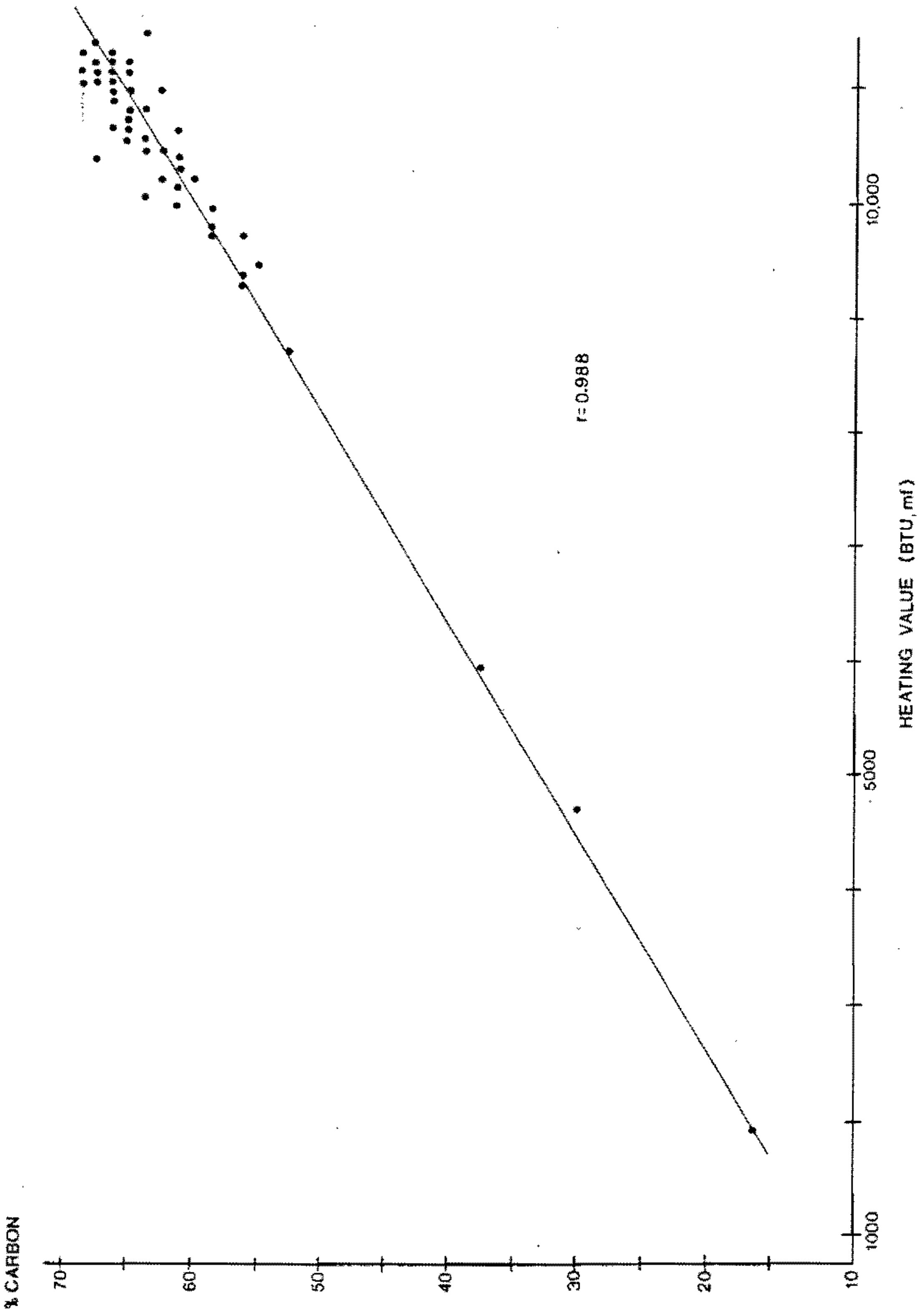
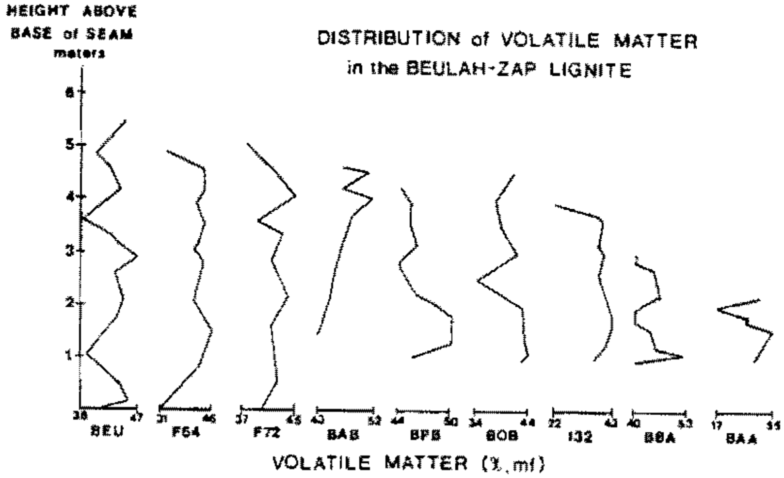
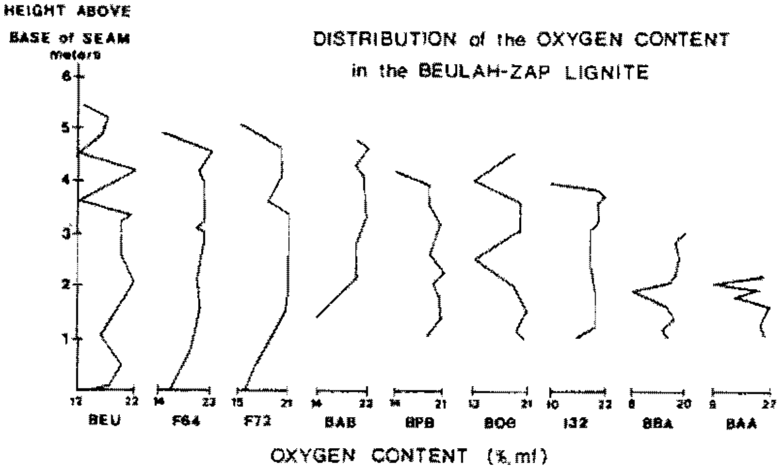

% CARBON
70
60
50
40
30
20
10
1000
5000
10,000
HEATING VALUE (BTU,mf)
r=0.988

Figure 13. Distribution patterns of : A) the volatile matter, B) oxygen, and C) hydrogen contents for the Beulah-Zap lignite (as determined by proximate and ultimate analyses, moisture free). Compiled from Appendix B.

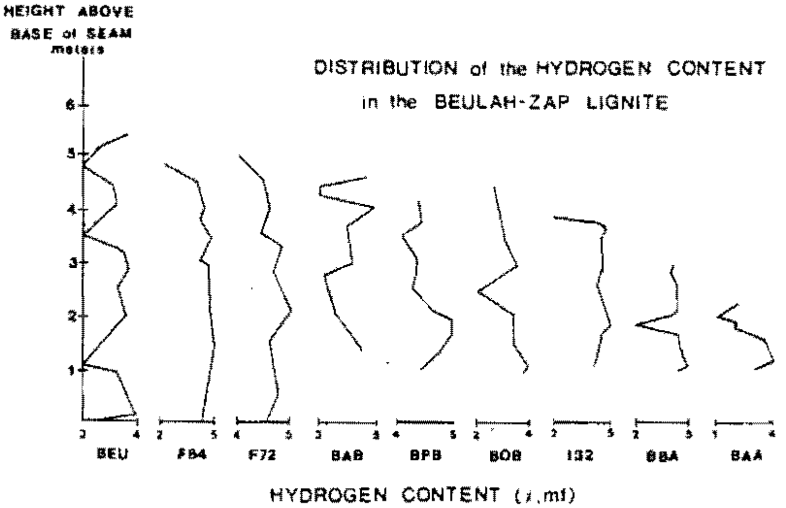
A.


HEIGHT ABOVE BASE of SEAM meters
DISTRIBUTION of VOLATILE MATTER in the BEULAH-ZAP LIGNITE
6
5
4
3
2
1
38
47
BEU
31
46
F64
37
45
F72
43
52
BAB
44
50
BPB
34
44
BOB
22
43
132
40
53
BBA
17
35
BAA
VOLATILE MATTER (%,mf)

B.


HEIGHT ABOVE BASE of SEAM meters
DISTRIBUTION of the OXYGEN CONTENT in the BEULAH-ZAP LIGNITE
6
5
4
3
2
1
17
22
BEU
14
23
F64
15
21
F72
14
22
BAB
14
21
BPB
13
21
BOB
10
22
132
8
20
BBA
8
27
BAA
OXYGEN CONTENT (%,mf)

C.


HEIGHT ABOVE BASE of SEAM meters
DISTRIBUTION of the HYDROGEN CONTENT in the BEULAH-ZAP LIGNITE
6
5
4
3
2
1
3
4
BEU
2
5
F84
4
5
F72
3
4
BAB
4
5
BPB
2
4
BOB
2
5
132
2
3
BBA
1
4
BAA
HYDROGEN CONTENT (%,mf)

1982). The oxygen content is also used in coal rank determination. The oxygen content is most often used in conjunction with the carbon content expressed as the ratio of carbon to oxygen (atomic weight percent). As the degree of coalification increases, so does the C/O value. Average values for Beulah-Zap lignite volatile matter, oxygen, and hydrogen are given in Table 7.

Nitrogen and Sulfur These two components are discussed together because of their inverse distribution relationship. The sulfur content is almost always higher at the top of the lignite than at the base (Figure 14). The sulfur content is not always related to the ash content. In several locations the sulfur content can be directly related to pyrite/marcasite occurrence. Average value for the sulfur content is 1.2% with a range from 4.4% to 0.1%.

The nitrogen content fluctuates more than sulfur, but has an overall increasing trend from the top to the bottom of the lignite (Figure 15). The nitrogen content generally is higher immediately above inorganically rich horizons. Nitrogen values are given in Table 7 and Appendix B.

Megascopic Associations

Lithotypes Lithotypes from two measured sections, BAB and BPB from the South Beulah Mine, were physically separated and analyzed. The proximate and ultimate analyses were performed on each lithotype. The analyses could not be performed on the fusain lithotype from all sampling localities due to the limited quantities available.

The results of the chemical analyses are in agreement with previously published data (ICCP, 1975). The ICCP (2nd supplement, 1975)

Table 7. Average chemical composition of Beulah-Zap lignite as determined by proximate and ultimate analyses (Appendix B). (%, Moisture-free basis)

Component	Mean	Maximum	Minimum	Std. Dev.
Volatile Matter	42.7	55.3	17.3	5.9
Fixed Carbon	43.9	53.8	2.7	10.0
Ash	13.4	80.0	5.1	13.2
Hydrogen	3.8	5.7	1.2	0.8
Total Carbon	60.9	68.4	8.7	10.8
Nitrogen	1.0	1.6	0.3	0.3
Sulfur	1.2	4.4	0.1	1.0
Oxygen	19.7	27.4	8.2	3.0
BTU	10,051	11,417	1,077	1,922

Figure 14. Distribution pattern of the sulfur content for the Beulah-Zap lignite (as determined by proximate and ultimate analyses, moisture free). Compiled from Appendix B.

Sulfur Distribution in Beulah-Zap Lignite

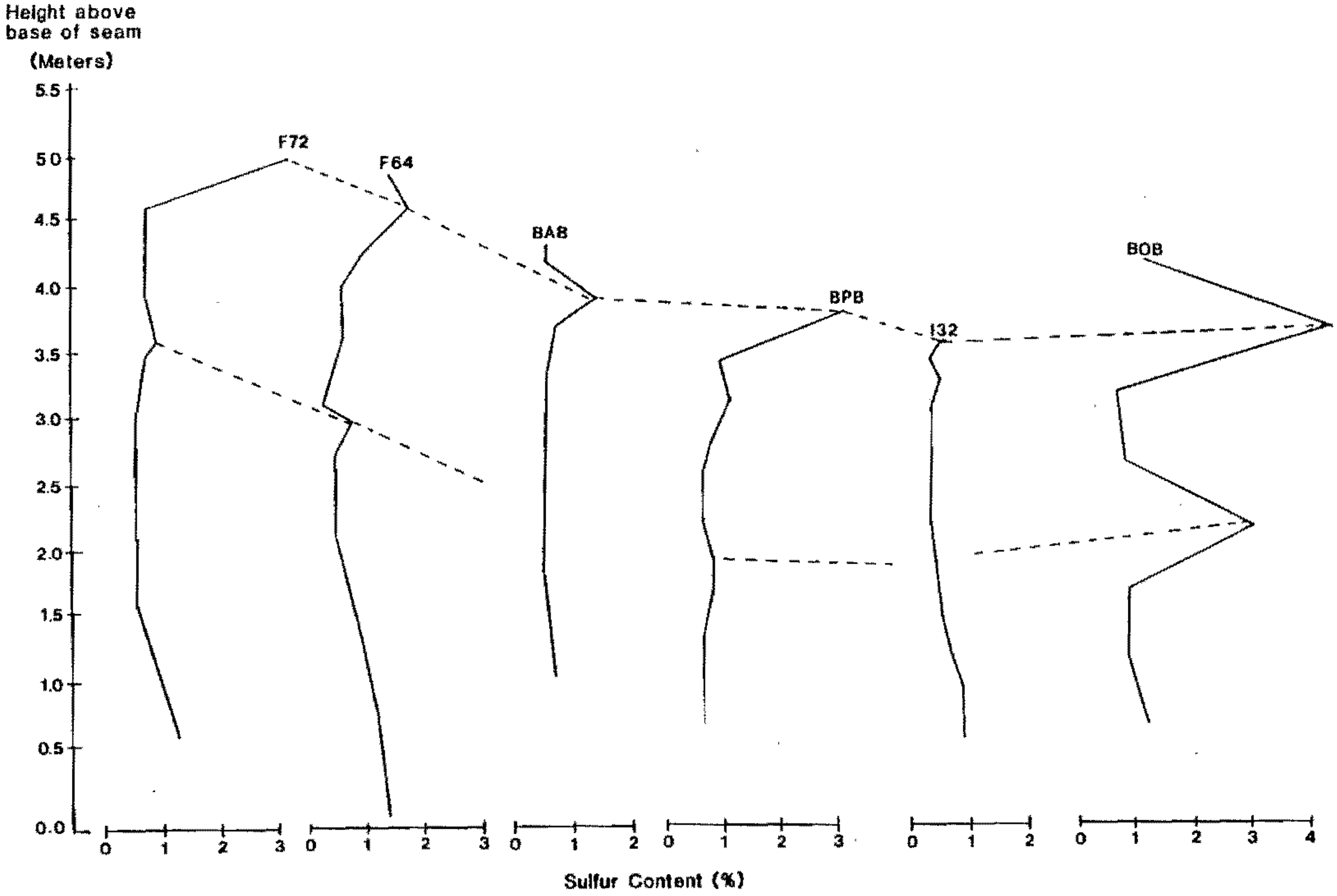
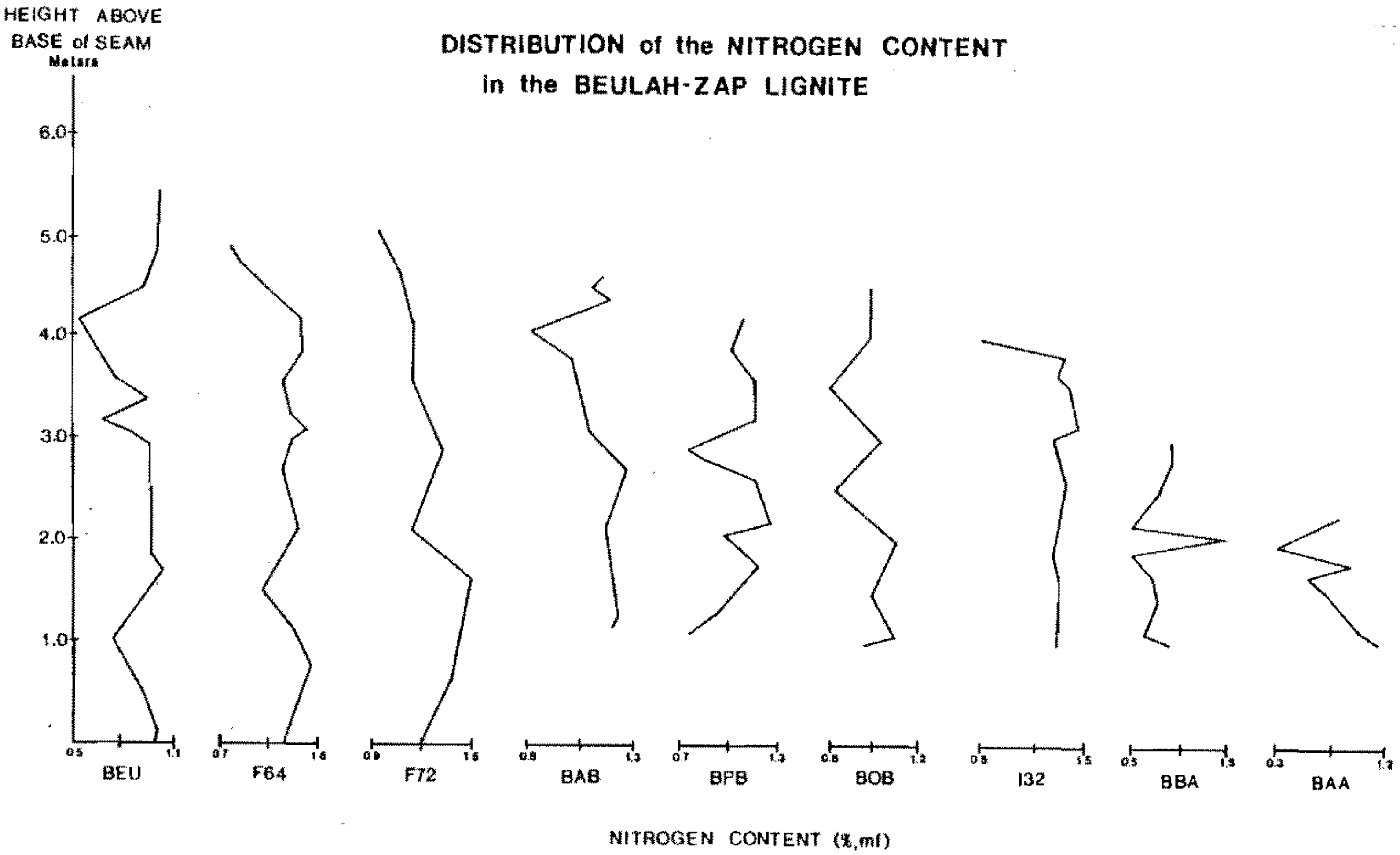


Figure 15. Distribution pattern of the nitrogen content for the Beulah-Zap lignite (as determined by proximte and ultimate analyses, moisture free). Compiled from Appendix B.



