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Palynology of the Hagel lignite bed and associated strata, Sentinel Butte Formation (Paleocene), in central North Dakota

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PALYNOLOGY OF THE HAGEL LIGNITE BED AND ASSOCIATED STRATA, SENTINEL BUTTE FORMATION (PALEOCENE), IN CENTRAL NORTH DAKOTA

by

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This thesis submitted by Edward N. Steadman 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.

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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.

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Signature Edward C. Ford

Date 5/17/85

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ABSTRACT

The Hagel bed is an economically important lignite and is the lowest named lignite in the Sentinel Butte Formation, Fort Union Group. The Hagel bed extends throughout the Knife River Basin coal-mining area of central North Dakota. Stratigraphic sections of the Hagel bed, including intercalated clastic rocks, were measured in the highwalls of the Center mine, Glenharold mine, and Falkirk mine.

Samples from the stratigraphic sections were described and analyzed, using standard palynological techniques, for their palynomorph content. Palynomorphs proved to be well preserved and abundant. Maceration of Hagel bed samples yielded a diverse collection of palynomorphs. A total of seventy-five palynomorph types consisting of thirty form genera, five extant genera, and thirty-seven morphotypes were described. Common constituents of the palynoflora include representatives of the modern classes Gymnospermae, Angiospermae, Filicineae, and Musci.

Palynologic evidence suggests that the contributing flora was dominated by swamp-forest taxa (e. g., Osmunda, Steriosporites antiquasporites, and some Taxodiaceae). Deciduous plants were dominated by riparian types (e.g., Alnus) and were consistently present but made small contributions to the palynoflora.

Palynologic percentage-frequency data were used to elucidate floral trends present. The palynomorphic associations present (based on groups of high taxonomic rank) were interpreted as a single, relatively consistent palynoflora.

A preliminary investigation of the relationship of palynologic

data to present-day coal chemistry was inconclusive. A correlation of palynomorphic and geochemical data suggested that palynomorphs have a potential utility as geochemical biomarkers with further study.

Palynologic evidence and corroborating lithologic evidence suggest that the alternating deposition of clastics and coal precursors was controlled by the lateral shifting of fluvial and lacustrine environments marginal to the forest-swamp environment. The local depositional basin was broad, laterally continuous, and possessed little relief. Relatively minor changes in water level may be responsible for laterally continuous alternating clastic-to-coal depositional sequences found in the study area.

Acknowledgments

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The staff of UNDERC provided a pleasant and efficient atmosphere in which to work, and I am indebted to staff members too many to mention individually. Members of the UNDERC staff who have been especially helpful include: Nita Ralston, for her general helpfulness, Paul Gronhovd, for his photographic and graphics expertise, Jean Vorachek for her assistance in computer applications, John Diehl for his tolerating a geologist working in a chemical laboratory, Dave Kleesattel for his cooperation and assistance in the field, and Steve Benson, who provided enthusiasm and assistance in the initial stages of this project. I also wish to thank Roy Severson for his x-ray fluorescence analysis, and Rae Ann Brown for her x-ray diffraction analysis.

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INTRODUCTION

Purpose and Definition of the Problem

It is the purpose of this study to investigate the palynology of the Hagel lignite bed and associated strata in the Knife River basin of Oliver, Mercer, and McLean Counties, central North Dakota. The Hagel bed is an economically important lignite and is the lowest named lignite in the Sentinel Butte Formation (Groenewold and others, 1979, p. 22). Microfossils, specifically pollen and spores (palynomorphs), are well preserved and abundant in the Hagel bed.

This study is intended to characterize the palynomorphs of the Hagel bed and to investigate their utility as stratigraphic, geochemical and paleoecologic tools for North Dakota lignite research. The primary objectives of this study are:

1. To describe the palynomorphs of the Hagel lignite bed and associated strata.
2. To differentiate and describe any palynomorphic associations or zonations present within the Hagel bed and associated strata.
3. To use the palynomorphs found within the Hagel bed to characterize the contributing flora.

The secondary objectives of this study are:

1. To identify and characterize chemical and mineralogical zonations or variations present within the Hagel bed and associated strata.
2. To compare the palynologic with the mineralogical and chemical variations present within the Hagel bed.

Although the Europeans had been studying the palynology of coal for several decades, the first significant palynologic investigation of Tertiary coals in North America was done by Traverse (1955). Traverse (1955, p. 8) discussed pollen analysis of Tertiary coals as follows:

> The fact that most Tertiary plants belong to modern taxonomic units increases the versatility of the method [palynology] for Tertiary sediments along lines more familiar to the student of Pleistocene and Recent pollen. Paleoecology depends on obtaining the maximum possible information about the fossil flora, and the microfossil flora is an integral part of the whole. Because of the speed with which preparations of fossil pollen from a Tertiary coal can be made, palynology is a most rewarding technique in terms of yield of information about the flora that contributed to coal. Paleoecological conclusions derived from knowledge of the total flora of a coal can be expected to contribute to the understanding of many features of a sediment such as low-rank coal that is almost entirely made of plant material, the deposition of which depended on climatic and edaphic factors intimately related to the nature of the contributing flora. For example, abundance of pollen of certain types of swamp plants in a coal of Tertiary age will allow one to draw conclusions about the contributing flora and about conditions in the basin of deposition during formation of the coal. This may help greatly in understanding the nature and origin of the sediment.

The use of palynology for paleoecological determinations relies on two basic but important assumptions: 1) the fossil pollen preserved in the strata accurately reflects the past flora, and 2) morphologic consistency, expressed in palynomorphs assignable to modern taxonomic units, is paralleled by physiologic constancy, thus allowing for paleoecologic inferences based on taxonomic determinations. These assumptions are fundamental to this study.

Location

The Hagel bed is present throughout the Knife River drainage basin as well as in adjacent areas in McLean and Oliver Counties (Groenewold and others, 1979, p. 1). The Hagel bed is mined at three locations: the Center Mine near Center, Oliver County, the Glenharold Mine south of Stanton, Mercer County, and the Falkirk Mine near Falkirk, McLean County (Figure 1). The Hagel bed lignite is used primarily as a boiler fuel for mine-mouth electricity generating utility plants.

Samples for this study were taken from mine high walls at each of the three mines. The mine high walls afforded samples which were fresh (not oxidized) and which possessed good stratigraphic control.

Previous Investigations

Previous Stratigraphic Works

The Hagel bed is late Paleocene in age and is included in the Sentinel Butte Formation of the Fort Union Group (Groenewold and others, 1979, p. 23). The Fort Union Group (Figure 2) is dominantly composed of fine grained clastics and lignites of terrestrial origin.

The Sentinel Butte was originally described by Leonard and Smith (1909) as the upper member of the Fort Union Formation. Leonard and Smith (1909, p. 18) contrasted the upper and lower members as follows:

> There is a very noticeable difference between the lower Fort Union beds, which outcrop in the bluffs bordering Little Missouri River, and the upper beds, occurring in the tops of the higher ridges, divides, and buttes, usually back some distance from the river. The lower member is composed of buff and light ash-gray clays and sands in alternate layers. The upper member is formed of strata considerably darker in appearance, mostly dark gray, with many brown, ferruginous, sandy nodules and concretions. The contrast between these members is so well marked and their contact so clearly defined that it can be readily distinguished at a distance and traced without difficulty wherever it is exposed.

The beds of the upper member of the Fort Union Formation were measured at Sentinel Butte by Leonard and Smith (1909, p. 20) and the name Sentinel Butte was given (p. 30) to the lignite beds occurring there.

Figure 1. General map of the area in which the study was made.

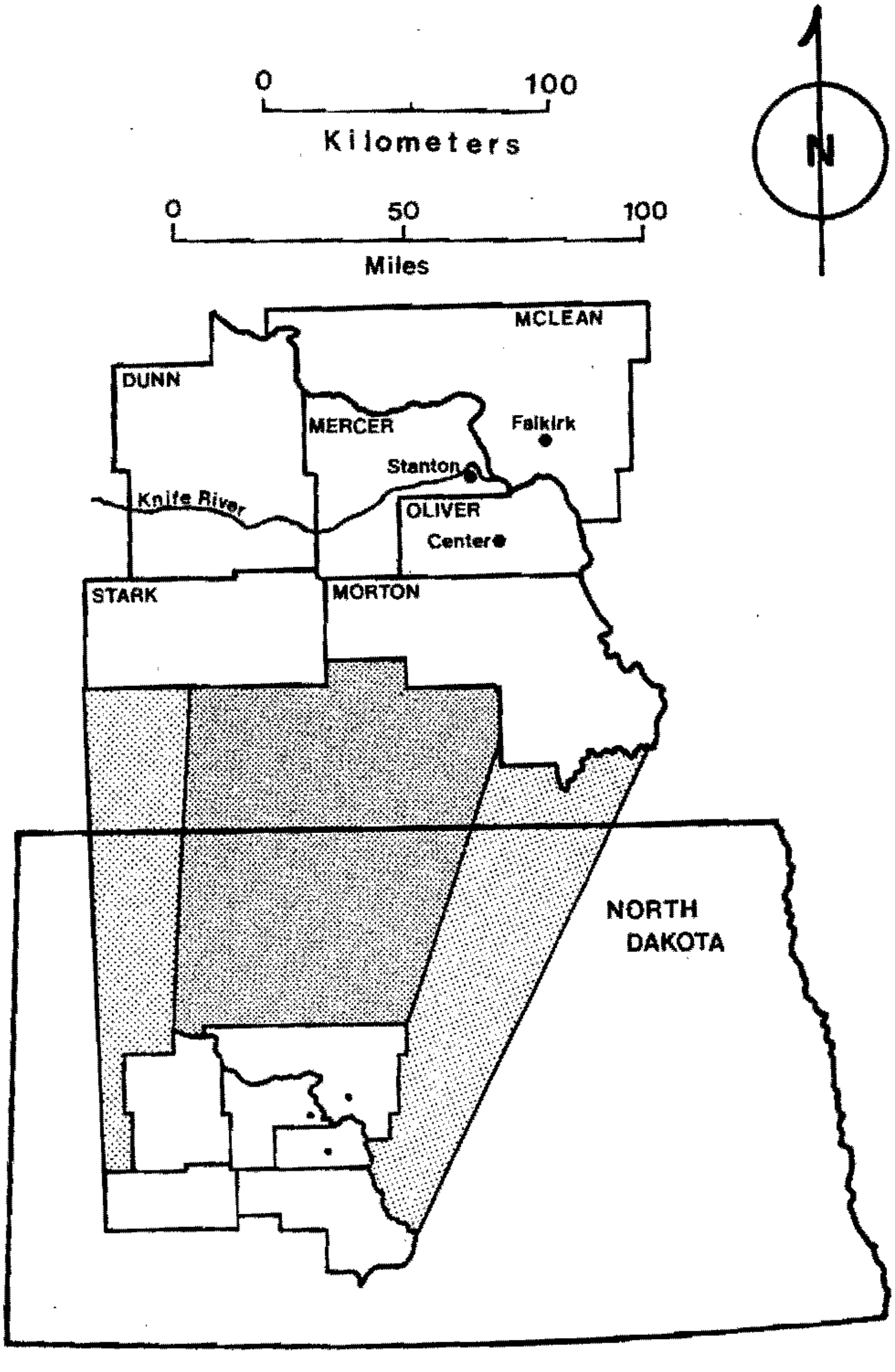
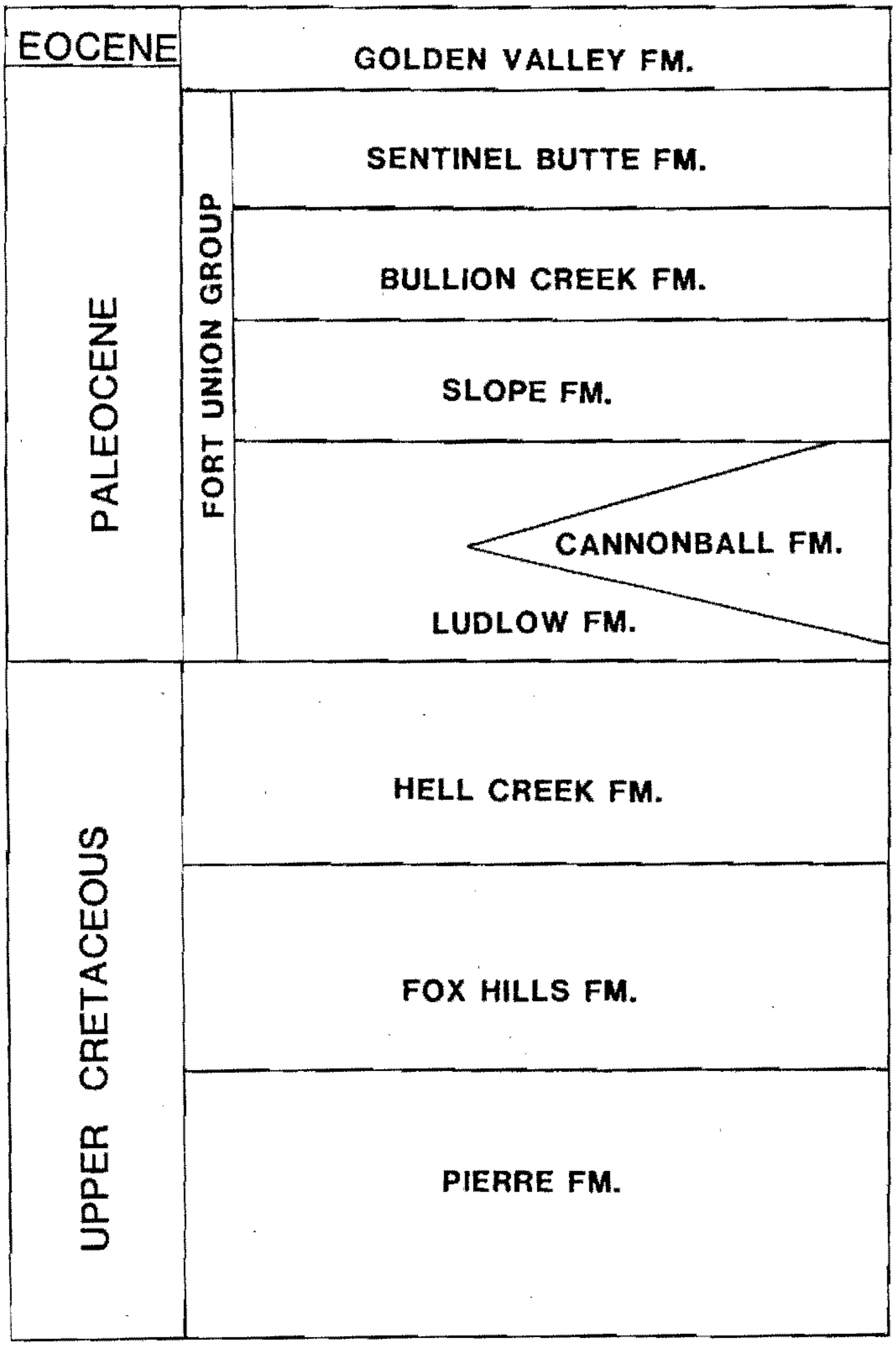

0
100
Kilometers
0
50
100
Miles
N
MCLEAN
DUNN
MERCER
Falkirk
Stanton
Knife River
OLIVER
Center
STARK
MORTON
NORTH
DAKOTA

Figure 2. Chart showing the age and nomenclature of Upper Cretaceous, Paleocene and lower Eocene strata in western North Dakota (after Clayton and others, 1977).


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.

The strata of Cretaceous and Tertiary age exposed in North Dakota and adjacent states were already a subject of controversy among geologists when Leonard and Smith (1909) published their work. Subsequently, the relatively similar lithology of the named units and the presumed continuous record of deposition of these strata, together with questions concerning the position of the Cretaceous-Tertiary contact, have caused numerous nomenclatural changes to occur. Royse (1967b, p. 48) elevated the Sentinel Butte to formational rank and he has provided (p. 39-48) a summary of the nomenclatural history of the unit.

The general depositional setting of the Fort Union Group strata was summarized by Royse (1972, p. 31) who stated:

> In western North Dakota, the Tongue River and Sentinel Butte Formations comprise the upper portion of a stratigraphic sequence that constitutes a depositonal continum from late Cretaceous time through the Paleocene. Upward the sequence is transitional from marine to terrestrial. Collectively, the sequence constitutes a "clastic wedge" spread eastward from the Rocky Mountains during successive episodes of Laramide orogeny. . .

Hickey (1977, p. 6) adopted the stratigraphic usage of the U. S. Geological Survey and treated the Fort Union as a formation and its subdivisions as members. Based on paleobotanical evidence, Hickey (1977, p. 18) assigned a latest Paleocene (Clarkforkian) age to the lower member of the Golden Valley Formation and an Eocene age to the upper member.

Clayton and others (1977), in an effort to resolve stratigraphic problems within the Fort Union Group, introduced two new formational names, the Slope and Bullion Creek Formations, for strata below the Sentinel Butte Formation. The terminology of Clayton and others (1977) is presently in use by the North Dakota Geologic Survey and will be used in this thesis.

Previous Macro-Paleobotanical Works

The paleobotany of the Fort Union Group and equivalent strata in North Dakota, Montana, South Dakota and Wyoming has been investigated by several authors in order to delineate the Cretaceous-Tertiary boundary and to elucidate depositional environments. Early work concerning the paleobotany of the Fort Union Group was compiled by Knowlton (1919). Knowlton's work (1919) included a list of plant species then known from the Mesozoic and Cenozoic of North America.

Dorf (1940) examined the floras of the type "Lance and Fort Union Formations". He found (p. 217) that the two floras shared less than 10 percent of the total number of species present in the two formations. This finding refuted a previous study by Knowlton (1909) which stated that the two formations contained very similar floras. Dorf attributed (p. 221) Knowlton's error to a misidentification of the upper Lance Formation.

Barghoorn (1951) did a statistical analysis of the generic compositions of Cenozoic and Tertiary floras. The study compared trends in native, exotic, and extinct genera with geologic time. Barghoorn pointed out (p. 742) a large exotic element, consisting primarily of American subtropical and tropical genera, in the flora of the Early Tertiary.

Brown (1962) studied the fossil flora of the Cretaceous and Tertiary strata of the Rocky Mountains and Great Plains in an effort to describe the Paleocene Series as a whole. Brown's study included an historical background of previous paleobotanical and stratigraphic works, as well as systematic descriptions of 170 species of megascopic plants.

Brown's conclusions (1962, p. 95-96), concerning the composition and ecologic significance of the Paleocene flora, included: 1) the absence of a complete floral break at the close of the late Cretaceous, 2) similarity between the Paleocene floras and modern temperate floras of the eastern United States and eastern Asia, and 3) the presence of a north-to-south floristic zonation related to climate.

Brown characterized (p. 12) the Paleocene environment of the Western Interior as a broad, swampy lowland; and he further postulated (p. 13) that the Paleocene coals were for the most part paralic, having formed in extensive coastal swamps. The coal beds were said to have been deposited during periods of relative stability within intermittently subsiding basins. Brown likened conditions of sedimentation in the Tertiary lignite areas to the modern-day basins of the Amazon and Parana Rivers of South America.

Ting (1972b) reported on a deposit of permineralized peat of Paleocene age in the Sentinel Butte Formation in Billings County, North Dakota. He said (p. 165) that the silicified peat was found within a lignite bed and was associated with several petrified tree stumps. Thin sections of silicified peat revealed conifer-wood structures, well preserved fern annuli, and a seed of possible conifer origin.

Hickey (1966, 1977) examined the sedimentational, environmental, climatic, and vegetational changes across the Paleocene-Eocene boundary found within the Golden Valley Formation in western North Dakota. Hickey (1977) contrasted the floras of the Bear Den (Paleocene) and Camels Butte (Eocene) Members of the Golden Valley Formation. He said

(p. 93) that the 41 species found in the Bear Den Member showed a high degree of similarity with the flora of the upper Fort Union. Hickey (1977, p. 104) further divided the Golden Valley flora into four general associations: (1) aquatic and marsh vegetation, (2) lowland forest, (3) possible upland plants, and (4) uncertain. The Golden Valley depositional environment was characterized as a low, swampy basin subject to fluvial deposition and possessing a warm, temperate climate.

Previous Palynological Works

The terrestrial strata which crop out in the Dakotas, Wyoming, and Montana are commonly rich in palynomorphs. The strata preserve a record (spanning the Late Cretaceous through the Tertiary) in which the number of palynomorph taxa assignable to modern genera increases greatly with the passing of geologic time. The utility of the plant microfossils increases in concert with increasing knowledge of their botanic affinities. Several authors (Table 1) have applied palynology to the study of the strata of the Western Interior, to the Cretaceous-Tertiary boundary problem, to the study of paleoenvironments, and to questions concerning past and present plant taxonomy.

The Bear Creek coal field in Carbon County, Montana, was analyzed for plant microfossils by Miner (1935, p. 616). Portions of the Fort Union and Kootenai Formations were found to contain five new species of fossil spores. Miner's (1935) work represents the first plant microfossil study of Fort Union strata. Wilson and Webster (1946) recognized seventeen species of plant microfossils in a Fort Union coal from the Kolarich Mine near Red Lodge, Montana.

TABLE 1. SUMMARY OF PREVIOUS PALYNOLOGICAL WORKS.

Authors	Location of Study	Strata Examined
Miner, 1935	Carbon Co. Montana	The Bear Creek field (Fort Union & Kootenai Formations)
Wilson & Webster, 1946	Red Lodge Montana	A Fort Union Coal
Kremp, Neavel and Starbuck, 1956	North and South Dakota	Two coal seams within the Fort Union Group
Gerhard, 1958	Harding Co., South Dakota	A coal within the Ludlow member of the Fort Union Formation
Stanley, 1960	Northwestern South Dakota	Fort Union Group
Trotter, 1963	Harding Co., South Dakota	Ludlow member, Fort Union Formation
Norton, 1963	Eastern Montana	Hell Creek Formation
Stanley, 1965	Northwestern South Dakota	Fort Union & Hell Creek Formations
Hall and Norton, 1966	Garfield Co., Montana	Bearpaw Shale to Lebo Formation
Leffingwell, 1966	Southeastern Wyoming	Upper Lance and Fort Union Formations
Norton and Hall, 1969	Eastern Montana	Bearpaw, Fox Hills, Hell Creek, Tullock and Lebo Formations
Oltz, 1969	East-central Montana	Hell Creek and Tullock Formations
Ting, 1972	Oliver Co. North Dakota	Hagel coal bed, Sentinel Butte
Artzner, 1974	South-central North Dakota	Fox Hills Formation
Spindel, 1974	Southeastern Montana	Tongue River Member, Fort Union Formation.
Roberston, 1975	North Dakota	Fort Union Group and Golden Valley Formation
Bebout, 1977	Western North Dakota	Golden Valley Formation
Melchior and Hall, 1983	Western North Dakota	Bullion Creek Formation
Robertson, 1983	Western North Dakota	Fort Union Group

Kremp and others (1956) investigated the palynology of two coal beds of Paleocene age in North Dakota and South Dakota. One of these beds was located (Kremp and others, 1956, p. 270) at the western side of Slim Buttes in Harding County, South Dakota, ". . . in the Ludlow member of the Fort Union formation . . . ." The other sample locality was sec. 34, T. 137 N., R. 100 W., Billings County, North Dakota (Kremp, and others, 1956, p. 271) from within what would now be the Bullion Creek Formation of the Fort Union Group. The investigation focused on relating petrographic characteristics of the coals to interpretations of the contributing flora based on palynology. They (p. 274) found a fluctuating, if not cyclic, variation between two floral groups, Taxodiaceae-Cupressaceae (conifers), and Myriceae-Betulaceae (angiosperms). The petrology of the coals was found (p. 275) to relate to the palynology in the following manner:

> The coal type, which is almost invariably a function of the relative amount of anthraxylous material, is definitely relatable to changing swamp-conditions as reflected in the changing pollen distribution. A portion of the seam high in Taxodiaceae-Cuppressaceae pollen yields a coal high in anthraxylous material. A portion of the seam high in Myricaceae-Betulaceae pollen yields a coal high in attrital resins and cuticular remains. If the factors which control the floral community can be established, a means of determining vertical as well as lateral variations in coal types may be effected.

The controls on the fluctuation of the floral groups were not precisely known but the authors suggested that water depth, as a function of tectonism or climate, was the controlling factor.

Gerhard (1958) investigated the palynology of a ". . . representative outcrop of a uraniferous lignite seam" in the Ludlow Formation in Harding County, South Dakota. Gerhard described 45 genera and 68 species; 4 genera and 23 species were described as new. The study indicated (p. 137) that trilete and monolete spores are of limited value in the correlation of Paleocene strata.

The palynology and stratigraphy of three lignite drill cores (Paleocene) from Harding County, South Dakota, were studied by Trotter (1963) to gather morphologic and paleoecologic information. Trotter reported (1963, p. 222) a flora composed of a mixture of temperate and subtropical forms and called (p. 223) for further work in the area to make palynostratigraphy a dependable tool for lignite operations in the Dakotas.

Norton (1963) examined the palynology of the type locality of the Hell Creek Formation. Three assemblages of palynomorphs were delineated; the palynomorphs totaled 144 species and 71 genera with 41 species and four genera considered (p. 46) new.

The Upper Cretaceous and Lower Tertiary strata of northwestern South Dakota were examined by Stanley (1960, 1965) to establish the types present, infer botanic affinities, and to establish a palynological zonation suitable for correlation. Ninety-nine species and 64 genera of plant microfossils were described; 60 species and three genera were described as new by Stanley (p. 215). Based on microfossil evidence, Stanley suggested (p. 216) a temperate climate for northwestern South Dakota during the Paleocene.

Hall and Norton (1967, p. 122) studied the palynology of an exposed section extending from the Cretaceous Bearpaw Shale to the Lebo Formation of Paleocene age in Garfield County, Montana. They showed (p. 130) a significant floristic change from the Cretaceous to the Tertiary. This change was expressed (p. 121) as a reduction in the percentage of gymnosperms. Climatic deterioration across the

Cretaceous-Tertiary boundary was suggested (p. 130) as a likely cause for the change in the flora.

Leffingwell (1966) described three "palynological assemblage zones" within the upper Lance (Late Cretaceous), and Fort Union (Paleocene) Formations in the type area of the Lance Formation and in the Spotted Horse and Gillette Coal fields of north-western Wyoming. "Assemblage A," characterized by a diverse and abundant angiosperm micro-flora, was considered (p. 14) to be Maestrichtian in age. "Assemblage B," dominated by fern spores, moss spores, and small, tricolpate and tricolporate, angiosperm pollen grains (p. 14) was considered (p. 19) at least partially Early Danian in age. "Assemblage C," characterized (p. 15) by abundant taxodiaceous-cupressaceous pollen and significant quantities of betulaceous and juglandaceous pollen was considered (p. 20) to be Paleocene in age. Leffingwell traced (p. 16) these floral assemblages throughout the northwestern Wyoming study area, and considered them synchronous time-stratigraphic markers. The floral changes described by the assemblages were observed in the type Hell Creek area, Montana, the Cave Hills area, South Dakota, and the type Cannonball area, North Dakota, by Leffingwell (1965, p. 16-17).

The Cretaceous Bearpaw, Fox Hills, and Hell Creek Formations as well as the Paleocene Tullock and Lebo Formations were palynologically analyzed by Norton and Hall (1969). The species present were divided (p. 6) into four assemblages. Of the 138 species found in the study, 43 percent were restricted to the Upper Cretaceous assemblage (p. 6). The lower Fort Union assemblage was said (p. 6) to contain only 17 percent of the total number of species; and was characterized (p. 9) by an abundance of tricolpate and tricolporate species. The transition assemblage (consisting of palynomorphs found in portions of both the Upper Cretaceous and Lower Paleocene) contained 20 percent of the total, while long-ranging species accounted for 22 percent of the 138 species found.

Artzner (1974) investigated the palynology of a volcanic ash within the Fox Hills Formation in south-central North Dakota. Artzner reported (p. 37) a high diversity and low frequency of palynomorph taxa as compared to other Cretaceous floras.

Oltz (1969) utilized original palynological data as well as the data produced by Stanley (1965) and Norton and Hall (1969) to produce a numerical analysis of the palynology of the Cretaceous and Early Tertiary strata of east-central Montana. Oltz reported 163 species representing 74 genera of pollen and spores, one genus and 30 species were regarded (p. 90) as new. Only one species, Cingulatisporites dakotaensis, was said (p. 115) to be present in all of the Tullock Formation sections and absent from all of the sections measured in the Hell Creek Formation. Oltz (1969, p. 115) also reported ecologically controlled changes in the flora reflected by the pollen record.

Ting (1972a) reported on the palynology of a silicified saprope-lic peat found within the Hagel lignite bed in Oliver County, North Dakota. The palynomorph assemblage, consisting of 18 taxa, included 47 percent Carpinus subtriangulata Stanley, 19 percent Bissaccata sp. (undifferentiated), 3.5 percent Tricolpites bathyreticulatus Stanley, and 3 percent Momipites sp. (p. 66).

Robertson (1975) studied the pollen and spores of the North Dakota Paleocene to examine their potential as stratigraphic indicators. The microfossils were divided into morphologic categories and paleoecologic inferences were made. Robertson (1975, p. 68.) divided the entire Paleocene sequence into six palynological zones on the basis of both qualitative and quantitative information. His "*Maceopolipollenites* zone" was made up of the strata extending from the uppermost "Tongue River" Formation to the top of the lower member of the Golden Valley Formation. The microflora of the "*Maceopolipollenites* zone" was interpreted by Robertson (1975, p. 78) as reflecting an increase in the members of Juglandaceae in the upper half of the Bullion Creek-Sentinel Butte interval.

Robertson (1975, p. 133) divided the Paleocene strata into three "fluvial facies" on the basis of textures, structures, palynomorph assemblages, and invertebrate fossils. Robertson (p. 115) described these "facies" within the Sentinel Butte Formation as "backswamp," "floodplain," and "channel fluvial."

Bebout (1977) did a systematic palynologic study of the Golden Valley Formation which yielded 136 species (p. 25). Bebout (1977, p. ix) compared his floral and paleoclimatic estimates with those of Hickey (1977) and found that they were in general agreement. Bebout said (p. 63-65) that floristic analysis indicated a warm-temperate climate for the Paleocene lower member and a subtropical climate for the Eocene aged upper member of the Golden Valley Formation.