DISTRIBUTION of the NITROGEN CONTENT in the BEULAH-ZAP LIGNITE reports analyses on coal which has been separated into the various macerals. Since the Beulah-Zap vitrain is mostly ulminite (63%), and fusain has high percentages of fusinite and semifusinite (45%); the lithotype and maceral chemical data can be compared to the ICCP values (Table 8). The attritus lithotype has a variable maceral composition, therefore can not be directly compared to ICCP values. The average values of the Beulah-Zap lignite fall within the range of data reported for several European lignites. The Beulah-Zap lithotype chemical analyses are from a limited data base; therefore it is not known whether these analyses are truly representative of the entire Beulah-Zap lignite.

Analyzing individual lithotypes separated from each lithobody would have been both time consuming and costly. An alternative method for comparing the lithotype chemical characteristics was attempted. This alternative method was performed by plotting each chemical component determined by proximate and ultimate analyses versus the relative height above the base of the seam. This procedure produced nine vertical profiles for each measured section. The relative abundances of the three lithotypes versus height were also plotted. The two sets of profiles were visually compared to determine whether trends of the chemical data could be directly attributed to lithotype occurrence.

The results of this experiment showed that vitrain was responsible for most of the variation of the basic chemical characteristics in the Beulah-Zap lignite. The total carbon, volatile matter, hydrogen, nitrogen content, and heating value had vertical distribution patterns which were most often related to vitrain occurrence. This may suggest that the Beulah-Zap vitrain has similar chemical characteristics

Table 8. Average chemical composition, as determined by proximate and ultimate analyses, from several European lignites.
(after ICCP, 1975)

Maceral	Carbon	Hydrogen	Oxygen	Nitrogen	Sulfur	Ash	Vol. Mat.
Ulminite	65.8	N.D.	24.8	2.2	2.6	12.7	N.D.
Attrinite	68.3	5.6	24.5	1.1	0.5	6.6	N.D.
Attrinite	63.8	4.9	28.7	0.7	1.9	6.2	N.D.
Attrinite	65.8	4.7	28.6	0.8	N.D.	5.3	N.D.
Desinite	64.8	4.9	28.9	1.4	N.D.	4.0	N.D.
Fusinite	70.9	3.9	N.D.	0.6	0.3	4.3	N.D.
Fusinite	74.3	4.0	20.3	0.9	0.5	N.D.	38.2
Fusinite	76.9	3.5	N.D.	0.6	0.8	9.6	28.8
Semifusinite	76.2	3.9	19.9	(*)	(*)	4.7	N.D.
Semifusinite	74.8	3.7	20.9	0.6	(*)	12.1	44.4
Semifusinite	71.4	4.2	15.9	1.4	6.6	22.4	45.3

N.D.= Not Determined.
(*) = Combined with Oxygen Value.

throughout the coal bed. The attritus lithotype also contributed to the nitrogen and volatile matter content distribution. The ash content distribution appears to be influenced by the occurrence of attritus, and to a lesser extent, fusain. This relationship is not in agreement with the data collected from the separated lithotypes (Table 9). The analyses of the separated lithotypes indicated that fusain has the highest ash content.

Lithobodies

The basic chemical components (as determined by proximate and ultimate analyses) of the Beulah-Zap lithobodies were examined. The lithobody classification, as previously discussed, was based entirely on megascopic characteristics. The chemical data from each sampling location were subjected to identical factoring and clustering statistical analyses as the lithotype data. The purpose of this experiment was to see if the same sample clustering, as in the lithobody classification, would occur using the chemical data. The results of this test showed that identical clustering does not occur. Instead many small clusters were formed with very little similarity to the lithotype-defined lithobodies. As a check of the clustering routine results, the next step in this experiment was to compare the chemical data of the lithobodies. Table 10 gives the range and average chemical values of the six lithobodies. The different lithobodies do not have unique chemical assemblages, as determined by proximate and ultimate analyses. This is not meant to suggest that the lithobodies do not have different chemical properties other than those determined for this report. Analyses presently being performed at UNDERC with Beulah-Zap

TABLE 9. Chemical composition of the separated Beulah-Zap lithotypes, as determined by proximate and ultimate analyses. (weight percent, moisture-free basis)

HT = Height above base of seam (in meters); VM = Volatile Matter; FC = Fixed Carbon
I.D. = Sample Identification (see Appendix A for sample descriptions)
ND = Not Determined.

I.D.	LITHOTYPE	HT	VM	FC	ASH	H	C	N	S	O	BTU
BAB-2	FUSAIN	3.67	38.7	22.0	39.3	2.98	36.58	0.74	0.43	19.97	6224
BAB-2	VITRAIN	3.67	48.6	40.9	10.5	4.42	61.22	1.05	0.63	22.18	10509
BAB-2	ATTRITUS	3.67	47.3	40.0	12.7	3.80	59.34	1.09	0.52	22.55	10003
BAB-4	FUSAIN	3.15	39.4	51.7	8.9	ND	ND	ND	ND	ND	ND
BAB-4	VITRAIN	3.15	46.7	47.7	5.4	ND	ND	ND	ND	ND	ND
BAB-4	ATTRITUS	3.15	49.2	43.5	7.3	ND	ND	ND	ND	ND	ND
BAB-5	FUSAIN	2.71	42.5	50.6	6.9	3.69	65.58	0.97	0.36	22.50	11227
BAB-5	VITRAIN	2.71	51.2	44.5	4.3	4.96	65.67	0.50	0.73	23.84	11516
BAB-5	ATTRITUS	2.71	42.5	50.1	7.4	3.84	64.20	1.00	0.40	23.16	10957
BAB-7	FUSAIN	1.71	40.2	49.8	10.0	3.32	64.80	0.74	0.43	20.71	10786
BAB-7	VITRAIN	1.71	46.5	45.4	8.1	4.27	63.28	0.96	0.45	22.94	10744
BAB-7	ATTRITUS	1.71	44.4	47.8	7.8	4.12	63.40	0.98	0.44	23.26	10676
BAB-8	FUSAIN	1.26	ND	ND	ND	ND	ND	ND	ND	ND	ND
BAB-8	VITRAIN	1.26	45.3	47.9	6.8	4.78	63.86	0.68	0.71	23.17	11334
BAB-8	ATTRITUS	1.26	43.4	50.4	6.2	4.22	65.01	1.00	0.47	23.10	11159
BAB-10	FUSAIN	0.49	38.5	51.4	10.1	3.59	65.50	0.54	1.53	18.74	11185
BAB-10	VITRAIN	0.49	47.1	48.0	4.9	4.96	65.66	0.58	1.03	22.87	12149
BAB-10	ATTRITUS	0.49	47.0	44.8	10.2	4.29	63.08	0.82	0.55	23.06	11075

TABLE 9 continued,

BPB-2	VITRAIN	3.20	47.7	43.6	8.7	4.22	65.04	1.39	1.67	18.99	10841
BPB-2	ATTRITUS	3.20	45.2	48.6	6.2	3.84	67.71	2.00	0.78	19.47	11016
BPB-3	VITRAIN	2.90	45.0	47.4	7.6	4.27	63.69	1.21	0.97	22.57	10613
BPB-3	ATTRITUS	2.90	47.3	42.0	10.7	4.10	62.04	1.54	0.84	20.78	10418
BPB-4	VITRAIN	2.59	49.0	47.0	4.0	4.66	67.78	0.97	0.89	21.69	11627
BPB-4	ATTRITUS	2.59	42.2	50.2	7.6	3.76	65.86	1.18	0.98	20.65	10725
BPB-5	VITRAIN	2.29	47.3	46.4	6.3	4.10	65.51	1.56	0.69	21.84	10786
BPB-5	ATTRITUS	2.29	43.4	50.6	6.0	3.62	67.46	1.28	0.66	20.98	10923
BPB-6	VITRAIN	1.98	49.0	46.0	5.0	4.10	65.71	1.11	0.75	23.33	10774
BPB-6	ATTRITUS	1.98	41.8	51.0	7.2	3.55	66.01	1.20	0.54	21.49	10618
BPB-7	VITRAIN	1.68	48.0	46.4	5.6	4.15	65.24	1.55	0.73	22.73	10699
BPB-7	ATTRITUS	1.68	44.5	47.3	8.2	4.08	63.27	1.38	0.57	22.50	10673
BPB-8	VITRAIN	1.37	47.4	48.5	4.1	4.17	64.56	0.92	0.78	25.48	10980
BPB-8	ATTRITUS	1.37	48.6	45.4	6.0	4.22	65.83	0.91	0.80	22.24	10826
BPB-9	VITRAIN	1.07	54.9	38.8	6.3	4.18	64.37	0.80	0.82	23.53	10854
BPB-9	ATTRITUS	1.07	56.6	36.3	7.1	4.39	64.98	0.92	0.85	21.76	10789
BPB-10	VITRAIN	0.76	48.0	46.4	5.6	4.62	65.48	0.76	0.65	22.89	11019
BPB-10	ATTRITUS	0.76	50.6	42.2	7.2	4.68	64.43	0.86	0.75	22.07	10895
BPB-11	VITRAIN	0.45	51.0	43.2	5.8	4.57	64.97	0.78	0.65	23.23	10956
BPB-11	ATTRITUS	0.45	49.6	44.0	6.4	4.73	65.32	0.71	0.69	22.15	10973
BPB-12	VITRAIN	0.15	46.9	44.2	8.9	4.30	62.52	0.21	0.73	23.34	10461
BPB-12	ATTRITUS	0.15	47.3	38.1	14.6	4.15	58.83	0.67	0.82	20.94	9720

Table 10. Average chemical composition of Beulah-Zap lithobodies as determined by proximate and ultimate analyses (Appendix B). (mean %, Moisture free basis)

COMPONENT	LITHOBODY A	 B	 C	 D	 E	 F
Volatile Matter	41.22	43.05	43.03	43.78	44.41	37.15
Fixed Carbon	50.81	47.81	46.92	46.56	46.78	30.58
Ash	7.97	9.14	10.05	9.65	8.81	32.27
Hydrogen	3.59	3.78	4.09	3.81	4.36	3.18
Total Carbon	66.61	65.16	64.18	64.22	64.66	46.47
Nitrogen	1.01	0.98	1.08	1.08	1.14	0.88
Sulfur	1.20	1.45	1.24	1.01	1.04	0.97
Oxygen	19.80	19.48	19.36	20.22	19.99	16.22
BTU	10,890	10,699	10,594	10,558	10,835	7,457

lignite lithobodies show significant differences in the abundances of water-soluble pyrolysis products, such as methanol and phenol (Ross, 1985). Future lithobody characterization will need to include the abundances of various organic compounds. The distribution of the pyrolysis-produced compounds appears to be more closely related to the lithotypes than do the components determined by proximate and ultimate analyses.

Scanning Electron Microscope/Microprobe

Inorganic elements, in major or trace amounts, have several modes of occurrence in lignite. The two main categories are: 1) elements directly associated with mineral phases down to sub-micron size (Finkelman, 1980), and 2) adsorbed elements bound to organic functional groups such as carboxylic acids (Given, 1984). This study served as the initial phase for an ongoing SEM/microprobe project at UNDERC. The purpose of this study, with respect to the SEM/microprobe, was to investigate the possibility of using such techniques for the chemical characterization of lignite components. Techniques examined include sample preparation, standardization of equipment for analyzing organic-rich materials, and statistical approaches for evaluating data.

Sample Preparation

The Beulah-Zap lignite samples used for microprobe analyses were the same epoxy pellets used for reflected light microscopy. The preparation procedure was previously discussed in the maceral section. The epoxy pellets were carbon coated prior to microprobe analysis.

Several coals were obtained from the National Bureau of Standards (NBS) for equipment standardization. These samples were received crushed to approximately 60 mesh. The standards were first vacuum-dried, then pulverized to 325 mesh in an alumina vessel with a Spex shatter box. The alumina vessel was used instead of tungsten carbide to keep possible contamination to a minimum. The alumina vessel does not introduce significant sample contamination (Hurley, 1985). After pulverizing, the coal standards were pressed into 1.25 inch diameter sample cups. The pressing procedure was accomplished by applying 12 to 15 tons of pressure per square inch in a hydraulic press for approximately one minute. The pressure must be released slowly (1 to 2 minutes) or the sample will rebound causing an irregular surface, useless for x-ray analyses. The pressed pellet should be kept in a desiccator with a fresh supply of desiccant (e.g., anhydrite).

Analytical Procedure

The SEM/microprobe was used to examine the inorganic elements associated with the Beulah-Zap lignite (Karner et al., 1984). An energy-dispersive detection system was used for quantitative elemental analysis. The major problem encountered was finding an elemental standard with similar chemical properties of the lignite to be examined. Four organic-rich materials, as previously stated, were purchased from the National Bureau of Standards (NBS). These materials included two subbituminous coals, NBS-1635 and NBS-1632a. The two other organic standards used from NBS were pine needles and tomato leaves. The elemental composition of these two standards was too dissimilar to lignite. The subbituminous coal NBS-1635 was chosen as the best standard to use in this project. The composition of this standard was similar to values expected for lignite and could be accurately reproduced with our analytical equipment (SEM/microprobe).

Lignite analysis was performed under the following equipment conditions: 1) beam current at 15 kev, 2) sample current at approximately 1000 picoamps, and 3) analysis time of 400 seconds. The scan area of the analyses ranged from approximately one to ten square microns. All data collected were stored by a Tracor Northern 2000 data reduction system.

Analyzing materials with low atomic weight matrices (e.g., organic compounds) can cause problems which may affect quantitative results. The causes of these problems may include: 1) the average atomic weight density of the target, 2) x-ray absorption due to interaction with the other elements of the sample, and 3) parasitic fluorescence caused by differences in characteristic elemental x-ray peak intensities (Goldstein et al., 1981). A computer program (ZAF) was used to correct for these three factors of the individual elements studied. The major elements determined in this study were Na, Mg, Al, Si, S, K, Ca, Ti, and Fe. The minor elements include Cl, P, and Mn. Most if not all of the chlorine found was introduced during sample preparation from the chlorine-rich epoxy mounting medium. The carbon, hydrogen, nitrogen, and oxygen contents were combined into one value. This value was determined by difference.

Chemistry of Coal Components

Lithotypes Separated lithotypes from the BAB sample channel were analyzed with the SEM/microprobe. Each of the three lithotypes were examined from the top, middle, and base of the seam. Twenty analyses of each lithotype were taken for this portion of the study. The locations of the analyses were based on observable morphologic components including fractures, cell walls, cell interiors, and massive areas (Karner et al., 1984). Positive identification of individual macerals could not be made using either the SEM/microprobe's optical microscope or electron image. The relative reflectance needed to distinguish macerals is not present in the scanning electron microscope.

Each of the lithotypes was found to have a wide variation in chemical characteristics (Table 11). This is most likely because the lithotypes are composed of a mixture of different macerals, which in turn, also vary in chemical composition (ICCP, 1963 and 1975).

The principal component factoring and clustering tests were used to determine whether the chemical data would group into the respective lithotypes. The chemical data did not cluster into lithotype groups. The clustering results indicate that the differences within the lithotypes are at least as significant as the variation between them. Since the chemical variation is probably related more to the maceral composition, the next step in the investigation was to analyze individual macerals.

Macerals and Maceral Groups Since macerals can not be identified by SEM electron images (secondary or backscattered), the macerals were first located and classified using reflected light microscopy. Individual macerals were marked with rub-on (Zipatone) circles. The

TABLE 11. Elemental analytical data of the separated Beulah-Zap lithotypes, as determined by SEM/microprobe.

I.D.	LITHOTYPE	Na	Mg	Al	Si	P	S	Cl	K	Ca	Ti	Mn	Fe	C+H+N+O
BAB10	Fusain	0.38	0.32	0.05	0.05	0.00	0.39	0.02	0.02	1.24	0.03	0.00	0.14	97.37
BAB10	Fusain	0.09	0.05	0.00	0.04	0.01	0.04	0.25	0.02	0.11	0.00	0.00	0.05	99.33
BAB10	Fusain	0.19	0.16	1.18	1.53	0.00	0.31	0.04	0.05	0.62	0.00	0.00	0.60	95.33
BAB10	Fusain	0.02	0.02	0.00	0.06	0.02	0.00	0.32	0.00	0.03	0.00	0.02	0.10	99.42
BAB10	Fusain	0.14	0.13	0.01	0.08	0.00	0.20	0.02	0.00	0.57	0.00	0.00	0.04	99.81
BAB10	Fusain	0.03	0.06	0.00	0.04	0.00	0.06	0.28	0.00	0.09	0.03	0.00	0.08	99.34
BAB10	Fusain	0.57	0.43	0.18	0.11	0.00	0.52	0.05	0.00	1.51	0.02	0.00	0.14	96.46
BAB10	Fusain	0.46	0.33	0.66	0.77	0.00	0.21	0.08	0.04	1.13	0.00	0.03	0.10	96.19
BAB10	Fusain	0.50	0.48	0.10	0.06	0.00	0.37	0.04	0.04	1.78	0.00	0.00	0.23	96.39
BAB-1	Fusain	0.21	0.23	0.02	0.06	0.00	0.17	0.07	0.00	1.04	0.00	0.02	0.05	98.14
BAB-1	Fusain	0.15	0.15	0.00	0.06	0.00	0.12	0.07	0.02	0.64	0.00	0.00	0.05	98.73
BAB-1	Fusain	0.21	0.20	0.02	0.06	0.00	0.16	0.07	0.00	0.79	0.04	0.00	0.00	98.45
BAB-1	Fusain	0.30	0.26	0.01	0.08	0.00	0.13	0.09	0.00	1.19	0.00	0.00	0.15	97.78
BAB-1	Fusain	0.33	0.33	0.02	0.07	0.00	0.17	0.06	0.00	1.51	0.02	0.00	0.16	97.32
BAB-1	Fusain	0.20	0.21	0.01	0.07	0.00	0.16	0.04	0.00	0.80	0.00	0.03	0.10	98.38
BAB-7	Fusain	0.23	0.19	0.01	0.05	0.00	0.27	0.07	0.03	0.71	0.00	0.00	0.09	98.34
BAB-7	Fusain	0.28	0.18	0.02	0.07	0.00	0.26	0.09	0.00	0.72	0.00	0.00	0.00	98.38
BAB-7	Fusain	0.60	0.55	0.07	0.08	0.00	0.35	0.06	0.00	1.91	0.02	0.00	0.21	96.16
BAB-7	Fusain	0.56	0.36	1.56	1.57	0.00	0.52	0.12	0.04	1.26	0.04	0.00	0.08	93.88
BAB-6	Vitrain	0.48	0.24	0.32	0.06	0.00	0.47	0.03	0.05	0.90	0.02	0.00	0.16	97.27
BAB-6	Vitrain	0.45	0.22	0.29	0.06	0.00	0.48	0.00	0.03	0.89	0.02	0.00	0.08	97.47
BAB-6	Vitrain	0.35	0.19	0.32	0.08	0.00	0.45	0.00	0.03	0.74	0.03	0.00	0.12	97.70
BAB-6	Vitrain	0.79	0.21	0.42	0.22	0.01	0.51	0.41	0.10	0.98	0.02	0.00	0.09	96.24
BAB-6	Vitrain	0.39	0.19	0.36	0.06	0.00	0.45	0.04	0.02	0.78	0.00	0.00	0.00	97.72
BAB-6	Vitrain	0.50	0.21	0.30	0.06	0.00	0.46	0.00	0.01	0.87	0.02	0.03	0.07	97.46
BAB-1	Vitrain	0.45	0.18	0.30	0.08	0.00	0.89	0.24	0.07	0.88	0.02	0.00	0.08	96.82
BAB-1	Vitrain	0.47	0.19	0.29	0.06	0.00	0.96	0.35	0.02	0.80	0.00	0.00	0.12	96.74
BAB-1	Vitrain	0.46	0.21	0.29	0.07	0.00	0.99	0.48	0.04	0.81	0.03	0.00	0.05	96.56
BAB-1	Vitrain	0.38	0.14	0.21	0.05	0.00	0.66	0.30	0.03	0.65	0.00	0.00	0.10	97.49

Table 11 continued,

I.D.	LITHOTYPE	Na	Mg	Al	Si	P	S	Cl	K	Ca	Ti	Mn	Fe	C+H+N+O
BAB-1	Vitrain	0.40	0.17	0.26	0.05	0.00	0.96	0.34	0.03	0.78	0.00	0.00	0.08	96.93
BAB-1	Vitrain	0.38	0.17	0.29	0.03	0.00	0.97	0.30	0.00	0.77	0.00	0.00	0.15	96.94
BAB-1	Vitrain	0.41	0.18	0.21	0.06	0.00	0.61	0.13	0.00	0.68	0.00	0.00	0.00	97.73
BAB-6	Vitrain	0.44	0.20	0.36	0.07	0.00	0.45	0.00	0.01	0.85	0.00	0.00	0.08	97.55
BAB-6	Vitrain	0.39	0.15	0.35	0.05	0.00	0.46	0.01	0.03	0.72	0.00	0.00	0.08	97.76
BAB-6	Vitrain	0.48	0.18	0.39	0.07	0.00	0.45	0.03	0.02	0.76	0.00	0.03	0.06	97.52
BAB-6	Vitrain	0.51	0.19	0.31	0.07	0.00	0.50	0.03	0.02	0.89	0.03	0.00	0.09	97.36
BAB-6	Vitrain	0.39	0.15	0.34	0.07	0.00	0.48	0.00	0.02	0.68	0.00	0.00	0.08	97.79
BAB-7	Vitrain	0.56	0.44	0.17	0.06	0.00	0.44	0.15	0.00	1.57	0.02	0.00	0.23	96.37
BAB-7	Vitrain	0.68	0.54	0.17	0.05	0.00	0.45	0.05	0.02	1.85	0.03	0.00	0.17	96.01
BAB10	Attritus	0.37	0.13	0.15	0.04	0.00	0.55	0.11	0.00	0.52	0.02	0.00	0.26	97.84
BAB10	Attritus	0.55	0.20	0.23	0.04	0.00	0.72	0.06	0.02	0.85	0.00	0.00	0.13	97.20
BAB10	Attritus	0.41	0.19	0.10	0.04	0.00	0.41	0.06	0.03	0.54	0.00	0.00	0.06	98.16
BAB10	Attritus	0.48	0.21	0.24	0.08	0.00	0.75	0.00	0.01	0.87	0.00	0.02	0.17	97.18
BAB10	Attritus	0.34	0.18	0.19	0.05	0.00	0.56	0.11	0.00	0.65	0.02	0.00	0.15	97.76
BAB10	Attritus	0.57	0.48	0.20	0.09	0.00	0.96	0.01	0.02	1.58	0.08	0.00	0.33	95.68
BAB10	Attritus	0.45	0.24	0.27	0.07	0.00	0.79	0.03	0.00	0.88	0.00	0.00	0.15	97.12
BAB10	Attritus	0.48	0.23	0.26	0.04	0.00	0.75	0.00	0.01	0.87	0.04	0.02	0.11	97.17
BAB10	Attritus	0.49	0.23	0.26	0.04	0.00	0.82	0.04	0.02	0.87	0.02	0.00	0.25	96.96
BAB-7	Attritus	0.71	0.49	0.26	0.09	0.00	0.66	0.02	0.02	1.63	0.02	0.00	0.07	96.03
BAB-7	Attritus	0.37	0.31	0.12	0.07	0.00	0.34	0.25	0.02	1.19	0.03	0.00	0.17	97.15
BAB-7	Attritus	0.63	0.47	0.17	0.14	0.00	0.57	0.03	0.01	1.61	0.04	0.02	0.22	96.09
BAB-7	Attritus	0.55	0.28	0.28	0.07	0.00	0.50	0.02	0.02	1.09	0.06	0.02	0.05	97.06
BAB-7	Attritus	0.72	0.53	0.17	0.05	0.00	0.42	0.09	0.02	1.80	0.05	0.00	0.19	95.95
BAB-7	Attritus	0.67	0.53	0.35	0.26	0.00	0.45	0.06	0.02	1.71	0.02	0.03	0.12	95.78
BAB-7	Attritus	0.64	0.34	0.29	0.06	0.00	0.52	0.02	0.00	1.23	0.04	0.00	0.13	96.72
BAB-7	Attritus	0.32	0.26	0.01	0.07	0.00	0.23	0.09	0.00	1.10	0.03	0.04	0.00	97.86
BAB-7	Attritus	0.43	0.33	0.02	0.06	0.00	0.20	0.94	0.06	1.35	0.00	0.00	0.00	96.59
BAB-7	Attritus	0.35	0.32	0.05	0.06	0.00	0.21	0.55	0.02	1.05	0.02	0.02	0.09	97.27
BAB-7	Attritus	0.59	0.38	0.25	0.13	0.00	0.45	0.05	0.00	1.49	0.06	0.00	0.20	96.40

macerals could then be located and later analyzed with the SEM/microprobe.

The chemical data obtained from the maceral analyses were subjected to the same statistical test as the lithotypes. These tests were performed on the maceral and maceral group levels to determine the possibility of natural grouping. The data base for these statistical tests was small. Two macerals, ulminite and semifusinite, were included in the maceral data. The ulminite had ten analyses, and the semifusinite had only three. All three maceral groups were represented with a total of 20 analyses.

Initial results show that the range in values within the maceral groups is such that natural groupings do not occur. The huminite maceral group chemical data does tend to group together, but both liptinite and inertinite observations do occur within those clusters. The preliminary results involving the individual macerals showed that significant chemical differences may be present. The ulminite data formed one major and a minor group. The semifusinite formed a discrete group from the ulminite. It must again be stated that this work was performed on a small data base and should be considered inconclusive. More work will need to be done in this area in order to expand the data base.

Minerals Discrete mineral grains were observed during the SEM examination of the Beulah-Zap lignite. Quantitative analyses were performed on all observed minerals. The major minerals include quartz, kaolinite, and pyrite. Trace amounts of rutile and monazite also occur in the Beulah-Zap lignite. Quartz was most abundant in the attritus lithotype, occurring as angular to sub-rounded grains ranging in size from 10 to 60 microns. Kaolinite and halloysite occur most frequently near the top of the lignite in the fusinite cell interiors. Halloysite was distinguished from kaolinite on the basis of morphology. Kaolinite occurs as irregular aggregates or in "book-like" structures, whereas the halloysite occurs with circular cross-sections (1 micron dia.). The pyrite was most commonly found associated with the vitrain lithotype. The pyrite occurs as cell fillings or as discrete framboids (20 to 60 microns dia.) contained within the more massive portions of the coal.

X-ray Diffraction

The overburden, underclays, and clay/silt partings associated with the Beulah-Zap lignite were collected and submitted for x-ray diffraction analysis. All analyses were performed on a Phillips 3600-02 x-ray system equipped with an automated mineral search program. The purpose was to examine the mineralogical variation throughout the study area. The overburden and underclay samples were collected near the contact with the lignite.

The results of this study shows that the major minerals in both the overburden and underclays are quartz, muscovite, and dolomite. The minor minerals are plagioclase, pyrite, kaolinite, illite, and chlorite. Very little mineralogical variation occurs between the overburden and underclays (Table 12). This relationship appears to be constant throughout the study area.

Table 12. Overburden and underclay mineralogy at the measured sections as determined by x-ray diffraction.

SAMPLE ID.	TYPE	MINERALS MAJOR	MINERALS MINOR
BAA-a	Overburden	Q., Musc., Dol.	Plag., Chl.
BAA-b	Overburden	Q., Musc., Dol.	Plag., Chl.
BAA-c	Overburden	Q., Musc., Dol.	Plag., Chl.
BAA-d	Overburden	Q., Musc., Cal.	Plag.
BAA-e	Overburden	Q., Musc.	
BAA-g	Underclay	Q., Jarosite	Illite
BAA-h	Underclay	Q., Musc.	Plag., Chl.
BAB-2	Clay Parting	Q., Clays (Al, Si)	
BAB-9	Clay Parting	Q., Musc.	
BAB-11	Underclay	Q., Musc.	Kaol., Pyrite
BAB-12	Underclay	Q., Musc.	Kaol., Pyrite
BPB-1	Overburden	Q., Sid., Plag.	Kaol., Musc.
BPB-13	Underclay	Q., Musc.	Kaol.
F64-800	Overburden	Q., Musc.	Chl.
F64-000	Underclay	Q., Musc.	
F72-500	Overburden	Q., Musc.	
F72-000	Underclay	Q., Musc.	
I32-003	Underclay	Q., Musc.	
I32-002	Underclay	Q., Musc.	
I32-001	Underclay	Q., Musc.	
BOB-1	Overburden	Q.	Lep., Pyrite, Gyp.
BEU 3-7A	Overburden	Q.	
BEU 3-6A	Clay Parting	Q., Musc.	
BEU 3-1A	Underclay	Q.	Musc.

Q = Quartz
Musc = Muscovite
Dol. = Dolomite
Plag. = Plagioclase
Chl. = Chlorite
Sid. = Siderite
Kaol. = Kaolinite
Lep. = Lepidolite
Gyp. = Gypsum

ENVIRONMENT OF DEPOSITION

General

A wide range of possible depositional environments has been proposed for the Tertiary lignitic sequences in the Williston Basin. Previous work involving the reconstruction of these depositional environments has been focused on the inorganic sediments associated with the lignitic sequences. The lignite-bearing strata in Montana, the Fort Union Formation, have been described by Flores (1981) as having two dominant depositional environments. These include fluvial-channel and fluvial-lake dominated facies. Flores (1981) postulates that the fluvial-channel systems produce thick, laterally continuous lignite, whereas the fluvial-lake facies yield thin, discontinuous, shaly coals. Royse (1967) and Winczewski (1982) also use a fluvial-dominated model to explain the depositional environments of the Paleocene in North Dakota. Royse states that well established stable channels are necessary for the development of backswamp (floodplain) environments.

Jacob (1976) examined specifically the upper portion of the Fort Union Group (Paleocene) in North Dakota. On the basis of associated sediments (gray siltstone and claystone), Jacob proposed a lower deltaic plain depositional environment for the lignite formation. The wide lateral extent of the Sentinel Butte and Bullion Creek (formerly Tongue River) Formations suggests that the deltaic flood basins were extensive. This interpretation is supported by the presence and association of characteristic deltaic channel sandstones (Jacob, 1976).

Recent studies of the Sentinel Butte Formation have placed more emphasis on lacustrine depositional models. Logan (1981) considered the possibility of integrated fluvial and lacustrine systems. Wallick (1984) suggested that at least the lower part of the Sentinel Butte deposition was strongly influenced by lacustrine environments with minor fluvial involvement.

The scope of this thesis did not include detailed investigations of the sediments associated with the lignite. A general reconnaissance of the overburden was performed in each mine. The overburden consisted of alternating sandstones, siltstones, and claystones. The individual lithologies appeared to be laterally extensive. Most of the rock units in the study area were poorly indurated, with the exception of several claystones. A channel sand deposit was noted in the overburden of the South Beulah Mine (Bravo Pit). The principal method for investigating the Beulah-Zap depositional sequence was by detailed petrographic characterization of the lignite components.

Origin of Petrographic Components

The lignite composition depends on three interrelated factors: 1) the ecological system, including climate, chemistry of soil and water, 2) plant assemblage, and 3) mode of coalification (Stach et al., 1982). The coal petrographer can form analogies between the present and ancient coal-forming systems by investigating these factors with respect to modern peat forming environments. Past studies in peat deposition suggest that there are at least four major types of plant assemblages.

These include 1) areas of open water with subaquatic plants, 2) reed and herbaceous marshes, 3) forest and bush swamps, and 4) upland moss bogs (Teichmuller and Teichmuller, 1958). Plant assemblages combined with the degree and mode of coalification produce characteristic petrographic constituents (lithobodies, lithotypes, and macerals) which can be used to determine the depositional environment. A brief discussion of the more important constituents is presented below.

Megascopic Constituents

The lithobodies are composed of varying lithotype mixtures. The lithotype origins have been ranked on the basis of the relative water depth in which they were formed (Stach et al., 1982; ICCP, 1975; van Krevelen, 1961).

Fusain

Fusain forms in the driest swamp conditions. One possible origin of fusain is fire, although rapid, aerobic biochemical oxidation may also contribute to its formation (Marshall, 1953 and Stach et al., 1982). In either situation, some degree of subaerial exposure is assumed. Fusain is formed in periods of slow subsidence or low groundwater levels.

Vitrain

The bright, xylonitic (woody) portions of the lignite represent possible flooding of the swamp environment. The water level was moderate (3 to 4 feet deep) and stable. Trees and other woody plants were capable of developing. When the trees fell into the swamp, the water level was sufficiently deep and stagnant enough to retard complete oxidation. Vitrain layers are representative of steady, rapid subsidence. The material deposited under these conditions was buried rapidly, under anaerobic conditions, hindering physical and biochemical degradation.

Attritus

This lithotype forms in relatively deep (5 to 7 feet), stagnant water. The subsidence and burial rate was low, causing excessive degradation of the vegetable material. The deeper water also influenced the original plant type. The attritus lithotype may represent a more herbaceous material (reeds, sedges, algae).

Carbonaceous Shale

This facies repesents the deepest water environment examined in this study. The carbonaceous shale formed in water more than 7 feet deep. The organic fraction of this sediment probably consists largely of algae and other simple plants.

Microscopic Constituents

The macerals are to some extent related to certain lithotypes; therefore, maceral occurrence can also be used to determine depositional environment. Maceral analyses are very time-consuming, whereas lithotype analyses are easier and quicker to perform. A detailed maceral analysis can yield important information on the degree and mode of coalification that simple lithotype analyses can not. The more important maceral environmental indicators, as described by Stach et al. (1982), are discussed below.

Huminite Maceral Group

Huminite macerals form in moderately deep water under weakly oxidative conditions (Stach et al., 1982). The degree of coalification, usually humification and gelification, can be determined by the occurrence of certain macerals. A continuum of poor, moderate, to high gelification is represented by textinite, ulminite, and gelinite, respectively. Other huminite macerals include attrinite and desinite. These macerals are indicative of depositional conditions in which the plant material was highly degraded by physical and chemical processes (ICCP, 1975).

Inertinite Maceral Group

Inertinite macerals are typically formed in shallow water to subaerially exposed conditions. Fusinite, with thin, well-preserved cell laminae, is indicative of rapid, complete oxidation, perhaps by fire. Semifusinite has thicker, less discrete cell laminae which are representative of slower, incomplete oxidation, probably due to biochemical processes. Macrinite is formed secondarily by oxidizing previously gelified plant material. It has been suggested that macrinite is completely biochemically produced (Stach et al., 1982).

Liptinite Maceral Group

Macerals of this group show little diagenetic alteration through the lignite stage (Francis, 1961 and van Krevelen, 1961). Important depositional information can be obtained through palynology and sporology using extracted liptinite macerals, in particular sporinite (Steadman, 1985). These types of investigations were beyond the scope of this project.

Occurrence of Beulah-Zap Petrographic Components

Detailed descriptions of the distribution patterns and lithotype and maceral abundances were presented in their respective sections. The most important results will be reiterated here. Vitrain lithotypes are composed of mostly huminite macerals, in particular ulminite. Vitrain-dominated lithobodies occur more frequently in the middle to lower portions of the seam. Vitrain comprises 40% to 60% of the Beulah-Zap lignite.

Fusain is more abundant near the top of the lignite, and is commonly associated with vitrain along the bedding surfaces. Inertinite macerals, fusinite and semifusinite, are more abundant in fusain. Fusain is the least common lithotype (generally <10%) found in the Beulah-Zap lignite.

Attritus, dominated by detrital macerals of the three maceral groups, occurs more frequently near the margins of the seams. Attritus makes up between 45% and 60% of the Beulah-Zap at the locations studied.

The significance of these associations and distributions with respect to the Beulah-Zap depositional environment is presented below.

Deposition of the Beulah-Zap Lignite

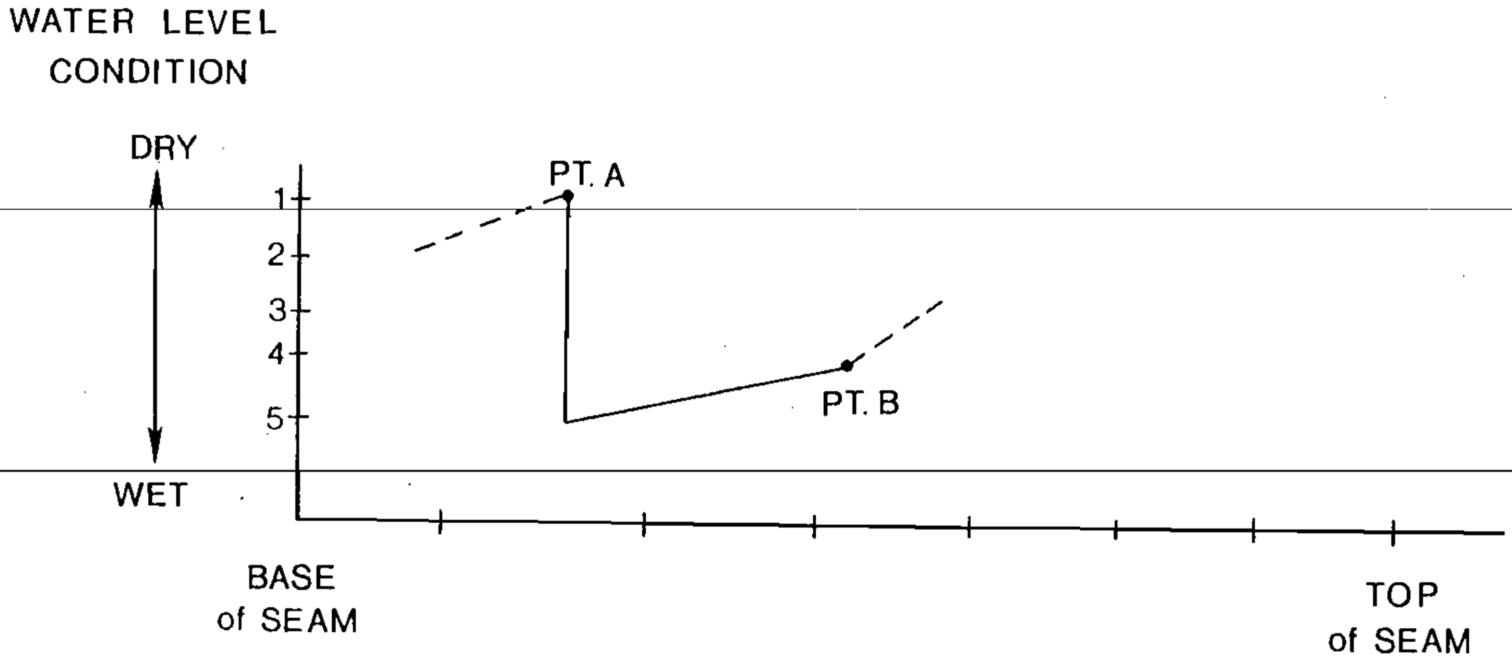
The sequence of depositional conditions, mainly relative water depth, can be deduced from the lithotype distribution and abundance. For the purpose of this evaluation, the seven lithobodies (including carbonaceous shale) were ranked according to their relative water depth at the time of formation. The ranking criteria included the different lithotype occurrences and abundances discussed above. The lithobody classification order from wettest to driest conditions is: 1) carbonaceous shale; 2) attritus; 3) attritus dominated with vitrain; 4) equal attritus and vitrain; 5) vitrain dominated with attritus; 6) vitrain; and 7) attritus dominated with fusain. Each lithobody was assigned a ranking value between one and seven. These values were then plotted respective to their height above the lignite base. The graph produced by this method is referred to as a seam formation curve (Tasch, 1960). This type of profile has been used to characterize and subsequently identify coal seams in Europe (Stach et al., 1982). Seam formation analyses were chosen as a preferred model for evaluating the Beulah-Zap lignite depositional history. Profiles were made for seven of the measured sections. Megascopic descriptions for the other measured sections were not available.