The most recent palynological studies in North Dakota include those by Melchior and Hall (1983) and Robertson (1983). Melchior and Hall (1983) analyzed the strata of the Wannagan Creek site (Bullion Creek Formation, Paleocene, Billings County, North Dakota) for environmentally controlled assemblages. The flora described by Melchior and Hall (1983, p. 133) consisted primarily of an "emergent and floating aquatic community" and a "woody dicotyledonacous flora." Robertson (1983) described pollen and spore assemblages for the Paleocene deposits exposed along the valley of the Little Missouri River of western North Dakota. Robertson pointed out a close relationship between the assemblages he found and those found by Leffingwell (1966) in northwestern Wyoming.

Methods of Research

Fieldwork

The fieldwork for this investigation was conducted largely during June and July, 1983. The work consisted of measuring, describing and sampling sections of mine highwalls. The sections were measured directly on the mine highwalls in areas which afforded the best exposures and the easiest access. The highwall face was cleared by use of a chisel-edge geologic hammer and shovel to expose as clean a face as possible. The exposure was then measured with a steel tape and the lithology described. The bottom of the section measured and sampled was commonly the bottom of the lowest rock in the seam which could be uncovered with hand tools. However, the lowest few feet of the coal seam was often obscured by rubble and irregular masses of solid coal. The upper limit of the section was usually picked at a convenient, arbitrary height above the coal seam (0.5 to 1.0 foot above the topmost coal).

Samples were taken at each change in lithology and at regular intervals (about one foot or one-third of a meter). Usually a sample was taken at the claystone-lignite contacts also. The samples were labeled with a Grand Forks sample number (GF#) and stored at the University of North Dakota Energy Research Center (ERC).

Laboratory Procedures

An efficient method to separate palynomorphs (acid-insoluble microfossils) from their confining matrices is a necessary prerequisite to a successful palynological study. This process is called maceration. A successful maceration leaves a residue containing relatively unaffected palynomorphs and a minimum of extrinsic organic and inorganic particles. Corrosion or differential destruction of palynomorphs should be avoided.

Palynomorphs are often well preserved and abundant in coals and there are numerous maceration methods for use on coals. Most coal maceration methods (Lee, 1964, p. 486) use strong oxidizing agents such as Schutze's solution ($2KClO_3:HNO_3$) or nitric acid. While strong oxidizing agents are effective in breaking down the organic matrix of coal, they can also have the effect of corroding and differentially destroying the organic-walled palynomorphs. For this reason, the coal is only oxidized for a short period of time. This partial oxidation is an attempt to reach a compromise of adequately dispersing palynomorphs from the matrix while leaving them relatively unaffected by the oxidation.

Maceration methods previously used on stratigraphically similar lignites (e. g. those used by Bebout, 1977, p. 353, and Nichols, 1970, p. 42) were attempted in order to macerate lignite samples in this study. The results of these early attempts at maceration were disappointing as the lignite appeared especially resistant to oxidation. Several oxidation agents were tried. It was found that an interrupted, partial oxidation procedure using concentrated nitric acid followed by 10 percent potassium hydroxide resulted in a maceration residue rich in apparently unharmed palynomorphs. This procedure proved to be a relatively quick, easy, and consistent means of macerating Hagel bed lignite and was subsequently used on all lignite samples.

Maceration Schedule for Lignite

The sample to be macerated consisted of approximately two grams of coal which was crushed by mortar and pestle, and then passed through a 60-mesh sieve. Larger particle sizes (up to 3 mm) were also macerated successfully. If samples of larger particle size were used (the 1 to 3 mm range), more coal was needed (up to 5 grams). If large pieces were left following the oxidation, these were carefully left behind when the residue was transferred from beaker to centrifuge tube.

The following procedure was done in a fume hood. The sieved sample was placed in a 250 ml borosilicate glass beaker. A violent foaming reaction usually took place when the nitric acid was added so only 10 ml was added initially and the remaining nitric acid was added when the reaction subsided. As an added precaution, a wash bottle of distilled water was kept handy. In the event that the sample threatened to bubble over, a small amount of the water was added. The water was used sparingly, as it rendered the nitric acid a less effective oxidant. The sample was left in the reagent for approximately 10 minutes. The length of time was varied according to the sample. Agitation was provided throughout the reaction. A hot plate with built-in magnetic stirrer worked well, but frequent manual agitation worked also.

During oxidation, the sample usually took on a light brown (5YR 4/4) color (Goddard and others, 1948). When the oxidation was complete, the residue was poured into 50 ml centrifuge tubes to approximately one-half the volume of the tube. Distilled water was added to fill the tubes and the samples were centrifuged. After centrifugation the supernatant liquid was poured off, distilled water was added, the samples were stirred, and centrifuged again. Following the second centrifuging, the sample was ready for washing with 10 percent potassium hydroxide.

Following the potassium hydroxide treatment, the sample was ready for standard (Doher, 1980, p. 20-27) staining and slide preparation techniques. Some bleaching of palynomorphs occurred in strongly oxidized samples.

Summary of Lignite Maceration Schedule

(DONE IN FUME HOOD)

1. Crush sample and place 2-5 grams in a 250 ml borosilicate glass beaker.
2. Add 10 ml of concentrated HNO_3 to sample.
3. Wait for reaction to become less violent and add 10 ml more concentrated HNO_3 to sample.
4. Stir frequently with a glass stirring rod or a magnetic stir bar.
5. Allow reaction to take place for approximately 10 minutes.
6. Pour residue into 50 ml centrifuge tube(s) to half full.
7. Fill the remainder of each tube with distilled H_2O.
8. Centrifuge and decant.
9. Add distilled H_2O to fill the tube and stir.
10. Centrifuge and decant.
11. Add 20 ml (or enough to cover the sample) of 10 percent KOH.
12. Allow reaction to take place for approximately 20 minutes stirring frequently.

13. Add distilled water to fill centrifuge tube.

14. Centrifuge and decant.

15. Proceed to U. S. G. S. (Doher, 1980, p. 20) standard staining procedure.

Maceration Schedule for Strata Associated with Lignite

The organic-rich siltstones and claystones associated with the lignite of the Hagel bed were variable in their resistance to maceration and no single method worked on all the samples. Some samples had to be treated with a strong oxidizing agent, while others did not. In some cases, a zinc chloride float-sink procedure (Kummel and Raup, 1965, p. 577) was needed to produce residues rich enough to count. A minimum amount of treatment was used in every case to avoid damaging grains.

Summary of Siltstone and Claystone Maceration

1. Crush sample and place 5-10 grams in a 250 ml plastic beaker.

2. Add concentrated (56 percent) HF and allow to stand overnight.

3. Pour residue into 50 ml plastic centrifuge tube(s) to half full.

4. Fill the remainder of each tube with distilled H_2O.

5. Centrifuge and decant (repeat twice).

6. Add 20 ml (or enough to cover sample) of 10 percent KOH.

7. Allow reaction to take place for approximately 20 minutes, stirring frequently.

8. Add distilled H_2O to fill centrifuge tube.

9. Centrifuge and decant.

10. Check for abundance of palynomorphs under microscope.
    a) If abundant enough for counting, proceed to U.S.G.S. standard (Doher, 1980, p. 20) staining procedure.
    b) If palynomorphs are scarce or absent, proceed to step 11.

11. Add 10 ml of concentrated HNO_3 to centrifuge tube.

12. Wait for reaction to become less violent and add 10 ml more HNO_3 to sample.

13. Allow reaction to take place for approximately 10 minutes.

14. Pour residue into 50 ml centrifuge tube(s) to half full.

15. Fill the remainder of each tube with distilled H_2O.

16. Centrifuge and decant.

17. Check for abundance of palynomorphs in microscope.
    a) If abundant enough for counting, proceed to U.S.G.S. (Doher, 1980, p. 20) standard staining procedure.
    b) If palynomorphs are scarce or absent proceed to step 18.

18. Mix residue of approximately 25 ml of $ZnCl_2$, (concentration of approximately 32 moles/liter, specific gravity of approximately 2.0), mix thoroughly.

19. Centrifuge at maximum speed for 20 minutes.

20. Pour supernatant into clean, labeled centrifuge tubes (to one-half the volume of the tubes).

21. Fill tubes of supernatant with distilled water and mix thoroughly.

22. Centrifuge at maximum speed for approximately 15 minutes and decant.

23. Add distilled water to fill tube(s) and stir.

24. Centrifuge and decant.

25. Proceed to U.S.G.S. (Doher, 1980, p. 20) standard staining procedure.

Analytical Procedures

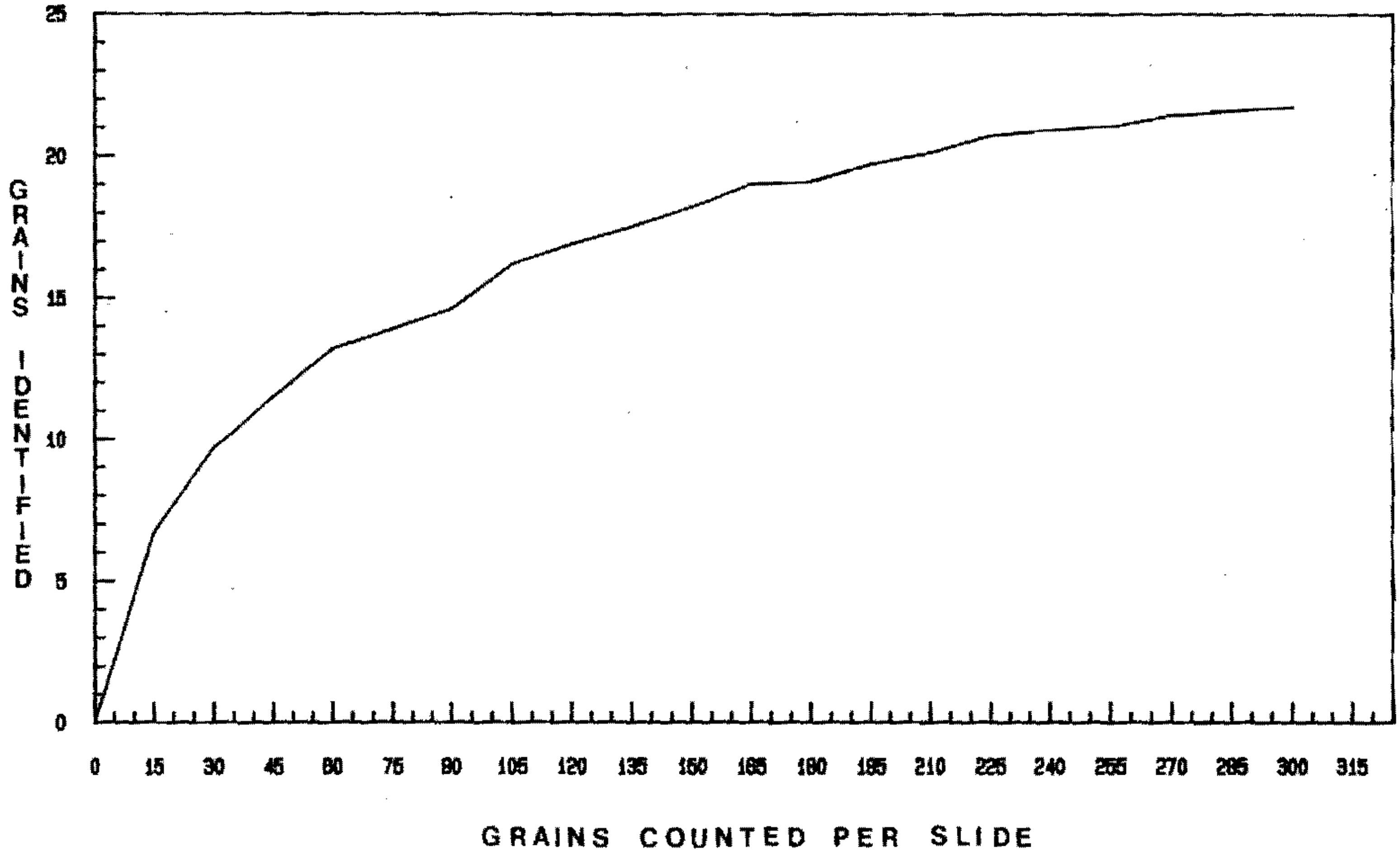
The initial phase of the palynological analysis consisted of scanning slides. When a palynomorph was observed for the first time it was described and its location on the slide noted. These descriptions were later refined into palynomorph type-sheets which included: (1) a diagnosis, (2) a photograph, (3) assignment to a published genus or species where possible, and (4) reference to authors of the assigned taxon. The type-sheets were organized according to apertural condition and served as guide to taxonomic assignments made throughout the study.

When the reference file of type-sheets was nearly complete, the actual counting of the palynomorphs from each sample was begun. During the course of counting the samples, further information was gathered to refine the reference file. Figure 3 illustrates the relationship between the number of grains identified and the number of different types found per slide. To insure consistency, a minimum of 300 grains per sample were counted.

The terminology of palynological morphology used in this study is largely in accordance with the "Morphologic Encyclopedia of Palynology" (Kremp, 1968). Fungal descriptive terminology used is largely in accordance with the "Annotated Glossary of Fungal Palynomorphs" (Elsik, 1983).

Locations of illustrated specimens were recorded by use of coordinates on the mechanical stage of the microscope. The horizontal coordinate is given first, followed by the vertical coordinate. As a means of relocating the specimens, each slide has an "X" inscribed on it with a diamond stylus and the coordinates of the intersection of the "X" are marked on each slide. By obtaining the coordinates of the intersection of the "X" with the mechanical stage on any other microscope and then calculating the difference in these values from the values of the coordinates marked on each slide, one obtains the set of values needed to convert the coordinates given for any specimen to equivalent coordinates on the microscope being used. This standard method is described in detail by Traverse (1958, p.208) and Pierce

Figure 3. The number of palynomorph types identified compared to the number of grains counted (per slide) calculated from the average of all slides counted in this study.


GRAINS IDENTIFIED
0
5
10
15
20
25
0 15 30 45 60 75 90 105 120 135 150 165 180 195 210 225 240 255 270 285 300 315
GRAINS COUNTED PER SLIDE

(1959, p. 337). The slide collection is stored in the paleontological collection at the University of North Dakota in Grand Forks.

Two parameters were considered as means of discerning the commonness of the palynomorphs found in this study; these parameters were frequency of occurrence and abundance. Frequency of occurrence of any particular palynomorph was expressed as the percentage of samples in which that palynomorph was found. Frequency determination for each palynomorph was made by dividing the number of samples in which that palynomorph was found by the total number of samples and converting this value to percent. Words used throughout this study to express the frequency of occurrence of palynomorphs are defined in Table 2.

The abundance of any particular palynomorph (in samples in which it is found) was expressed as a cumulative mean percentage value. Abundance determination for each palynomorph was made by dividing the total number of a particular palynomorph type found (in the entire study) by the total number of samples; this value is an average value for the abundance of particular palynomorphs. Words used throughout this study to express the abundance of palynomorphs are defined in Table 3. No abundance determinations are listed for palynomorphs considered too rare to count or for those lumped into larger morphotypic categories.

Chemical Analysis

Each of the lignite samples used in this study was analyzed using proximate and ultimate techniques (Montgomery, 1978, p. 194-218). The coal was analyzed on an as-received basis and the results were calculated to obtain moisture-free and moisture- and ash-free values. These analyses were performed by the coal analysis laboratory at the University of North Dakota Energy Research Center. Proximate analysis

TABLE 2. FREQUENCY TERMS

Frequency term	Percentage of samples present
Rare	less than 6%
Infrequent	6 - 20%
Common	20 - 30%
Frequent	30 - 50%
Dominant	greater than 50 %

TABLE 3. ABUNDANCE TERMS

Abundance term	Cumulative mean percentage
Rare	less than 0.1%
Uncommon	0.1 - 1.0%
Common	1 - 10%
Abundant	10 - 30%
Very Abundant	greater than 30%

measures moisture, volatile matter, fixed carbon (calculated by difference), and ash. Ultimate analysis measures hydrogen, carbon, nitrogen, sulfur, oxygen (calculated by difference), and ash. The heating value analysis quantifies in calorific heating units and in British Thermal Units (BTU) per pound of coal.

The siltstones and claystones associated with the Hagel bed were analyzed by x-ray diffraction (Klug and Alexander, 1974, p. 505) and x-ray fluorescence techniques (Benson and others, 1980, p. 35). These techniques were used to measure the mineralogic and elemental characteristics of the samples used in this study. The x-ray diffraction and x-ray fluorescence analyses were done at the Coal Utilization Research Laboratory of ERC.

Rock Descriptions

Lignite samples investigated in this study were each described using a variable power (1x to 7x) binocular stereomicroscope. The methodology of the description followed that of Chao and others (1983, p. 30-31). The relative percentages of the lithotypes vitrain, fusain, and durain-clarain were visually estimated. The relationship of the lithotypes, layering, texture, color, luster, and miscellaneous features were recorded for each lignite sample.

The characteristics recorded for each non-lignite sample included the standard rock-color designation (Goddard and others, 1948), visually estimated average particle size, sedimentary structures, a rock name, and miscellaneous lithologic features.

STRATIGRAPHY

Definition of the Hagel bed and Position in the Sentinel Butte Formation

General

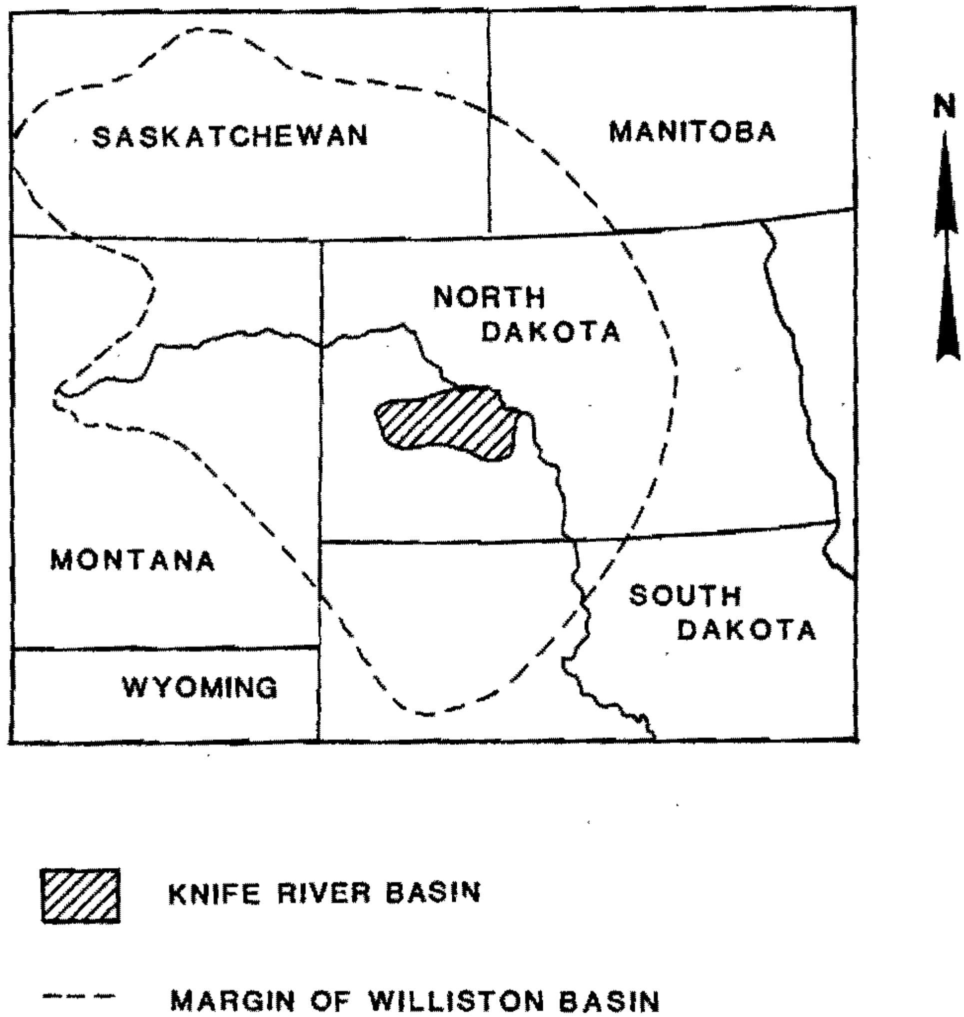
The area of the study is located within the Williston Basin, a broad structural and sedimentary basin which contains strata from the Cambrian through Tertiary systems (Carlson and Anderson, 1970). Illustrated in Figure 4 is the extent of the Williston basin and its relationship to the area of the study.

The Paleocene sequence in the Knife River basin is dominantly composed of fine- to medium-grained clastics and lignites. The Paleocene sequence is composed (in ascending order) of the Ludlow, the Cannonball, the Slope, the Bullion Creek, and the Sentinel Butte Formations of the Fort Union Group and part of the Golden Valley Formation (Figure 2). Of these, only the Cannonball Formation is considered marine in origin.

The strata examined in this study lie entirely within the Sentinel Butte Formation. The Sentinel Butte Formation is overlain by the Golden Valley Formation of Paleocene and Eocene age, and the Sentinel Butte is underlain by the Bullion Creek Formation. The Hagel bed is the lowest named lignite in the Sentinel Butte Formation (Groenewold and others 1979, p. 22).

The Hagel bed was named by Johnson and Kunkel (1959) for the Hagel mine in Oliver County, North Dakota. Johnson and Kunkel (1959, p. 40) further described the Hagel bed as ". . . extensive in central and south-central Oliver County along Square Butte Creek and its

Figure 4. The extent of the Williston Basin (outline taken from Laird, 1956, p. 16) and the position of the Knife River basin (from Groenewold and others, 1979, p. 2).


SASKATCHEWAN
MANITOBA
N
NORTH DAKOTA
MONTANA
SOUTH DAKOTA
WYOMING
KNIFE RIVER BASIN
MARGIN OF WILLISTON BASIN

tributaries."

For the purposes of this study the Hagel bed is defined in accordance with the work of Groenewold and others (1979, p. 22) who described the bed as follows:

> . . . black to brownish-black coal having the rank of lignite. It characteristically slacks rapidly when exposed to the atmosphere. It may include dark-brown to black carbonaceous clay locally and is usually characterized by one or more brown or gray clay partings. Silt or sand lenses may be included locally.

The Hagel bed occurs 82 feet (24.6 m) above the top of the Tavis Creek lignite bed in the type test hole (Groenewold and others, 1979, p. 23). Groenewold and others (1979) trace the Hagel bed throughout the Knife River Basin on the basis of its stratigraphic position in a known sequence of beds. The relationship of the Hagel bed to other coals and the names applied by previous workers are summarized in Figure 5.

Position of Measured Sections

Only the uppermost (mined) portion of the Hagel Bed was sampled. The measured sections from each mine were taken from the upper seam of the Hagel Bed. Groenewold and others (1979) trace this seam of the Hagel Bed (with variations in thickness and presence of claystone partings) throughout the study area. The strata examined in each measured section are, therefore, considered equivalent. Figure 6 shows the approximate stratigraphic positions of the measured sections in a cross section modified from Groenewold and others (1979). Figure 7 illustrates the measured sections and sample locations within each section.

Figure 5. The relationship of the Hagel bed to other coals and the names applied by other workers (modified from Groenewold and others, 1979, p. 19).

	Groenewold and others (1979)	Benson (1952)	Johnson and Kunkel (1959)	Barclay (1974)	Hemish (1975)	Moran, et al. (1976)
Sentinel Butte Formation	Harnish	Harnish				C
	Twin Buttes	Twin Buttes	Byer(?)			B
	Schoolhouse	Schoolhouse	Otter Creek			A
	Beulah-Zap	Beulah-Zap	Herman			Dunn Center
	Spaer	Spaer				E
	Jim Creek					F, G
	Antelope Creek		Yeager- (eastern Oliver County Buckmann- (western Oliver County)			H
	Kinneman Creek	Star Hazen B- (Beulah area)	Berg Kuether (eastern Oliver Co.) "Beulah-Zap"- (western Oliver Co.)			I
	Hagel	Stanton Hazen B upper and lower Hazen A splits in Hazen area	Hagel	Richter	Underwood A	J
Upper Bullion Creek Formation	Tavis Creek	Knoop		Tavis Creek	TR	K
	Coal Lake Coulee	Hancock (?)				L(?)
	Welter Slough					

Figure 6. Cross section of the Hagel lignite bed in area studied; the approximate stratigraphic positions of the three sections measured are indicated. Cross section from Groenewold and others (1979, plates 10 and 16).

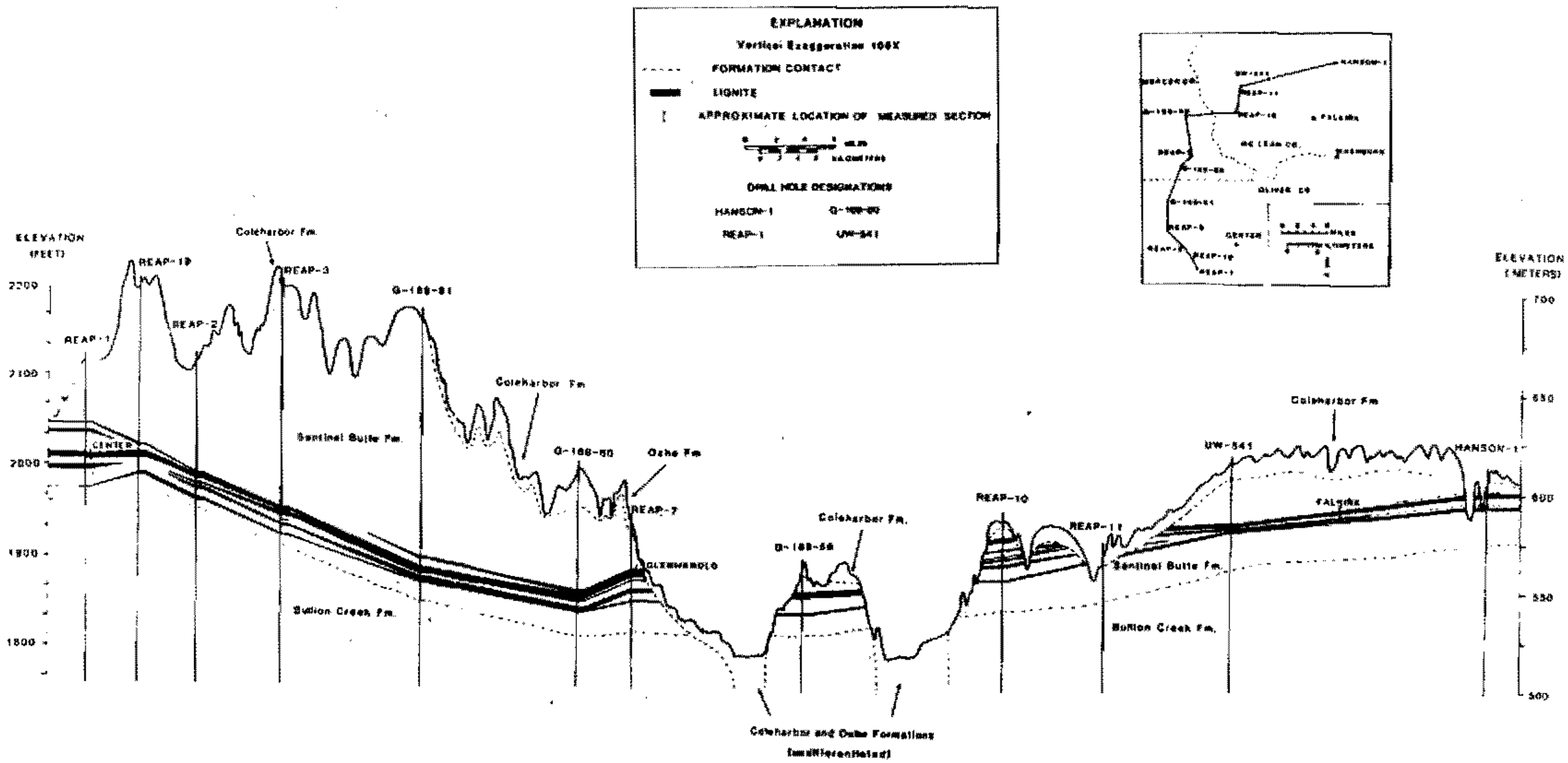
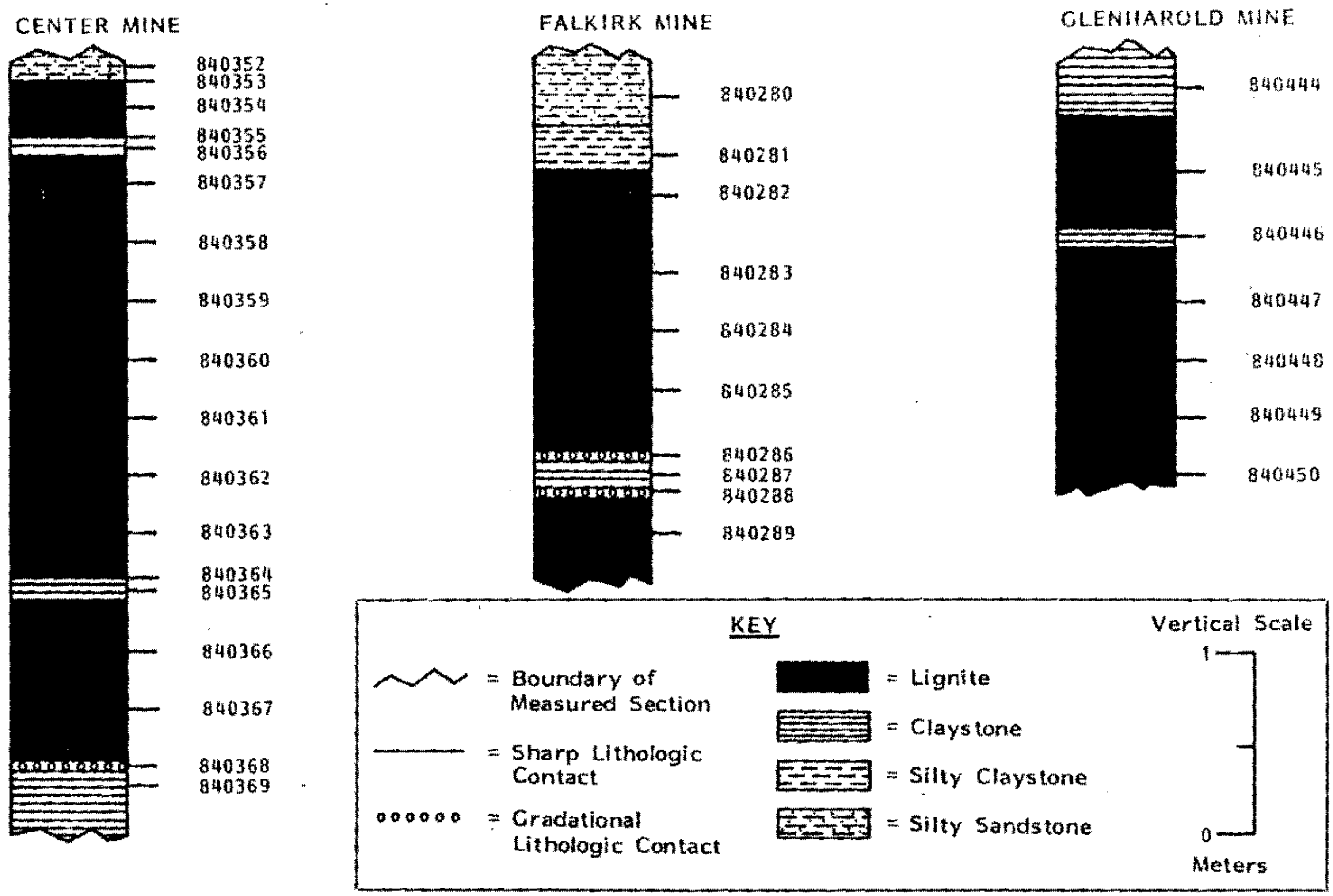

EXPLANATION
Vertical Exaggeration 106X
FORMATION CONTACT
LIGNITE
APPROXIMATE LOCATION OF MEASURED SECTION
DRILL HOLE DESIGNATIONS
HANSON-1
REAP-1
UW-541
ELEVATION (FEET)
2200
2100
2000
1900
1800
ELEVATION (METERS)
700
650
600
550
500
REAP-1
REAP-19
REAP-2
REAP-3
CENTER
Colehardor Fm.
Sentinel Butte Fm.
Sutton Creek Fm.
REAP-7
G-166-50
Osho Fm.
REAP-10
REAP-11
UW-541
HANSON-1
FALKIRK
Coleharbor and Osho Formations (undifferentiated)

Figure 7. Measured sections and sample locations within them.