Seam Formation Profiles

Seam formation profiles were constructed by plotting relative water depth conditions (represented as horizontal bars) versus height above the base of the seam. By convention (Tasch, 1960), the base of the seam is on the left with the height increasing to the right. The driest depositional conditions (lowest water level) are represented at the top with increasing water levels towards the bottom. Oblique or horizontal lines are drawn between the points on the graph. If the water conditions between the two points (from left to right) tend to get drier, then the line is drawn having a positive slope, regardless of the number of horizontal bars it intersects. If the water depth increases, then the slope of the line will be negative. Should the water level increase between any two points such that the oblique line will intersect more than one horizontal bar, a vertical line must first be drawn to the top of the next deeper water level. For example, consider the system where there are five water level conditions with #1 being the driest and #5 the wettest. If point A is at level #1 and point B is at level #4, a vertical line must first be drawn to level #5, then the oblique line is drawn to point B (Figure 16). Even though these conventions are confusing, the final product is graphical, sequential representation of the depositional events.

Seam formation profiles were constructed for the Beulah-Zap lignite to see if environmental fluctuations were characteristic throughout the depositional basin. Also if the indivdual lignite seams had characteristic seam formation profiles, then that characteristic "fingerprint" should be apparent where the seams merge to form a

Figure 16. Example of seam formation profile.


WATER LEVEL CONDITION
DRY
WET
1
2
3
4
5
PT. A
PT. B
BASE of SEAM
TOP of SEAM

vertically continuous unit.

The uppermost Beulah-Zap seam fluctuates in thickness and in character. This seam is not laterally extensive, and was only examined in the South Beulah Mine. The seam formation curve (Figure 17) shows that the depositional environment of the uppermost seam was unstable. The profile indicates that the majority of deposition was in moderate to shallow water, with an overall shallowing trend toward the end of deposition.

The middle Beulah-Zap seam, where discrete, produced characteristic seam profiles (Figure 18). The initial deposition of this seam was in relatively shallow water. The water level then increased throughout most of the basin. This is represented by typical deep-water lithotype occurrence. The middle portion of this seam formed in generally moderate to deep water, but did fluctuate at the different locations. A major deepening, then shallowing sequence, is indicated in the upper one-third to one-quarter of the seam. The drying sequence at the end of the coal seam deposition appears to be common in the Beulah-Zap lignite.

The seam formation profile of the lowest seam was examined only in the Freedom Mine where the lignite occurs as one continuous unit. The lowest seam generally formed in deep water, with a steady and gradually shallowing water level. The importance of the Freedom Mine seam formation profiles is that the contact between the lower and middle seams can be seen (Figure 19). As stated previously, the middle seam starts with a shallow then rapid deepening water sequence. This same sequence can be seen at approximately 1.5 to 2.0 m above the coal base in the Freedom Mine. The average thickness of the lowest seam is 1.5 to 2.0 m, so it would not be unreasonable to make this correlation.

Figure 17. Seam formation curve for measured section BBA, South Beulah Mine, Bravo pit, "A" seam. Compiled from Appendix A.

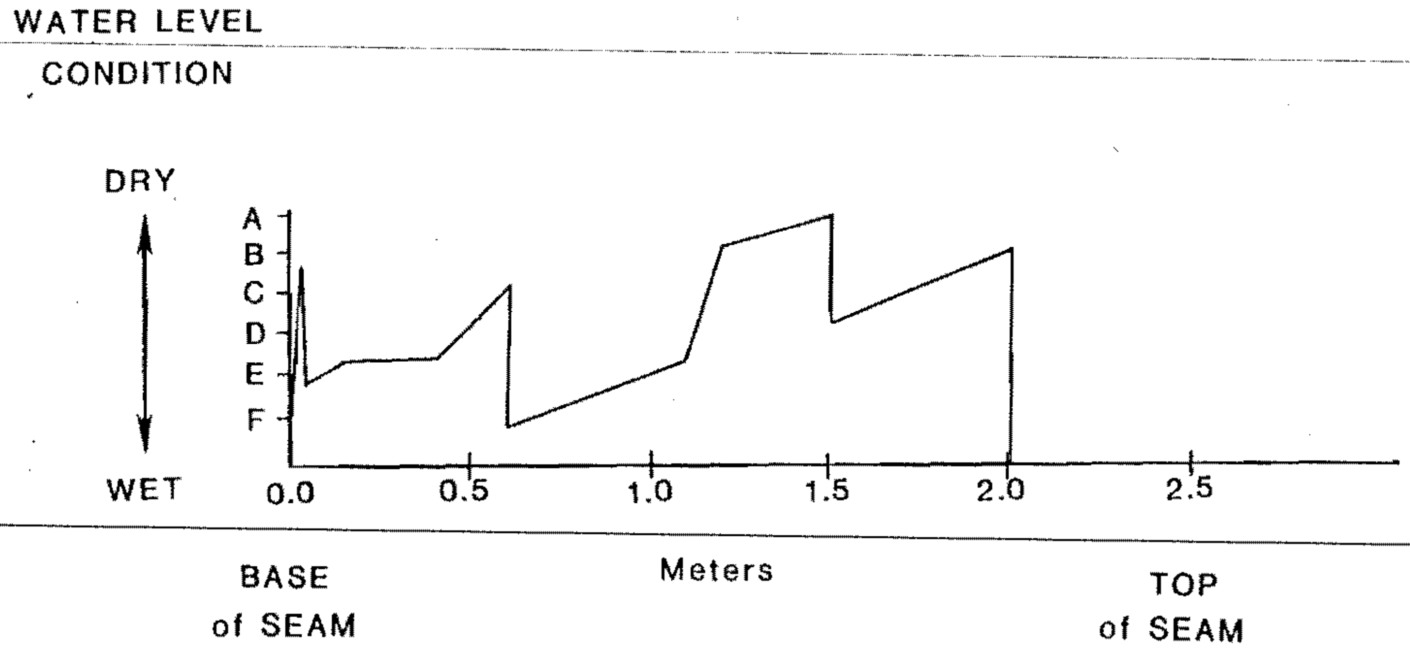

WATER LEVEL
CONDITION
DRY
WET
A
B
C
D
E
F
0.0
0.5
1.0
1.5
2.0
2.5
BASE
of SEAM
Meters
TOP
of SEAM

Figure 18. Seam formation curves for the measured sections BAB, BPB, BOB, and I32 from the South Beulah and Indianhead Mines, "B" (or "main") seam. Compiled from Appendix A.

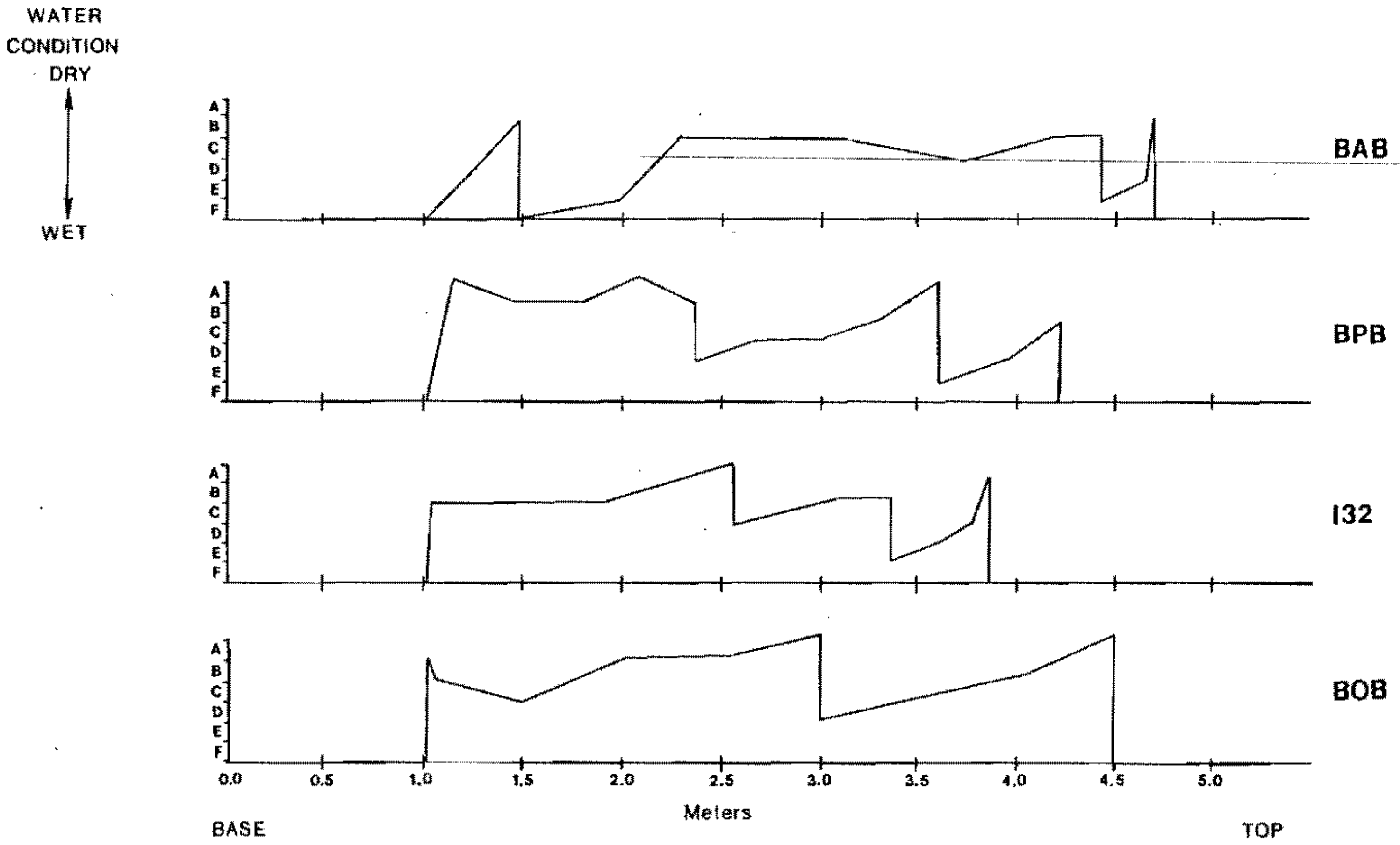
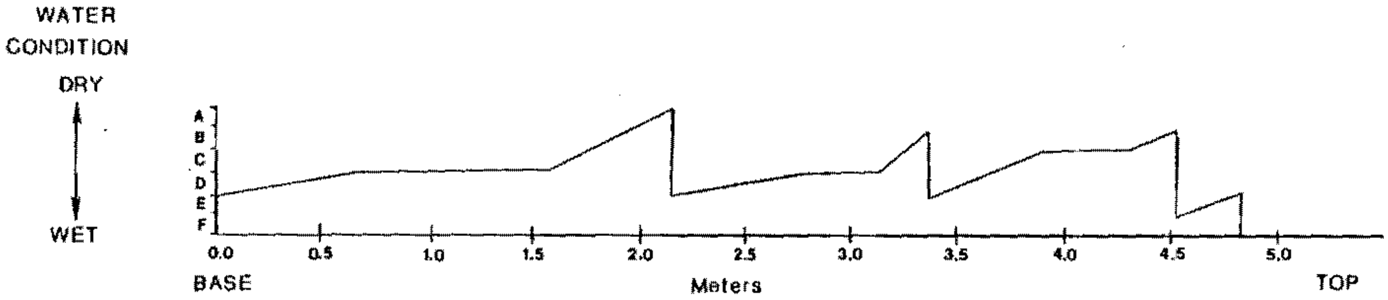
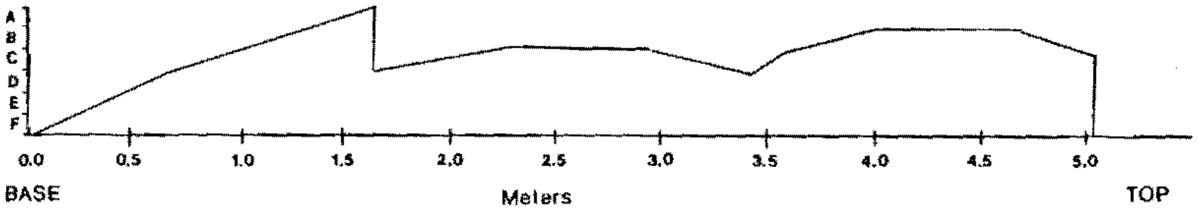

WATER CONDITION
DRY
WET
A
B
C
D
E
F
BAB
BPB
I32
BOB
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
Meters
BASE
TOP

Figure 19. Seam formation curves for measured sections F64 and F72 from the Freedom Mine. The curves represent the entire thickness of the Beulah-Zap lignite bed. Compiled from Appendix A.


WATER
CONDITION
DRY
WET
A
B
C
D
E
F
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
BASE
Meters
TOP

F64


A
B
C
D
E
F
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
BASE
Meters
TOP

F72

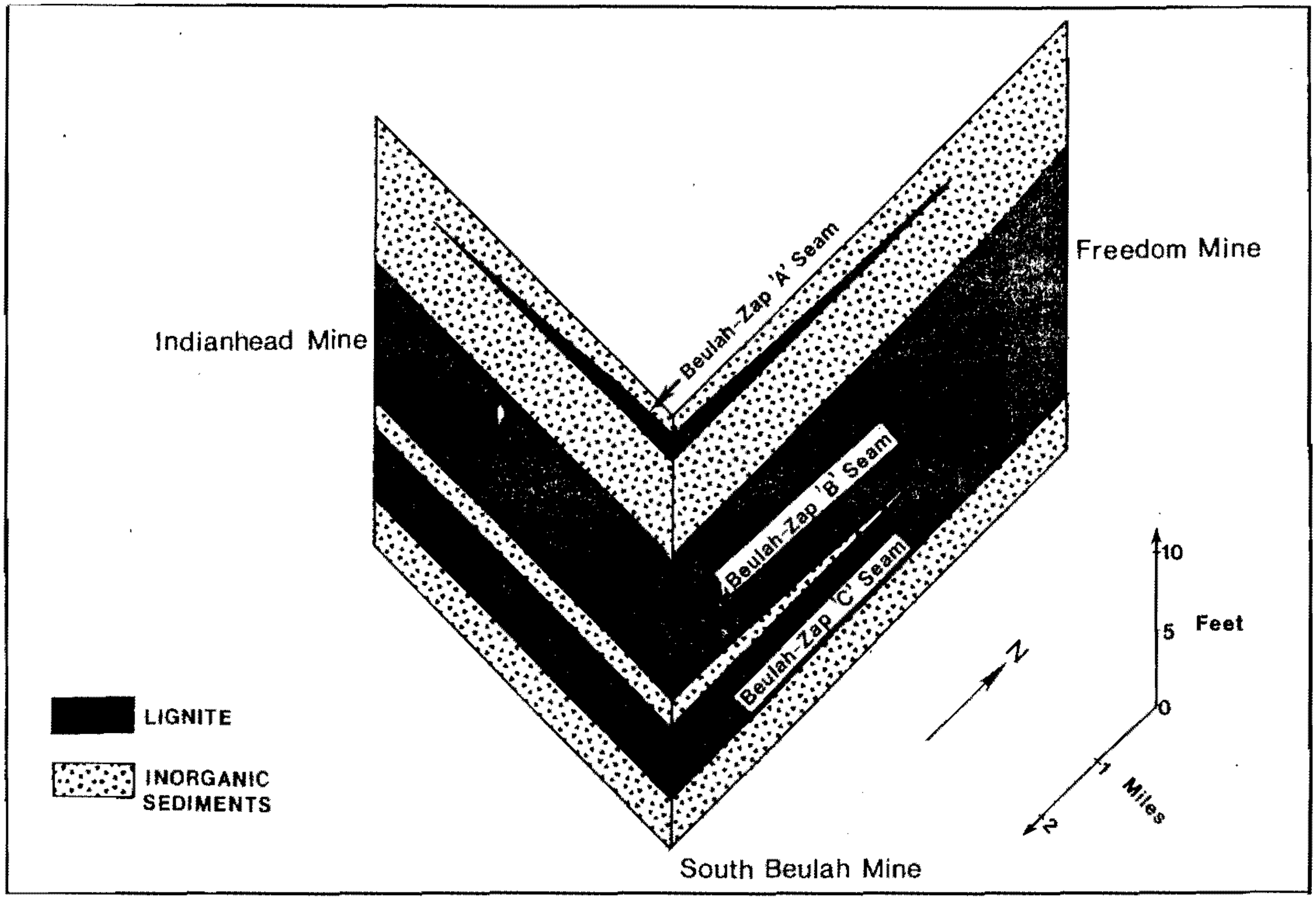
The upper two-thirds of the Freedom Mine measured section, pit 64 (F64), repeats the characteristic seam profile exhibited by the middle Beulah-Zap seam in the two other mines. The other Freedom Mine section (F72) does not show the characteristic pattern as well, but the general trend is present. The reason for this is probably because the sampling intervals were larger, possibly concealing detail. The uppermost lignite seam in the South Beulah Mine does not appear to be present in the Freedom Mine sections. The uppermost seam probably does not merge with the main Beulah-Zap bed in the Freedom Mine area (Figure 20). A detailed study of electric logs between the mines would probably confirm this observation, but was not performed for this project.