CENTER MINE
840352
840353
840354
840355
840356
840357
840358
840359
840360
840361
840362
840363
840364
840365
840366
840367
840368
840369
FALKIRK MINE
840280
840281
840282
840283
840284
840285
840286
840287
840288
840289
GLENHAROLD MINE
840444
840445
840446
840447
840448
840449
840450
KEY
= Boundary of Measured Section
= Sharp Lithologic Contact
= Gradational Lithologic Contact
= Lignite
= Claystone
= Silty Claystone
= Silty Sandstone
Vertical Scale
1
0
Meters

Rock Descriptions

General

The petrologic analysis of samples used in this study is considered in two parts: those analyses done on lignite samples, and those analyses done on clastic rocks. Lignite samples were analyzed by proximate and ultimate techniques. Clastic rocks were analyzed by x-ray fluorescence and x-ray diffraction techniques. All samples considered in this study were visually described and analyzed for palynomorph frequency and abundance.

The clastic rocks examined are not laterally homogeneous throughout the study area and the lignite of the Hagel bed varies in thickness laterally. Therefore, no attempt has been made to correlate individual rock samples contained in the measured sections; rather, the following two sections are meant to describe and compare the strata examined.

Characteristics of Lignite Sampled

Coal is a sedimentary rock derived from the build-up of vegetal remains in an anaerobic environment. Typically, coal is formed when peat (or similar partially decayed vegetal matter) undergoes diagenetic changes which result in increased carbon and decreased volatile matter. Coal is described in two ways, by coal rank and by coal type.

Coal type refers to the description of the recognizable components of the coal. These recognizable components are remnants of the initial heterogenity of the coal and differences in them reflect changes in the environment of deposition and the contributing flora. Macroscopically recognizable components are called lithotypes; these commonly occur in layers or bands. Components of coals which are visible only by use of a microscope are called macerals and are analogous to the minerals which make up other types of rock. The analogy falls short, however, in that macerals are not uniform in chemical composition or physical properties. These characteristics change among different coals and with increasing rank.

Lignite samples used in this study were described in terms of macroscopically recognizable features. Characteristics noted of each coal sample include (1) percentages (visually estimated) of lithotypes present, (2) relationships among different lithotypes, (3) layering, (4) texture, (5) color and luster, and (6) miscellaneous features.

The lignite samples are heterogeneous, but some generally similar characteristics can be noted for all three measured sections. The lignite is generally well banded, possesses vitrain lenses and thin tabular sheets of fusain dispersed in a durain-clarain matrix. Much of the coal breaks into small (1-10 cm) tabular chunks of material morphologically resembling wood due to the presence of small stuctures similar to wood grain (xylites). Larger scale fractures (10 cm - 1 m) are characteristically conchoidal or at right angles. Detailed macroscopic descriptions of the individual samples can be found in Appendix I.

Rank is a term used to describe the degree of metamorphism a coal has undergone. Coal is ranked according to fixed carbon (%) and calorific value (BTU/lb.). The Hagel bed has the rank of lignite with a characteristically low calorific value as well as high volatile matter and moisture contents.

A summary of the values obtained by proximate and ultimate techniques gathered from each of the three measured sections examined in this study are given in Table 4; data from proximate and ultimate analysis are compared by mine in Figure 8; for complete data refer to Appendix B.

The data from proximate and ultimate analysis were analyzed using the SAS Institute Statistical Analysis System (SAS). The data were manipulated by using correlation, factor and cluster analyses. The correlation analysis produced Pearson product-moment correlation coefficients for all the variables. The correlation analysis was meant to determine the statistical relationships of the variables to each other. Hierarchical cluster analysis was used to help identify which samples have similar attributes (based on the variables). A factor analysis was performed to determine which variables most influenced the creation of the clusters.

The correlation analysis showed a significant relationship between sulfur and nitrogen (Figure 9). Berkowitz (1979, p. 37) has pointed out that sulfur and nitrogen are not systematically related to coal rank and are always minor components of the organic substance of coal. Altschuler and others relate (1983, p. 221) the distribution and fixation of sulfur in Everglades peat to the primary distribution of organic sulfur and the subsequent formation of pyrite at the expense of the organic sulfur by sulfur reducing bacteria. It seems reasonable to assume that the original chemistry of the contributing flora and post-depositional but pre-diagenetic chemical reactions play a significant role in the distribution of elements in coal. Spackman and Barghoorn (1966, p. 695-707) have proposed that as available nitrogen is biochemically fixed into decaying vegetation, the microbiological fixation of sulfur diminishes. This phenomenon may be partially

TABLE 4. SUMMARY OF VALUES (IN PERCENT) FROM PROXIMATE AND ULTIMATE ANALYSES

Variable	MEAN				STANDARD DEVIATION			
	All Samples	Center Mine	Falkirk Mine	Glenharold Mine	All Samples	Center Mine	Falkirk Mine	Glenharold Mine
Volatile matter	49.67	49.58	49.34	50.10	2.43	2.80	1.53	2.75
Fixed Carbon	43.37	43.71	42.70	43.70	2.68	2.90	3.23	1.98
Ash	6.96	6.71	7.96	6.20	1.76	1.90	1.93	1.03
Hydrogen	4.39	4.68	3.70	4.80	0.61	0.30	0.32	0.55
Carbon	61.77	68.12	49.5	67.70	8.51	1.70	3.62	1.99
Nitrogen	0.85	1.03	0.76	0.77	0.22	0.19	0.11	0.21
Sulfer	0.56	0.30	0.60	0.79	0.30	0.15	0.24	0.32
Oxygen	21.67	19.16	26.14	19.70	3.44	1.70	1.90	1.69
Number of samples	20	10	5	5	20	10	5	5

Figure 8. Average, by mine, of proximate analysis data on a moisture-free basis (based on five samples in the Glenharold Mine and Falkirk Mine sections and ten samples in the Center Mine section).

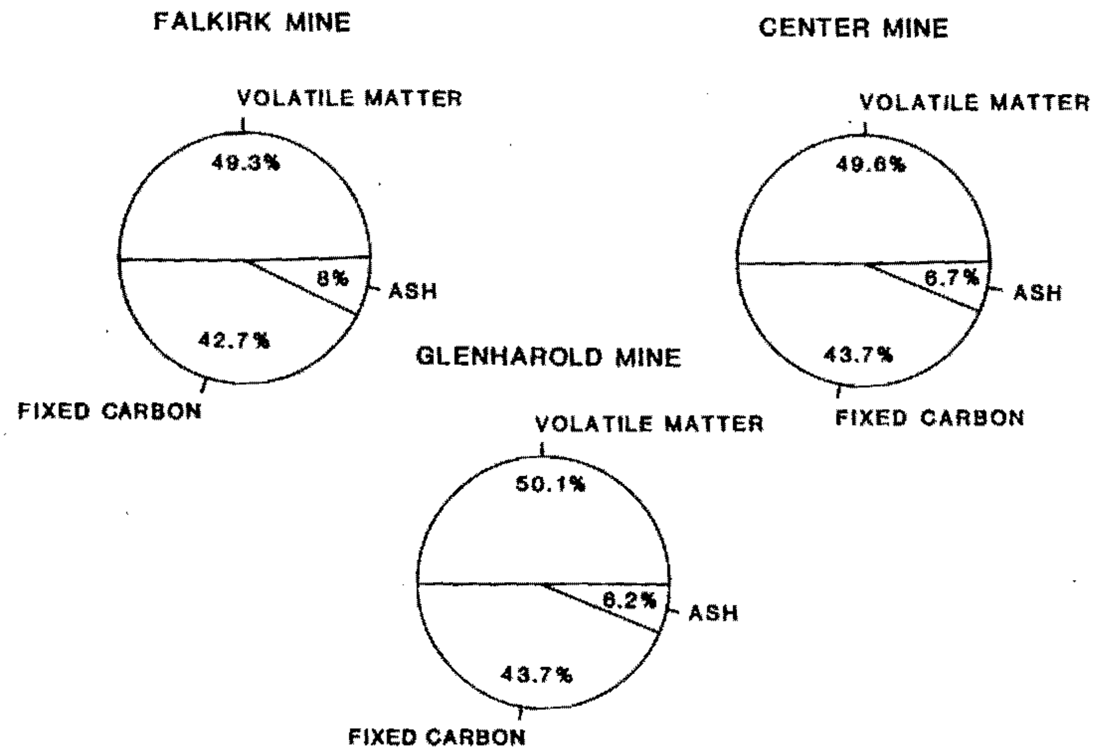
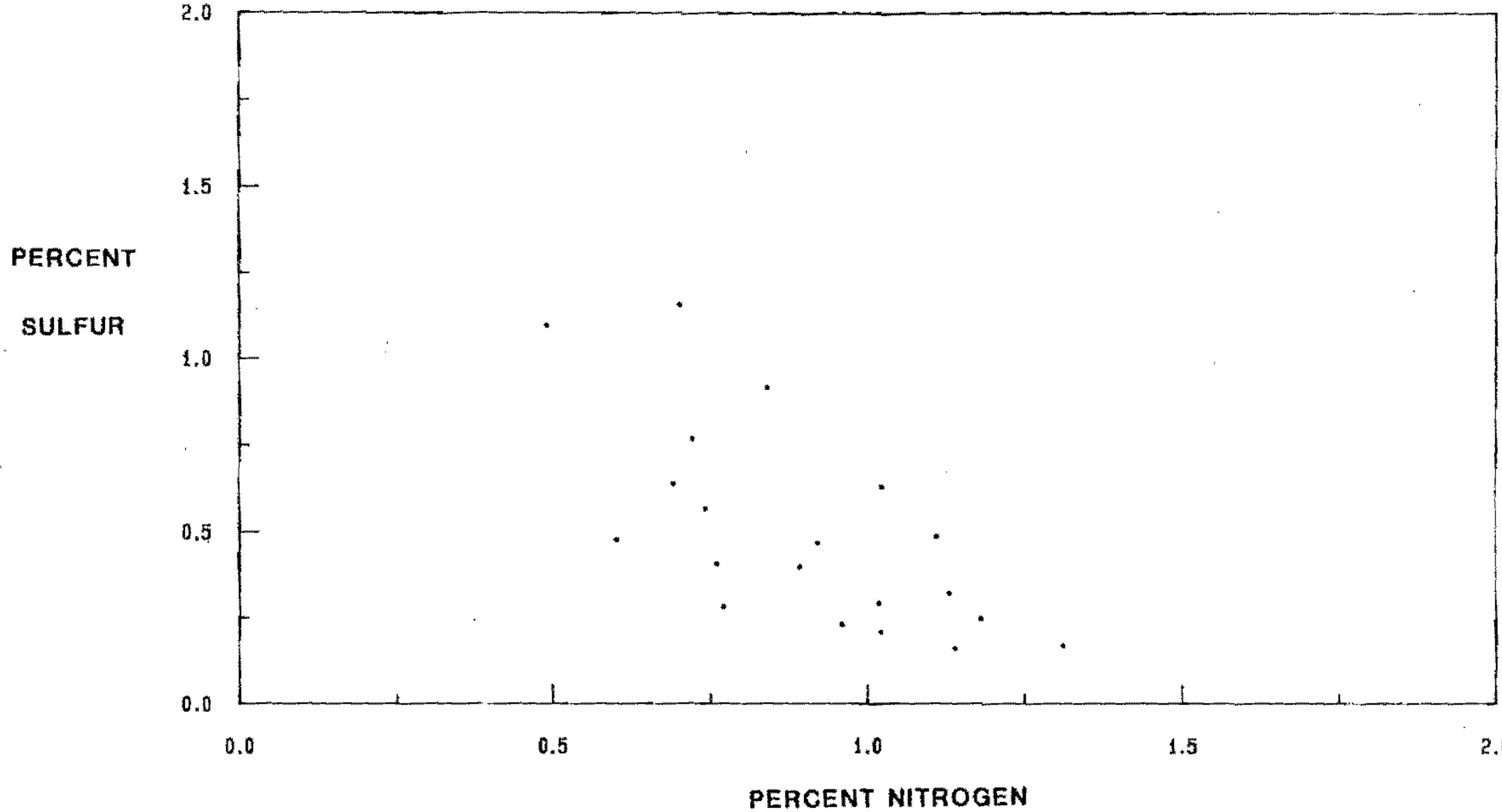

FALKIRK MINE
VOLATILE MATTER
49.3%
8%
ASH
42.7%
FIXED CARBON
CENTER MINE
VOLATILE MATTER
49.6%
6.7%
ASH
43.7%
FIXED CARBON
GLENHAROLD MINE
VOLATILE MATTER
50.1%
6.2%
ASH
43.7%
FIXED CARBON

Figure 9. Scatter diagram showing the relationship between nitrogen and sulfur in Hagel lignite samples (on a moisture- and ash-free basis).


PERCENT
SULFUR
PERCENT NITROGEN
2.0
1.5
1.0
0.5
0.0
0.0
0.5
1.0
1.5
2.0

responsible for the inverse relationship of sulfur and nitrogen.

The results of cluster analysis applied to the proximate and ultimate analysis data are illustrated in Figure 10. The samples do not cluster strongly or consistently on the basis of stratigraphic position (vertically or laterally) but they do seem to group (in a general way) by measured section (i.e., Center mine samples appear more likely to cluster with other Center mine samples). The results of factor analysis suggest that volatile matter, carbon, ash, hydrogen, oxygen and calorific values all play a significant role in producing the clusters.

In the course of modern coal studies, various classification schemes have been implemented. Since oxygen, volatile matter and calorific values all vary directly or inversely with carbon content, these parameters are commonly used to develop classification systems.

Hagel bed samples plotted on Mott's (1948) classification are illustrated in Figure 11. Mott's classification is based on plotting volatile matter against calorific value and is one of the best known coal classification schemes. The broad black band (labeled with coal ranks) represents the zone in which most of the world's coals can be plotted. The Hagel bed samples cluster in a group with slightly higher volatile matter contents than found in the typical lignite. It is important to note that Mott's classification is calculated on a dry mineral matter free (dmmf) basis and that the calculations made on Hagel bed samples were on a dry ash free (daf) basis. The significance of the difference between these two methods for expressing analytical results is a subject of concern (particularly in the case of low-rank coals) and has been discussed by Given (1976, p. 256), Kiss and King (1977, p. 340), and Given and Spackman (1978, p. 319). This classifi-

Figure 10. Hierarchical cluster analysis of proximate and ultimate analyses results of Hagel bed samples.

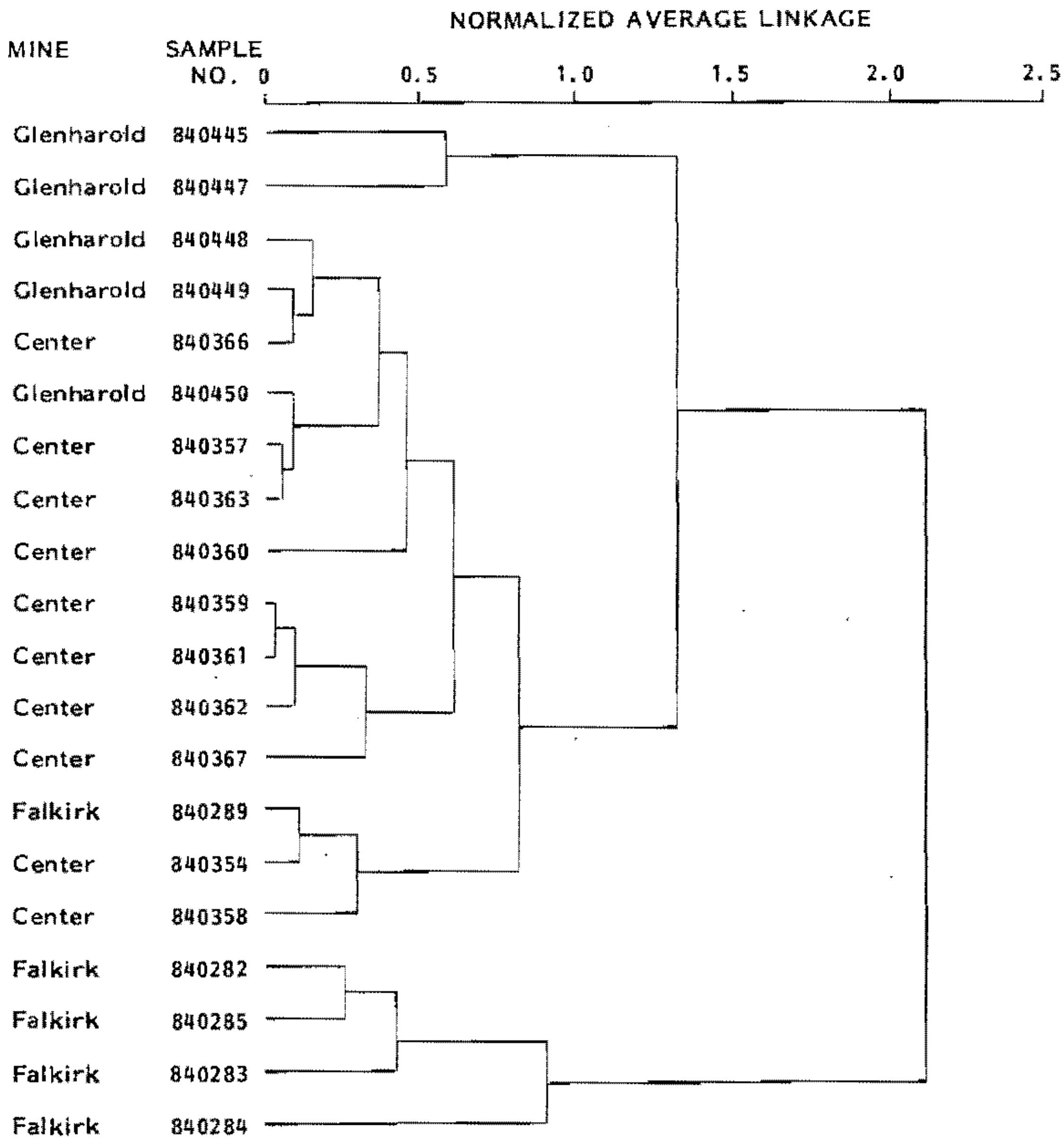
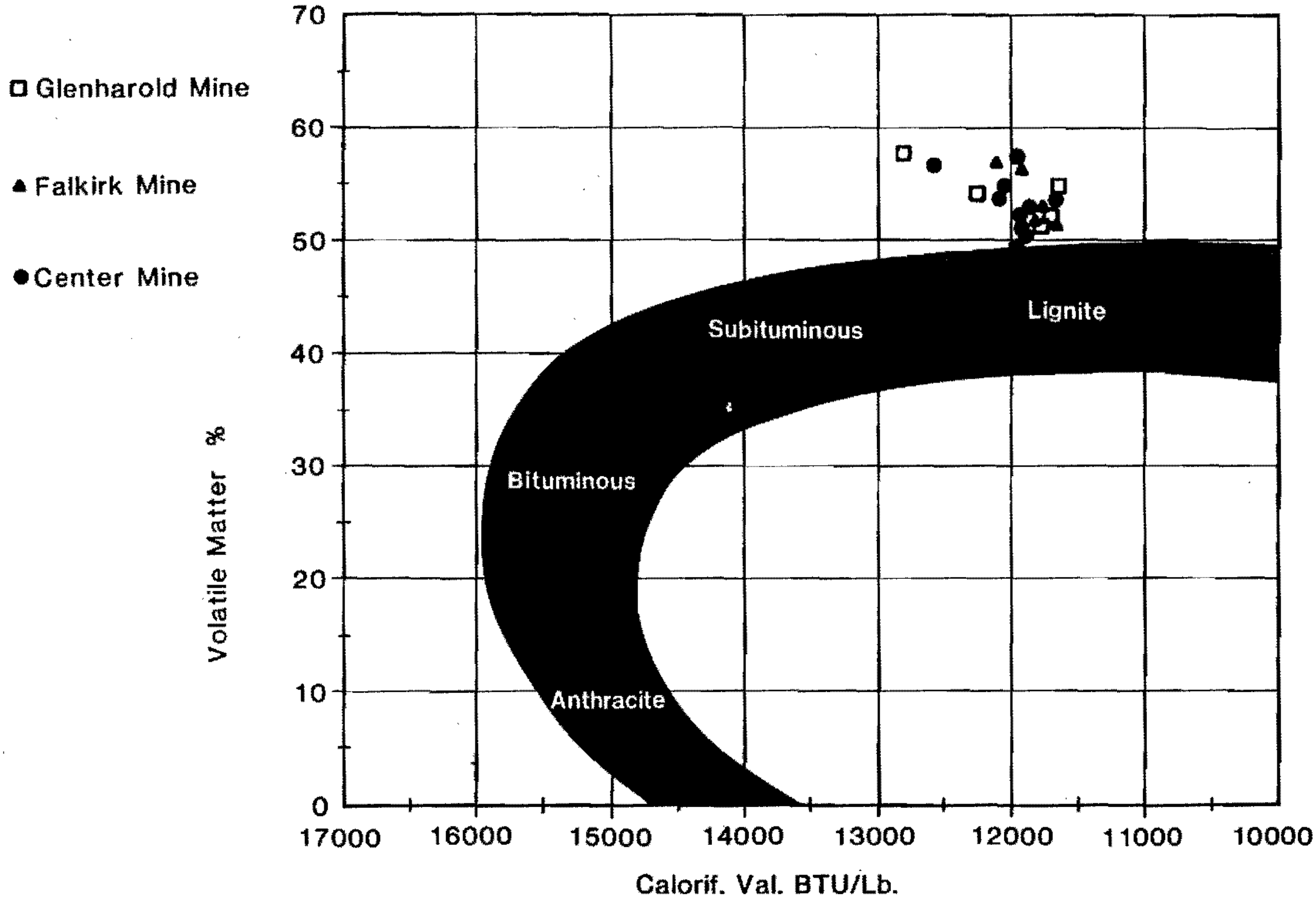

NORMALIZED AVERAGE LINKAGE
MINE
SAMPLE NO.
0
0.5
1.0
1.5
2.0
2.5
Glenharold 840445
Glenharold 840447
Glenharold 840448
Glenharold 840449
Center 840366
Glenharold 840450
Center 840357
Center 840363
Center 840360
Center 840359
Center 840361
Center 840362
Center 840367
Falkirk 840289
Center 840354
Center 840358
Falkirk 840282
Falkirk 840285
Falkirk 840283
Falkirk 840284

Figure 11. Hagel bed samples plotted on Mott's classification.


Glenharold Mine
Falkirk Mine
Center Mine
70
60
50
40
30
20
10
0
Volatile Matter %
Subituminous
Lignite
Bituminous
Anthracite
17000
16000
15000
14000
13000
12000
11000
10000
Calorif. Val. BTU/Lb.

cation of Hagel bed lignite is presented here merely as a means of illustrating the general relationship of the Hagel bed to other coals.

Hagel bed samples also have lower hydrogen values than are typically found in lignites. However, low-rank coals are often difficult to fit into standard classification schemes.

Sample Characteristics of Clastic Rocks Sampled

The lithologies immediately above, interbedded within, and below the Hagel lignite bed were sampled where possible. These lithologies were analyzed to determine their gross mineralogical and elemental characteristics. The results of these analyses were used to characterize mineralogical and chemical zonations or variations present and to augment palynologic data to enhance the understanding of the shifting depositional environments which resulted in the interbedded siltstones, claystones, and lignites preserved in the area.

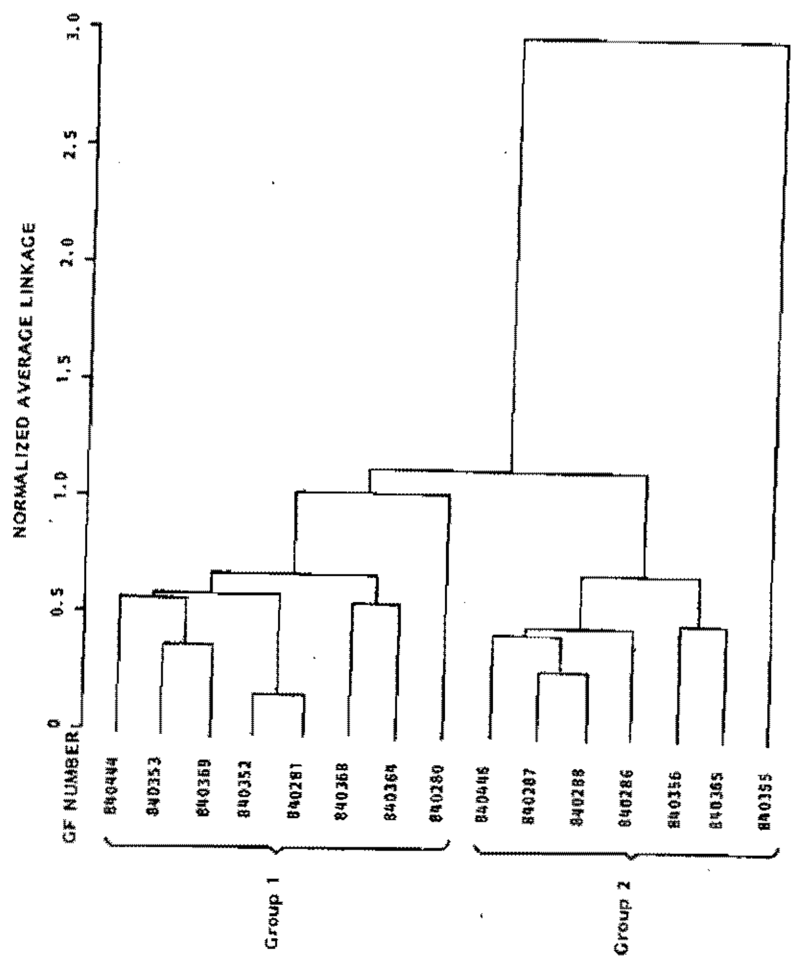
The non-lignite samples were described prior to other analyses. Characteristics noted for each sample included (1) visually estimated particle size (2) organic content, (3) sedimentary structures present, (4) color and (5) miscellaneous features. The samples were typically composed of light-olive-gray to dark-gray clay to silty clay, and contained a great deal of dark organic matter. The organic matter was usually concentrated into thin laminae or in the form of small lenticular lignitic inclusions. The sedimentary structures present were usually laminae. These laminae were thin, parallel to irregular, and composed of varve-like, alternating, darker (apparently organic-rich) and lighter layers. Detailed descriptions of the individual samples can be found in Appendix A.

The gross mineralogical constituents of the non-lignitic samples were determined using x-ray diffraction techniques. The rocks generally contained quartz and muscovite as dominant components. Chlorite, plagioclase, and lepidolite were also common constituents. Major and minor element analyses were performed using x-ray fluorescent techniques on the non-lignite samples as well. These analyses were meant to provide a quantified chemical data base to compare with trends in the palynology of the non-lignite samples.

Hierarchical cluster analysis provides some insight into the major oxide relationships present. By separating the dendogram shown in Figure 12 into two clusters, it can be seen that the non-lignite samples from above and below the lignite seams are grouped with each other, as are the samples taken from sedimentary rocks interbedded in the lignite seams. The interbedded sedimentary rocks from all three measured sections appear to be similar to one another. Therefore, vertical stratigraphic position appears more important than lateral stratigraphic position in determining the compositional relationships in the clastic samples studied. Complete x-ray diffraction major-oxide analyses of samples are provided in Appendix B.

The dominant elements present in non-lignite samples examined were aluminum, silicon, potassium, and iron. The minor element analyses revealed no obvious stratigraphic relationships in the samples analyzed. The distribution of the minor elements is due to several complex and interrelated variables (e.g., ground-water geochemistry, diagenesis, and original geochemical characteristics). A thorough investigation is beyond the scope of this study. Complete minor-element analysis data are presented in Appendix B.

Figure 12. Hierarchical cluster-analysis dendogram of major oxides in non-lignitic samples.


NORMALIZED AVERAGE LINKAGE
0
0.5
1.0
1.5
2.0
2.5
3.0
GF NUMBER
840444
840353
840369
840352
840281
840368
840364
840280
840446
840287
840288
840286
840356
840365
840355
Group 1
Group 2

PALEOECOLOGY

Philosophy and Systematic Procedure

General

The three objectives of this study to be addressed by palynological analysis are: to differentiate and describe any palynomorphic associations present, to use the palynomorphs present to characterize the contributing flora, and to compare the palynologic variations present with the chemical and mineralogic characteristics of the sediments. To fulfill these objectives percentage-frequency data using both phylogenetic and morphologic classification schemes were used.