Diagenesis

The diagenesis or coalification of a peat deposit can be interpreted by the maceral assemblages. As previously discussed, there are two major types of coalification processes, those being humification and gelification. Another coalification process which occurs less frequently is fusinitization. This process involves the nearly complete carbonization (by oxidation) of vegetable material prior or soon after deposition. The mechanism for fusinitization is generally accepted to be by fire, although some forms of biochemical alteration can have the same effect (Stach et al., 1982).

Detailed diagenetic evaluation of the lignite was beyond the scope of this project, therefore only generalized diagenetic processes with respect to the Beulah-Zap lignite will be presented. The most important

Figure 20. Generalized fence diagram showing the relative positions of the seams in the Beulah-Zap lignite.


Indianhead Mine
Freedom Mine
South Beulah Mine
Beulah-Zap 'A' Seam
Beulah-Zap 'B' Seam
Beulah-Zap 'C' Seam
N
10
5
0
Feet
1
2
Miles
LIGNITE
INORGANIC SEDIMENTS

coalification process in the Beulah-Zap lignite is humification. This is supported by the dominance of huminite macerals, in particular ulminite. The Beulah-Zap lignite is often composed of 55-65% ulminite. The second most important coalification process was gelification. This process was particularly important in horizons immediately overlying inorganic-rich zones or carbonaceous shales. The huminite macerals appear to have been gelified after humification. This is verified by nearly completely gelified ulminite retaining some of the original plant cell structures. Fusinitization had only a minor role in Beulah-Zap coalification. This process occurred more frequently near the end of deposition, during the time of periodic subaerial exposure. Most fusinitization of the Beulah-Zap lignite was by fire. This is appearent from the occurrence of well preserved fusinite macerals (ICCP, 1975).

Depositional Model

Since this project was not designed to study the associated inorganic sediment in great detail, it becomes difficult to specify the exact depositional setting. Most of the previous work performed in this area used fluvial-dominated systems based on lithologies and sedimentary structures (Jacob, 1976; and Royse, 1967). Recent studies (Wallick, 1984; and Logan, 1981) have considered the possibility of lacustrine-dominated systems for the Sentinel Butte deposition. This detailed study of the Beulah-Zap lignite also yields evidence of lacustrine deposition.

The formation of thick, laterally continuous coal suggests a stable, low relief environment (Corvinus and Cohen, 1984). Analogies between the Sentinel Butte lignites and the Okefenokee swamp have been made by Ting (1972b). The Okefenokee swamp is a large inland marsh-lake complex, drained by the Suwannee River. This swamp covers approximately 1700 sq. km (650 square miles), depositing a nearly continuous, thick layer of peat (Cohen, 1984). The Beulah-Zap depositional swamp had an estimated aerial extent of 400 square miles (1050 sq. km) (Leonard et al., 1925).

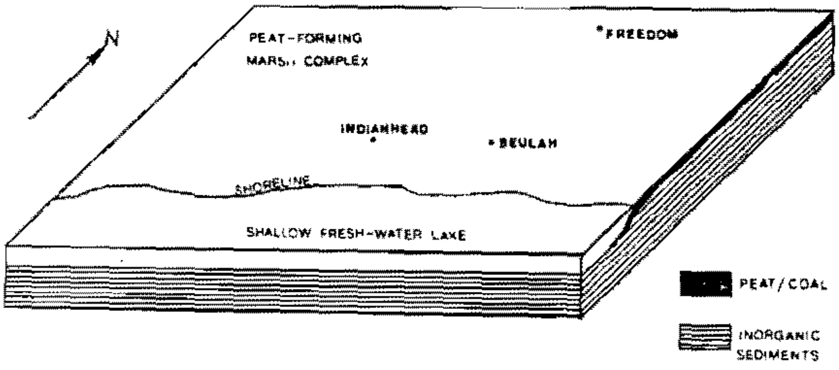
The evidence for lacustrine deposition, as seen in field observations at the three mining exposures, includes fine grained sediments (clay and silt size) in finely laminated underclays and partings within the lignite. There was no evidence of any channel structures, sand deposits or peat erosion within the lignite to suggest a meandering fluvial system.

The clay/silt partings within the lignite are wedge-shaped and pinch out to the north. Such partings have been explained by crevasse-splay deposition in fluvially-dominated backswamp environments (Flores, 1981). The partings associated with the Beulah-Zap lignite are fine grained (mostly clay), finely laminated, and reach thicknesses of over one meter within the study area. These partings probably represent a facies relationship with transgression and regression sequences of an associated marsh-lake system (Figure 21).

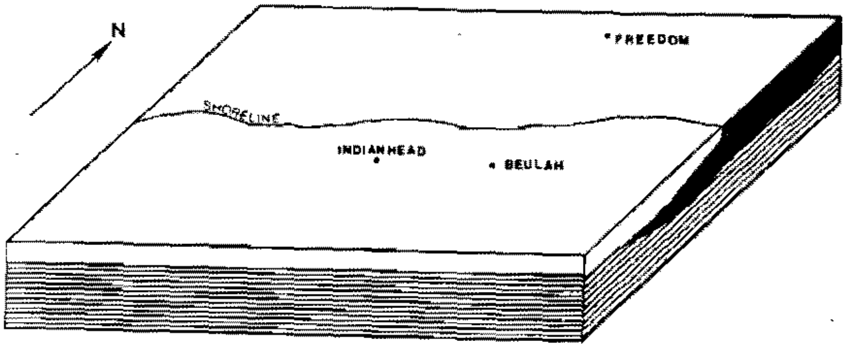
Future work in this area should include a detailed sedimentological evaluation of the clay/silt partings. These partings probably contain genetic structures which were overlooked in this study. Detailed mapping of occurrence and thickness of individual partings may prove

Figure 21. Generalized block diagrams showing the major peat~ forming events during the Beulah-Zap deposition.

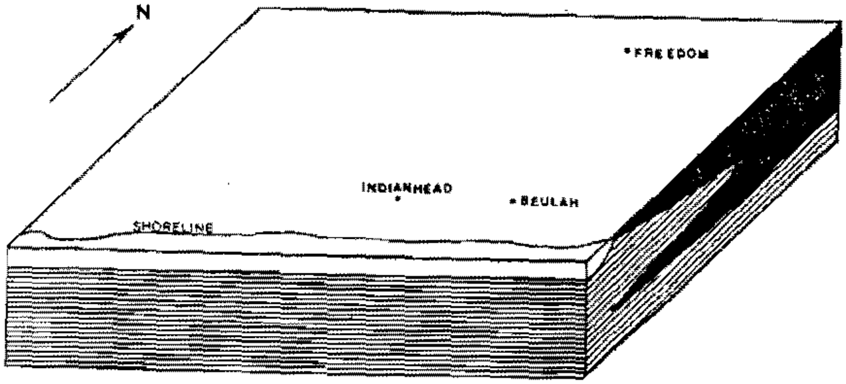
A.


N
PEAT-FORMING
MARSH COMPLEX
*FREEDOM
INDIANHEAD
•BEULAH
SHORELINE
SHALLOW FRESH-WATER LAKE
PEAT/COAL
INORGANIC
SEDIMENTS

B.


N
*FREEDOM
SHORELINE
INDIANHEAD
•BEULAH

C.


N
*FREEDOM
INDIANHEAD
•BEULAH
SHORELINE

important in the correct interpretation of the origins and depositional relationship.

SUMMARY OF CONCLUSIONS

Petrographic Characterization

1. Six lithobody types were defined on the basis of lithotype occurrence and abundance. These lithobodies are naturally occurring and megascopically observable.

2. Terminology best suited for the description of the Beulah-Zap lignite was taken from the Stopes-Heerlen and Thiessen-Bureau of Mine classification systems. Three lithotypes were identified in the Beulah-Zap lignite: 1) vitrain, 2) fusain, and 3) attritus.

3. Lithotype abundances for the Beulah-Zap lignite were estimated at vitrain 50%, attritus 45%, and fusain 5% (by volume). Vitrain vs. attritus and vitrain vs. fusain occurrences have inverse relationships.

4. The vertical distribution patterns of the different lithotypes are as follows: fusain occurs more frequently at the top of the lignite seams; vitrain occurs most frequently in the middle and at the very bottom of the seams; attritus occurs more frequently in the lower one-third and at the top of the lignite.

5. The maceral groups have the following decreasing abundance order: huminite, inertinite, and liptinite. The liptinite macerals were probably under-estimated because of the lack of fluorescence microscopy for identification purposes. Liptinite and inertinite macerals probably have nearly equal abundances.

6. Maceral groups and lithotypes of the Beulah-Zap lignite have the following association: 1) vitrain is composed of mostly huminite group macerals, in particular ulminite; 2) fusain is predominately inertinite group macerals with fusinite and semifusinite composing the majority; and 3) attritus is composed of detrital macerals of all three groups, but is predominately humodetrinite (attrinite and desinite).

Chemical Characterization

1. The lithobodies, as defined on the basis of megascopic differences, do not appear to have unique assemblages of chemical properties as determined by proximate and ultimate analyses.

2. The vitrain lithotype is responsible for most of the variation of the basic chemical characteristics of the Beulah-Zap lignite. The total carbon, volatile matter, hydrogen, nitrogen contents and heating value had vertical distribution patterns which were most often related to vitrain occurrence. The sulfur content appears to have a positive correlation with fusain occurrence.

3. The ash content, as determined by proximate and ultimate analyses, is higher at the lignite margins. The ash content value may be used to locate inorganic rich horizons in the lignite bed which cannot be detected megascopically.

4. Lithotypes were found to have a wide elemental variation as determined by the SEM/microprobe. Individual lithotypes do not appear to have unique elemental assemblages. The variation within the lithotypes are at least as significant as between them.

5. Preliminary SEM/microprobe analyses suggest that individual maceral types have unique elemental compositions, in particular ulminite and semifusinite. More research in this area is needed to confirm these observations.

Correlation of Beulah-Zap Lignite Bed and Seams

1. The defined lithobodies are visibly traceable within a given mine exposure. Evidence suggests that the lithobodies are correlatable between mines as well. The maceral groups, which are closely related to lithobody occurrence, can be used to correlate the individual seams to discrete horizons within the vertically continuous lignite bed.

2. Chemical distribution patterns (ash and sulfur content) also aid in the correlation of individual seams to discrete horizons in the complete lignite bed. Sulfur and ash are more abundant at the top of the Beulah-Zap lignite seams.

3. The application of maceral analyses of bulk samples for North Dakota lignite bed identification is not valid. All North Dakota lignite beds examined have similar average maceral composition. Maceral analyses of stratigraphically controlled samples may yield unique distribution patterns for different North Dakota lignites.

Depositional Environment

1. Beulah-Zap deposition started in moderately deep water. Two major water level increases occurred, stopping vegetation growth and depositing clay and silt in the southern portion of the deposition basin. Beulah-Zap deposition ended with a major drying episode followed by an extensive flooding event which terminated peat accumulation throughout the basin.

2. The Beulah-Zap lignite was probably deposited in a marsh-dominated lacustrine system. The local relief of the basin was extremely low. The peat accumulation and basin subsidence were in equilibrium producing a thick, laterally continuous carbonaceous-shale-free lignite.

APPENDICES

APPENDIX A

DESCRIPTIONS OF MEASURED SECTIONS

DESCRIPTIONS OF MEASURED SECTIONS

These descriptions of the discernible lithologic units of the Beulah-Zap lignite were compiled from both field and laboratory examination. Terminology for the lithotypes is according to the International Committee on Coal Petrology. Each unit is listed by its position relative to the lowest coal/underclay contact.

Measured section BAA

Measured section in South Beulah Mine, Alpha Pit, "A" seam. Total thickness of the "A" seam at this location was 1.67 meters. Samples were collected from an inorganic rich, poorly indurated lignite. A series of overburden and underclay samples were collected in conjunction with the lignite.

SAMPLE ID.	INTERVAL (HT. ABOVE BASE in METERS)	DESCRIPTION (G.F. No.)
BAA-a	2.90-3.15	OVERBURDEN (83-1263), Light grey fine silty sand, poorly indurated.
BAA-b	2.75-2.90	OVERBURDEN (83-1264), Dark brown to black sandy silt.
BAA-c	2.50-2.75	OVERBURDEN (83-1265), Yellow, poorly sorted, poorly indurated, till appearance, well rounded pebbles and boulders in fine sand matrix.
BAA-d	2.43-2.50	OVERBURDEN (83-1266), Dark brown silty clay, sharp contact above and below.
BAA-e	1.67-2.43	OVERBURDEN (83-1267), Light grey clay, contains "clasts" of lignite.
BAA-f1	0.99-1.67	LIGNITE (84-949), Dull black, few bedding planes, high inorganic content; behaves more like a poorly indurated soil than coal.
BAA-f2	0.94-0.99	LIGNITE (84-950), Dull, hard but brittle, has some vitreous layers, exhibits poorly developed bedding plane structures.
BAA-f3	0.74-0.94	LIGNITE (84-951), Very dull, sharp contact with layer above, well bedded, iron oxide staining on fractures, plant structures well preserved.

continued

BAA-f4	0.43-0.74	LIGNITE (84-561), Dull, well defined bedding planes, iron oxide staining on fractures, vitreous layers included in dull matrix.
BAA-f5	0.30-0.43	LIGNITE (84-562), Moderately bright, massive bedding structure, few cleat fractures.
BAA-f6	0.15-0.30	LIGNITE (84-563), Dull, sharp contact with overlying layer, bedding planes are curved, coal has a woody appearance, slightly brown in color.
BAA-f7	0.00-0.15	LIGNITE (84-564), Bright, vitreous luster, sharp contact with overlying layer, iron oxide staining on fractures, well developed fracture system.
BAA-g	-0.1-0.0	UNDERCLAY (83-1275), Dark brown, silty clay, finely laminated, gradual contact with overlying lignite.
BAA-h	-0.2-0.1	UNDERCLAY (83-1275), Medium to dark grey clay, very thin laminae, weathers to a reddish yellow color, well indurated.

Measured Section BBA

Measured section in South Beulah Mine, Bravo Pit, "A" seam. Total thickness of the "A" seam at this location was 2.0 meters. Samples were collected by Steven A. Benson and Steven Braun of UNDERC. This area of the mine is reported to have above average sodium content. Underclay, but no overburden was collected.

SAMPLE ID.	INTERVAL (HT. ABOVE BASE in METERS)	DESCRIPTION (G.F. No.)
BBA-11	2.00-2.10	LIGNITE (83-594), Bright, very massive, woody coal; well developed horizontal fractures, poorly developed vertical fractures; major bedding planes 5-8 cm. apart with gypsum mineralization on the bedding plane surfaces; fine grained attrital coal has subconchoidal fractures; fibrous vitrain with well preserved plant structures; sparse fusain fragments on bedding planes.
BBA-10	1.90-2.00	LIGNITE (83-593), Moderate to bright, very hard and massive; vitrain layers (3-15 mm.) with conchoidal fracture; Medium to coarse grained attritus; poorly developed vertical and well developed horizontal fractures; major bedding planes 3-8 cm. apart with large (10 x 15 mm.)fusain fragments and pyrite framboids on the surface.
BBA-9	1.70-1.90	LIGNITE (83-592), Dull, very friable, attrital coal; vitrain layers (2-5 mm.) in coarse attrital matrix; large (10 x 15 mm.) fusain fragments are abundant on bedding plane surfaces; gypsum and pyrite on fracture surfaces; well developed horizontal planes.

continued

BBA-8	1.35-1.70	LIGNITE (83-591), Moderately bright, massive, hard, with a woody appearance; poorly developed vertical fractures; major bedding planes 2-5 cm. apart, with irregular horizontal fractures; fine grained attritus abundant.
BBA-7	1.15-1.35	LIGNITE (83-590), Dull to moderately bright, very massive, vitrain layers (2-4 mm.) in fine attrital matrix; sparse fusain fragments in matrix; gypsum on major bedding planes (5-8 cm. thick) surfaces; poorly developed fracture system.
BBA-6	1.00-1.15	LIGNITE (83-589), Dull, massive, appears to have a high percentage of inorganic material; very poorly developed fracture system; behaves more like a carbonaceous shale.
BBA-5	0.70-1.00	LIGNITE (83-588), Moderate to bright, moderately massive, thick vitrain (2 cm.) with well preserved plant structures; fine grained, bright attritus; poorly developed fracture system; major bedding planes 3-5 cm. apart.
BBA-4	0.50-0.70	LIGNITE (83-587), Bright, massive, hard,vitrain coal; well developed fracture system with large fusain fragments (5 x 10 mm.) on major bedding plane surfaces (2-3 cm. apart); vitrain layers (2-4 mm.) in medium grained attritus.
BBA-3	0.20-0.50	LIGNITE (83-586), Dull to moderately bright, massive attrital coal; fine to medium grained attritus; well developed fracture system; major bedding planes 2-4 cm. apart.

continued

BBA-2	0.05-0.20	LIGNITE (83-585), Dull to moderately bright, very friable, thinly bedded (2-4 mm.), coarse attrital coal; well developed fracture system.
BBA-1	0.00-0.05	CARBONACEOUS SHALE (84-933), Dull, dark grey, inorganic rich (silty clay), thinly bedded, contains thin (<1 mm.) vitreous lenses.

Measured Section BAB

Measured section in South Beulah Mine, Alpha Pit, "B" seam. Total thickness of seam "B" at this location was 3.94 meters. Overburden was not collected at this location due to slumping. One major clay parting occurred at this sampling location.

SAMPLE ID.	INTERVAL (HT. ABOVE BASE in METERS)	DESCRIPTION (G.F. No.)
BAB-1	3.66-3.94	LIGNITE (84-565), Dull, massive, hard, fine grained attrital coal; major bedding planes 2 cm. apart; well developed fracture system; sparse fusain fragments on major bedding planes.
BAB-2	3.64-3.66	LIGNITE (84-566), Dull, thin, inorganic rich zone, thin vitrain lenses (<3 mm.), light brown clay minerals or pyrite throughout.
BAB-3	3.53-3.64	LIGNITE (84-567), Moderately bright to bright, friable, fusain rich, coarse grained attrital coal; well developed fracture system; major bedding planes 2-4 cm. apart with fusain fragments (3 x 8 mm.) on the surface; vitrain layers 3-5 mm. thick with well preserved internal plant structures.
BAB-4	3.00-3.53	LIGNITE (84-568), Dull to moderately bright, friable coal; poorly developed vertical fractures; thinly bedded (<1 cm.); coarse attritus has fine to large fibrous fusain fragments; the interval contains one thick fusain layer (>2 cm.)
BAB-5	2.37-3.00	LIGNITE (84-569), Dull, friable, coarse, granular attrital coal; well developed fracture system; vitrain has woody appearance; major bedding structures 2-3 cm. apart; fusain abundant on bedding surfaces and in the attrital matrix.

continued

BAB-6	1.50-2.37	LIGNITE (84-570), Dull to moderately bright, massive, hard; thin vitrain layers in medium to coarse grained attritus matrix; well developed horizontal fractures; major bedding planes 2-3 cm. apart.
BAB-7	1.48-1.50	LIGNITE (84-571), Dull, extremely friable, fusain rich layer; vitreous layers (1-2 mm.) within the fusain; Attritus composed of fine fusain particles.
BAB-8	1.20-1.48	LIGNITE (84-572), Dull to moderately bright, massive, hard; well developed fracture system; vitrain very woody with well preserved internal plant structures; major bedding planes 2-4 cm. apart with small (2 x 5 mm.) fusain fragments on the surface; attritus is fine grained.
BAB-9	1.07-1.20	CLAY/SILT PARTING (83-1283), Dark grey, thinly bedded (<.5 mm.), few large lignite fragments included.
BAB-10	0.21-1.07	LIGNITE (84-573), Moderately bright, massive, hard; well developed fracture system; major bedding planes 2-4 cm. apart with sparse fusain fragments on the surfaces; vitrain layers 3-8 mm. thick with conchoidal fractures; attritus is fine grained.
BAB-11	0.11-0.21	UNDERCLAY (83-1602), Dark grey, thinly bedded (1-2 mm), organic rich, silty clay.
BAB-12	0.0-0.11	UNDERCLAY (83-1606), Medium grey, silty clay; thin vitrain lenses included in the clay.

Measured Section BPB

Measured section in South Beulah Mine, Purple Pit, "B" seam. Total thickness of "B" seam at this location was 3.35 meters. Overburden and underclay samples were also collected. Lignite samples were collected at one foot intervals.

SAMPLE ID.	INTERVAL (HT. ABOVE BASE in METERS)	DESCRIPTION (G.F. No.)
BPB-1	3.35-3.45	OVERBURDEN (84-745), Light grey, silty clay; finely bedded (<2 mm.).
BPB-2	3.04-3.35	LIGNITE (84-574), Dull to moderately bright, friable, attrital coal; tan clay inclusions appear to be root casts; major bedding planes 1-2 cm. apart; fusain fragments (2 x 5 mm.) on bedding planes; thin vitrain layers (2-4 mm.) in coarse grained attritus matrix; well developed fracture system; vitrain fragments have well preserved plant structures.
BPB-3	2.74-3.04	LIGNITE (84-575), Dull, very massive, attrital coal; major bedding planes 2-4 cm. apart; moderately developed fracture system thin vitreous lenses (<1 mm.) in fine grained attritus matrix; attritus has conchoidal fracture.
BPB-4	2.43-2.74	LIGNITE (84-576), Moderately bright, very massive, hard, "woody" textured, vitreous coal; well preserved internal plant structures in woody portion; appears to be highly gelified; major bedding planes 8-10 cm. apart.
BPB-5	2.13-2.43	LIGNITE (84-577), Dull to moderately bright, interbedded vitrain and attrital coal, major bedding planes 1-2 cm. apart with fusain frgments on the surfaces; well developed horizontal bedding planes; well preserved plant structures; coarse to medium grained attrital coal.

continued

BPB-6	1.83-2.13	LIGNITE (84-578), Dull, friable, attrital coal; well developed vertical fractures; thin vitrain layers in coarse grained attritus; major bedding planes 2-4 cm. apart; tan clay root casts on bedding surfaces.
BPB-7	1.52-1.83	LIGNITE (84-579), Dull to moderately bright, slightly massive, interbedded attrital and vitreous coal; well developed fracture system, thin vitrain layers in coarse grained attritus; major bedding planes 2-4 cm. apart with fine fusain fragments on the surfaces.
BPB-8	1.21-1.52	LIGNITE (84-580), Bright, massive, hard, woody coal; vitrain layers 5-8 mm. thick with conchoidal fracture, some internal plant structures; moderately developed fracture system; fine grained attritus; major bedding planes 3-5 cm. apart.
BPB-9	0.91-1.21	LIGNITE (84-581), Moderately bright to bright, very massive, hard, vitreous coal; major bedding planes 8-10 cm. apart; vitrain layers 5-15 mm. thick with conchoidal fractures; fine grained attritus; pyrite, gypsum, and fusain on the bedding plane surfaces; well developed horizontal fractures.
BPB-10	0.61-0.91	LIGNITE (84-582), Dull to moderately bright, slightly massive, vitreous coal; major bedding plane 1-2 cm. apart with sparse fusain fragments on the surfaces; poorly developed fracture system; medium to coarse grained attritus; vitrain layers have woody appearance.
BPB-11	0.30-0.61	LIGNITE (84-583), Dull to moderately bright, massive, hard, brittle coal; thinly bedded (<2 cm.); poorly developed fracture system; very fine grained attritus with conchoidal fracture.

continued

BPB-12	0.00-0.30	LIGNITE (84-584), Bright, massive, woody, hard, vitreous coal; vitrain layers have woody appearance with conchoidal fractures; poorly developed fracture system; fine grained attritus.
BPB-13	-0.10-0.00	UNDERCLAY (84-746), Medium to light grey, silty clay; sharp contact with the lignite; finely laminated.

Measured Section BOB

Measured section in South Beulah Mine, Orange Pit, "B" seam. Total thickness of the "B" seam at this location was 4.0 meters. Samples were collected by UNDERC personnel; Steven Benson, Frank Karner, Don McCollar, and David Kleesattel. This location in the mine is reported to have a low sodium content. Overburden and underclays were also collected.

SAMPLE ID	INTERVAL (HT. ABOVE BASE in METERS)	DESCRIPTION (G.F. No.)
BOB-10	4.0-4.5	OVERBURDEN (82-3117), Light grey, silty clay; sharp contact with the lignite.
BOB-9a	3.8-4.0	LIGNITE (82-3116), Dull to moderately bright, massive, attrital coal; coarse grained attritus interbedded with thin vitrain layers; major bedding planes 2-3 cm. apart; poorly developed fracture system; abundant fusain fragments on the major bedding plane surfaces.
BOB-9b	3.5-3.8	LIGNITE (82-3115), Moderately bright, massive, vitreous coal; thick vitrain layers (2-4 cm.) with conchoidal fractures; well developed vertical fractures; fine grained attritus.
BOB-8	3.0-3.5	LIGNITE (82-3114), Dull, moderately friable, attrital coal; coarse grained attritus with granular texture; well developed horizontal fractures; sparse fusain fragments on the bedding plane surfaces.
BOB-7	2.5-3.0	LIGNITE (82-3113), Dull, massive coarse grained attrital coal; major bedding planes 2-4 cm. apart with abundant fusain fragments on the surfaces; poorly developed fracture system; vitrain layers have well preserved plant structures.

continued

BOB-6	2.0-2.5	LIGNITE (82-3112), Moderately bright, massive, hard, vitreous coal; vitrain layers have a woody texture; poorly developed fracture system; coarse grained attritus; major bedding planes 2-4 cm. apart with few fusain fragments on the suface.
BOB-5	1.5-2.0	LIGNITE (82-3111), Bright, massive, very hard, vitreous coal; vitrain is very woody; major bedding planes 4-6 cm. apart with fine fusain fragments on the surface; well developed fracture system; the interval contains one thick fusain layer (2 cm.) with large fusain fragments (15 x 25 mm.); fine grained attritus is composed of small fusain fragments and thin vitrain layers.
BOB-4	1.0-1.5	LIGNITE (82-3110), Moderately bright to bright, massive, very hard, vitreous coal; thick vitrain layers (5-15 mm) have a fibrous texture and well developed fracture system; major planes 2-3 cm. apart with large fusain fragments (5 x 10) on the surfaces; coarse grained attritus has a granular texture.
BOB-3	0.5-1.0	LIGNITE (82-3109), Moderately bright to bright, massive interbedded attrital and vitreous coal; vitrain layers with conchoidal fracture in medium grained attritus; major bedding 1.5-4.0 cm. apart with abundant fusain fragments on the surface; moderately developed fracture system.
BOB-2	0.0-0.5	LIGNITE (82-3108), Bright, very massive, very hard, highly gelified, vitreous coal; conchoidal fractures; well developed horizontal fractures, well preserved structures in the vitrain.
BOB-1	-0.05-0.0	UNDERCLAY (82-3107), Black, friable, organic rich clay; gradual contact with the coal; includes thin vitreous lenses.

Measured Section I32

Measured section in the Indianhead Mine, Pit 32, "Main" Beulah seam. Total thickness of the "Main" Beulah seam at this location was 2.92 meters. Overburden and underclays were collected as part of the sample series.

SAMPLE ID	INTERVAL (HT. ABOVE BASE in METERS)	DESCRIPTION (G.F. No.)
I32-400	2.92-3.00	OVERBURDEN (84-1724), "Blackjack" coal; Dull, black, carbonaceous shale; includes small fragments of coalified plant material; very gradual contact with the lignite.
I32-303	2.79-2.92	LIGNITE (84-1724), Dull, coarse grained, attrital coal; thin vitrain layers interbedded with the more abundant attritus; large (20 mm. dia.) pyrite nodules in the coal; poorly developed vertical fractures.
I32-302	2.69-2.79	LIGNITE (84-1725), Moderately bright to bright, massive, medium to coarse grained, attrital coal; very thin vitreous layers (<1 mm.); poorly developed fracture system; major bedding planes 1-2 cm. apart with fusain fragments (5 x 10 mm.) on the surfaces.
I32-301	2.51-2.69	LIGNITE (84-1726), Dull, friable, coarse grained, attrital coal; vitrain has well preserved plant structures; large fusain fragments (10 x 40 mm.) abundant on the bedding surfaces; moderately developed vertical fractures.
I32-204	2.29-2.51	LIGNITE (84-1727), Bright, massive, vitreous coal; thick vitrain layers (5-15 mm.) show few preserved plant structures; major bedding planes 2-4 cm. apart with fusain on the surfaces; fine grained attritus.

continued

I32-203	1.98-2.29	LIGNITE (84-1728), Bright, massive, vitreous coal; poorly developed horizontal fractures; most vitrain shows preserved plant structures; attritus is fine grained and bright with conchoidal fractures; several large (4 mm. dia.) resinous bodies were observed.
I32-202	1.42-1.98	LIGNITE (84-1729), Moderately bright, hard, attrital coal; well developed fracture system; major bedding planes 2-3 cm. apart with fusain on the surfaces; fusain fragments are commonly associated with small (2 mm. dia.) clay inclusions; vitrain has a fibrous texture; fine grained, bright attritus makes up most of the matrix.
I32-201	0.76-1.42	LIGNITE (84-1730), Moderately bright to bright, massive, hard, vitreous coal; vitrain layers interbedded with very fine grained attritus; major bedding planes 5-8 cm. apart with fusain fragments on the surfaces; poorly developed vertical fractures; small resin bodies (<1 mm.) were common on bedding plane surfaces.
I32-103	0.61-0.76	LIGNITE (84-1731), Moderately bright, massive coal; major bedding planes 4-6 cm. apart with sparse fusain on the surfaces; vitrain layers have well developed vertical fractures; dull, coarse grained attritus has well developed fracture system with mineral deposits in the vertical cleats.
I32-102	0.38-0.61	LIGNITE (84-1732), Moderate to bright, massive, coarse grained attrital coal; vitrain layers show well preserved plant structures; major bedding 5-8 cm. apart with large (5 x 10 mm.) fusain fragments on the surfaces; thin (<.5 mm.) clay inclusions along the bedding planes.

continued

I32-101	0.00-0.38	LIGNITE (84-1733), Bright, massive, hard, vitreous coal; vitrain layers have well developed vertical fractures; major bedding planes 3-4 cm. apart with sparse fusain on the surfaces; many of the vitrain layers are very bright and show no internal structures; attritus is fine grained and has conchoidal fractures.
I32-001	-0.65-0.00	UNDERCLAY (84-1737) Light grey, finely laminated clay; sharp contact with the lignite.
I32-002	-1.25-0.65	UNDERCLAY (84-1736) Medium grey, silty clay; bedding difficult to distinguish; well indurated.
I32-003	-1.90-1.25	UNDERCLAY (84-1735) Medium to dark grey, carbonaceous, silty clay; finely laminated; well indurated.

Measured Section F64

Measured section in the Freedom Mine, Pit No. 6, Marker No. 4. Total thickness of the lignite at this location was 5.18 meters. Sample series represents the entire thickness of the "B" and "C" seams. No interburden was observed between the seams. Overburden and underclays were collected as part of the sample series.

SAMPLE ID	INTERVAL (HT. ABOVE BASE in METERS)	DESCRIPTION (G.F. No.)
F64-800	5.18-5.35	OVERBURDEN (84-935), Dark grey, silty friable, clay; thinly bedded (1-2 mm.); contains very thin fragments of coalified material.
F64-701	4.88-5.13	LIGNITE (84-946), Dull, massive medium to coarse grained attrital coal; poorly developed horizontal fractures; abundant gypsum mineralization in the vertical fractures; few fusain fragments on bedding planes.
F64-702	4.57-4.88	LIGNITE (84-947), Bright coal; mostly vitrain with well preserved plant structures; well developed vertical fractures with gypsum on the surfaces; major bedding planes 1-2 cm. apart with fusain fragments (1 x 5 mm.) on the surfaces.
F64-703	4.26-4.57	LIGNITE (84-948), Dull, massive, attrital coal; major bedding planes 5 cm. apart with large fusain fragments (5 x 10 mm.) on the surfaces; vitrain layers are duller than normal with well preserved plant structures; poorly developed vertical fractures.
F64-601	3.25-4.26	LIGNITE (84-945), Moderately bright, massive coal; interbedded attritus and vitrain; coarse grained attritus; major bedding planes 2-4 cm. apart with very fine fusain fragments on the surfaces.

continued

F64-500	3.20-3.25	LIGNITE (84-944), Dull, friable, attrital coal; well developed fracture system; abundant thin, clay inclusions; fractures have a thin oxidized layer producing a blue-purple sheen; major bedding planes 1 cm. apart.
F64-401	2.95-3.20	LIGNITE (84-943), Bright, massive coal; mostly vitrain with well preserved plant structures; major bedding planes 15 mm. apart with sparse fusain fragments on the surfaces; poorly developed vertical fractures; coarse grained attritus.
F64-310	2.90-2.95	LIGNITE (84-942), Moderately bright, hard, thinly bedded, fine grained, attrital coal; surface oxidized to a steel blue sheen; conchoidal fractures; well developed horizontal fractures; this unit is laterally continuous throughout the pit.
F64-300	2.13-2.90	LIGNITE (84-941), Dull, massive, attrital coal; poorly developed fracture system; major bedding planes 5-8 cm. apart with small fusain fragments and light grey, silty clay inclusions on the surfaces; fine grained attritus.
F64-201	1.52-2.13	LIGNITE (84-940), Moderately bright, massive, interbedded vitrain and attrital coal; vitrain exhibits well preserved plant structures; poorly developed fracture system; major bedding planes 5 cm. apart; fined grained attritus.
F64-202	0.91-1.52	LIGNITE (84-939), Very bright, massive, hard vitrain dominated coal; vitrain has slight reddish brown color, conchoidal fracture, and poorly developed vertical fractures; coarse grained attritus; major bedding planes 5 cm. apart with sparse fusain occurrence on the surfaces.

continued

F64-101	0.61-0.91	LIGNITE (84-938), Moderately bright to dull, massive, hard, attrital coal; thin vitrain layers interbedded with fine grained, bright attritus; conchoidal fractures; major bedding planes 5-10 cm. apart with resin accumulations in the vertical fractures; vitrain has fibrous texture with well preserved plant structures.
F64-102	0.02-0.61	LIGNITE (84-937), Bright, very massive, hard, attrital coal; very fine grained attritus; vitrain has fibrous structure and well developed vertical fractures with pyrite mineralization on the surfaces; major bedding planes 10-15 cm. apart.
F64-103	0.00-0.02	LIGNITE (84-936), Bright, massive, very hard, fine grained, attrital coal; has a well developed, blocky fracture system; sharp contact with the underclay.
F64-000	-0.05-0.00	UNDERCLAY (84-934), Light grey, hard, well indurated, clay; poorly developed bedding structures.

Measured Section F72

Measured section in the Freedom Mine, Pit No. 7, Marker No. 2. Total thickness of the lignite at this location was 5.3 meters. Sample series represent the entire thickness of the "B" and "C" seams. No interburden was observed between the two seams. Overburden and underclays were collected as part of the sample series.

SAMPLE ID	INTERVAL (HT. ABOVE BASE in METERS)	DESCRIPTION (G.F. No.)
F72-500	5.3-5.4	OVERBURDEN (84-1189), Dark grey, organic rich, silty clay; well indurated; massive with conchoidal fracture.
F72-403	4.8-5.3	LIGNITE (84-1199), Dull, friable, coarse grained, attrital coal; well developed fracture system with abundant pyrite on the surfaces, major bedding planes 1-2 cm. apart with fusain fragments on the surfaces; vitrain layers have fibrous texture and conchoidal fractures.
F72-402	4.5-4.8	LIGNITE (84-1198), Moderately bright, vitrain dominated coal; major bedding planes 3-6 cm. apart with fusain fragments (2 x 5 mm.) on the surfaces; coarse grained attritus; moderately developed fracture system; vitrain has fibrous, woody texture.
F72-401	3.7-4.5	LIGNITE (84-1197), Dull, moderately massive, woody, vitrain dominated coal; medium to coarse grained attritus; major bedding planes 3-8 cm. apart with very fine fusain fragments on the surfaces; poorly developed fracture system; the more massive areas consist of interbedded attritus and thin vitrain layers.

continued

F72-301	3.6-3.7	LIGNITE (84-1196), Moderately bright to bright, friable, interbedded vitrain and attrital coal; well developed fracture system with pyrite and large fusain fragments (5 x 10 mm.) on the surfaces; coarse grained attritus.
F72-204	3.3-3.6	LIGNITE (84-1195), Dull, massive, coarse grained attrital coal; thin vitrain layers have poorly developed vertical fractures; major bedding planes 1-2 cm. apart with fusain fragments (2 x 5 mm.) on the sufaces.
F72-203	2.6-3.3	LIGNITE (84-1194), Moderately bright, hard, interbedded vitrain and attrital coal; fine grained attritus; vitrain layers exhibit well preserved plant structures; major bedding planes 5 cm. apart with large fusain fragments (5 x 10 mm.) on the surfaces.
F72-202	2.0-2.6	LIGNITE (84-1193), Bright, very massive, very hard, interbedded vitrain and attrital coal; well developed fracture system; thin vitrain layers (3 mm.) interbedded with fine grained attritus; major bedding planes 3-8 cm. apart with large fusain fragments (5 x 10 mm.) on the surfaces.
F72-201	1.3-2.0	LIGNITE (84-1192), Moderately bright, massive, woody appearance, vitrain dominated coal; vitrain has a fibrous texture; thick (8-10 cm.), dull , woody fragments are interbedded with fine grained attritus; major bedding planes 8-10 cm. apart; poorly developed fracture system.

continued

F72-101	0.0-1.3	LIGNITE (84-1191), Bright, very massive and hard, attrital coal; well developed fracture system with pyrite on the surfaces; conchoidal fractures; thin vitrain (2-3 mm.) interbedded with very fine grained attritus; major bedding planes 5-8 cm. apart; thick vitrain layers have well preserved plant structures.
F72-000	-0.05-0.0	UNDERCLAY (84-1190), Medium grey, silty clay; finely laminated; well indurated.