The systematic treatment of palynomorphs is, regrettably, without a single, agreed-upon, classification scheme. This problem manifests itself in nomenclature but is rooted in the inherent complexity of paleobotanic taxonomy.

The taxonomy of plant microfossils is complex for several reasons: 1) the phylogenetic relationships, on which plant taxonomy is based, become increasingly clouded (if not obscured altogether) with the problems of fossil preservation and increasing geologic age, and 2) plant microfossils represent only a portion of a plant's life cycle and as such are imperfect states; this makes assignments to modern whole organism taxa difficult and necessitates the use of organ genera and form genera. These problems are especially acute when one considers the taxonomy of Tertiary floras which invariably contain both extinct and extant taxa. These difficulties, however, do not negate the value of information gained through palynology on the stratigraphy, paleoenvironments, and evolution of Tertiary floras.

One result of this difficult taxonomic situation is a proliferation of differing systematic procedures among authors. These procedures usually reflect the author's personal philosophy and address the practical concerns required to fulfill the individual goals of the different studies. An excellent review of the divergent systematic procedures used in palynology is provided by Schopf (1969, p. 49). Wingate 1983, p. 97) has provided a summary of some more recent treatments of systematic palynology.

Regardless of the systematic procedure used, stratigraphic palynologists should strive to exploit all the information provided by plant microfossils, both taxonomic and purely morphologic. The value of taxonomic determinations, which link fossil palynomorphs with modern taxa, is obvious. Palynomorphs determined to have well-understood, modern, botanic affinities can be used to enhance our understanding of phylogenetic relationships and to interpret paleoenvironments. Phylogenetically correct names are superior because they place the organism into the taxonomic classification scheme of the plant kingdom. Rigid taxonomic treatment of palynomorphs enhances the amount of information communicated, standardizes the names through nomenclature, and reduces the problem of convergence in characteristics. The problem with classifying palynomorphs phylogenetically is that the taxonomic decisions needed to do so are often tenuous (or impossible) and are rarely well agreed upon. These uncertainties have prompted some workers to reject the phylogenetic treatment of palynomorphs and apply artificial or strictly morphologic classification systems.

Morphologic systems are not taxonomic in nature and use morphologic terminology rather than nomenclature (Schopf, 1969, p. 62). They have the advantage of relatively rapid implementation. Fewer subjective decisions are needed to make assignments. Morphologic classifications have proven themselves useful for biostratigraphic correlation. Further, consistently identified morphologic types might be assigned to established taxa later with an increased understanding of phylogenetic relationships.

Since a strict adherence to either a phylogenetic or a morphologic classification allows a Tertiary palynologist the use of only a portion of the information available, a combination of the two would seem a useful compromise. Unfortunately, combining morphologic and phylogenetic systems brings us back to the myriad of systematic procedures mentioned earlier.

This study is primarily concerned with the information that can be gained from palynology leading toward better understanding the strata examined. For these purposes, I have endeavored to glean the most palynologic information possible, given the limited time available for the project. This necessitated the utilization of both palynomorphs assigned to previously described species and morphologic types of my own design (morphotypes). However, I have treated these classifications as separate entities. This dual system is intended as a working compromise between a completely artificial system and a formal taxonomic study.

Each palynomorph type found in any significant number was assigned a three-digit, alpha-numeric, palynomorph-type designation. These designations were meant to serve as symbols for percentage count data and statistical manipulations. The palynomorph-type designations were short-hand symbols meant to designate palynomorphs assigned to previously described species, whereas the palynomorph-type designations were the only names applied to the morphotypes.

Palynomorphs Assigned to Previously Described Species

Taxonomic assignments were made, with prudence, only when I was reasonably sure that the palynomorph found in my study was equivalent to a taxon previously published. This conservative attitude in taxonomic assignments was adopted because of the preliminary nature of this study and because a more formal taxonomic treatment would be premature. However, published names for taxa were used, when possible, to facilitate communication and provide information otherwise unattainable within the scope of this project.

Taxonomic assignments were made through careful study and comparison of illustrations and descriptions of taxa in the literature. The literature search was not exhaustive and when possible the assignments were made according to the information provided by the Pennsylvania State University "Catalog of Fossil Spores and Pollen" (CFSP) edited by Traverse, Ames, and Spackman, (1961, 1979). The CFSP was preferentially used because of its inclusive and ongoing nature and its widespread availability; these attributes provided as much taxonomic unanimity available to the study at this time as possible. For cases in which taxa were not found in the CFSP palynomorphs were assigned to taxa found in other published works and the publications referred to accordingly. The botanical affinities of formally treated taxa listed in this work represent determinations made from the literature. Each affinity listed, therefore, is ascribed to the publication in which the determination was made.

Due to the incomplete taxonomic treatment of forms found in this study, no new names are proposed. Forms not assignable to previously published forms were treated as morphotypes and not considered in a strict taxonomic (phylogenetic) sense.

Morphotypes

Palynomorphs classified on the basis of gross morphologic characters are referred to as morphotypes. The morphotype designations presented herein represent an artificial system of classification. The morphotypes have significance only within the strict context of this study. The system was devised for practicality and meant to fulfill the objectives of this study only.

The use of artificial classification schemes in palynology is not new. Tschudy (1957, p. 277) suggested the use of "formulae" meant to classify fossil pollen easily and consistently. Schopf (1969, p. 62), while acknowledging the weak points of artificial classifications, stated ". . . almost any consistent system of microfossil classification will provide relatively rapid and useful results." Schopf (1969, p. 63) went on to say:

> An informal system has the further advantage of making available practical results of palynologic study during early phases of microfossil exploration when announcement of formal taxonomic results would be premature.

While formally treated names are the most accurate and best conceived classifications for any purpose, the practical limits of this study also justify the use of a more readily applied artificial system. Most of the palynomorphs encountered have levels of preservation permitting rapid assignment to morphologic categories, but assignment of formal names at the species level to particular specimens were commonly tenuous if not impossible. The relatively subtle characteristics needed to make specific determinations were, in many cases, absent even where the more fundamental morphologic characters (such as apertural condition) were well preserved.

The use of a morphologic classification scheme based on supra-specific characteristics permitted the systematic counting of a far greater number of grains. The morphotypes were well established and documented by palynomorph type-sheets (as described in the section on methods of research) meant to facilitate consistency in the assignments made throughout this study. Thus, the morphologic categories (although not necessarily representative of single-plant species) were consistently applied, and are therefore useful for discerning changes in abundance of the palynomorphs present in the samples. I feel the use of the morphotype categories represents a more calculated and consistent compromise than the compromise needed to make assignments to previously-named species on the basis of questionable morphologic characters. In this manner, a conservative attitude in making taxonomic assignments was preserved while using the maximum amount of palynologic data.

The morphotype classification scheme was devised on the basis of logical relationships (e. g., grouping all fungal spores) as well as on the basis of ease of application (e. g., all porates were grouped together). The aim of the morphologic grouping was to provide a classification which would adequately demonstrate changes in the palynoflora. The morphotypes presented fall roughly into four categories.

The first category contains morphotypes which have distinctive characteristics but are not readily assignable to named species.

Morphotype C14 is a palynomorph within this category. Morphotypes of this sort could, perhaps (with further taxonomic study), be fit into a taxon in a phylogenetic scheme.

A second category of morphotypes includes those classified strictly by apertural condition. Morphotype PUD falls within this morphologic category. The designation PUD stands for "porate undifferentiated". This designation signifies that a pore (or pores) is present but that further systematic refinement is impossible or tenuous.

The third type of category has only one representative morphotype, TCU. This category includes the single most abundant morphotype counted. The morphotype TCU stands for "Taxodiaceae-Cuperaceae undifferentiated". This type represents the combination of morphotypes TC3 and TC4 when the grains were not indentifiable to species level. These types were of similar morphology and were often badly folded necessitating the use of the combination morphotype TCU. The types making up this morphotype are closely related and this makes the counting of this broad category significant.

The fourth morphotype category is represented by FUD (Fungal undifferentiated) and AQ1 (Aquilapollenites type). The morphotype FUD is a combination of all the fungal spores encountered, while AQ1 represents any palynomorph whose form resembled that of an Aquilapollenites species.

Palynological Analysis

General

The reconstruction of past floras and environments based on palynology requires several assumptions: 1) the fossil pollen preserved accurately reflects the past flora, 2) assignments of fossil palynomorphs to modern taxonomic units are valid, and 3) morphologic constancy, expressed in palynomorphs assignable to modern taxonomic units, is paralleled by physiologic constancy. Although these assumptions are reasons for genuine concern, one can generally circumvent major misinterpretations by restricting the scope of each assumption.

The validity of assuming that the palynoflora accurately reflects the past flora was addressed by using percentage-frequency data. By counting a statistically significant number of palynomorphs per sample, one can better assume that the frequency and abundance of palynomorphs present will reflect the composition of the contributing flora.

The validity of assigning fossil palynomorphs to modern taxonomic units is another cause of concern. This problem was handled by grouping palynomorphs into taxonomic units of high rank. The use of "supra-ordinal taxa" was discussed by Hall and Norton (1967, p. 22) who stated:

> Although generic assessment of pollen forms may be tenuous, most sporomorphae from the Late Cretaceous onward can be confidently referred to supra-ordinal taxa; the lycopods, ferns, gymnosperms and dicotyledons are for the most part readily circumscribed.

Supra-ordinal grouping may have made some paleoenvironmental determinations less precise, but it was felt that less specific paleoenvironmental interpretations based on well-founded data were preferable to more specific interpretations based on tenuous taxonomic assignments. In many cases morphotypes could be reliably assigned botanic affinities of higher taxonomic rank. These assignments were based on morphologic characters considered consistent within supra-ordinal taxonomic groups. Supra-ordinal grouping provided information on the total flora and reflected changes in the flora due to shifting environments.

The palynoflora of the Hagel bed is listed in Table 5. Both the palynomorphs assigned to previously described species and morphotypes are listed in Table 5. The morphotypes are all of questionable taxonomic affinity and are meant to be relevant only within the context of this study. They are presented in Table 5 as a means of enumerating the palynoflora of the Hagel bed as described and used for paleoenvironmental interpretations by the writer.

More specific paleoenvironmental interpretations were made using palynomorphs with well-accepted generic-level botanic affinities. In cases where generic assignments appeared to be generally accepted in the literature, one can feel justified in using these taxa to make specific paleoenvironmental determinations.

Assuming that morphologic constancy expressed in palynomorphs is paralleled by physiologic constancy was justified primarily by the use of palynologic associations and corroborating lithologic evidence. Some taxa present were probably not fully physiologically differentiated in the Paleocene and habitat preferences may have changed since. However, the dominance of taxa representative of modern-day plants with swampy environmental habitat preferences (e.g., the present-day swamp taxa Taxodiaceae and Sphagnum) in strata necessarily derived from swampy peat-forming depositional environments (lignite) lends credence to the assumption that these taxa have maintained a high degree of physiologic constancy since the Paleocene.

As a means of discerning changes in the palynoflora, two palyno-

TABLE 5. LIST OF SPECIES IDENTIFIED

Kingdom Plantae
- Subkingdom Thallobionta
  - Incertae Familiae - spores
    - Perisporiacites? sp. (F12)
    - Polyporisporites sp. (F13)
    - Exesisporites sp. (F16)
    - Morphotype F10
    - Morphotype F11
    - Morphotype F14
    - Morphotype F15
    - Morphotype F17
    - Morphotype F18
    - Morphotype FUD
  - Division Chlorophyta
    - Class Zygnemaphyceae
      - Ovoidites ligneolus (Pontinie), Thompson and Pflung (I10)
- Subkingdom Embryobionta
  - Division Bryophyta
    - Class Bryopsida
      - Family Sphagnaceae
        - Stereiosporites antiquasporites (Wilson and Webster) Dettman, 1953 (L15)
        - Cingulatisporites dakotaensis Stanley, 1965 (L10)
  - Division Tracheophyta
    - Subdivision Lycophytina
      - Class Lycopsida
        - Family Lycopodiaceae
          - Foveosporites cyclicus Stanley, 1965 (L22)
      - Class Filicophytina
        - Family Gleicheniaceae
          - Cardioangulina diaphana (Wilson and Webster) Stanley, 1965 (L25)
        - Family Hymenophyllaceae
          - Hymenophyllumsporites furcosus Stanley, 1965 (L19)
        - Family Osmundaceae
          - Osmunda comaumensis (Cookson) Stanley, 1965 (L16)
        - Family Polypodiaceae
          - Laevigatosporites haardti (Pontinie and Venitz) Thompson and Pflung, 1953 (L13)
          - Laevigatosporites anomalus Norton, 1969 (L21)
        - Incertae Familiae - spores
          - Leiotriletes pseudomaximus (Pflung and Thompson) Stanley, 1965, (L24)
          - Schizosporis complexus Stanley, 1965 (I13)
          - Reticulatasporites cristatus Stanley, 1965 (I15)
      - Incertae Class - spores
        - Morphotype L12
        - Morphotype L14
        - Morphotype L17
        - Morphotype L18
        - Morphotype LTU

Subdivision Spermatophytina
  Class Cycadopsida
    Family Cycadaceae
      Cycadopites giganteus Stanley, 1965 (S15)
    Incertae Familiae - pollen
      Morphotype S11
      Morphotype S12
  Class Coniferopsida
    Family Pinaceae
      Laricoidites magnus (Pontinie) Pontinie, Thompson and Thiergart (I08)
    Family Taxodiaceae
      Sequoiapollenites paleocenicus Stanley, 1965 (TC3)
      Taxodiaceaepollenites hiatus (Pontinie) Kremp, 1949 (TC4)
    Incertae Familiae - pollen
      Monosulcites crescentus Norton, 1969 (S10)
      Morphotype BUD
      Morphotype TCU
      Morphotype I16
  Class Ginkgopsida
    Incertae Familiae - pollen
      Ginkgo shiabensis Simpson (1961) (C09)
  Class Angiospermopsida
    Subclass Dicotyledonidae
      Family Anacardiaceae
        Rhoipites pisinnus Stanley, 1965 (CP4)
        Rhoipites crassus Stanley, 1965 (CP5)
      Family Betulaceae
        Betula infrequens Stanley, 1965 (P21)
        Carpinus subtriangula Stanley, 1965 (P13)
        Corylus granilabrata Stanley, 1965 (P15)
        Morphotype P20
      Family Ericaceae
        Ericaceoipollenites rallus Stanley, 1965 (I09)
      Family Junglandaceae
        Pterocarya levis Stanley, 1965 (P09)
        Engelhardtia microfoveolata Stanley, 1965 (P17)
      Incertae Familae-pollen
        Momipites parvus Norton, 1969 (P16)
        Triporopollenites maximus Norton, 1969 (P11)
        Triporopollenites plektosus Anderson, 1960 (P12)
        Morphotype L20
        Pseudotricolpites reticulatus Stanley, 1965 (I12)
    Subclass Monocotyledonidae
      Family Liliaceae
        Liliacidites variegatus Couper, 1953 (S16)
        Pandaniidites texus Elsik, 1968 (P22)
    Incertae Subclass - pollen
      Morphotype CP2
      Morphotype CP6
      Morphotype C13
      Morphotype C16
      Morphotype P14
      Morphotype P18

Morphotype P19
Morphotype P23
Morphotype PUD

PALYNOMORPHS NOT ASSIGNED TO TAXONOMIC GROUPS

Morphotype I11
Morphotype I14
Morphotype IUD
Morphotype C14
Morphotype C15
Morphotype CTU
Morphotype CPT
Morphotype SMU
Morphotype UN1
Morphotype AQ1

morph classifications were constructed. These classifications were devised on the basis of both morphologic and taxonomic criteria, and intended to be consistently and readily applied in order to elucidate changes in the overall flora. A conservative attitude was adopted concerning the botanic affinities assigned; the resulting groups (Figure 13) are broad, and of high taxonomic ranks.

Classification one divided the palynomorphs into three groups: 1) the palynomorphs belonging to the Division Tracheophyta excluding the Subdivision Spermatophytina (pteridophytes), 2) the class Angiospermopsida (angiosperms), and 3) the gymnosperms (consisting of the classes Cycadopsida, Ginkgopsida, Coniferopsida, and Gnetopsida). The palynomorph type designations grouped according to classification one are listed in Table 6.

Classification two is the result of a combination of morphologic and taxonomic criteria. This classification was based on paleoenvironmental significance and ease of application. Classification two divided the palynomorphs into four groups: 1) Taxodiaceae-Cupressaceae, 2) bisaccates, 3) pteridophytes, and 4) angiosperms. The palynomorphs with botanical affinities in the modern Families Taxodiaceae and Cupressaceae were grouped because it is usually difficult to distinguish between the genera of these taxa; they are the dominant palynologic element, and they seem to have dominated the swamp environment in which the Hagel bed was deposited. Bisaccates are morphologically distinctive palynomorphs produced by conifers and are attributed (Hopkins, 1969, p. 1109) to "upland habitats". Pteridophytes and angiosperms were important enough to consider separately as they are easily and consistently identified, and (as groups)

Figure 13. Palynomorphs separated into basic taxonomic groups.

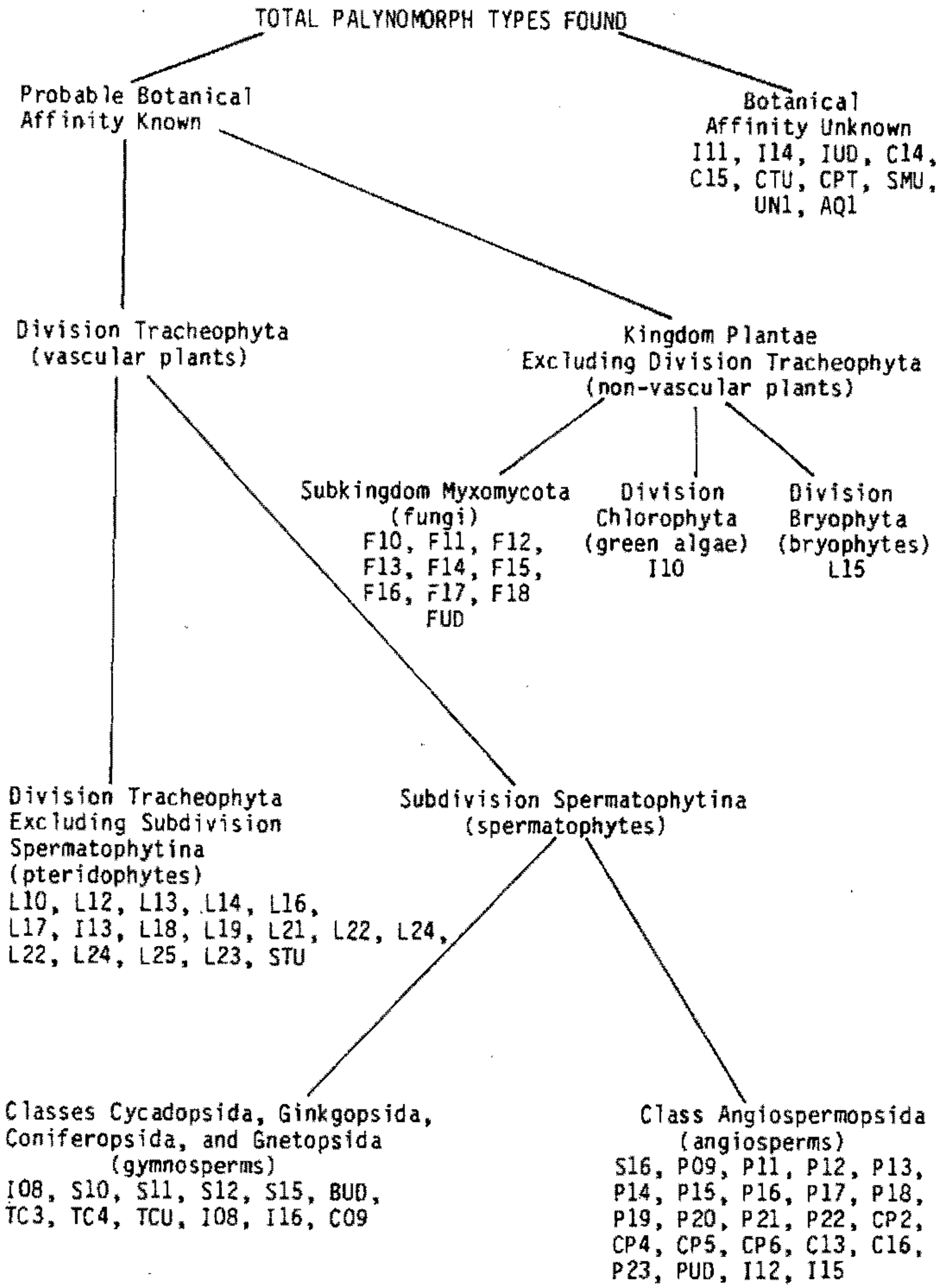

TOTAL PALYNOMORPH TYPES FOUND
Probable Botanical Affinity Known
Botanical Affinity Unknown
I11, I14, IUD, C14, C15, CTU, CPT, SMU, UN1, AQ1
Division Tracheophyta (vascular plants)
Kingdom Plantae Excluding Division Tracheophyta (non-vascular plants)
Subkingdom Myxomycota (fungi)
F10, F11, F12, F13, F14, F15, F16, F17, F18 FUD
Division Chlorophyta (green algae)
I10
Division Bryophyta (bryophytes)
L15
Division Tracheophyta Excluding Subdivision Spermatophytina (pteridophytes)
L10, L12, L13, L14, L16, L17, I13, L18, L19, L21, L22, L24, L22, L24, L25, L23, STU
Subdivision Spermatophytina (spermatophytes)
Classes Cycadopsida, Ginkgopsida, Coniferopsida, and Gnetopsida (gymnosperms)
I08, S10, S11, S12, S15, BUD, TC3, TC4, TCU, I08, I16, C09
Class Angiospermopsida (angiosperms)
S16, P09, P11, P12, P13, P14, P15, P16, P17, P18, P19, P20, P21, P22, CP2, CP4, CP5, CP6, C13, C16, P23, PUD, I12, I15

TABLE 6. PALYNOMORPH CLASSIFICATION ONE (modified from Stace, 1980, p. 250, 251).

CLASSIFICATION	VERNACULAR NAMES		GROUPS	PALYNOMORPHS INCLUDED
Divisions				
Subdivisions				
Classes				
Subclasses				
Tracheophyta	Vascular plants	vascular plants		
Psilophytina	Whisk-ferns			L10, L12, L13, L14, L16,
Lycophytina	Club-mosses			L17, L18, L19, L21, L22,
Lycopsida				L24, L25, STU, I13
Isoetopsida				
Sphenophytina	Horse-tails		pteridophytes	
Filicophytina	Ferns			
Eusporangiopsida	Eusporangiate ferns			
Leptosporangiopsida	Leptosporangiate ferns			
Spermatophytina	Seed-plants, spermatophytes			
Cycadopsida	Cycads			I08, I16, S10, S11, S12,
Ginkgopsida	Ginkgo, maidenhair tree			S15, BUD, C09, TC3, TC4,
Coniferopsida	Conifers			TCU
Gnetopsida			gymnosperms	
Ephedridae				
Welwitschiidae				
Gnetidae				
Angiospermopsida	Flowering plants			S16, P09, P11, P12, P13, I12,
Dicotyledonidae	Dicotyledons (dicots)		angiosperms	P14, P15, P16, P17, P18, PUD,
Monocotyledonidae	Monocotyledons (monocots)			P19, P20, P21, P22, CP2, I15,
				CP4, CP5, CP6, C13, C16, P23

contributed significant paleoenvironmental information. The palynomorph type designations grouped according to classification two are listed in Table 7.

Stratigraphic Palynology

Changes in the relative abundance of the palynologic groups were examined on the basis of lithology, lateral variation, and vertical variation. The samples' lithologies were divided into those from strata consisting of coal, those from claystone or siltstone, and those taken at contacts between the coal and associated strata (transition samples). Transition samples consisted of approximately 2 cm of coal above, and 2 cm of clastic rock below sharp contacts; in cases where the transition from clastic rock to lignite was gradational, the rock between the lowest lignite and highest clastic rock was sampled.

Since one section was measured per mine, lateral variation was examined by grouping samples on the basis of the mine from which they originated. Vertical variation among palynomorph groups was discerned by considering each sample in the vertical context of its respective measured section.

Palynomorphs were compared (according to classification one) to the three basic lithologies considered in this study (Figure 14). Several general tendencies in the palynoflora are apparent in Figure 14: 1) the increased dominance of gymnosperm pollen in the coals, 2) the angiosperm abundance is greatest in the claystone samples, and 3) a marked increase in pteridophyte abundance in transition samples.

When classification two is considered relative to basic lithologic types, tendencies similar to those discerned by utilization of classification one appear (Figure 15). The group Taxodiaceae-Cupressaceae is

TABLE 7. PALYNOMORPH CLASSIFICATION TWO (modified from Stace, C. A., 1980, p. 250, 251).

CLASSIFICATION		VERNACULAR NAMES	GROUPS	PALYNOMORPHS INCLUDED

Divisions
  Subdivisions
    Classes
      Subclasses				

Tracheophyta	vascular plants			
Psilophytina Lycophytina Lycopsida Isoetopsida Sphenophytina Filicophytina Eusporangiopsida Leptosporangiopsa		pteridophytes	pteridophytes	L10, L12, L13, L14, L16, L17, L18, L19, L21, L22, L24, L25, STU, I13
Spermatophytina				
Cycadopsida Ginkgopsida Coniferopsida Gnetopsida Ephedriae Welwitschiidae Gnetidae		gymnosperms	Taxodiaceae-Cupressaceae	I16, C09, TC3, TC4, TCU
			bisaccates	BUD
Angiospermopsida Dicotyledonidae Monocotyledonidae		angiosperms	angiosperms	S16, P09, P11, P12, P13, P14, P15, P16, P17, P18, P19, P20, P21, P22, PUD, CP2, CP4, CP5, CP6, C13, C16, P23, I12, I15

Figure 14. Palynomorph abundance according to classification one (angiosperms, gymnosperms, and pteridophytes) in the three lithologic types sampled in this study.

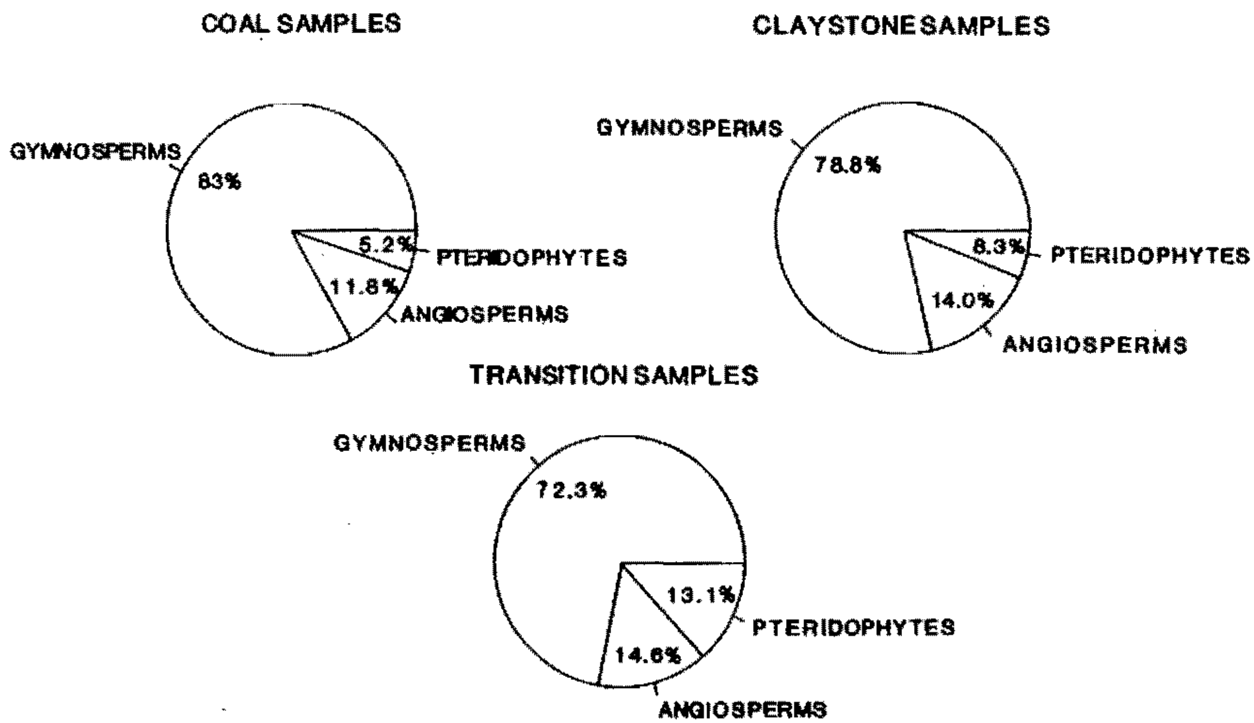
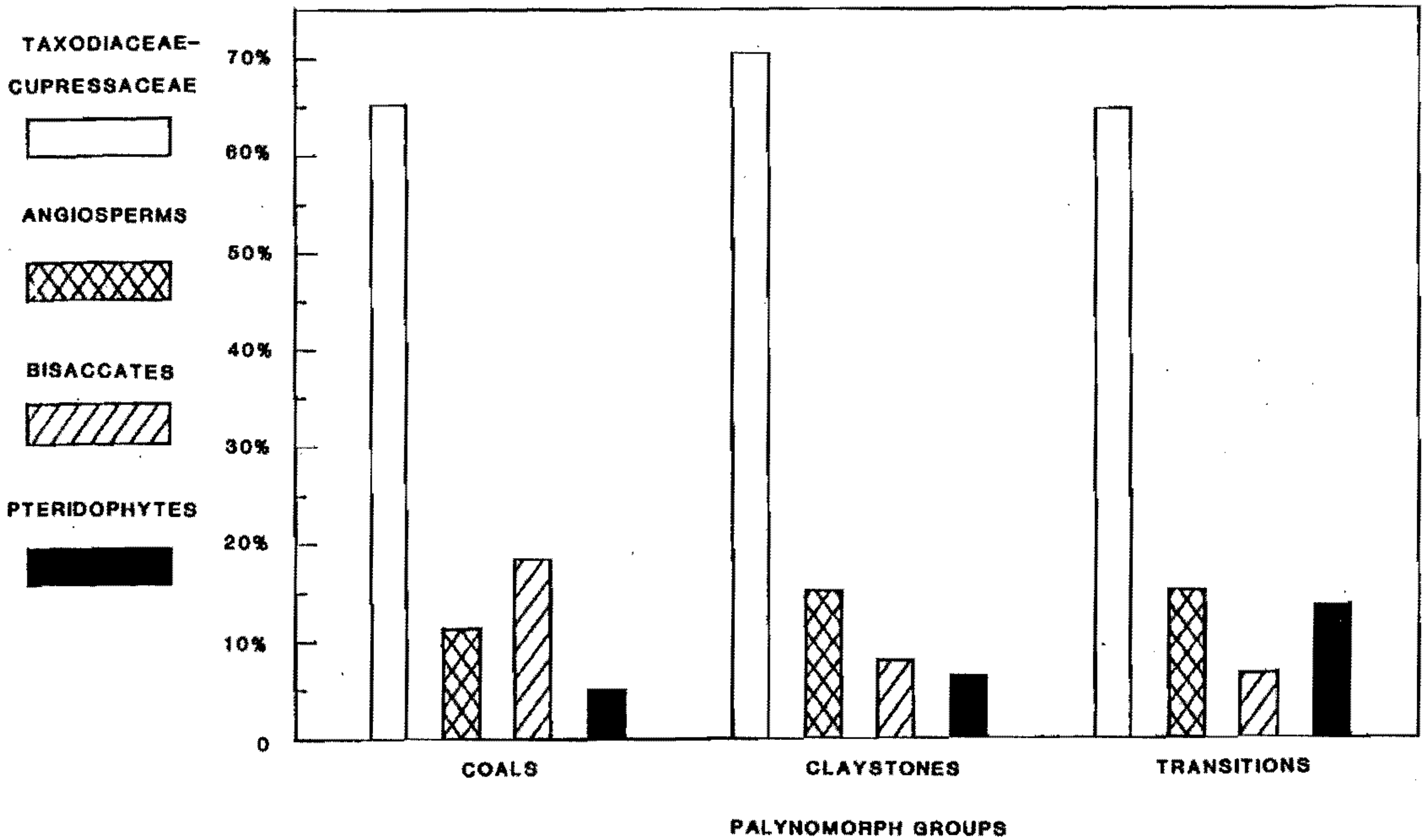

COAL SAMPLES
GYMNOSPERMS
83%
5.2%
PTERIDOPHYTES
11.8%
ANGIOSPERMS
CLAYSTONE SAMPLES
GYMNOSPERMS
78.8%
8.3%
PTERIDOPHYTES
14.0%
ANGIOSPERMS
TRANSITION SAMPLES
GYMNOSPERMS
72.3%
13.1%
PTERIDOPHYTES
14.6%
ANGIOSPERMS

Figure 15. Abundance of palynomorphs according to classification two (Taxodiaceae-Cupressaceae, angiosperms, bisaccates, and pteridophytes) in the three lithologies sampled in this study.