Measured Section BEU

Measured section in the South Beulah Mine, "B" and "C" seams. Samples collected by UND geology personnel, Frank Karner and David Brekke. Total thickness of the measured section was 5.5 meters. Underclay and clay/silt partings were collected. All samples had been crushed prior to this study; therefore no megascopic descriptions were available. Samples from all the intervals were not available for microscopic analyses. Sample location and gross description for available samples are given below.

SAMPLE ID	INTERVAL (HT. ABOVE BASE in METERS)	DESCRIPTION (G.F. No.)
BEU 2-22	5.2-5.5	LIGNITE (82-3691)
BEU 2-13	5.1-5.2	LIGNITE (82-3682)
BEU 2-12	4.8-5.1	LIGNITE (82-3681)
BEU 2-11	4.5-4.8	LIGNITE (82-3680)
BEU 2-10	4.2-4.5	LIGNITE (82-3679)
BEU 2-8	3.6-4.2	LIGNITE (82-3678)
BEU 2-7	3.4-3.6	LIGNITE (82-3695)
8EU 2-6	3.3-3.4	LIGNITE (82-3677)
BEU 2-5	2.9-3.0	LIGNITE (82-3676)
BEU 2-3	2.6-2.9	LIGNITE (82-3675)
BEU 2-2	2.1-2.6	LIGNITE (82-3674)
BEU 2-1	1.7-1.8	LIGNITE (82-3673)
BEU 3-7	1.6-1.7	CLAY PARTING (82-3672)
BEU 3-6	1.0-1.1	CLAY PARTING (82-3671)
BEU 3-5	0.9-1.0	LIGNITE (82-3670)
BEU 3-4	0.5-0.9	LIGNITE (82-3669)
BEU 3-3	0.1-0.5	LIGNITE (82-3668)
BEU 3-2	0.0-0.1	LIGNITE (82-3667)
BEU 3-1	-0.05-0.0	UNDERCLAY (82-3666)

APPENDIX B

PROXIMATE AND ULTIMATE ANALYTICAL DATA

PROXIMATE AND ULTIMATE ANALYTICAL DATA

The tabulated data reported here were determined by proximate and ultimate analyses as described in the Chemical Analysis section of this report. All values in this appendix are reported on a moisture-free basis. Abbreviations for the chemical components are as follows:

VM = Volatile Matter
FC = Fixed Carbon
H = Hydrogen
C = Carbon (Total)
N = Nitrogen
S = Sulfur
O = Oxygen
BTU = Heating Value in British Thermal Units
HT = Height above base of seam (in meters)

MEASURED SECTION BAA

I.D.	GFNO	HT	VM	FC	ASH	H	C	N	S	O	BTU
BAA-f1	84-0949	1.36	41.5	20.1	38.4	1.85	36.49	0.75	0.80	21.70	5126
BAA-f2	84-0950	1.00	17.3	2.7	80.0	1.23	8.69	0.31	0.10	9.66	1077
BAA-f3	84-0951	0.86	39.5	19.9	40.6	2.30	34.24	0.86	0.66	21.34	5000
BAA-f4	84-0561	0.73	36.7	13.1	50.2	2.27	30.13	0.65	0.82	15.93	4438
BAA-f5	84-0562	0.59	55.3	29.3	15.4	3.21	52.51	0.45	1.04	27.40	8078
BAA-f6	84-0563	0.23	53.9	29.1	17.0	3.67	55.33	0.99	0.78	22.23	8913
BAA-f7	84-0564	0.08	51.1	22.3	26.6	2.65	43.90	1.13	1.14	24.59	6522

MEASURED SECTION BBA

I.D.	GFNO	HT	VM	FC	ASH	H	C	N	S	O	BTU
BBA-11	83-0594	2.00	40.15	50.91	8.94	3.96	64.62	0.83	1.62	20.03	10506
BBA-10	83-0593	1.80	40.06	49.85	10.09	3.99	64.93	0.89	1.77	18.33	10507
BBA-9	83-0592	1.50	44.36	48.47	7.17	4.59	65.40	0.73	2.25	19.86	11067
BBA-8	83-0591	1.20	45.66	43.79	10.55	4.71	60.94	0.48	4.38	18.94	10605
BBA-7	83-0590	1.10	41.14	39.15	19.71	4.20	55.80	1.46	2.11	16.72	9702
BBA-6	83-0589	0.90	18.95	7.90	73.15	1.88	15.77	0.39	0.61	8.20	1900
BBA-5	83-0588	0.60	43.47	41.75	14.78	4.51	60.03	0.77	2.54	17.37	10203
BBA-4	83-0587	0.40	45.25	45.40	9.35	4.80	62.67	0.71	2.77	19.70	10903
BBA-3	83-0586	0.10	53.25	33.60	13.15	5.66	63.44	0.56	2.46	14.73	11417
BBA-2	83-0585	0.05	40.38	43.00	16.62	4.19	59.01	0.89	4.23	15.06	9886

MEASURED SECTION BAB

I.D.	GFNO	HT	VM	FC	ASH	H	C	N	S	O	BTU
BAB-1	84-0565	3.69	47.9	39.1	13.0	4.23	61.66	1.10	0.53	19.48	10366
BAB-2	84-0566	3.67	51.4	34.2	14.4	3.59	59.12	1.05	0.55	21.28	9720
BAB-3	84-0567	3.41	47.6	40.2	12.2	3.50	62.15	1.12	1.26	19.77	10134
BAB-4	84-0568	3.15	52.1	41.6	6.3	4.27	66.19	0.82	0.73	21.69	10910
BAB-5	84-0569	2.71	48.2	45.8	6.0	3.86	66.39	0.97	0.43	22.34	10948
BAB-6	84-0570	2.05	46.2	47.9	5.9	4.05	67.03	1.03	0.55	21.45	11049
BAB-7	84-0571	1.71	45.1	46.7	8.2	3.57	65.56	1.27	0.47	20.93	10642
BAB-8	84-0572	1.26	44.6	40.6	14.8	3.69	59.84	1.15	0.58	20.94	9641
BAB-9*	83-1283	1.13	ND	ND	ND	ND	ND	ND	ND	ND	ND
BAB-10	84-0573	0.49	43.1	42.0	14.9	4.11	64.35	1.25	0.73	14.65	10754

* = Carbonaceous shale sample (clay parting)
ND = Values not determined

MEASURED SECTION BPB

I.D.	GFNO	HT	VM	FC	ASH	H	C	N	S	O	BTU
BPB-2	84-0574	3.20	44.1	43.6	12.3	3.92	65.47	1.12	3.10	14.09	10714
BPB-3	84-0575	2.90	45.2	43.1	11.7	4.08	62.96	1.00	0.95	19.32	10404
BPB-4	84-0576	2.59	46.9	44.3	8.8	3.75	65.41	1.13	1.14	19.78	10730
BPB-5	84-0577	2.29	46.7	47.3	6.0	3.98	67.12	1.13	0.76	21.01	11002
BPB-6	84-0578	1.98	43.4	49.6	7.0	3.95	66.65	0.75	0.68	20.96	10862
BPB-7	84-0579	1.68	44.4	45.3	10.3	3.87	64.04	1.15	0.62	20.02	10521
BPB-8	84-0580	1.37	46.7	48.2	5.1	4.31	66.51	1.28	0.88	21.91	11094
BPB-9	84-0581	1.07	48.9	45.6	5.5	4.68	67.26	0.95	0.78	20.83	11328
BPB-10	84-0582	0.76	50.4	43.6	6.0	4.72	67.08	1.15	0.69	20.35	11320
BPB-11	84-0583	0.45	50.7	42.9	6.4	4.39	65.97	0.88	0.72	21.64	10990
BPB-12	84-0584	0.15	45.8	34.2	20.0	4.00	55.53	0.75	0.64	19.08	9395

MEASURED SECTION BOB

I.D.	GFNO	HT	VM	FC	ASH	H	C	N	S	O	BTU
BOB-10	82-3116	3.50	40.70	48.87	10.4	2.35	65.58	0.92	1.20	19.55	10597
BOB-9	82-3115	3.00	36.69	47.63	15.7	2.53	63.14	0.89	4.39	13.35	9980
BOB-8	82-3114	2.50	37.97	53.48	8.5	2.60	66.63	0.79	0.73	20.75	10818
BOB-7	82-3113	2.00	41.43	51.71	6.9	2.99	68.13	1.04	0.86	20.08	11004
BOB-6	82-3112	1.50	34.73	52.29	13.0	2.03	67.17	0.82	3.05	13.93	10294
BOB-5	82-3111	1.00	42.37	50.85	6.8	2.90	68.38	1.09	0.89	19.94	11016
BOB-4	82-3110	0.50	43.97	49.35	6.7	2.95	67.11	0.91	0.89	21.44	11027
BOB-3	82-3109	0.05	44.34	48.80	6.8	3.35	67.84	1.13	0.92	19.96	11016
BOB-2	82-3108	0.00	42.69	50.16	7.1	3.17	67.18	0.91	1.17	20.47	10981

MEASURED SECTION I32

I.D.	GFNO	HT	VM	FC	ASH	H	C	N	S	O	BTU
I32-401	84-1724	2.95	22.0	21.7	56.3	2.22	29.96	0.60	0.44	10.49	4666
I32-303	84-1725	2.86	39.2	52.2	8.6	3.96	65.63	1.14	0.40	20.27	10579
I32-302	84-1726	2.74	40.9	52.5	6.6	4.00	65.83	1.11	0.43	22.03	10843
I32-301	84-1727	2.56	40.2	53.8	6.0	3.96	68.17	1.24	0.41	20.22	11074
I32-204	84-1728	2.33	40.0	53.6	6.4	4.01	66.16	1.41	0.39	21.63	10892
I32-203	84-1729	2.06	41.4	52.1	6.5	4.35	67.17	1.03	0.41	20.55	11027
I32-202	84-1730	1.57	40.4	52.8	6.8	4.05	68.30	1.21	0.39	19.25	11245
I32-201	84-1731	0.86	43.7	49.7	6.6	4.70	66.49	1.04	0.48	20.69	11030
I32-103	84-1732	0.64	43.3	50.5	6.2	4.42	67.02	1.16	0.64	20.56	11190
I32-102	84-1733	0.42	42.2	51.0	6.8	4.35	66.73	1.17	0.86	20.10	11122
I32-101	84-1734	0.05	36.2	37.2	26.6	3.89	52.02	1.12	0.84	15.52	8674

MEASURED SECTION F64

I.D.	GFNO	HT	VM	FC	ASH	H	C	N	S	O	BTU
F64-701	84-0946	4.88	31.4	25.6	43.0	2.24	37.88	0.73	1.47	14.69	5895
F64-702	84-0947	4.57	43.4	48.1	8.5	3.63	61.84	0.91	1.87	23.25	9925
F64-703	84-0948	4.27	44.3	45.1	10.6	4.12	61.85	1.39	1.05	20.99	10074
F64-601	84-0945	3.96	43.4	48.6	8.0	3.98	64.11	1.35	0.62	21.94	10487
F64-500	84-0944	3.65	44.6	49.8	5.6	4.48	66.78	1.23	0.59	21.32	11117
F64-401	84-0943	3.35	41.0	53.0	6.0	3.92	66.44	1.37	0.56	21.71	10847
F64-310	84-0942	3.11	39.8	46.5	13.7	3.76	60.96	1.41	0.39	19.77	9892
F64-300	84-0941	3.05	44.8	48.1	7.1	4.24	64.99	1.30	0.79	21.58	10716
F64-201	84-0940	2.74	43.7	50.6	5.7	4.37	66.85	1.19	0.55	21.33	11112
F64-202	84-0939	2.13	42.0	52.6	5.4	4.47	67.67	1.34	0.42	20.70	11035
F64-101	84-0938	1.52	46.3	47.3	6.4	4.70	66.98	1.00	0.78	20.15	11182
F64-102	84-0937	0.76	43.8	47.2	9.0	4.51	64.30	1.56	1.19	19.44	10740
F64-103	84-0936	0.00	38.8	42.1	19.1	4.12	56.62	1.24	1.29	17.63	9369

MEASURED SECTION F72

I.D.	GFNO	HT	VM	FC	ASH	H	C	N	S	O	BTU
F72-403	84-1199	5.05	37.0	41.7	21.3	3.56	55.88	0.91	3.13	15.21	9228
F72-402	84-1198	4.65	40.1	51.5	8.4	4.07	65.56	1.01	0.62	20.33	10653
F72-401	84-1197	4.05	45.5	44.8	9.7	4.22	63.63	1.07	0.70	20.67	10417
F72-301	84-1196	3.60	39.8	46.5	13.7	3.97	61.74	1.03	0.76	18.80	10224
F72-204	84-1195	3.45	43.9	50.3	5.8	4.54	66.57	1.17	0.62	21.30	11191
F72-203	84-1194	2.95	41.9	50.5	7.6	4.23	65.40	1.22	0.49	21.06	10889
F72-202	84-1193	2.30	44.9	49.4	5.7	4.65	66.69	1.01	0.57	21.37	11251
F72-201	84-1192	1.65	41.3	53.4	5.3	4.16	67.45	1.51	0.45	21.12	11106
F72-101	84-1191	0.65	43.4	49.2	7.4	4.45	65.38	1.44	1.14	20.20	11160

MEASURED SECTION 8EU

I.D.	GFNO	HT	VM	FC	ASH	H	C	N	S	O	BTU
BEU2-22	82-3691	5.40	45.24	43.17	11.6	4.01	60.69	1.06	3.81	18.83	10457
BEU2-13	82-3682	5.20	42.40	48.46	9.1	3.34	64.69	1.09	1.41	20.37	10748
BEU2-12	82-3681	4.80	40.12	47.93	12.0	3.13	62.77	1.04	1.28	19.78	10411
BEU2-11	82-3680	4.50	42.31	41.63	16.1	3.72	59.72	0.94	2.86	16.66	9934
BEU2-10	82-3679	4.20	43.34	50.28	6.4	3.86	64.78	0.53	1.52	22.91	11062
BEU2-8	82-3678	3.60	38.65	46.07	15.3	3.13	61.38	0.70	0.88	18.61	10027
BEU2-7	82-3695	3.40	42.50	51.93	5.6	3.76	66.60	0.90	1.08	22.06	11155
BEU2-6	82-3677	3.30	43.26	49.38	7.4	3.90	64.60	0.64	1.68	21.78	10946
BEU2-5	82-3676	2.95	47.65	45.29	7.1	4.07	65.29	0.92	1.13	21.49	10981
BEU2-3	82-3675	2.60	43.52	48.93	7.6	3.78	65.50	0.90	1.07	21.15	10922
BEU2-2	82-3674	2.10	44.86	47.91	7.2	3.98	64.60	0.92	0.99	22.31	10969
BEU2-1	82-3673	1.75	43.97	45.24	10.8	3.76	61.30	1.02	1.13	21.99	10550
BEU3-5	82-3670	1.05	39.58	38.24	22.2	3.17	49.82	0.76	4.37	19.68	9224
BEU3-4	82-3669	0.50	45.10	47.61	7.3	3.84	65.56	0.92	0.83	21.55	10957
BEU3-3	82-3668	0.10	46.60	44.93	8.5	4.21	64.25	1.05	1.38	20.61	10818
BEU3-2	82-3667	0.05	41.29	41.41	17.3	3.29	57.09	1.00	2.48	18.84	9794

APPENDIX C

MACERAL POINT COUNT DATA

MACERAL POINT COUNT DATA

The data reported here were collected using standard point counting techniques (Stach et al., 1982), and reflected light microscopy (ICCP, 1963, 1971, and 1975). Detailed descriptions of these analyses are given in the discussion of macerals in this report. The abbreviations used in this appendix are as follows:

U = Ulminite
A = Attrinite
D = Desinite
G = Gelinite
CO = Corpohuminite

SP = Sporinite
CU = Cutinite
R = Resinite
SB = Suberinite
L = Liptodetrinite

F = Fusinite
SE = Semifusinite
M = Macrinite
SC = Sclerotinite
I = Inertodetrinite
IN = Inorganics (minerals)

tr = trace amount (<1%)
HT = Height above base of seam (in meters)

MEASURED SECTION BAA

I.D.	GFNO	HT	U	A	D	G	CO	SP	CU	R	SB	L	F	SE	M	SC	I	IN
BAA-f1	84-0949	1.36	11	8	7	0	1	0	0	1	0	1	12	13	0	0	29	17
BAA-f2	84-0950	1.00	2	3	5	0	0	0	0	0	0	0	1	2	0	0	16	70
BAA-f3	84-0951	0.86	21	19	4	tr	0	1	tr	1	0	1	8	6	1	tr	18	20
BAA-f4	84-0561	0.73	9	27	4	tr	0	0	0	1	0	3	5	9	0	1	15	28
BAA-f5	84-0562	0.59	50	19	2	0	tr	2	1	1	0	5	5	3	0	0	7	5
BAA-f6	84-0563	0.23	15	33	3	0	0	1	0	1	0	4	2	7	0	2	13	19
BAA-f7	84-0564	0.08	67	12	3	0	0	0	2	1	0	2	0	2	0	0	0	13

MEASURED SECTION BBA

I.D.	GFNO	HT	U	A	D	G	CO	SP	CU	R	SB	L	F	SE	M	SC	I	IN
BBA-11	84-0594	2.00	40	22	3	tr	0	1	3	2	0	4	8	7	8	1	6	4
BBA-10	84-0593	1.80	55	14	3	1	1	1	2	2	0	4	4	7	tr	0	4	2
BBA-9	84-0592	1.50	20	29	1	1	2	2	1	1	2	4	12	7	tr	1	13	2
BBA-8	84-0591	1.20	51	18	4	1	4	1	1	1	1	6	3	2	0	1	4	3
BBA-7	84-0590	1.10	69	13	3	0	1	1	2	1	tr	4	0	1	0	0	2	3
BBA-6	84-0589	0.90	18	23	3	0	1	0	1	tr	0	1	1	2	0	tr	13	38
BBA-5	84-0588	0.60	35	31	2	0	0	1	1	tr	0	3	6	4	0	tr	15	3
BBA-4	84-0587	0.40	27	34	4	0	1	1	1	1	1	2	4	4	0	0	14	6
BBA-3	84-0586	0.10	71	13	1	0	tr	0	1	tr	1	4	0	1	0	0	1	6
BBA-2	84-0585	0.05	36	11	9	0	1	0	1	0	0	3	0	0	0	0	0	39