TAXODIACEAE-
CUPRESSACEAE
ANGIOSPERMS
BISACCATES
PTERIDOPHYTES
70%
60%
50%
40%
30%
20%
10%
0
COALS
CLAYSTONES
TRANSITIONS
PALYNOMORPH GROUPS

overwhelmingly dominant in all three lithologies considered. Angiosperms are more dominant in claystones and transition samples. Bisaccates are most abundant in the coal samples. The lesser number of bisaccates in the clastic rocks is probably due to selective winnowing out of these unusually large grains prior to the deposition of the fine-grained clastic sediments. Pteridophytes are more abundant in the transition samples than they are in either the coal or claystones.

When the palynomorph groups are compared on the basis of mine location some trends can be discerned. Figure 16 shows the palynomorph groups of classification number one compared by mine. The sections measured at the three mines appear to possess quite similar palynofloras as based on classification one. The palynoflora enclosed within the strata measured at all three mines is dominated by gymnosperms, and possesses many fewer angiosperms and pteridophytes. The Falkirk Mine measured section possessed a significantly greater amount of angiosperms than either the Center or the Glenharold Mine. The Center Mine measured section has the greatest number of pteridophytes present. This is probably because the Center Mine section contains the most claystone-coal contacts, a sample type which typically has an abnormally high percentage of pteridophytes present.

Palynomorph groups of classification two were compared by mine location as well (Figure 17). Again, the similarity between the palynofloras of each mine is apparent. The palynoflora of the Falkirk mine appears the most dissimilar from the others and possesses higher percentages of both angiosperm and bisaccate palynomorphs.

Vertical variation within the samples of each measured section was considered to determine palynofloral changes. Again, the three mines

Figure 16. Abundance of palynomorphs (in groups according to classification one) compared by mine locations.

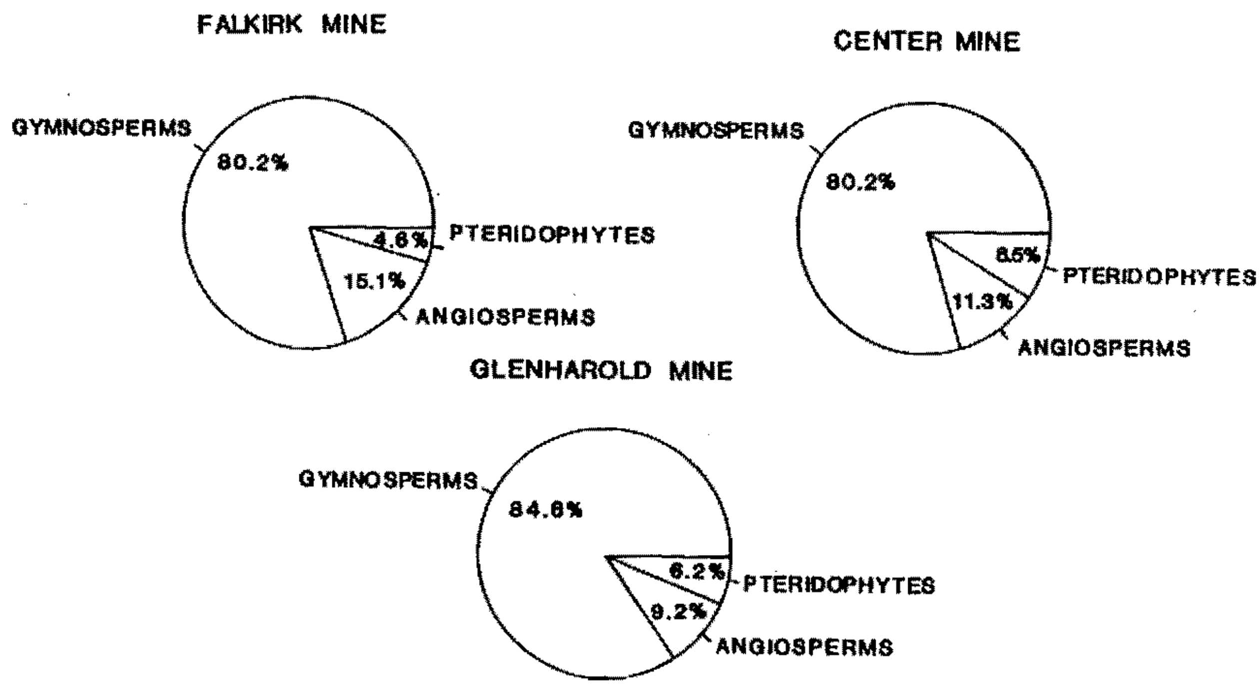
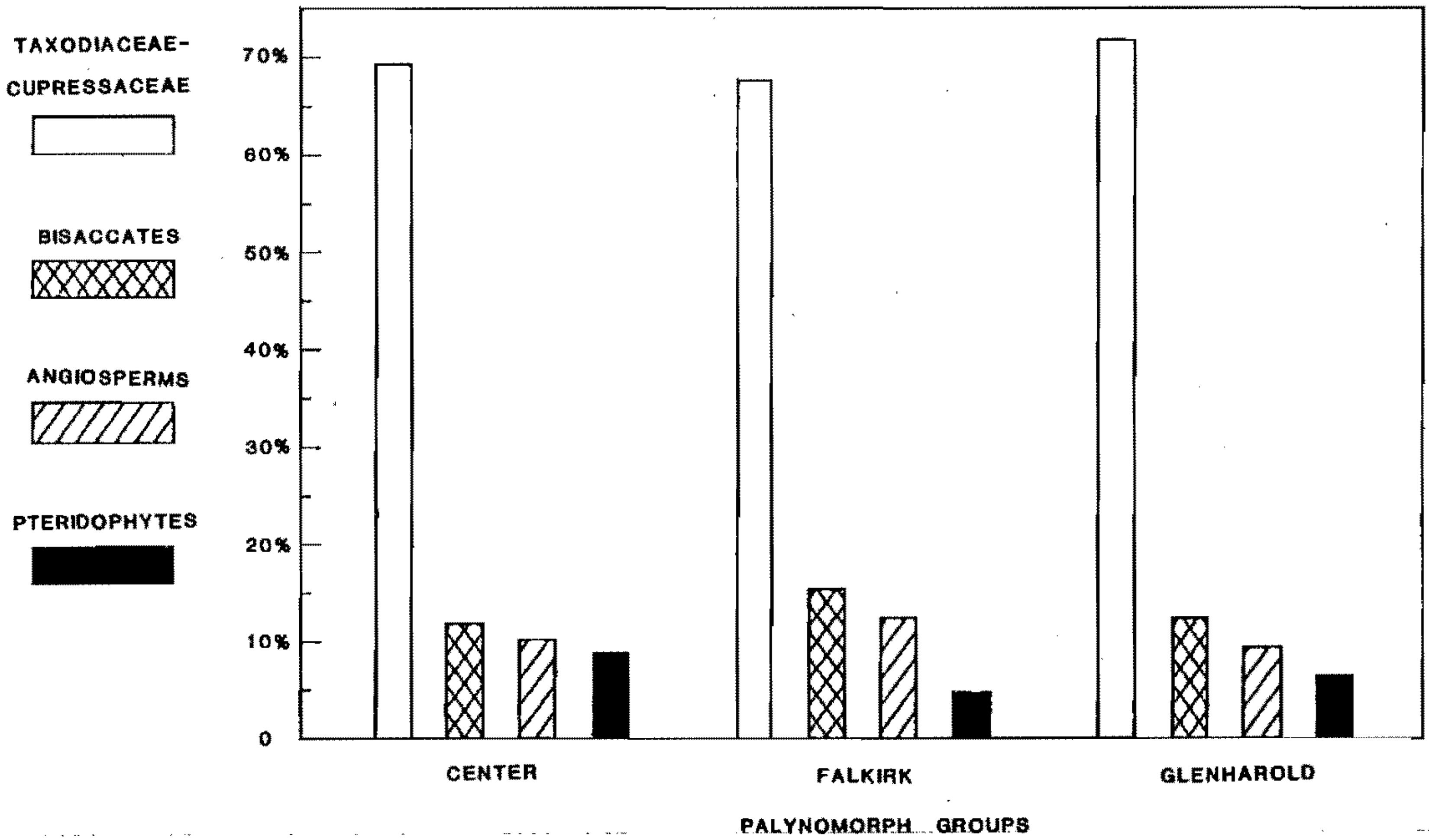

FALKIRK MINE
GYMNOSPERMS
80.2%
4.6%
PTERIDOPHYTES
15.1%
ANGIOSPERMS
CENTER MINE
GYMNOSPERMS
80.2%
8.5%
PTERIDOPHYTES
11.3%
ANGIOSPERMS
GLENHAROLD MINE
GYMNOSPERMS
84.6%
6.2%
PTERIDOPHYTES
9.2%
ANGIOSPERMS

Figure 17. Abundance of palynomorph groups (according to classification two) compared by mine location.


TAXODIACEAE-
CUPRESSACEAE
BISACCATES
ANGIOSPERMS
PTERIDOPHYTES
70%
60%
50%
40%
30%
20%
10%
0
CENTER
FALKIRK
GLENHAROLD
PALYNOMORPH GROUPS

possess generally similar patterns of palynomorph abundance: 1) gymnosperms (notably Taxodiaceae-Cupressaceae) are always dominant, 2) angiosperms are generally more abundant near coal seam margins, and 3) pteridophytes have greater abundance at claystone-coal contacts and within some claystones than at other levels. The palynofloras of the measured sections are dissimilar enough, however, to warrant separate discussion of the palynofloras of each section.

Gymnosperms dominated (Figure 18) the flora throughout the section in the Center Mine. Angiosperm abundance appears related to detrital influences since it increases near coal margins and in claystone and siltstone samples. The claystone underlying the lignite had the greatest relative abundance of angiosperm pollen of all the samples considered; the abundance of angiosperm pollen suggests that angiosperms were a more important floral element in the strata immediately beneath the Hagel bed than within the bed itself. Alternatively, the abundance of angiosperm-type pollen (present in the claystone underlying the lignite measured at the Center Mine) may reflect a palynoflora carried in from an upland source area. The characteristic increase in angiosperm pollen in claystone above coal was absent in the claystone above the lowermost coal seam (sample 840365) measured at the Center mine. This may be due to the relatively poor preservation of the grains in this sample; the poor preservation may be indicative of selective preservation reducing the number of identifiable angiosperms.

The section measured at the Falkirk Mine (Figure 19) had a palynoflora with a more consistent pattern than that of the Center Mine. Angiosperms were a consistently major element (relative to the other

Figure 18. Abundance of palynomorph groups (according to classification one) plotted against the section measured at the Center Mine.

CENTER MINE MEASURED SECTION

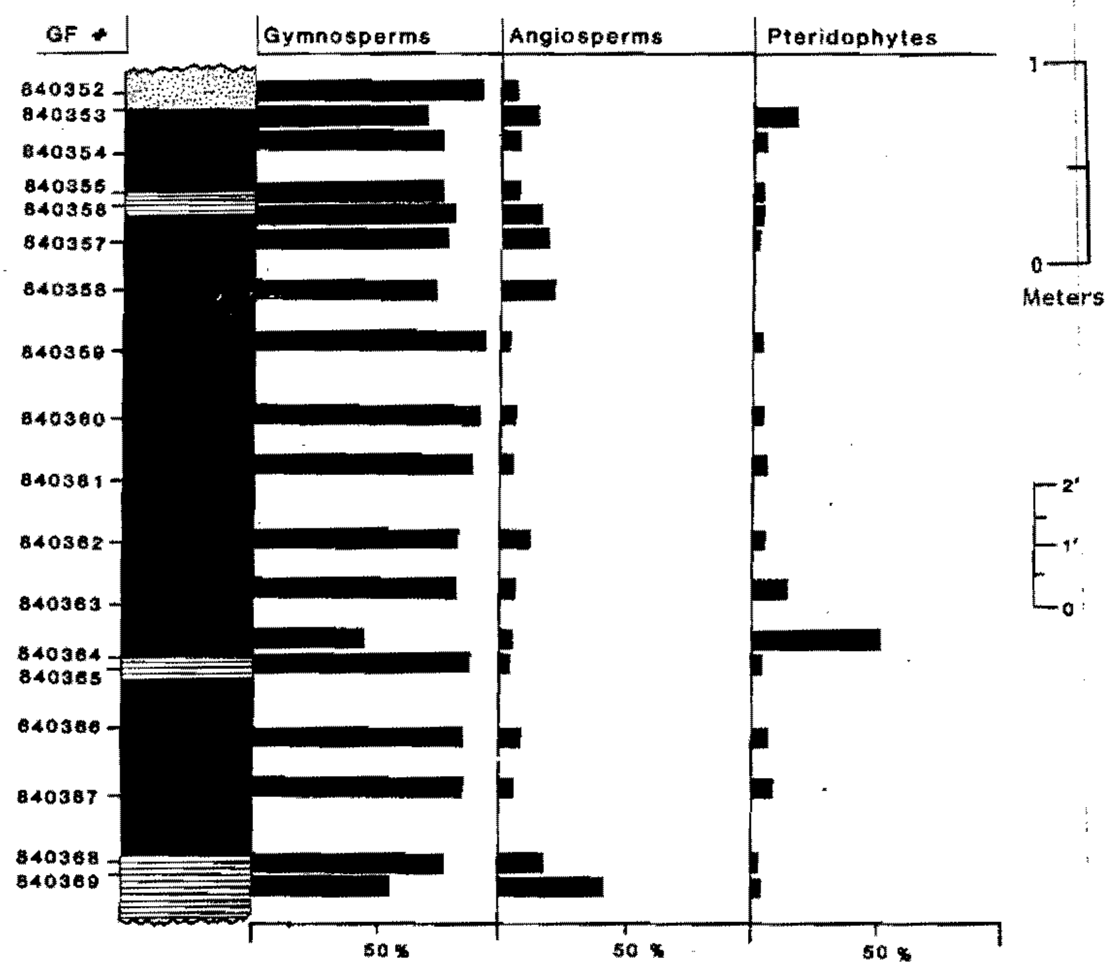
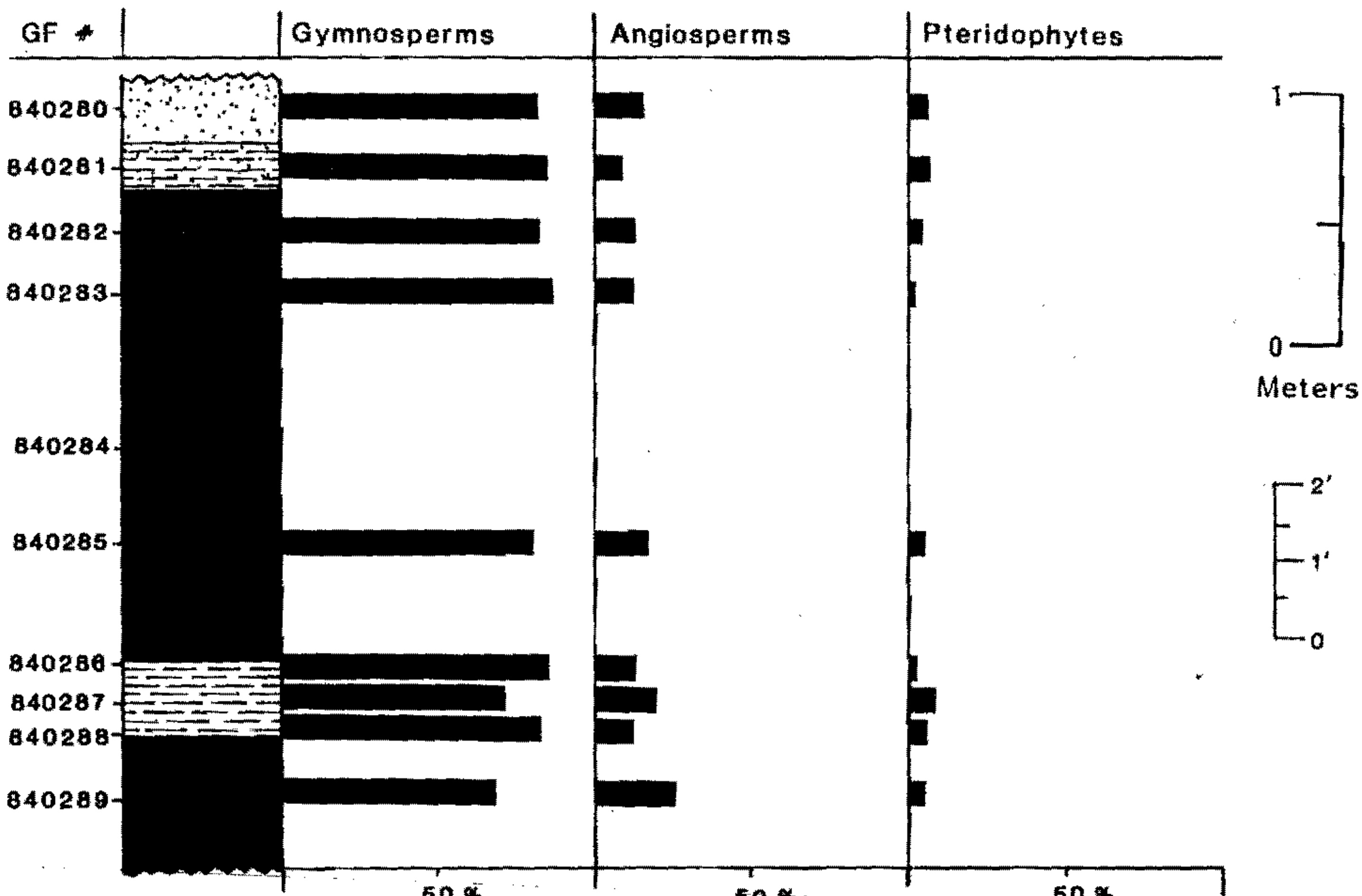


Figure 19. Abundance of palynomorph groups (according to classification one) plotted against the section measured at the Falkirk Mine.

FALKIRK MEASURED SECTION



measured sections) with only slightly greater abundance within claystone layers. Pteridophytes were reduced in abundance, when compared to the other sections, with only slightly greater values associated with claystone layers.

Angiosperm abundance increased slightly near the margins of the coal seams and in claystones (Figure 20) at the Glenharold Mine measured section. Pteridophytes characteristically increased in the claystone layers.

The measured sections were also compared using palynomorph classification two (Figures 21, 22, and 23). The same tendencies in angiosperms and pteridophytes abundance as mentioned above are apparent. The Taxodiaceae-Cupressaceae group remains dominant throughout. The abundance of bisaccates appears highly variable throughout the sections. A rather regular increase in bisaccate abundance towards the mid-point of the thickest coal seam measured is apparent at the Center Mine measured section. It is possible that the bisaccates represent (at least in part) floral elements characteristic of the mature, stable Taxodiaceae swamp environment and were not brought into the depositional environment as detritus.

Paleoenvironmental Interpretations

Paleoenvironmental interpretations were made using four distinct types of data: 1) percentage frequency data manipulated into paleoenvironmentally related groups of palynomorphs, 2) stratigraphic, palynological data based on large taxonomic groups used to discern major floral trends, 3) the occurrences of individual, paleoenvironmentally significant palynomorphs with well established, modern, floral equiva-

Figure 20. Abundance of palynomorph groups (according to classification one) plotted against the section measured at the Glenharold Mine.

GLENHAROLD MINE MEASURED SECTION

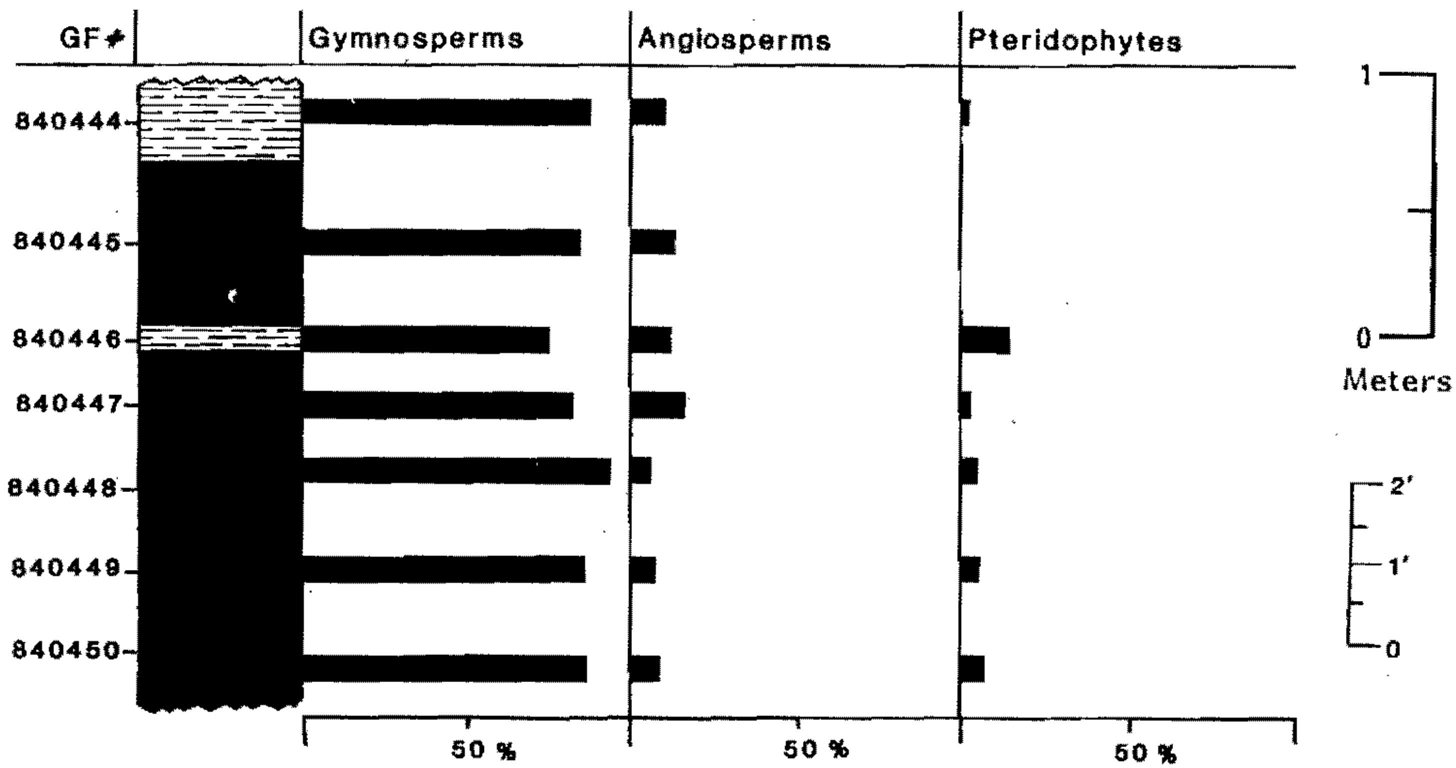


Figure 21. Abundance of palynomorph groups (according to classification two) plotted against the section measured at the Center Mine.

Center Mine Measured Section

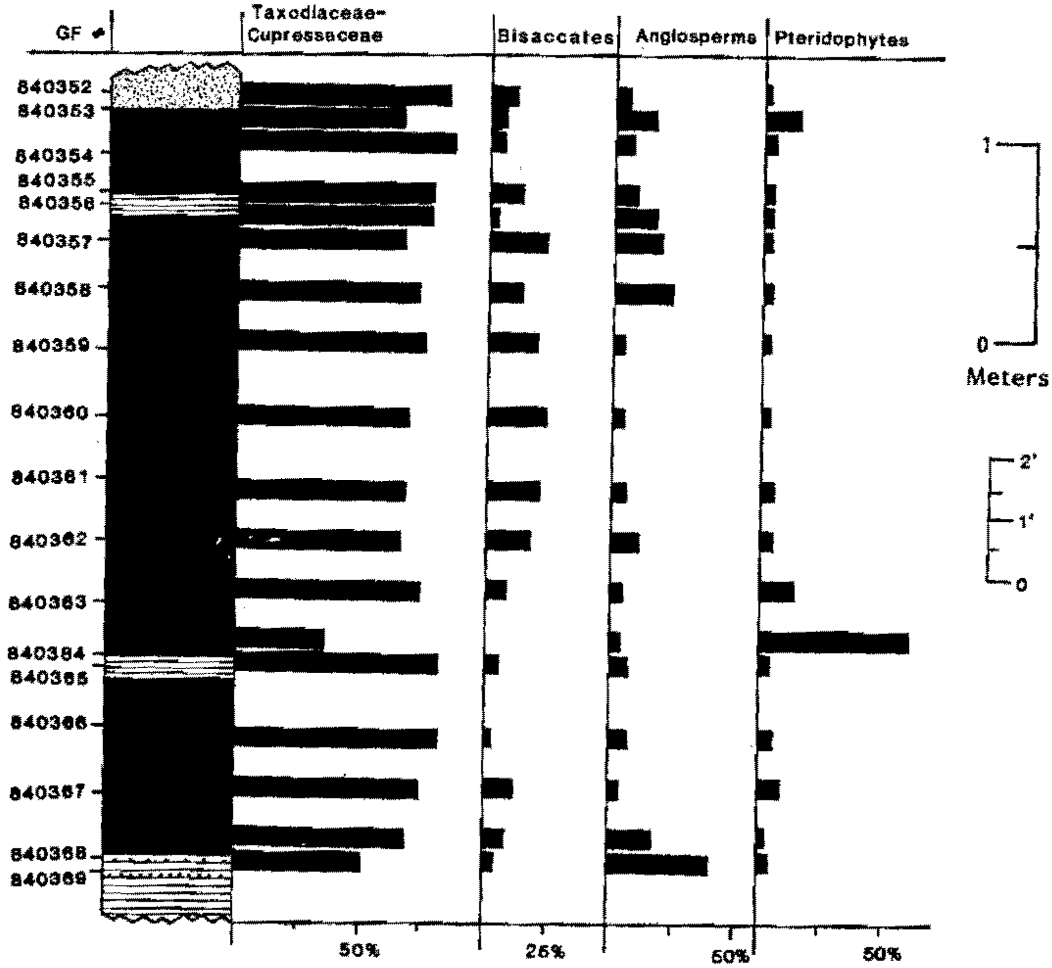


Figure 22. Abundance of palynomorph groups (according to classification two) plotted against the section measured at the Falkirk Mine.

Falkirk Measured Section

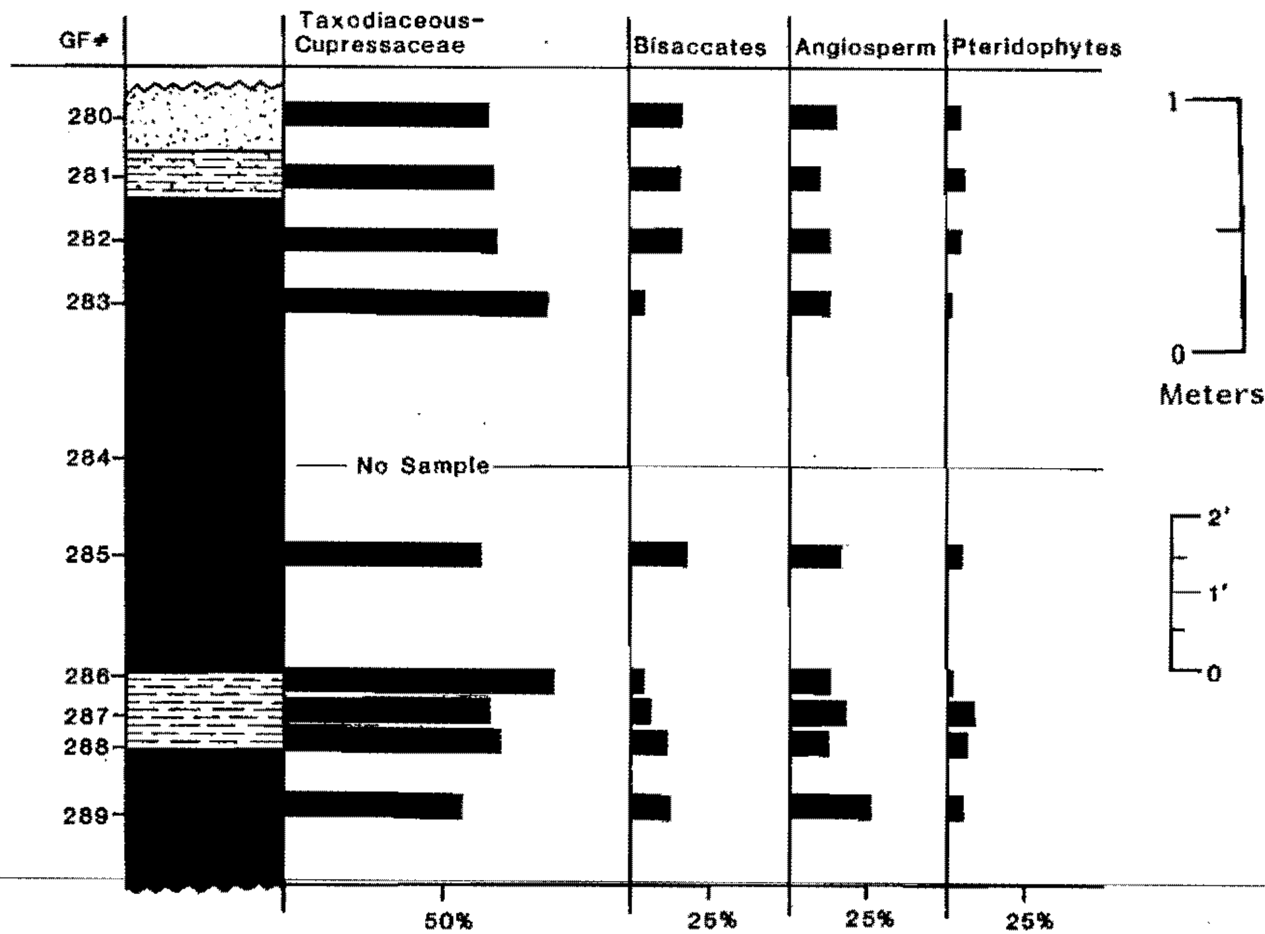
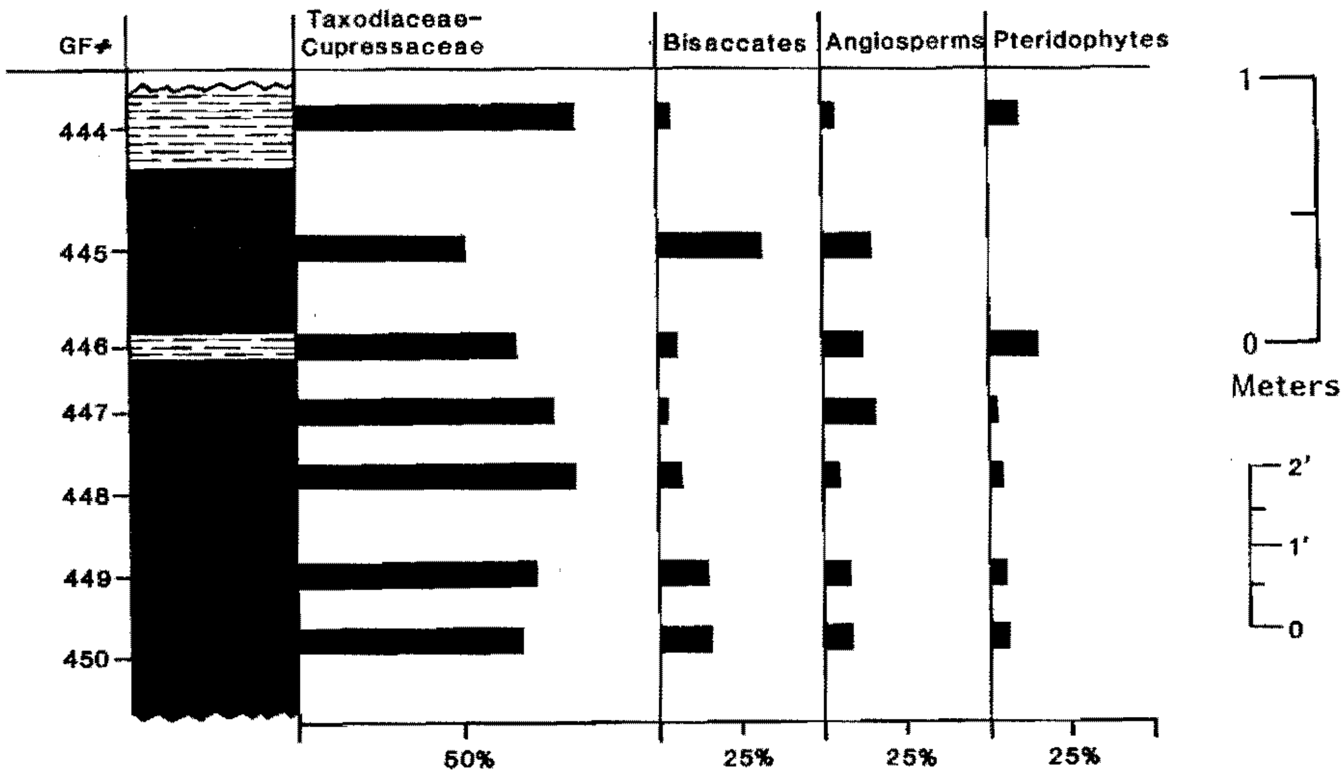


Figure 23. Abundance of palynomorph groups (according to classification two) plotted against the section measured at the Glenharold Mine.

Glenharold Mine Measured Section



lents, and 4) evidence from preserved plant tissues. A combination of stratigraphic palynologic data (to discern major trends) and data provided by individual paleoenvironmentally significant palynomorphs provided the majority of the information used to make paleoenvironmental interpretations.

Percentage frequency data was analyzed using the SAS Institute Statistical Analysis System (SAS). Factor and hierarchical cluster analysis was used as a means of discerning any palynomorph assemblages present. The resulting analysis showed essentially no clustering among the palynomorph types. This was interpreted as representative of a single consistent, major flora present in all samples. Differences in palynomorph abundance among the samples are probably due to differential deposition and preservation of floral elements present throughout the samples. Although the relative percentages of major palynomorph groups change in a somewhat systematic way with changes in lithology (e.g., greater abundance of angiosperm pollen associated with more clastic intervals), the abundances of infrequently occurring palynomorph types appear to be related to chance occurrences.

Paleoenvironmentally-related palynomorphs were grouped in order to use percentage-frequency data as a means of determining trends in the palynoflora. The palynomorphs were divided into three basic groups: fern-conifer swamp taxa, upland-riparian taxa, and miscellaneous taxa of less paleoenvironmental significance. The fern-conifer swamp taxa consisted of palynomorph type designations I08, I10, L15, L16, L24, TC4, and TCU; palynomorph type designations CP4, CP5, P09, P13, P15, P17, P20, P21, I09, and BUD were considered upland-riparian taxa, while the remaining palynomorphs were considered miscellaneous taxa. The miscellaneous taxa were converted into percentage values of the total number of palynomorphs present; the number of remaining environmentally significant palynomorphs was then normalized to 100 percent.

Figures 24, 25, and 26 represent the measured sections with palynomorph percentages by paleoenvironmental groups. The results of the paleoenvironmental grouping show an almost complete dominance of the fern-conifer swamp taxa and a relatively consistent flora, but the large and fluctuating percentage of miscellaneous taxa makes more accurate conclusions based on these data impossible.

Stratigraphic palynology using supra-ordinal taxonomic groups provided significant paleoenvironmental data concerning trends in the overall flora. Major trends interpreted from stratigraphic data include: 1) a relatively constant palynoflora, 2) an increased abundance of angiosperms in claystones and in coals near claystones and siltstones, and 3) an increase of pteridophytes at many claystone-coal contacts.

The increase of angiosperm pollen in claystones and in coals near claystone and siltstone layers may be due to the angiosperms being dominantly riparian. Because of their association with clastics and their dominantly riparian paleoenvironmental characteristics, the angiosperms appear to represent pollen carried into the depositional environment primarily as detritus. The increase in pteridophyte palynomorphs at many claystone-coal contacts may be the result of a successional change from a claystone depositional environment into the coal-depositing environment. As conditions changed to allow for the deposition of peat, it appears that the pteridophytes colonized the clay surface first, thus marking the commencement of autochthnonous

Figure 24. Palynomorphs grouped according to environment and plotted against the section measured at the Center Mine.

Center Mine Measured Section

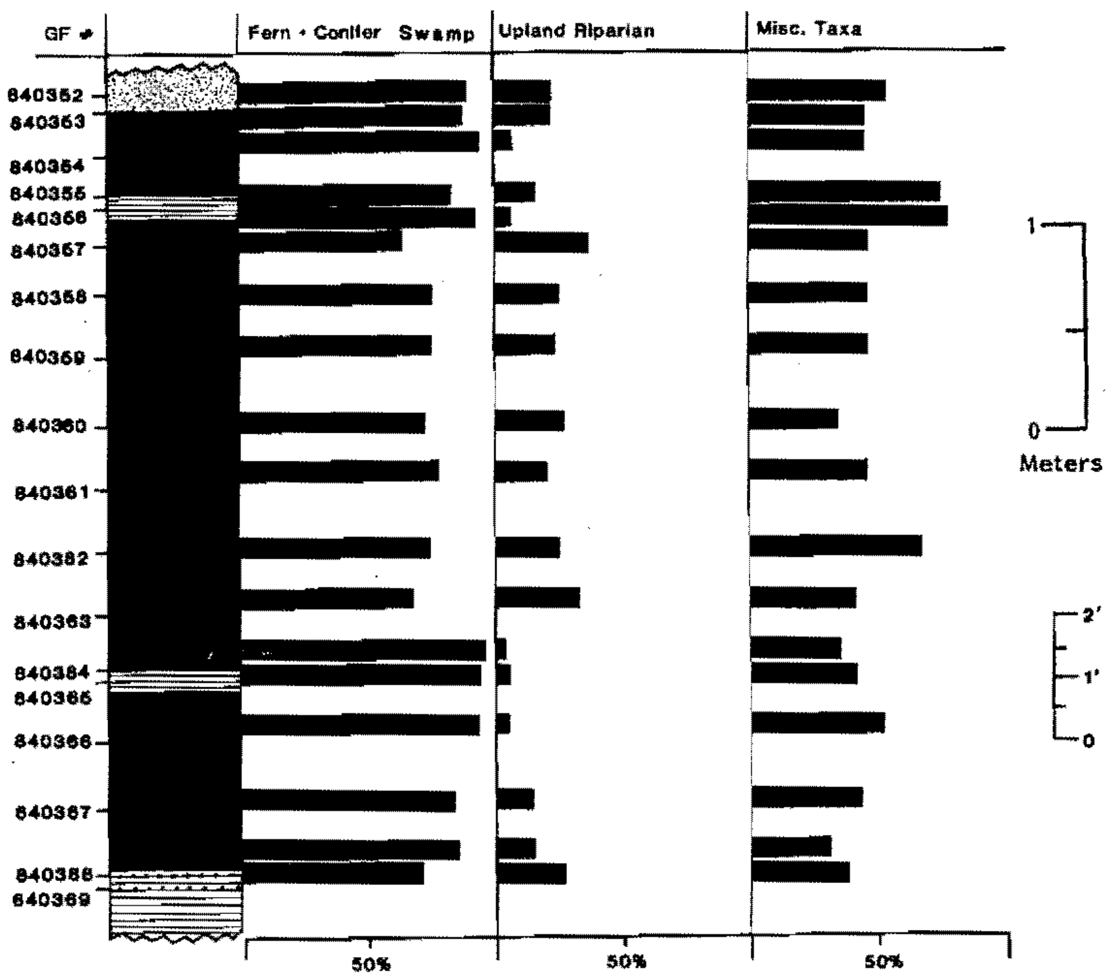


Figure 25. Palynomorphs grouped according to environment and plotted against the section measured at the Falkirk Mine.

Falkirk Measured Section
Enviromental Groups

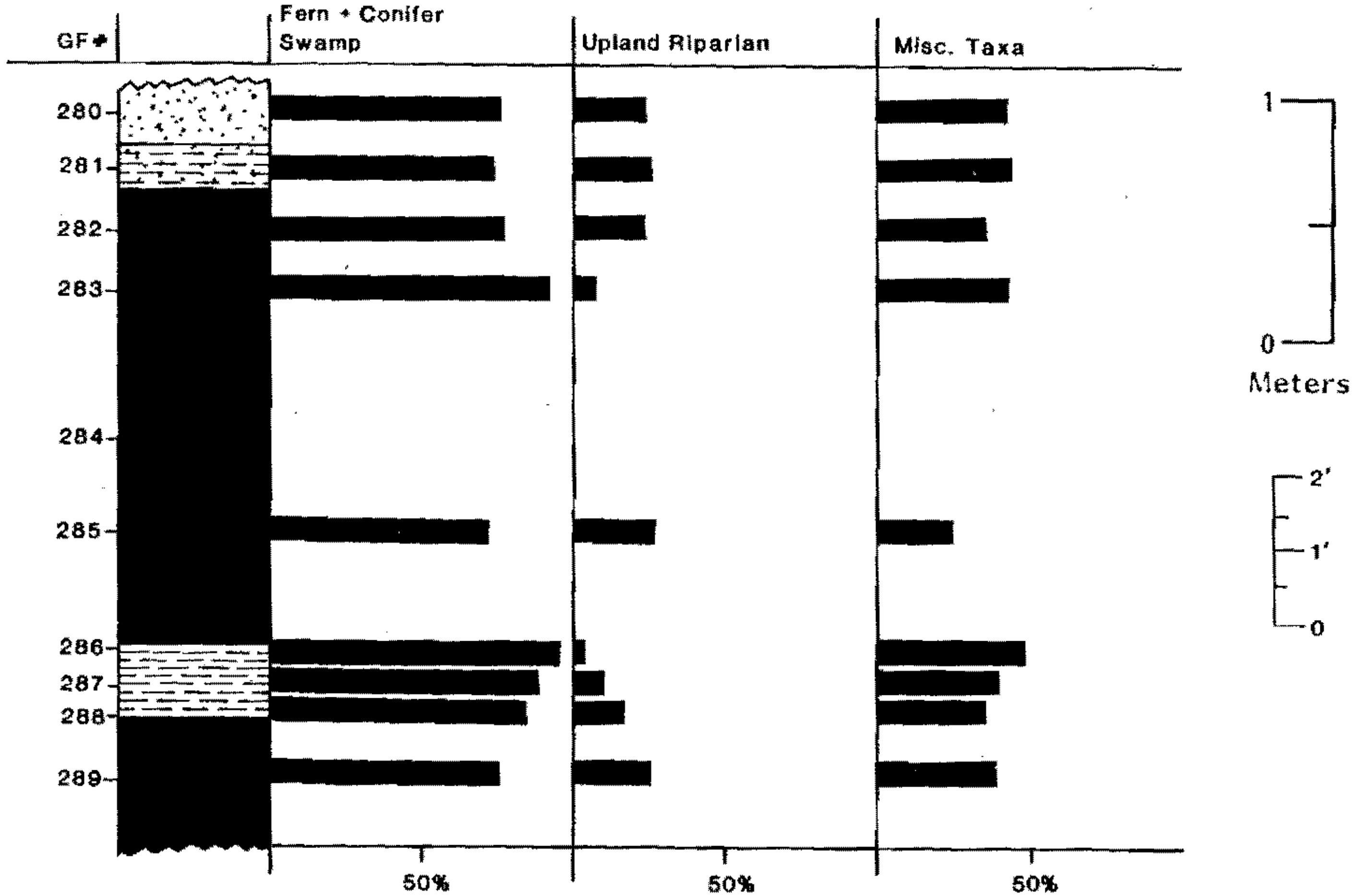
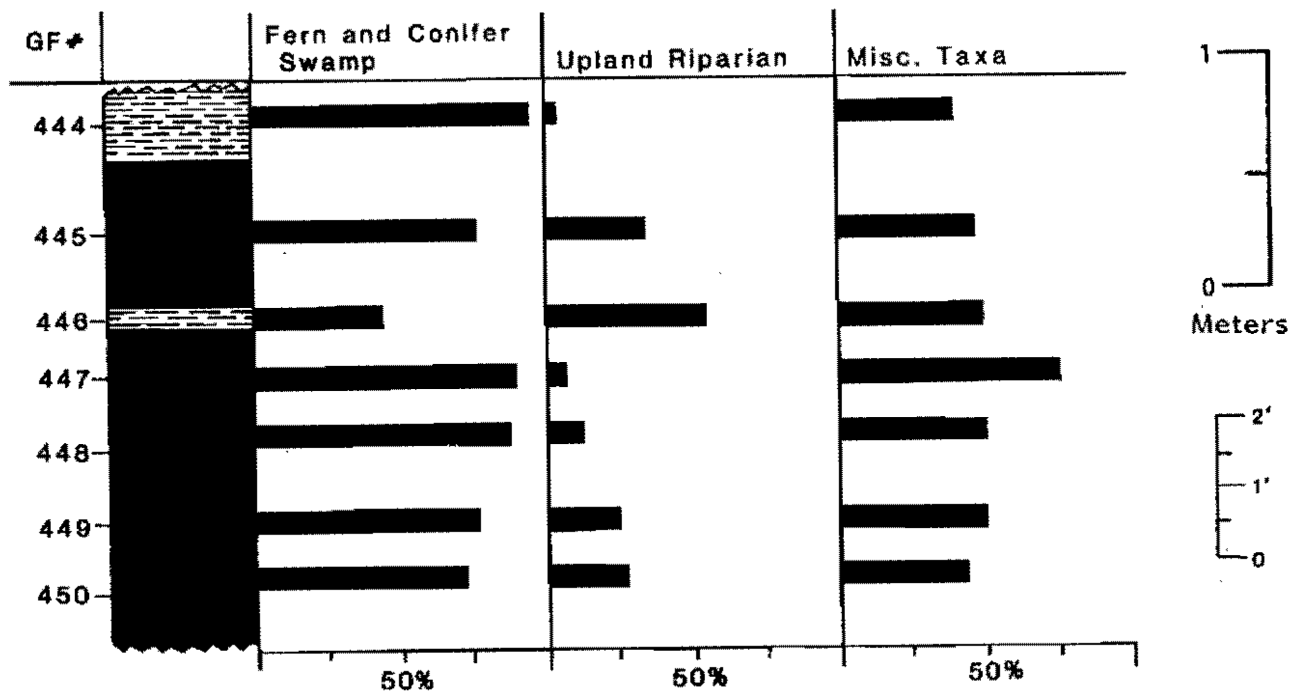


Figure 26. Palynomorphs grouped according to environment and plotted against the section measured at the Glenharold Mine.

Glenharold Mine Measured Section

Environmental Groups



organic deposition. Elsik (1978, p. 30) related herbaceous (including a variety of fern spores) palynomorphs to an open swamp or lake-fringing depositional environment.

The presence and abundance of a few paleoenvironmentally-diagnostic palynomorph taxa with sound modern botanic affinities provided significant paleoenvironmental information. A summary of paleoenvironmentally diagnostic palynomorphs is given by Table 8.

Palynomorphs indicative of a cypress forest-swamp environment are the dominant floristic element throughout the strata examined; these are the Taxodiaceae-Cupressaceae type of pollen (although a broad grouping) which are consistently dominant and ubiquitous in the Hagel bed samples examined. Associated fern types (i.e. Osmunda) indicative of swampy conditions are also common constituents. The dominance of Steriosporites antiquasporites (equivalent to modern Sphagnum) suggests the presence of "floating peat islands" (Rich and Spackman, 1979, p. 221) similar to those present in the Okefenokee swamp in Georgia. Steriosporites undoubtedly represented a major element of the local flora as evidenced by its consistent appearance and the presence of a Steriosporites sporangium found in sample number 840361 (plate 6, Figure O).

The deciduous elements are dominated by riparian types. Alnus is a frequent contributor to the samples as is Corylus and Carpinus. These deciduous taxa are small but consistent contributors to the overall palynoflora.

Morphologically well-preserved plant tissues provide more paleoecologic evidence. Macroscopic "xylites" (Stach and others, 1982, p. 286) were commonly observed in the Hagel bed. Microscopically, well

TABLE 8. PALEOENVIRONMENTALLY DIAGNOSTIC PALYNOMORPHS

PALYNOMORPH	FREQUENCY	ABUNDANCE	BOTANICAL AFFINITY	PALEOECOLOGICAL INFERENCE
TCU	dominant	very abundant	Taxodiaceae-Cupressaeceae	*Taxodium* (cypress) swamp, standing water
TC4	dominant	abundant	*Taxodium*	*Taxodium* (cypress) swamp, standing water
TC3	dominant	common	Taxodiaceae, possible *Sequoia*	brushy bog conditions
I08	common	uncommon	*Larix*?	bog conditions to moist woodlands (Hopkins, 1969, p. 1108)
I10	common	uncommon	Zygnenataceae	stagnant freshwater peat environments (Rich, 1982, p. 26)
L16	common	uncommon	*Osmunda*	bogs, shaded, moist woodlands (Hopkins, 1969, p. 1108)
L15	dominant	common	*Sphagnum*	"floating island" peat (Rich, 1984, p. 449)
P20	frequent	common	*Alnus*	bogs, wet woodlands, riparian
P21	rare	rare	*Betula*	uplands to bog and wooded swamp (Hopkins, 1969, p. 1108)
P13	common	uncommon	*Carpinus*	uplands to moist woodlands
P15	dominant	common	*Corylus*	uplands to moist woodlands

preserved coalified wood tissue (see plate 6, Figure M) was a common and abundant constituent of Hagel bed maceration residues. This abundance of preserved plant tissues suggests deposition in a subaqueous environment with the water providing protection from decay. This process of subaqueous preservation of plant tissue morphology is common (Stach, and others, 1982, p. 286) in sediments of a forest-swamp environment and is indicative of an environment with a great deal of standing water present.

The environment inferred from the palynomorphs of the Hagel bed is that of an arborescent-dominated swamp-forest characterized by cypress trees and associated bog-dwelling herbaceous ferns and mosses. This environment of deposition possessed a long hydroperiod and was primarily covered with standing water. Evidence of deciduous (relatively more upland-dwelling) flora was a consistent but minor constituent of the palynoflora of the Hagel bed in the areas studied. These taxa probably represent a swamp-marginal, riparian element.

Interpretation of Sedimentary Enviroments

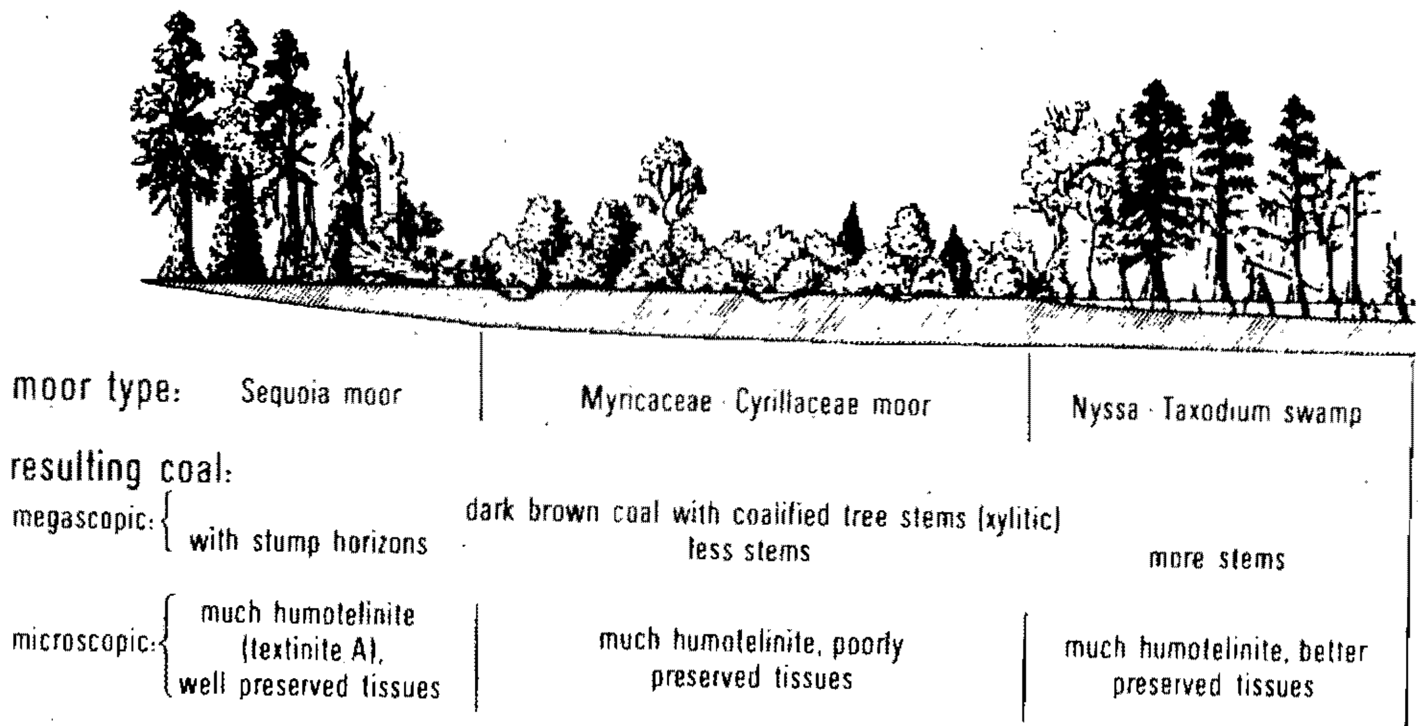
The palynological analysis of the Hagel bed and associated sediments indicated a relatively consistent palynoflora. This is indicative of a relatively stable environment in which changes in sediment deposition were controlled by shifting physical conditions. It is important to remember, however, that concentrating on the lignite and intimately associated strata provides self-imposed environmental limitations. Perhaps one should not expect a wide paleoenvironmental disparity between laterally equivalent coal seams; in this respect the consistency of the palynoflora lends credence to the paleoenvironmental interpretations made for the Hagel bed.

There is a lack of obvious environmental succession associated with the change from lignite to associated fine-grained clastic sequences examined. This may reflect: 1) a lack of environmental succession between these strata, 2) palynological analysis too confined by the limitations of paleoenvironmental analysis to elucidate environmental succession, or 3) a lack of data due to incomplete sampling.

The lignite of the Hagel bed was probably deposited in an environment floristically and physically similar to the present-day Okefenokee swamp in Georgia. The flora of the Okefenokee has been likened (Rich and Spackman, 1979, p. 219) to the "Tertiary lignite and brown coal swamps of North America and Europe". The dominance of Taxodiaceae-Cupressaceae pollen argues for a swampy terrain with an abundance of taxodium-type trees. The abundance of xylitic material indicates subaqueous deposition of plant remains and the presence of standing water. This environment appears to have been laterally extensive; although relatively more upland "moor" (Stach and others, 1982, p. 287) areas are probably laterally associated (Figure 27) or compose isolated islands within the taxodium swamp environment (Figure 28).

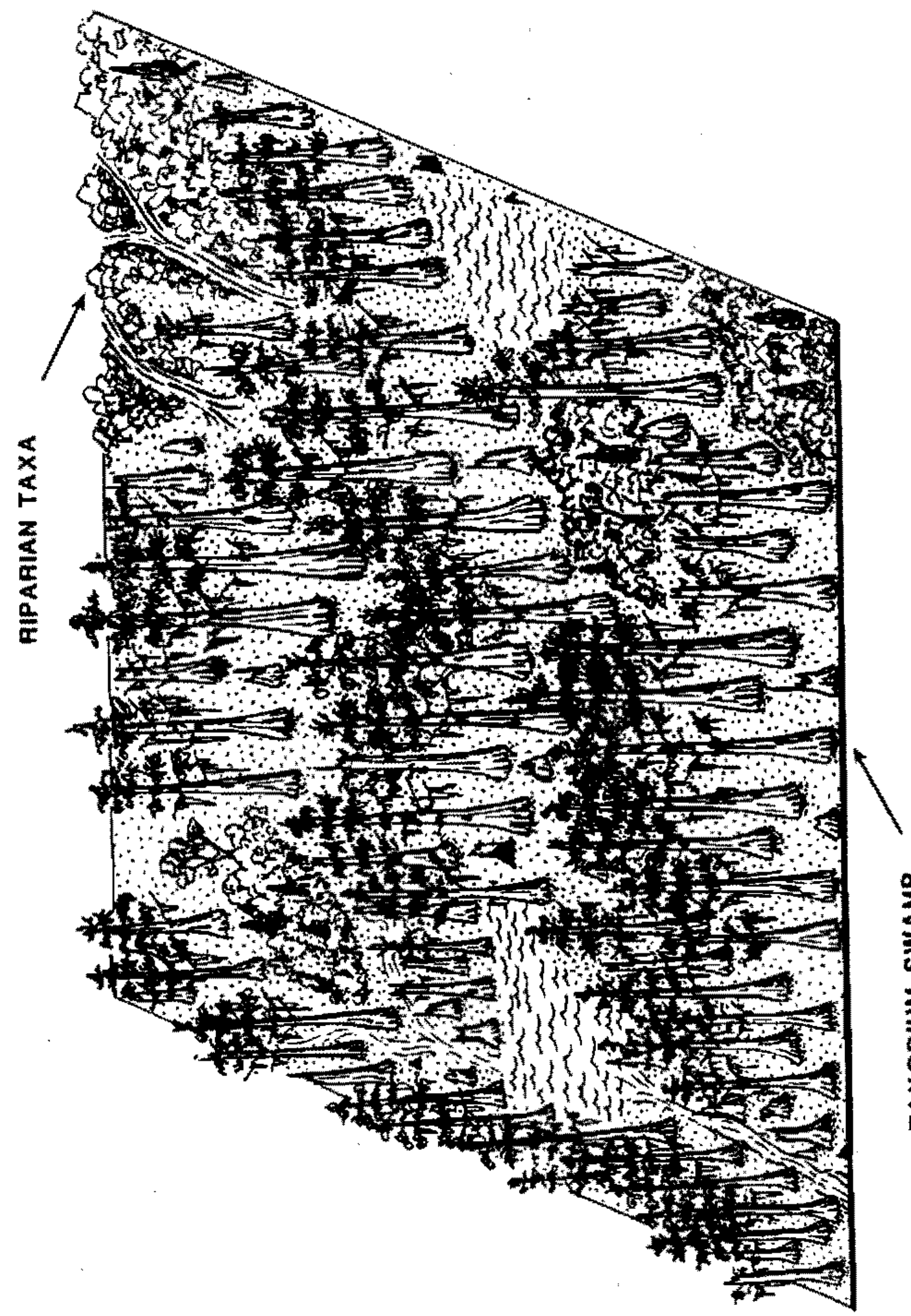
The claystone layers intercalated with the Hagel bed are typically composed of pure organic-rich clay. The dark organic material was usually in the form of lignitic particles (lignite rip-up clasts?) or in thin beds concentrated into rhythmite-like beds. The contacts between the coal and intercalated claystones were typically sharp. The extremely fine-grained nature of the deposits indicates a low-energy depositional environment. The claystones may have formed as a result of the periodic inundation of the taxodium swamps with suspended sedi-

Figure 27. Diagram of basic coal-forming environments interpreted as being represented in this study (modified from Stach and others, 1985, p. 287).



moor type: Sequoia moor
Myricaceae · Cyrillaceae moor
Nyssa · Taxodium swamp
resulting coal:
megascopic: dark brown coal with coalified tree stems (xylitic)
with stump horizons
less stems
more stems
microscopic: much humotelinite (textinite A), well preserved tissues
much humotelinite, poorly preserved tissues
much humotelinite, better preserved tissues

Figure 28. Proposed generalized environment present in the area studied during deposition of the Hagel bed (drawing by L. Steadman).