MEASURED SECTION BAB

I.D.	GFNO	HT	U	A	D	G	CO	SP	CU	R	SB	L	F	SE	M	SC	I	IN
BAB-1	84-0565	3.69	16	24	9	3	0	2	0	2	tr	3	1	16	0	tr	13	9
BAB-2	84-0566	3.67	40	23	2	1	tr	4	0	1	1	2	1	15	tr	tr	9	1
BAB-3	84-0567	3.41	49	16	1	tr	0	2	1	1	0	2	0	18	0	tr	7	3
BAB-4	84-0568	3.15	53	24	3	1	1	5	1	1	1	3	1	1	0	tr	1	4
BAB-5	84-0569	2.71	60	11	2	1	2	2	0	1	1	2	2	4	0	tr	8	3
BAB-6	84-0570	2.05	49	17	2	tr	2	2	1	1	1	4	5	6	0	1	4	5
BAB-7	84-0571	1.71	38	17	3	1	1	2	1	1	1	2	5	11	0	tr	11	5
BAB-8	84-0572	1.26	44	29	tr	2	0	4	2	tr	0	6	1	1	0	tr	3	6
BAB-9	83-1283	0.97	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BAB-10	84-0573	0.49	33	31	4	1	tr	4	2	2	0	4	3	5	0	1	4	4

MEASURED SECTION BP8

I.D.	GFNO	HT	U	A	D	G	CO	SP	CU	R	SB	L	F	SE	M	SC	I	IN
BPB-2	84-0574	3.20	38	17	3	tr	1	2	1	2	0	4	8	15	0	1	7	2
BPB-3	84-0575	2.90	37	27	4	tr	tr	2	tr	tr	0	5	4	10	tr	1	6	2
BPB-4	84-0576	2.59	46	15	4	1	12	1	tr	2	0	2	6	13	1	1	6	1
BPB-5	84-0577	2.29	51	10	4	tr	1	1	1	1	tr	2	7	13	2	tr	6	1
BPB-6	84-0578	1.98	50	6	2	1	1	tr	1	1	tr	2	6	15	tr	0	13	1
BPB-7	84-0579	1.68	37	17	9	tr	0	1	tr	1	0	4	5	8	1	1	16	tr
BPB-8	84-0580	1.37	64	9	10	tr	1	1	1	tr	1	4	2	3	tr	tr	4	2
BPB-9	84-0581	1.07	58	16	6	1	tr	2	1	tr	0	3	2	3	1	tr	5	3
BPB-10	84-0582	0.76	21	37	15	1	1	5	2	0	1	9	2	1	0	1	4	2
BPB-11	84-0583	0.45	47	22	11	1	2	3	2	tr	1	3	tr	4	0	1	1	2
BPB-12	84-0584	0.15	32	27	14	1	1	3	tr	0	1	5	tr	0	0	tr	2	12

MEASURED SECTION BOB

I.D.	GFNO	HT	U	A	D	G	CO	SP	CU	R	SB	L	F	SE	M	SC	I	IN
BOB-10	82-3116	3.50	29	37	3	1	1	2	2	tr	0	5	40	4	0	1	8	4
BOB-9	82-3115	3.00	34	19	3	1	1	1	1	2	0	3	12	9	0	1	12	2
BOB-8	82-3114	2.50	22	13	5	1	1	1	1	3	0	5	7	9	0	tr	27	6
BOB-7	82-3113	2.00	39	21	6	2	1	2	1	3	0	3	4	7	tr	tr	8	3
BOB-6	82-3112	1.50	42	13	2	0	1	1	1	1	0	4	8	11	1	0	12	4
BOB-5	82-3111	1.00	38	25	4	1	tr	1	2	3	tr	4	5	7	0	1	8	2
BOB-4	82-3110	0.50	49	27	2	tr	2	2	2	2	0	5	tr	2	0	1	5	1
BOB-3	82-3109	0.05	39	29	4	tr	3	4	2	3	1	8	0	2	0	tr	1	4
BOB-2	82-3108	0.00	44	17	6	2	3	2	2	1	1	13	tr	2	0	1	1	5

MEASURED SECTION I32

I.D.	GFNO	HT	U	A	D	G	CO	SP	CU	R	SB	L	F	SE	M	SC	I	IN
I32-401	84-1724	2.95	37	3	5	0	0	0	0	0	0	2	tr	2	0	tr	15	35
I32-303	84-1725	2.86	29	13	4	1	1	tr	1	2	0	4	6	21	tr	tr	15	3
I32-302	84-1726	2.76	48	19	2	1	2	1	2	2	1	2	4	9	tr	0	8	1
I32-301	84-1727	2.56	46	13	3	1	2	0	2	1	tr	3	5	14	tr	tr	9	1
I32-204	84-1728	2.33	41	12	2	tr	0	2	2	2	0	5	5	19	0	1	9	1
I32-203	84-1729	2.06	39	21	4	1	2	1	1	1	1	4	4	11	0	tr	9	1
I32-202	84-1730	1.57	28	14	3	1	1	2	tr	1	0	2	7	25	1	0	12	3
I32-201	84-1731	0.88	51	21	4	1	1	2	2	2	tr	3	1	6	0	tr	3	1
I32-103	84-1732	0.64	57	17	4	0	2	1	2	1	tr	2	4	3	tr	0	4	1
I32-102	84-1733	0.42	52	16	3	1	3	2	2	1	1	2	2	5	0	tr	5	3
I32-101	84-1734	0.05	43	20	7	0	tr	3	3	tr	1	7	0	1	0	1	1	13

MEASURED SECTION F64

I.D.	GFNO	HT	U	A	D	G	CO	SP	CU	R	SB	L	F	SE	M	SC	I	IN
F64-701	84-0946	4.88	15	21	3	tr	tr	1	0	1	0	9	4	8	0	0	16	21
F64-702	84-0947	4.57	57	7	1	3	4	1	1	3	tr	2	6	6	0	1	5	2
F64-703	B4-0948	4.27	40	25	3	0	1	2	1	2	0	5	5	4	0	1	11	1
F64-601	84-0945	3.96	45	22	3	0	1	1	1	1	0	5	6	6	0	1	8	1
F64-500	84-0944	3.65	56	21	2	1	2	2	1	tr	0	3	3	2	0	1	5	1
F64-401	84-0943	3.35	37	14	3	0	1	1	2	2	0	8	13	8	0	1	8	2
F64-310	84-0942	3.11	34	6	2	2	0	2	tr	1	0	11	0	17	0	1	21	5
F64-300	84-0941	3.05	46	15	2	2	1	2	1	1	0	4	5	11	0	1	7	2
F64-201	84-0940	2.74	53	16	4	tr	1	1	1	1	1	4	4	7	0	tr	5	1
F64-202	84-0939	2.13	45	16	3	0	1	1	2	tr	0	8	5	10	0	1	8	0
F64-101	84-0938	1.52	48	21	3	1	2	2	1	tr	1	5	3	4	0	tr	6	2
F64-102	84-0937	0.76	55	33	2	1	0	2	1	tr	0	3	0	1	0	tr	1	2
F64-103	84-0936	0.00	69	12	2	0	0	1	1	tr	0	4	tr	1	0	tr	1	6

MEASURED SECTION F72

I.D.	GFNO	HT	U	A	D	G	CO	SP	CU	R	SB	L	F	SE	M	SC	I	IN
F72-403	84-1199	5.05	33	14	4	0	1	1	0	1	tr	3	7	14	0	tr	14	8
F72-402	84-1198	4.65	27	30	2	0	0	1	1	1	0	5	8	12	3	1	7	2
F72-401	84-1197	4.05	37	25	2	1	0	2	1	2	1	4	5	11	tr	1	7	1
F72-301	84-1196	3.60	34	20	4	1	1	2	1	1	0	5	5	15	0	1	8	4
F72-204	84-1195	3.45	41	22	5	1	1	2	1	2	0	5	7	9	0	1	4	1
F72-203	84-1194	2.95	48	14	4	0	2	2	1	1	0	3	7	10	1	1	8	1
F72-202	84-1193	2.30	51	18	2	1	2	1	1	1	0	4	5	6	0	tr	6	1
F72-201	84-1192	1.65	35	16	4	tr	2	1	1	2	tr	7	8	17	1	1	6	1
F72-101	84-1191	0.65	55	11	6	0	1	2	1	tr	0	5	3	8	0	tr	5	2

MEASURED SECTION BEU

I.D.	GFNO	HT	U	A	D	G	CO	SP	CU	R	SB	L	F	SE	M	SC	I	IN
BEU2-22	82-3691	5.40	45	23	10	0	1	1	4	1	1	10	0	tr	0	1	1	3
BEU2-13	82-3682	5.20	36	23	3	1	2	2	1	1	0	5	5	7	0	tr	10	6
BEU2-12	82-3681	4.80	17	23	4	tr	1	1	1	1	tr	4	7	18	0	0	22	1
BEU2-11	82-3680	4.50	30	27	3	1	tr	2	1	1	tr	8	3	10	tr	0	6	6
BEU2-10	82-3679	4.20	57	10	2	1	4	0	1	1	tr	2	7	8	0	tr	6	2
BEU2-8	82-3678	3.60	32	12	4	1	tr	1	1	1	0	6	5	13	0	tr	20	5
BEU2-7	82-3695	3.40	49	14	3	1	3	1	tr	1	1	4	5	6	0	tr	9	3
BEU2-6	82-3677	3.30	43	25	4	1	2	1	2	1	1	6	2	4	0	1	6	1
BEU2-5	82-3676	2.95	26	40	2	1	2	4	1	tr	1	7	1	4	0	0	9	2
BEU2-3	82-3675	2.60	42	22	1	0	1	1	2	1	tr	3	3	13	0	1	9	1
BEU2-2	82-3674	2.10	46	23	2	tr	2	3	2	tr	1	5	5	2	0	1	4	2
BEU2-1	82-3673	1.75	50	22	4	1	1	3	2	1	0	7	tr	4	0	tr	tr	6
BEU3-5	82-3670	1.05	59	20	1	tr	1	1	1	1	0	2	1	2	0	0	2	8
BEU3-4	82-3669	0.50	33	27	5	2	2	2	1	1	0	5	4	5	1	1	10	1
BEU3-3	82-3668	0.10	21	44	4	tr	tr	6	2	3	tr	8	1	1	0	tr	7	3
BEU3-2	82-3667	0.05	60	16	6	2	1	2	2	tr	tr	4	0	1	0	0	1	6

APPENDIX D

MACERAL POINT COUNT DATA FOR INDIVIDUAL LITHOTYPES

MACERAL POINT COUNT DATA FOR INDIVIDUAL LITHOTYPES

Lithotypes from each sample collected at measured sections BAB and BPB were separated for analyses. This table lists the results for the maceral analyses. Detailed desciptions of the analyses are given in the maceral discussion of this report. The abbreviations used in this appendix are as follows:

U = Ulminite
A = Attrinite
D = Desinite
G = Gelinite
CO = Corpohuminite

SP = Sporinite
CU = Cutinite
R = Resinite
SB = Suberinite
L = Liptodetrinite

F = Fusinite
SE = Semifusinite
M = Macrinite
SC = Sclerotinite
I = Inertodetrinite
IN = Inorganics (minerals)

tr = trace amount (<1%)
NA = not applicable
HT = Height above base of seam (in meters)

MEASURED SECTION BAB, FUSAIN LITHOTYPE

I.D.	GFNO	HT	U	A	D	G	CO	SP	CU	R	SB	L	F	SE	M	SC	I	IN
BAB-1	84-0565	3.69	2	3	2	0	0	0	9	10	0	tr	46	26	tr	0	1	0
BAB-2	84-0566	3.67	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BAB-3	84-0567	3.41	37	6	tr	2	1	0	0	4	2	2	3	34	0	0	9	0
BAB-4	84-0568	3.14	0	0	0	2	0	0	0	tr	0	0	82	13	0	0	5	1
BAB-5	84-0569	2.71	19	4	3	1	1	0	2	1	0	3	40	19	0	0	6	0
BAB-6	84-0570	2.05	2	5	tr	2	0	0	tr	3	0	1	42	22	tr	0	22	0
BAB-7	84-0571	1.71	10	4	4	0	0	tr	0	2	0	3	41	27	0	0	8	0
BAB-8	84-0572	1.26	6	6	tr	25	tr	0	tr	2	0	3	21	25	tr	tr	11	0
BAB-9	83-1283	0.97	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BAB-10	84-0573	0.49	3	7	0	5	0	tr	0	7	0	5	23	27	tr	tr	22	0

MEASURED SECTION BAB, VITRAIN LITHOTYPE

I.D.	GFNO	HT	U	A	D	G	CO	SP	CU	R	SB	L	F	SE	M	SC	I	IN
BAB-1	84-0565	3.69	65	12	0	13	0	0	0	4	0	5	0	0	0	0	0	tr
BAB-2	84-0566	3.67	48	18	4	13	0	2	1	tr	1	4	0	0	0	tr	9	0
BAB-3	84-0567	3.41	67	tr	0	1	0	0	0	4	2	0	11	0	0	0	6	0
BAB-4	84-0568	3.15	44	10	6	26	1	1	1	tr	4	4	0	tr	0	tr	1	tr
BAB-5	84-0569	2.17	77	3	6	5	2	0	tr	0	0	2	5	0	0	0	0	2
BAB-6	84-0570	2.05	48	5	12	20	3	0	1	tr	1	8	0	tr	0	0	tr	0
BAB-7	84-0571	1.71	43	9	13	7	1	tr	3	1	1	7	0	5	0	tr	9	0
BAB-8	84-0572	1.26	10	5	0	80	0	1	0	0	0	3	0	1	0	0	tr	0
BAB-9	83-1283	0.97	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BAB-10	84-0573	0.49	20	2	0	73	0	0	0	1	0	3	0	0	0	0	0	2

MEASURED SECTION BAB, ATTRITUS LITHOTYPE

I.D.	GFNO	HT	U	A	D	G	CO	SP	CU	R	SB	L	F	SE	M	SC	I	IN
BAB-1	84-0565	3.69	4	11	2	3	0	0	0	3	0	10	1	3	1	0	60	tr
BAB-2	84-0566	3.67	33	10	27	5	1	tr	tr	1	0	6	0	5	tr	0	12	0
BAB-3	84-0567	3.41	16	22	tr	2	1	0	1	3	1	5	tr	31	0	0	15	tr
BAB-4	84-0568	3.15	8	20	25	28	1	3	tr	tr	1	3	0	0	0	1	10	0
BAB-5	84-0569	2.71	19	14	41	7	1	0	0	0	0	4	0	4	1	tr	7	tr
BAB-6	84-0570	2.05	27	28	15	5	1	tr	2	0	2	5	tr	3	2	tr	9	0
BAB-7	84-0571	1.71	31	15	15	8	1	0	1	1	0	6	2	10	0	8	0	0
BAB-8	84-0572	1.26	18	19	21	21	1	1	0	2	1	5	3	tr	0	tr	7	tr
BAB-9	83-1283	0.97	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BAB-10	84-0573	0.49	42	26	9	5	0	2	0	0	1	6	0	0	0	tr	6	1

MEASURED SECTION BPB, FUSAIN LITHOTYPE

I.D.	GFNO	HT	U	A	D	G	CO	SP	CU	R	SB	L	F	SE	M	SC	I	IN
BPB-2	84-0574	3.20	19	3	1	1	1	tr	1	3	0	1	46	17	0	0	3	tr
BPB-3	84-0575	2.90	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
BPB-4	84-0576	2.59	14	1	0	0	0	tr	0	2	0	tr	60	18	0	0	2	0
BPB-5	84-0577	2.29	3	1	1	tr	1	tr	0	3	0	1	58	30	0	0	3	0
BPB-6	84-0578	1.98	19	7	4	2	1	tr	tr	5	tr	3	37	10	1	0	10	0
BPB-7	84-0579	1.68	9	2	0	2	tr	0	1	2	0	2	49	22	0	tr	11	tr
BPB-8	84-0580	1.37	20	11	10	tr	tr	tr	0	2	0	3	35	11	0	1	6	0
BPB-9	84-0581	1.07	3	3	0	2	2	tr	0	5	0	1	79	2	0	0	1	1
BPB-10	84-0582	0.76	5	3	0	1	2	0	0	3	0	1	56	12	0	0	12	2
BPB-11	84-0583	0.45	2	tr	0	1	2	0	0	3	0	0	64	17	0	tr	8	3
BPB-12	84-0584	0.15	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

MEASURED SECTION BPB, VITRAIN LITHOTYPE

I.D.	GFNO	HT	U	A	D	G	CO	SP	CU	R	SB	L	F	SE	M	SC	I	IN
BPB-2	84-0574	3.20	81	3	2	3	2	tr	1	tr	0	1	tr	1	0	tr	4	tr
BPB-3	84-0575	2.90	46	9	13	4	0	2	1	2	0	7	2	7	0	0	7	tr
BPB-4	84-0576	2.59	72	4	0	3	6	1	1	0	2	3	0	4	0	0	2	1
BPB-5	84-0577	2.29	80	4	0	2	2	tr	1	tr	0	1	5	0	0	0	3	tr
BPB-6	84-0578	1.98	62	3	3	7	3	tr	4	1	1	4	2	5	0	0	4	tr
BPB-7	84-0579	1.68	74	5	5	2	2	1	1	0	1	3	2	0	0	1	3	0
BPB-8	84-0580	1.37	89	1	0	7	0	0	0	0	0	1	0	0	0	0	1	1
BPB-9	84-0581	1.07	87	tr	0	1	2	3	1	0	0	6	0	0	0	tr	0	1
BPB-10	84-0582	0.76	80	2	1	3	5	2	1	0	0	2	0	0	0	1	tr	2
BPB-11	84-0583	0.45	70	13	6	1	2	2	1	0	0	3	0	0	0	0	1	1
BPB-12	84-0584	0.15	89	7	0	0	tr	0	0	0	1	2	0	0	0	0	0	1

MEASURED SECTION BPB, ATTRITUS LITHOTYPE

I.D.	GFNO	HT	U	A	D	G	CO	SP	CU	R	SB	L	F	SE	M	SC	I	IN
BPB-2	84-0574	3.20	42	22	2	2	1	2	1	1	tr	5	12	0	0	tr	10	0
BPB-3	84-0575	2.90	12	22	36	11	2	2	0	0	0	16	0	tr	0	0	0	0
BPB-4	84-0576	2.59	39	25	11	2	4	1	1	1	1	3	1	7	0	0	6	tr
BPB-5	84-0577	2.29	40	15	13	2	2	1	1	1	1	2	14	0	0	0	10	1
BPB-6	84-0578	1.98	42	6	6	2	tr	1	1	2	0	2	10	13	tr	0	16	0
BPB-7	84-0579	1.68	19	19	23	4	1	2	1	0	0	10	0	6	0	1	12	2
BPB-8	84-0580	1.37	53	12	11	1	1	2	3	1	0	6	1	1	0	0	8	1
BPB-9	84-0581	1.07	43	23	8	2	0	3	3	0	0	6	2	0	tr	1	6	1
BPB-10	84-0582	0.76	39	25	12	1	2	9	4	0	0	6	0	0	0	tr	4	1
BPB-11	84-0583	0.45	35	14	25	1	1	3	3	0	1	10	0	1	0	0	1	tr
BPB-12	84-0584	0.15	46	18	8	1	tr	3	3	1	tr	16	0	tr	0	tr	0	1

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