RIPARIAN TAXA
TAXODIUM SWAMP

ments from fluvial systems feeding the extensive swamp. Alternatively, the clays may represent changes in base level, which formed shallow lakes.

Palynoflora Related to Present-Day Coal Chemistry

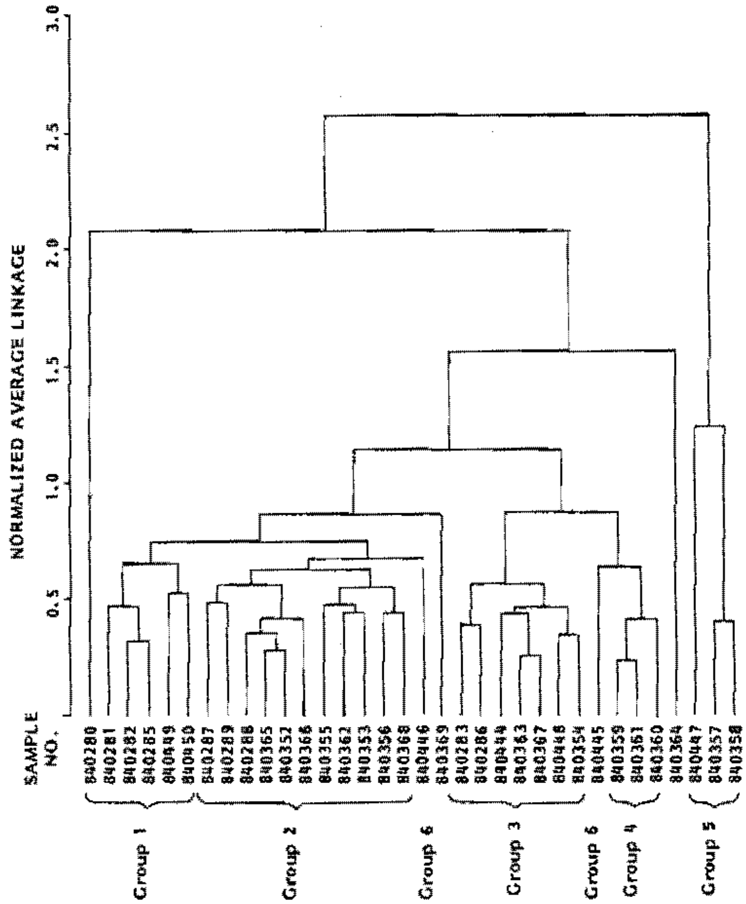
Knowledge of the depositional environmental and the flora which makes up a coal seam may be one way to aid understanding variations in coal chemistry. The heterogeneity of the Hagel bed lignite is due to a combination of the initial heterogeneity of the contributing plant material and the differential diagenetic effects which have taken place since deposition. A comparison of the chemical characteristics of the sediments and palynological analysis may elucidate the relative importance of the original botanic chemistry and post-depositional effects on the composition of the coal.

Figure 29 represents the results of a SAS hierarchical, cluster-analysis comparison of palynologic percentage-frequency data and samples. On the basis of palynomorph content, the samples group roughly into categories which relate to their positions within the measured sections.

The lateral position appears to be relatively unimportant as the groups are not consistent when considering mine location. Groups one, two, and three are composed of clastic samples and coals primarily near the margins of the seams, whereas groups four and five represent coals from the central portions of the seams. This suggests that there is some sequential relationship between the palynoflora and coal deposition. The nature of the relationship is not clear, but may be investigated by correlation of the palynologic and coal chemistry data.

Palynologic counts were correlated with proximate and ultimate

Figure 29. Cluster analysis of total palynomorph frequency by sample.


NORMALIZED AVERAGE LINKAGE
0.5
1.0
1.5
2.0
2.5
3.0
SAMPLE NO.
840280
840281
840282
840285
840449
840450
840287
840289
840288
840365
840352
840366
840355
840362
840353
840356
840368
840446
840369
840283
840286
840444
840363
840367
840448
840354
840445
840359
840361
840360
840364
840447
840357
840358
Group 1
Group 2
Group 6
Group 3
Group 6
Group 4
Group 5

coal chemistry data and x-ray fluorescence data to determine any statistically valid relationships that might be present. The correlation analysis resulted in Pearson product-moment correlation coefficients for the palynomorph types, major oxides and minor elements as determined by x-ray fluorescence and variables from proximate and ultimate analysis. Appendix D lists the results of the correlation analysis. The statistically significant correlations between palynomorph frequency data and chemical data are listed.

One trend of probable significance can be noted in the relationships of palynologic and geochemical data. Ash percentages display a positive correlation with several colpate and porate palynomorphs. These palynomorphs have been related to detrital origins, making this positive correlation explainable. An investigation of the geochemical and biochemical relationships between these variables is beyond the scope of this study and would depend on a more complete understanding of geochemistry of the strata examined. The correlations are presented herein only as preliminary data concerning the potential of palynology as a means of investigating the origin of compositional differences in Great Plains lignites.

Discussion

The coals of the Hagel bed were deposited in laterally extensive, swampy environments dominated by arborescent plants. Using the Okefenokee Swamp as a modern analogue, one can estimate the rate of deposition of the Hagel bed. Cohen and others (1984, p. 504) estimated the rate of peat deposition in the Okefenokee to be about 1 cm per 20 years. Stach and others (1982, p. 18) estimated the compaction ratio of peat to "soft brown coal" to be about two to one. Using the above estimates, the rate of deposition of Hagel bed coal was approximately one meter of coal in 4,000 years. The rate of deposition for the Hagel bed was very rapid in terms of geologic time. The alternation of coal and clastic depositional episodes took place rapidly and was probably controlled by shifting of laterally associated depositional environments.

The clastic rocks associated with the Hagel bed are fine-grained, thin, laterally extensive and intercalated within the major lignite zones. Sedimentary structures present suggest quiet water deposition. The sharp nature of the lignite-claystone contacts may represent relatively abrupt influxes of fine-grained clastics into the swamp environment.

Clastic influxes into swamp environments could take place by fluvial processes. In a fluvially dominated environment, crevasse splays could cause a sudden influx of suspended clastic material into adjacent backswamp areas. However, the lateral continuity of both the coals and claystones of the Hagel bed and the lack of associated well-defined channels argue against a fluvially dominated crevasse-splay type depositional environment.

Clastic influxes into the swamp environments of the Hagel bed could have taken place due to lateral migration of lacustrine environments. Coal deposition might have taken place in a broad, wet lowland adjacent to a major lake. A relatively small rise in depth of the lake would cause the inundation of a broad expanse of the adjacent swamp. The deposition of clays would take place from suspended sediments within the lake and the palynoflora would reflect riparian and adjacent swamp environments. The lignite-claystone contacts display a larger percentage of herbaceous pteridophyte-type palynomorphs perhaps indicative of a successional palynoflora sequence from a lake-marginal flora to the typical forest-swamp assemblage present in the coals. At the present time it is not clear if the lateral continuity of the lignites in the area studied have resulted from a time-transgressive laterally migrating depositional environment, or if major lignites represent time-synchronous units. The strata examined here are too limited stratigraphically to confidently suggest major laterally-associated environments.

Alternatively, the clastic-to-coal depositional sequences could represent the alternation of lacustrine and swamp deposition in the same basin. A small rise in water depth in a swamp-type environment would form a broad, shallow lake; this was followed by normal lacustrine succession into a swamp environment. Such a basin-wide alternation of environments could explain the lateral continuity of environments that is implied by the three localities studied.

Since no major shifts in environment are indicated by the palynoflora, the "shallow lake", referred to above, may be a result of an episodic clastic inundation from fluvial systems feeding the swamp. The resulting rise in water level would be short lived and clastic deposition (from suspended sediments settling out of the water) would result by temporarily replacing, and overwhelming, organic deposition. When water levels reached normal, the swamp-forest environment of peat deposition could resume.

While the palynoflora of the three measured sections considered was fairly consistent, the measured section of the Falkirk Mine section possesses a greater abundance of angiosperm and bisaccate pollen types than in the sections of the other mines. I have interpreted these pollen groups to be indicative of an upland flora and are present in the depositional environment (at least in part) as detritus. Further, the Falkirk mine section possess the coarsest-grained clastics of the three mines examined. For these reasons, I interpret the Falkirk mine to be more closely associated with fluvial depositional environments, perhaps associated with the fluvial system which supplied the taxodium-swamp environments of the Center and Glenharold Mines. Logan (1981, p. 69) proposed these depositional environments based on a sedimentological investigation of the clastic interval overlying the Hagel bed in the Falkirk, Glenharold and Center Mines. There is a great amount of lithologic variability within each mine however, and more work is needed to more completely characterize the depositional environments present in each mine.

The unique (of the three areas considered) depositional environment present in the Falkirk area may be partially responsible for some differences in the coal chemistry of this mine. Coals of the Falkirk Mine characteristically have lower sodium values than do the coals of the Center and Glenharold Mines. This could be due to a response of the mobile sodium ion to a hydrologically more dynamic depositional system in the area of the Falkirk Mine than in the areas of the other mines. The fluvially-dominated system in the area of the Falkirk Mine may have deposited strata depleted in sodium relative to those in the Glenharold and Center Mines.

It is important to remember that this study is concerned with a portion of the Hagel bed and the clastic sediments immediately associated with the coal. This limits the implications of this study; the clastic depositional model proposed here may not be particularly relevant to the major clastic units between the zones of coal deposition. There may be major floristic and sedimentary successions between these major clastic units and the overlying and underlying coal-bearing zones. The underclay at the Center mine possessed the greatest abundance of angiosperm pollen found in this study. This suggests that the major, clastic, depositional sequences between lignite zones may be floristically and environmentally distinct from the lignite zones.

Suggestions For Further Study

Problems for further study include stratigraphic extension of palynofloras and further work relating paleofloristic characteristics with coal composition. The results of this study suggest that palynology can be a useful tool in the investigation of the Paleocene lignite-bearing strata.

Stratigraphic extensions and palynologic investigations of more strata could probably be best addressed by using cores. Stratigraphically located rock cores would lend themselves to palynologic investigations as they would provide for continuous sampling, and, typically, only a small amount of sample is needed.

Lateral extension of the Hagel bed palynoflora could provide information on the lateral extent of the Hagel bed depositional environments and possibly elucidate equivalent environments outside the confines of the Knife River basin. A look at the Hagel bed at smaller vertical intervals (1.0 cm ?) may provide a key to subtle successional changes within the lignite and associated claystones.

Since the Hagel bed provided a relatively consistent palynoflora, perhaps other laterally extensive, major lignites (i. e., the Beulah-Zap bed or the Harmon bed) possess a consistent palynoflora as well. If the palynologic characteristics of these beds proved to be distinctive, they could be used for correlation and characterization of the lignite beds.

A palynologic investigation of a major clastic interval and the confining major lignite beds may provide some clues to the controls on the depositional sequences of the North Dakota Paleocene-aged rocks. A study of any acid-soluble (calcareous and silicious) microfossils present in the clastic rocks could provide paleoenvironmental information as well. A palynologic study done in combination with a detailed sedimentologic study could further relate the palynomorphic content to the sedimentary environments present.

As a means of further investigating the utility of palynolgic investigations of coal seams, a study combining the petrology and palynology of a coal could be beneficial. Both methods provide insights into the original botanic compostiton of the coal; the relationship of the original botanical variability to the chemical and physical characteristics of the coal would seem a fundamental step in understanding the coal variability. Knowledge of the contributing flora may aid directly in understanding the original botanic chemistry and paleochemistry of the coal.

The relationship of palynologic trends in the coal to chemical trends was touched upon in this study. The complexity of such an undertaking was underestimated in the initial zeal of starting this project. A full treatment of this relationship would require a considerable multidisciplinary undertaking. The portions of coal chemistry that could be related to original botanic chemistry are certainly more subtle than the data provided by proximate and ultimate analysis. A more detailed approach to the chemistry of coal is warranted.

A comparison of the chemistry of recent and fossil sporopollenin might allow one to demonstrate the changes in molecular structure which have taken place during the coal's diagenesis. The inert nature of sporopollenin makes it an attractive first step in understanding changes which have taken place during coalification because the changes that have occurred are relatively minor. Understanding the diagenetic changes that have occurred in a single constituent might provide insight to the changes that have taken place in overall coal chemistry.

Palynomorphs are potentially very useful chemical bio-markers for the following reasons: 1) palynomorphs are made of sporopollenin, a poorly understood carotenoid polymer, probably one of the most resistant organic materials of direct biological origin found in geologic samples (Brooks and Shaw, 1978); 2) palynomorphs often retain morphologic characteristics which allow them to be positively identified microscopically, thus their botanic origin is well known; 3) the consistent morphology of palynomorphs over geologic time implies a consistent biochemistry as well; and 4) studies of the molecular structure of modern sporopollenin show a remarkable consistency among all plant groups providing a perfect present-day analogue for studies of the fossil sporopollenin.

SUMMARY OF CONCLUSIONS

1. Maceration of the Hagel bed lignite (Sentinel Butte Formation, Paleocene in age) and associated clastic strata from three mines in the Knife River basin of North Dakota yielded a diverse collection of palynomorphs. A total of seventy-five palynomorph types consisting of thirty form-genera, five extant genera and thirty-seven morphotypes were described.

2. The palynomorphic associations present were interpreted as a single, relatively consistent palynoflora. Differences in abundances of infrequently-occurring palynomorph types appear to be related to chance occurrences and differential preservation or deposition.

3. Palynologic and corroborating lithologic evidence within the Hagel bed indicates that the contributing flora was composed of a mixture of swamp and riparian taxa. The families Taxodiaceae-Cupressaceae (characteristic of a cypress forest-swamp environment) represent the dominant floral elements present. Associated fern types (e. g., *Osmunda*) and other taxa indicative of swamp-type environments (e. g., *Steriosporites antiquasporites*) are common constituents of the palynoflora as well. Deciduous taxa are dominated by riparian types (e. g., *Alnus*) and are consistent but small contributors to the palynoflora. The flora can be compared favorably to the present-day flora of the Okefenokee swamp in Georgia.

4. The coals examined proved to be relatively consistent in a gross chemical sense. The associated clastic rocks were similar to each

other among the three mines, as well. There is some indication that the area of the Falkirk mine was more closely associated with fluvial environments while the areas of the Center and Glenharold mines appears associated with lacustrine deposition. These differences in depositional environments may be partially responsible for trends in coal chemistry. Further work is needed to more completely characterize the depositional environments and lithological characteristics of each mine site.

5. A comparison of palynologic data with lithologic data provided some insights into the relationship of palynomorphs to depositional environments. Angiospermous pollen is more abundant in clastic rocks indicating that the angiosperms were dominantly riparian and were likely to have been carried into the depositional environment as detritus. Pteridophytes show a marked increase in abundance at contacts of clastic rocks and the overlying coal. This relationship infers a successional sequence between episodes of clastic deposition and peat deposition. Pteridophytes may represent dominantly lake-marginal taxa, or pioneering plants in a secondary succession after an episode of clastic deposition.

6. Correlation of palynomorphic and geochemical data shows a potential for the utility of palynomorphs as geochemical biomarkers with further study.

Subkingdom Thallobionta
Incertae Familiae - spores

Perisopriacites (?) sp.

Plate: 1, Figure: A

Palynomorph type designation: F12

Diagnosis: Globular fruiting body with small apical ostiole. Composed of many polygonal cells. Exine psilate and dark in color. Diameter 15-40 microns.

Material: Sample 840285, 90.3 x 11.5.

Remarks: Perisporiacites (?) sp. was described and illustrated by Elsik, 1983, p. 35, as a fungal fruiting body. Frequency of occurrence: frequent.

Polyporisporites sp.

Plate: 1, Figure: B

Palynomorph type designation: F13 (Lumped with FUD in counts)

Diagnosis: Monoporate, monocellate (aseptate) obovate, fungal spore; with simple pore. Exine psilate and dark in color. Diameter 1-15 microns.

Material: Sample 840283, 80.8 x 22.2

Remarks: Polyporisporites sp. was described and illustrated by Elsik, (1983, p. 33). Frequency of occurrence: infrequent.

Exesisporites sp.

Plate: 1, Figure: C

Palynomorph type designation: F16 (lumped with FUD for counts)

Diagnosis: Monoporate, monocellate (aseptate), circular, fungal spore with simple pore; exine psilate and dark in color. Size approximately 10 microns.

Material: Sample 840283, 69.1 x 21.5

Remarks: Exesporites sp. was described and illustrated by Elsik (1983, p. 33). Frequency of occurrence: common.

Morphotype: F10 (lumped with FUD for counts)

Plate: 1, Figure: D

Diagnosis: Monoporate, multicellate phragmospore. Monocellate, and uniseriate, with simple pore. Multiseptate with annulate septal flaps. Exine is psilate and darkly pigmented. Size ranges from 15 to 30 microns in length.

Material: Sample 840285, 92.2 x 7.0

Remarks: Elsik (1983, p. 35) described and illustrated this form as a "Scolecospore." Robertson (1975, p. 129) assigned this form to "Pluricellaesporites" and commented that these palynomorphs may be vegetative (hyphae) rather than reproductive units. Frequency of occurrence: frequent.

Morphotype: F11 (lumped with FUD for counts)

Plate: 1, Figure: E

Diagnosis: Inaperturate, multicellate uniseriate phragmospore. Septa are entire and simple with no septate pore visible. Shape curved elliptic. Size variable (due to breakage) but up to 40 microns long.

Material: Sample 840285, 87.8 x 7.4

Remarks: This form resembles morphotype F10 except for the lack of distinct septal flaps.

Morphotype: F14 (lumped with FUD for counts)

Plate: 1, Figure: F

Diagnosis: Inaperturate, monocellate (aseptate) spherical fungal spore. Exine psilate, and possesses irregular radial fissures which can reach the mid-point of the spore. Diameter 14-18 microns.

Material: Sample 840283, 77.3 x 24.2

Remarks: Frequency of occurrence: infrequent.

Morphotype: F15 (lumped with FUD for counts)

Plate: 1, Figure: G

Diagnosis: Diporate, monocellate fungal spore. Exine psilate, pores are simple. Long axis 20-25 microns; diameter 7-10 microns.

Material: Sample 840449, 92.3 x 15.7.

Remarks: A similar form was illustrated and described and assigned to <u>Dyadosporites</u> sp. by Elsik (1983, p. 33, Figure 10). Frequency of occurrence: rare.

Morphotype: F17 (lumped with FUD for counts)

Plate: 1, Figure: H

Diagnosis: Inaperturate, monocellate (aseptate) fungal spore. Shape elliptic, with a curved laesura-like fold or furrow at the mid-point. This feature is about 2/3 the length of the entire grain. Long dimension 8-14 microns.

Material: Sample 840285.

Remarks: Frequency of occurrence: infrequent.

Morphotype: F18 (lumped with FUD for counts)

Plate: 1, Figure: I

Diagnosis: Monocellate (aseptate), circular to elliptical, fungal body; margins convolute; exine psilate. Diameter 3-8 microns.

Material: Sample 840448, 78.5 x 9.0.

Remarks: These palynomorphs were said to resemble the developmental stages of several genera of microthyriaceous fungi and were described and illustrated by Elsik (1968, p. 282) as "Microthyriaceous germlings." Frequency of occurrence: rare.

Morphotype: FUD (fungal undifferentiated)

Plate: 1, Figure: J

Diagnosis: This morphotype, for the purpose of frequency and abundance determinations, includes morphotypes F10, F11, F14, F15, F17, F18, as well as palynomorph types F12, F13, F16, and other palynomorphs determined to be fungal remains on the basis of a dark colored, psilate, and intectate (simple) exine. The figure is included by way of example of a palynomorph falling within this category.

Material: Sample 840361, 61.5 x 20.9.

Remarks: Frequency of occurrence: dominant. Abundance: very abundant.

Division Chlorophyta (green algae)
Class Zygnemaphyceae

Ovoidites ligneolus (Pontinie, Thompson, and Pflung)

Plate: 1, Figure: L

Palynomorph type designation: I10

Diagnosis: Inaperturate, fusiform grain; a fissure dividing the grain into halves characteristically present; exine appears dark and thick and has distinct but irregular reticulate sculpture. Length of polar axis 40-60 microns; diameter 25-35 microns.

Material: Sample 840285, 84.6 x 4.95.

Remarks: O. ligneolus was described and illustrated by Stanley (1965, p. 316). The CFSP assigns this form (vol. 14, p. 122) to both Sporites ligneolus and Pollenites (?) ligneolus (vol. 4, p. 158) and lists the form as the "type species of the Genus Ovoidites." Rich and others (1982) commented on the taxonomy and paleoecological significance of the genus Ovoidites. Rich and others (1982) related Ovoidites to freshwater peat deposits and stated (p. 19) "Ovoidites is an ovoid zygospore or aplanospore of the Zygnemataceae. . ." thus assigning the palynomorph to freshwater algal plankton. Frequency of occurrence: common. Abundance: uncommon.

Subkingdom Embryobinonta
Division Bryophyta (byrophytes)
Class Bryopsida
Familiy Sphagnaceae

Stereiosporites antiquasporites (Wilson and Webster) Dettman, 1953

Plate: 1, Figure: M

Palynomorph type designation: L15

Diagnosis: Trilete spore, slightly convex triangular in polar view; laesurae extend approximately 1/2 to 4/5 of the spore radius; exine psilate; thicker at the apices than on the sides. Diameter 15-20 microns.

Material: Sample 840448P, 63.0 x 18.0.

Remarks: S. antiquasporites was described and illustrated (p. 131) by Robertson, (1975) and assigned (p. 131) to the modern genus Sphagnum. This form appears close to Sphagnum-sporites stereoides (Potonie and Venitz, 1934) forma minor Raatz (1937) as found in the CFPS (vol. 21, p. 46). Frequency of occurrence: dominant. Abundance: common.

Cingulatisporites dakotaensis Stanley, 1965

Plate: 1, Figure: N

Palynomorph type designation: L10

Diagnosis: Trilete, subcircular to subtriangular microspore; tetrad mark often indistinct. Possesses a distinct cingulum, and a "y-shaped thickened area that is rotated 60 degrees in relation to the tetrad mark" (Stanley, 1965, p. 244). Exine is psilate and thin (about 1 micron). Equatorial diameter 15-22 microns.

Material: Sample 840285, 92.4 x 5.1.

Remarks: C. dakotaensis was described and illustrated by Stanley (1965, p. 243). Stanley gave "Possibly Selaginella" as a botanic affinity for this species. Robertson related (1975, p. 132) this form to Sphagnum and stated, "This form seems to be stratigraphically limited in its range and is a potential marker for the lowermost Paleocene in the Williston basin." This form was found only in samples 840281 and 840285.

Division Tracheophyta (vascular plants)
Subdivision Lycophytina
Class Lycopsida
Family Lycopodiaceae

Foveosporites cyclicus Stanley, 1965

Plate: 1, Figure: 0

Palynomorph type designation: L22

Diagnosis: Trilete spore, outline subtriangular to subcircular; laesurae extend approximately 1/2 the spore radius; exine distinctly foveate with circular lumina in the proximal region becoming progressively elongated near the spore periphery. Equatorial diameter 37-45 microns (according to Stanley, 1965, p. 241).

Material: Sample 840285, 83.2 x 20.3.

Remarks: F. cyclicus was described and illustrated by Stanley (1965, p. 241) who listed the genus Lycopodium as a botanic affinity for this species. This type was found only in samples 840289 and 840285.

Class Filicophytina
Family Gleicheniaceae

Cardioangulina diaphana (Wilson and Webster) Stanley, 1965

Plate: 2, Figure: A

Palynomorph type designation: L25

Diagnosis: Trilete, triangular spores with well rounded apexes. Length of laesura about 1/2 of spore radius. Exine psilate. Equatorial diameter 20-30 microns.

Material: Sample 840362, 86.1 x 7.4.

Remarks: *C. diaphana* was described and illustrated by Stanley (1965, p. 248) who provisionally assigned the genus *Cardioangulina* to the Family Gleicheniaceae. Frequency of occurrence: infrequent.

Family Hymenophyllaceae

Hymenophyllumsporites furcosus Stanley, 1965

Plate: 2, Figure: B

Palynomorph type designation: L19

Diagnosis: Trilete, subtriangular to subcircular isospore; trilete mark distinct, runs approximately 3/4 of spore radius, possesses a thickened lip, often with forked distal ends. Exine approximately 1.5 microns thick and psilate. Equatorial diameter 35-50 microns.

Material: Sample 840362, 73.0 x 22.6.

Remarks: *H. furcosus* was described and illustrated by Stanley (1965, p. 249) and assigned (p. 248) to the Hymenophyllaceae. Frequency of occurrence: rare. Abundance: uncommon.

Family Osmundaceae

Osmunda comaumensis (Cookson) Stanley, 1965

Plate: 2, Figure: C

Palynomorph type designation: L16

Diagnosis: Trilete, spherical grain; trilete mark distinct to indistinct, rays long, but stop short of the equator. Exine sculpture consists of densely spaced, distinct clavae. Diameter 30-60 microns.

Material: Sample 840362, 70.8 x 7.4.

Remarks: O. comaumensis was described and illustrated by Stanley (1965, p. 250). Osmundacidites wellmanii Couper (1953) CFSP (vol. 2, p. 115) appears to be an equivalent form. Frequency of occurrence: common. Abundance: uncommon.

Family Polypodiaceae

Laevigatosporites haardti (Pontinie and Venite)
Thompson and Pflung, 1953

Plate: 2, Figure: D

Palynomorph type designation: L13

Diagnosis: Monlete, reniform bean-shaped isospore; laesura runs approximately 3/4 the length of the grain. Exine psilate. Length of long-axis is 25-60 microns.

Material: Sample 840288, 95.7 x 10.4.

Remarks: L. haardti was described and illustrated by Stanley (1965, p. 252). This form also closely resembles L. anomolus (Norton and Hall, 1969, p. 20) but lacks the "foveate sculpturing on the proximal surface." Both Stanley (1965, p. 252) and Norton and

Hall (1969, p. 252) attributed the genus Laevigatosporites to the modern Family Polypodiaceae. Frequency of occurrence: dominant. Abundance: common.

Laevigatosporites anomalus Norton, 1969

Plate: 2, Figure: E

Palynomorph type designation: L21

Diagnosis: Monolete, reniform in shape; laesura runs approximately 2/3 the length of the grain. Exine psilate except on proximal surface (especially near the laesura) where it is foveate. "Length of major diameter 48-58 microns" (Norton and Hall, 1969, p. 20).

Material: Sample 840362, 87.8 x 8.6.

Remarks: L. anomalus was described and illustrated by Norton and Hall (1969, p. 20) and can be distinguished from L. haardti by the foevea on the proximal surface. Frequency of occurrence: infrequent. Abundance: uncommon.

Incertae Familiae - spores

Leiotriletes pseudomaximus (Plfung and Thompson) Stanley, 1965

Plate: 2, Figure: F

Palynomorph type designation: L24

Diagnosis: Trilete, outline in polar view subtriangular to subcircular; trilete mark distinct with length of about 1/2 radius. Exine psilate and often folded. "Equatorial diameter 45-70 microns" (Stanley, 1965, p. 254).

Material: Sample 840446, 79.0 x 4.9.

Remarks: L. pseudomaximus was described and illustrated by Stanley (1965, p. 254). A very similar form, L. paramaximus (CFPS, vol. 19, p. 76), described by Kurtch (1959, p. 56), was deemed an unwarranted subdivision of a Leiotriletes form by Stanley (1965, p. 254). Frequency of occurrence: frequent. Abundance: common.

Schizosporis complexus Stanley, 1965

Plate: 2, Figure: G

Palynomorph type designation: I13

Diagnosis: Inaperturate, spherical to oblate pollen grain; possesses a characteristic "fissure or tear" (Stanley, 1965, p. 268). Exine distinctly reticulate with lumina varying in size, up to 3 microns. "Maximal diameter 36-60 microns" (Stanley, 1965, p. 268).

Material: Sample 840285, 79.1 x 15.7.

Remarks: S. complexus was described and illustrated by Stanley (1965, p. 267). Cookson and Dettman (1959, p. 216) stated that Schizosporis resembles pollen of Rapatea sepectabilis Pilger and Cephalostemon angustatus Malme. Frequency of occurrence: infrequent. Abundance: uncomon.

Recticulatasporite cristatus Stanley, 1965

Plate: 2, Figure: H

Palynomorph type designation: I15

Diagnosis: Inaperaturate, spherical microspore. Exine sculpture consists of anastomosing cristae forming a dense reticulum; cristae length about 5 microns; lumen width 3-4 microns. Size 40-53 microns (abbreviated from Stanley, 1965, p. 266).

Material: Sample 840362, 67.8 x 8.7.

Remarks: R. cristatus was described and illustrated by Stanley (1965, p. 266). Frequency of occurrence: rare. Abundance: rare.

Incertae Class - Spores

Morphotype: L12

Plate: 2, Figure: I

Diagnosis: Trilete, convex to concave triangular grains; leasura are indistinct and extend to about the full-length of the radius. Exine appears thin and is foveate, giving the grain a knobby appearance. Equatorial diameter is 16-25 microns.

Material: Sample 840448P, 76.5 x 4.8.

Remarks: This morphotype matches Stanley's description (1965, p. 239) of Foveasporis triangulus well except for the smaller size (Stanley reported an equatorial diameter of 32-40 microns). Stanley (1965, p. 239) listed the Lycopodiaceae as a botanical affinity for Foveasporis. Frequency of occurrence: infrequent. Abundance: uncommon.

Morphotype: L14

Plate: 2, Figure: J

Diagnosis: Monolete, broadly reniform in shape; laesura runs approximately 2/3 the length of the body length. A distinct lip present at the margin of the laesura. Exine psilate. These grains are often folded. Length of major axis 20-30 microns.

Material: Sample 840283, 30.2 x 109.9.

Remarks: This morphotype resembles forms of Laevigatosporites (Stanley, 1965, p. 251) but has a characteristic lip at the margin of the laesura. Frequency of occurrence: dominant. Abundance: common.

Morphotype: L17

Plate: 2, Figure: K

Diagnosis: Trilete, convex triangular grain; laesura run the entire radius. Laesura are dark, with a distinct raised margo. Exine sculpturing consists of a distinct reticulate pattern. Diameter of grain 20-30 microns.

Material: Sample 840362, 81.4 x 10.6.

Remarks: This form resembles several Sphagnum sp. described and illustrated by Elsik (1968, p. 296). This form was described from two specimens in samples 840281 and 840262, and further systematic treatment was not warranted.

Morphotype: L18

Plate: 2, Figure: L

Diagnosis: Trilete, spherical to fusiform grain; laesura often open and broad. This grain, prone to breakage in my preparations, often gives the appearance of a monosulcate grain. Exine sculpture consists of irregular bacula, intermittently stout and slender (these irregular bacula are this grain's most prominent features). Diameter 25-60 microns.

Material: Sample 840446, 68.7 x 4.2.

Remarks: Except for larger size, this morphotype fits Hopkins (1969, p. 1112) description for _Osmunda irregulites_. Frequency of occurrence: infrequent. Abundance: uncommon.

Morphotype: LTU (trilete undifferentiated)

Plate: 2, Figure: M

Diagnosis: This morphotype includes all pollen grains which have been determined to have a trilete apertural condition, but further systematic refinement is tenuous or impossible.

Material: Sample 840285, 89.7 x 6.7

Remarks: This morphotype was included with the pteridophytes because a trilete apertural condition is characteristic of this group; especially so in the palynomorphs present in my study. Frequency of occurrence: common. Abundance: uncommon.

Subdivision Spermatophyta
Class Cycadopsida
Family Cycadaceae

Cycadopites giganteus Stanley, 1965

Plate: 2, Figure: O

Palynomorph type designation: S15

Diagnosis: Monosulcate, large, elongate fusiform pollen grain; sulcus runs the length of the grain, overlaps in the center and likely to be open at the ends. Exine psilate and thin (approximately 1.5

microns) for the size of the grain. Often badly folded due to thin exine. Length approximately 40-70 microns, width 10-35 microns.

Material: Sample 840288, 84.0 x 22.7

Remarks: C. giganteus was described and illustrated by Stanley (1965, p. 270). Frequency of occurrence: frequent. Abundance: common.

Incertae Familiae - pollen

Morphotype: S11

Plate: 3, Figure: A

Diagnosis: Monosulcate, fusiform grain with pointed ends. Sulcus runs entire length of grain and has a lipped margin. Exine sculpture irregularly baculate to verrucose. Size 28-35 microns in length and 10-15 microns in diameter.

Material: Sample 840285, 30.6 x 106.8.

Remarks: This form resembles Glyptostrobus vacuipites CFPS (vol. 1, p. 62). Frequency of occurrence: infrequent. Abundance: uncommon.

Morphotype: S12

Plate: 3, Figure: B

Diagnosis: Monosulcate, broadly fusiform grain; sulcus open, broad and lipped, extending most of the length of the grain. Exine psilate. Length is approximately 30 microns, width is approximately 23 microns.

Material: Sample 840448P, 81.9 x 7.8.

Remarks: This form matches Monosulcites latus described and illustrated (p. 27) by Norton and Hall (1969) except that M. Latus is described as having a scabrate exine. The lack of scabrae may be a reminent of processing. Frequency of occurrence: infrequent. Abundance: uncommon.

Class Coniferopsida
Family Pinaceae

Laricoidites magnus (Pontinie) Pontinie and Thompson and Thiergart

Plate: 3, Figure: C

Palynomorph type designation: I08

Diagnosis: Inaperturate, roughly spherical shaped pollen grains. Exine indistinctly scabrate to psilate. Grains are mostly badly folded. Diameter 80-100 microns.

Material: Sample 840449, 81.6 x 8.1.

Remarks: L. magnus was described and illustrated by Stanley (1965, p. 278). Stanley (1965, p. 278) gives "Larix?" as a botanical affinity for L. magnus. This form is equivalent to Pollenites magnus (CFPS, vol. 14, p. 776). Frequency of occurrence: common. Abundance: uncommon.

Family Taxodiaceae

Sequoiapollenites paleocenicus, Stanley, 1965

Plate: 3, Figure: D

Palynomorph type designation: TC3

Diagnosis: Inaperturate, spherical to fusiform pollen grains with a ligula; ligula usually bent, about 3 microns wide, in some cases a distal pore can be observed. Exine thin (about 0.5 microns) and scabrate. Grains are usually badly folded due to thin exine. Body of grain has a diameter of 20-30 microns.

Material: Sample 840283, 68.9 x 23.7.

Remarks: S. paleocenicus was described and illustrated by Stanley (1965, p. 282) who gave "Taxodiaceae; possible Sequoia" as a botanic affinity of the genus Sequoiapollenites. Inaperturopollenites ligularis (CFPS, vol. 21, p. 139) and Sequioa-pollenites polyformosus (CFPS, vol. 21, p. 139) are similar forms. Frequency of occurrence: dominant. Abundance: common.

Taxodiaceaepollenites hiatus (Pontinie) Kremp, 1949

Plate: 3, Figures: E, F

Palynomorph type designation: TC4

Diagnosis: Inaperturate round to oblate grains; a large gaping split in exine characteristically present along the mid-point of the grain. This split (or rupture) often bordered by distinct lip. Exine psilate to scrabrate. The exine thin and often folded. Diameter 20-30 microns.

Material: Sample 840285, 86.0 x 6.9.

Remarks: T. hiatus was described and illustrated by Robertson (1975, p. 152). Stanley asigned (1965, p. 273) a similar form to Thuja? hiatus. Other apparently similar forms include Taxodium hiatipites (CFPS, vol. 1, p. 61) and Pollenites hiatus (CFPS, vol. 21, p. 141). Frequency of occurrence: dominant. Abundance: abundant.

Incertae Familae - pollen

Monosulcites crescentus Norton, 1969

Plate: 3, Figure: G

Palynomorph type designation: S10

Diagnosis: Monosulcate, fusiform grain, sulcus a long, single furrow on distal face extending the entire length of the grain. Sulcus bordered by crescentic folds which run the entire length. Exine from 0.5 microns to 1.0 microns thick and densely granulate. Grain often splits open at one end. Length from 20 microns to 32 microns; diameter from 8 microns to 12 microns.

Material: Sample 840285, 29.9 x 112.7.

Remarks: M. cresentus was described and illustrated by Norton and Hall (1969, p. 26) who assigned (p. 26) this form to the Gymnospermae. Frequency of occurrence: dominant. Abundance: common.

Morphotype: BUD (Bisaccate undifferentiated)

Plate: 3, Figures: L, M

Diagnosis: This morphotype includes all the pollen grains which possess a bisaccate body form.

Material: Sample 840448P, 61.1 x 19.0.

Remarks: Bisaccate pollen grains were common constituents of the Hagel bed palynoflora but were characteristically badly folded and abraded; consequently all were assigned to one morphotypic category. Bisaccate pollen grains are characteristic of the modern Family Pinaceae. Frequency of occurrence: dominant. Abundance: common.

Morphotype: TCU (Taxodiaceae-Cupressaceae undifferentiated)

Plate: 3, Figures: K, L

Diagnosis: This morphotype includes the morphotypes TC3 and TC4 when their condition is such that assignment to these forms would be tenuous. It also includes all pollen grains which have a thin, folded psilate to scabrate exine in the size range of 20-40 microns, which look like a "folded cellophane bag" (Rich, 1984).

Material: Sample 840448P, 74.6 x 16.2.

Remarks: This morphotype is representative of the modern Families Taxodiaceae and Cupressaceae. Inaperturate gymnosperm-type pollen are commonly assigned (Robertson, 1975, p. 15; Kremp and others, 1956) to a group composed of these two closely related families. This morphotype represents the most abundant palynomorph found throughout this study. Frequency of occurrency: dominant. Abundance: very abundant.

Morphotype: I16

Plate: 3, Figure: M

Diagnosis: Inaperturate circular grain; appears zonosulcate due to a circular thin area in the middle of the grain. Often has a conspicuous leptoma which gives the appearance of a spur or ligula. The exine is rugulate except in the middle (within the thin area) which appears scabrate. Diameter 15-25 microns.

Material: Sample 840285, 79.1 x 22.0.

Remarks: This morphotype resembles Taxus sp. (Hopkins, 1969, p. 1117) but a lack of definite features in Hopkins' description made assignment of this form to Taxus tenuous. Frequency of occurrence: infrequent. Abundance: uncommon.

Class Ginkgopsida
Incertae Familiae - pollen

Ginkgo shiabensis Simpson, 1961

Plate: 3, Figure: N

Palynomorph type designation: C09

Diagnosis: Monocolpate, narrowly fusiform grain with pointed ends. Colpus extends the entire length of the grain; characteristically folded and overlapping causing a dark, narrowly fusiform fold at the mid-point of the grain. Exine psilate to micro-scabrate in sculpture. Length 25-30 microns, width 15-20 microns.

Material: Sample 840448P, 61.0 x 17.6.

Remarks: G. shiabensis was described and illustrated in CFPS (vol. 34, p. 189) by Simpson (1969). Frequency of occurrence: dominant. Abundance: common.

Class Angiospermopsida
Subclass Dicotyledonidae
Family Anacardiaceae

Rhoipites pisinnus Stanley, 1965

Plate: 3, Figure: O

Palynomorph type designation: CP4

Diagnosis: Fusiform tricolporate grains; colpi are distinct; extending to the end of the grain or nearly so. Pores equatorially located, elongate and distinct (about 2.5 x 1.5 microns in size). Exine finely but distinctly reticulate with lumina about 0.5 microns in diameter. Polar axis is 15-19 microns; diameter is 14-16 microns.

Material: Sample 840285, 98.7 x 17.1.

Remarks: R. pisinnus was described and illustrated by Stanley (1965, p. 286). Stanley (1965) listed (p. 285) "Unknown-Anacardiaceae?" as a botanic affinity for the genus Rhiopites. Frequency of occurrence: common. Abundance: abundant.

Rhiopites crassus Stanley, 1965

Plate: 4, Figure: A

Palynomorph type designation: CP5

Diagnosis: Tricolpate prolate grain; colpi long with circular to equatorially elongate pores (diameter of 3 microns). Exine very thick (about 2 microns) and scabrate. Length of polar axis is approximately 42 microns, diameter approximately 28 microns.

Material: Sample 840362, 85.2 x 11.3.

Remarks: R. crassus was described and illustrated by Stanley (1965, p. 285). Frequency of occurrence: infrequent. Abundance: uncomon.

Family Betulaceae

Betula infrequens Stanley, 1965

Plate: 4, Figure: B

Palynomorph type designation: P21

Diagnosis: Triporate, sublobate, roughly circular in polar view; pores are round and possess a labrum, an annulus, and a vestibulum. Exine sculpture psilate to faintly granulate. Exine appears very thick relative to grain size (due to folding?). Equatorial diameter 15-25 microns.

Material: Sample 840283, 79.7 x 17.7.

Remarks: B. infrequens was described and illustrated by Stanley (1965, p. 290) who distinguished pollen grains belonging to this modern genus by the distinct vestibula they possess. This species was identified from two specimens found in samples 840285 and 840283.

Carpinus subtriangula Stanley, 1965

Plate: 4, Figure: C

Palynomorph type designation: P13

Diagnosis: Triporate, oblate, subtriangular in polar view, possess a labrum, and are slightly to moderately aspidate. Exine finely scabrate and thin (approximately 0.5 microns thick). Equatorial diameter 24-30 microns. Often badly folded due to thin exine.

Material: Sample 840285, 80.5 x 11.4.

Remarks: C. subtriangula was described and illustrated by Stanley (1965, p. 291) who assigned this form to the modern genus Carpinus. Frequency of occurrence: common. Abundance: uncommon.

Corylus granilabrata Stanley, 1965

Plate: 4, Figure: D

Palynomorph type designation: P15

Diagnosis: Triporate, circular to subtriangular pollen grain; pores are approximately 2 microns in diameter, circular to ellipsoidal and possess a moderate to well developed labrum. Exine scabrate except in pore region, where it is granulate. Equatorial diameter 20-28 microns.

Material: Sample 840362, 72.0 x 9.9.

Remarks: C. granilabrata was described and illustrated by Stanley (1965, p. 293) who assigned this form to the modern genus Corylus. Frequency of occurrence: dominant. Abundance: common.

Morphotype: P20

Plate: 4, Figures: E, F

Diagnosis: Triporate to polyporate; typically three of four pores situated at rounded apices. Shape a reflection of the pore number, i.e., triporates are triangular. Distinct arci present which run from pore to pore parallel to sides of grain in triporate form. The quadriporate forms possess arci which are "deeply convex inward so that any two arci meeting at a pore are usually parallel to each other for a short distance before they reach the pore" (Stanley, 1965, p. 288). Exine scabrate, equatorial diameter 13-24 microns.

Material: Sample 840448P, 76.9 x 17.3.

Remarks: This morphotype is representative of the modern genus Alnus and is a combination of the species Alnus quaternaria, Stanley (1965, p. 288) and Alus trina, Stanley (1965, p. 289). Alnus quadrapollenites (CFPS, vol. 25, p. 82) appears to be a form equivalent form A. quaternaria. Frequency of occurrence: frequent. Abundance: common.

Family Ericaceae

Ericaceoipollenites rallus Stanley, 1965

Plate: 4, Figure: G

Palynomorph type designation: I09

Diagnosis: Inaperturate, composed of four roughly circular grains arranged into a tetragonal tetrad; weak colpi sometimes observable which are granular in appearance. Exine thin (approximately 1.0 microns) and scabrate. Size of tetrad 25-40 microns.

Material: Sample 840283, 73.2 x 10.0.

Remarks: E. rallus was described and illustrated by Stanley (1965, p. 296) who gave "Kalmia ?-Ericaceae" as the botanic affinity for this form. Frequency of occurrence: infrequent. Abundance: uncommon.

Family Juglandaceae

Pterocarya levis Stanley, 1965

Plate: 4, Figure: H

Palynomorph type designation: P09

Diagnosis: Polyporate, outline a reflection of pore number, usually 5 or 6, sides straight or slightly concave. Exine psilate, double layered and about 1.5 microns thick. Equatorial diameter 15-19 microns.

Material: Sample 840448P, 61.0 x 17.6.

Remarks: P. levis was described and illustrated by Stanley (1965, p. 303) who gave "Pterocarya? Alnus?" as the botanic affinity for this form. Frequency of occurrence: rare. Abundance: rare.

Engelhardtia microfoveolata Stanley, 1965

Plate: 4, Figure: I

Palynomorph type designation: P17

Diagnosis: Triporate, triangular pollen grain; sides slightly concave to slightly convex, with rounded apices. Pores are 1.5-2.5 microns and meridionally elongated. Exine sculpture appears finely gemmate. Stanley, (1965, p. 301) reported the exine sculpture as "a fine punctation with lumina approximately 0.3 microns wide." Some specimens have an arc-like area which surrounds each pore region. Equatorial diameter 18-25 microns.

Material: Sample 840285, 43.1 x 112.6

Remarks: *E. microfoveolata* was described and illustrated by Stanley (1965, p. 300) who gave "*Engelhardtia*?, Juglandaceae" as the botanical affinity for this form. Frequency of occurrence: common. Abundance: uncommon.

Incertae Famila‌e - pollen

Momipites parvus Norton, 1969

Plate: 4, Figure: J

Palynomorph type designation: P16

Diagnosis: Triporate, convex triangular grain; pores equatorially located, meridionally elongate, and 2-3 microns in size. Exine psilate to microscabrate, more strongly scabrate near pores. Grains often folded with folds commonly running towards pores giving a tricolporate appearance. Diameter 18-30 microns.

Material: Sample 840285, 45.2 x 112.4.

Remarks: M. parvus was described and illustrated by Norton and Hall (1969, p. 37). M. parvus closely resembles Engelhartia microfoveolata, but M. parvus was distinguished by its characteristic folding pattern and less rounded apices. Frequency of occurrence: dominant. Abundance: common.

Triporopollenites maximus Norton, 1969

Plate: 4, Figure: K

Palynomorph type designation: P11

Diagnosis: Triporate, convex triangular to spherical grain; pores aspidate, possessing an annulus with a diameter of about 1.4 microns. "Colpus-like furrows" (Norton and Hall, 1969, p. 40) extend away from the pore area. Exine about 1 micron thick and microscabrate. Equatorial diameter 15-25 microns.

Material: Sample 840449, 82.3 x 12.7.

Remarks: T. maximus was described and illustrated by Norton and Hall (1969, p. 40) who gave "Platycarya" as the botanic affinity for this form. Frequency of occurrence: frequent. Abundance: common.

Triporopollenites plektosus Anderson, 1960

Plate: 4, Figure: L

Palynomorph type designation: P12

Diagnosis: Triporate, prolately spheroidal grain; pores circular with a slightly developed annulus. Exine psilate to microscabrate, and thin (0.5 microns). Often badly folded, folds are crescent-shaped and independent of pore structure. Diameter 20-25 microns.

Material: Sample 840449, 88.6 x 11.4.

Remarks: T. plektosus was described and illustrated by Anderson (1960, C.F.P.S., vol. 23, p. 137). Frequency of occurrence: infrequent. Abundance: uncommon.

Morphotype: L20

Plate: 4, Figure: M

Diagnosis: Trilete spherical grain; trilete mark indistinct, laesurae extend to only about 1/2 of the spore radius. Exine is variously sculptured, but most often is covered with large distinct irregular gemmae. Diameter 6-10 microns.

Material: Sample 840281, 77.7 x 18.2

Remarks: This morphotype is similar to Pistillipollenites sp. described and illustrated by Robertson (1975, p. 179), who distinguished it from Pistillipollenites magregoriill because of its "lack of pores and more random distribution of its gemmae." Most of the specimens found in this study are considerably smaller than those described by Robertson.

Pseudotricolpites reticulatus Stanley, 1965

Plate: 4, Figure: N

Palynomorph type designation: I12

Diagnosis: Inaperturate, prolate, pseudotricolpate pollen grains; two indentations resembling colpi extend nearly the length of the grain. A split in the exine is characteristically present in the position which would normally be occupied by the third colpus in a tricolpate grain. Exine sculpture consists of densely spaced clavae which form a distinct reticulate pattern. Length of equatorial axis 17-21 microns; diameter 9-15 microns.

Material: Sample 840285, 35.5 x 97.2.

Remarks: P. reticulatus was described and illustrated by Stanley (1965, p. 317) who described the genus Pseudotricolpites and assigned it to Incertae Familiae pollen of the Class Angiospermae. Frequency of occurrence: dominant. Abundance: common.

Subclass Monocotyledonidae
Family Liliaceae

Liliacidites variegatus Couper, 1953

Plate: 4, Figure: O

Palynomorph type designation: S16

Diagnosis: Monosulcate, roughly circular grains; sulcus runs approximately 3/4 the length of the grain. Exine is reticulate in sculpture. Equatorial diameter 20-28 microns.

Material: Sample 840285, 96.6 x 5.0.

Remarks: L. variegatus was described and illustrated by Robertson (1975, p. 183) who assigned the form to the Family Liliaceae. This form was found only in sample 840285.

Incertae Familiae - pollen

Pandaniidites texus Elsik, 1968

Plate: 5, Figure: A

Palynomorph type designation: P22

Diagnosis: Monoporate, spherical grain; pores indistinct. "The grain gives a laesurate appearance due to a characteristic split in the exine" (Elsik, 1968, p. 314). The exine is distinctly tectate and is echinate in sculpture. Diameter 8-16 microns.

Material: Sample 840285, 96.4 x 22.1.

Remarks: P. texus was described and illustrated by Elsik (1968, p. 314) who gave the modern genus "Pandanus" as a botanical affinity for this form. Elsik (1968, p. 314) stated that modern Pandanus are coastal or marsh trees of the tropics. Robertson stated (1975, p. 184) that P. texus ". . . seems to be a brackish or estuarine habitat indicator." This grain was found only in the Glenharold mine samples. Frequency of occurrence: infrequent. Abundance: uncommon.

Incertae Subclass - pollen

(These morphotypes have been included with the Class Angiospermopsida but taxonomic assignment within this class is tenuous or impossible.)

Morphotype: CP2

Plate: 5, Figure: B

Diagnosis: Tricolporate, prolate grain; colpi long and interrupted at the equator by small, but distinct circular pores. Exine psilate. Length of polar axis 14-16 microns; diameter 10-12 microns.

Material: Sample 840448P, 64.1 x 16.9.

Remarks: This form resembles Stanley's (1965, p. 285) description of the genus Rhiopites but a lack of definite diagnostic features on this morphotype prevented assignment to a species. Frequency of occurrence: infrequent. Abundance: uncomon.

Morphotype: CP6

Plate: 5, Figure: C

Diagnosis: Tricolporate, fusiform grain; colpi run the entire length of the grain, pore is in center of the colpi (at the equator) and is round. Exine appears psilate to chagrenate. Length of polar axis 15-20 microns; diameter 5-7 microns.

Material: Sample 840448P, 73.1 x 18.0.

Remarks: CP6 resembles Castnea sp. Miller (Hopkins, 1969, p. 1119) but was not found in sufficient quantity to safely assign it to this genus. Frequency of occurrence: rare. Abundance: rare.

Morphotype: C13, (grouped with CTU in counts)

Plate: 5, Figure: D

Diagnosis: Tricolpate, outline in polar view circular with gaping colpi making each segment roughly triangular. Exine distinctly reticulate with lumina of varying size up to 1.5 microns across. Diameter about 35 microns.

Material: Sample 840385, 95.5 x 8.2.

Remarks: This morphotype appears quite similar to Tricolpites bathyreticulatus Stanley (1965, p. 320, pl. 47, fig. 18-23). Stanley listed "Fraxinus ?" as the possible botanic affinity for T. bathyreticulatus.

Morphotype: C16

Plate: 5, Figure: E

Diagnosis: Tricolpate, prolate grain; colpi run the length of the grain, colpi indistinct, wide, with jagged, irregular margins. Exine psilate to finely grannular. Length of polar axis approximately 15 microns; diameter approximately 10 microns.

Material: Sample 840449, 76.3 x 4.6.

Remarks: This morphotype resembles the pollen of the modern genus Quercus except for its smaller size. Frequency of occurrence: frequent. Abundance: uncommon.

Morphotype: P14

Plate: 5, Figure: F

Diagnosis: Triporate, convex subtriangular grain; pores apparently all in one hemisphere, slightly ovoid and perhaps slightly annulate; exine microscabrate to psilate. Diameter 20-26 microns.

Material: Sample 840448P, 72.5 x 9.6.

Remarks: Morphotype P14 resembles Caryae?-pollenites simplex (C.F.P.S., vol. 14, p. 126) and Triporopollenites rugatus (Norton and Hall, 1969, p. 40) but was found in insufficient quantities and qualities to warrant assignment to one of these species. Frequency of occurrence: infrequent. Abundance: uncommon.

Morphotype: P18 (grouped with PUD in counts)

Plate: 5, Figure: G

Diagnosis: Triporate, triangular grain; pores located at rounded apices; indistinct colpi (or colpi-like structures) running from pore to pore in a rounded syncolporate pattern; pores poorly defined; exine indistinctly reticulate. Diameter 18-22 microns.

Material: Sample 840285, 86.2 x 10.2.

Remarks: Morphotype P18 resembles Syncolporites minimus (Leffingwell, 1971, p. 49) but the diagnostic characters of the single specimen found (sample 840285) are inconclusive.

Morphotype: P19

Plate: 5, Figure: H

Diagnosis: Triporate, subtriangular grain; pores non-annulate, ovoid, about 3 microns across; exine psilate and thin (about 1.0 micron thick); polar axis 25-26 microns long.

Material: Sample 840448P, 73.2 x 9.7.

Remarks: Morphotype P19 resembles Caryapollenites simplex Lenk, 1961 (Robertson, 1975, p. 154) but was found in insufficient quantity and quality to warrant assignment. Frequency of occurrence: rare. Abundance: rare.

Morphotype: P23

Plate: 5, Figure: I

Diagnosis: Triporate, triangular to slightly concave triangular grains; pores apically located with an "apertural collar" present. Exine distinctly reticulate. Equatorial diameter 10-15 microns.

Material: Sample 840449, 96.0 x 11.5.

Remarks: Morphotype P23 resembles Proteacidites retusus (Stanley, 1965, p. 307) but is considerably smaller in size. Frequency of occurrence: infrequent. Abundance: uncommon.

Morphotype: PUD (porate undifferentiated)

Plate: 5, Figures: J, K

Diagnosis: This morphotype includes all the pollen grains which have at least one visible pore, but further systematic refinement is tenuous or impossible.

Material: Sample 840362, 83.7 x 6.2.

Remarks: This morphotype was assigned to the Class Angiospermae on the basis of the porate apertural condition. Frequency of occurrence: dominant. Abundance: abundant.

Palynomorphs Not Assigned to Taxonomic Groups

INAPERTURATE GRAINS

Morphotype: I11

Plate: 5, Figure: L

Diagnosis: Inaperturate, elliptical grains; can be of almost any shape due to tendency toward folding. Exine psilate, thin, (0.5 microns - 1.0 microns thick) and characteristically folded into long, irregular folds. Diameter of 20-40 microns.

Material: Sample 840361, 63.4 x 24.3.

Remarks: Morphotype I11 resembles *Pollenites magnus* forma *dubius* (C.F.P.S., vol. 4, p. 100) and *Inaperturopollenites dubius* (Robertson, 1975, p. 185); however, due to the broad range of palynomorphs included by the above diagnosis and the lack of distinctive diagnostic characters, Morphotype I11 was not assigned to a previously described species. Frequency of occurrence: dominant. Abundance: uncommon.

Morphotype: I14

Plate: 5, Figure: M

Diagnosis: Inaperturate, spherical to elliptical grain. Characteristically badly folded. Exine psilate and dark in color. Diameter 15-30 microns.

Material: Sample 840448P, 59.9 x 18.7.

Remarks: Morphotype I14 is morphologically similar to Morphotype I11, but is distinguished by its smaller size and dark colored exine. May be of fungal origin on the basis of its thin, dark colored, psilate exine. Frequency of occurrence: dominant. Abundance: common.

Morphotype: IUD (inaperatuate undifferentiated)

Plate: 5, Figures: N, O

Diagnosis: This morphotype includes all the palynomorphs (except fungal remains) which are inaperturate except for the two preceeding morphotypes, and for which further systematic refinement is tenuous or impossible.

Material: Sample 840447, 74.5 x 20.4.

Remarks: Morphotype IUD represents a broad palynomorph group based solely on apertural condition. Various taxa produce inaperturate pollen. Frequency of occurrence: dominant. Abundance:

abundant.

COLPATE GRAINS

Morphotype: C14

Plate: 6, Figure: A

Diagnosis: Tricolpate, prolate spheroidal grain; colpi distinct running more or less the length of the grain. Exine distinctly tectate (intrabaculate or intragranulate), sculpturing indistinctly scabrate. Length of polar axis approximately 22 microns; diameter approximately 13 microns.

Material: Sample 840285, 28.6 x 109.9.

Remarks: Morphotype C14 was not found in sufficient quantity or quality to make an assignment to a previously described species. Frequency of occurrence: rare. Abundance: rare.

Morphotype: C15

Plate: 6, Figure: B

Diagnosis: Tricolpate, prolate grain; distinct colpi run the entire length of the grain. Exine finely baculate to clavate forming a distinct reticulate pattern. Length of polar axis is 18-25 microns; diameter 10-15 microns.

Material: Sample 840285, 35.2 x 95.3.

Remarks: Morphotype C15 resembles *Tricolpopollenties reticulatus* (CFPS, vol. 21, p. 103) except for its smaller size; this size disparity prevented assignment of Morphotype C15 to *T. reticulatus*. Frequency of occurrence: dominant. Abundance: common.

Morphotype: CTU (tricolpate undifferentiated)

Plate: 6, Figures: C, D, E

Diagnosis: This morphotype includes all the pollen grains which have a tricolpate apertural condition except for the two preceeding morphotypes and for which further systematic refinement is tenuous or impossible.

Material: Sample 840283, 83.3 x 24.5.

Remarks: Morphotype CTU represents a broad palynomorph group based solely on the presence of three colpi. Various taxa produce pollen with a tricolpate apertural condition. Frequency of occurrence: frequent. Abundance: abundant.

COLPORATE GRAINS

Morphotype: CPT (tricolporate undifferentiated)

Plate: 6, Figures: F, G

Diagnosis: This morphotype includes all the pollen grains which have a tricolporate apertural condition, but for which further systematic refinement is tenuous or impossible.

Material: Sample 840285, 81.9 x 8.7.

Remarks: Morphotype CPT represents a broad palynomorph group based solely on a tricolporate apertural condition. Various taxa produce pollen with a tricolporate apertural condition. Frequency of occurrence: common. Abundance: uncommon.

SULCATE GRAINS

Morphotype: SMU (Monosulcate undifferentiated)

Plate: 6, Figures: H, I

Diagnosis: This morphotype includes all the pollen grains which have a monosulcate aperatural condition, but for which further systematic refinement is tenuous or impossible.

Material: Sample 840448P, 67.0 x 8.9.

Remarks: Morphotype SMU represents a broad palynomorph group based solely on a monosulcate apertural condition. Various taxa produce pollen with a monosulcate apertural condition. Frequency of occurrence: dominant. Abundance: common.

MISCELLANEOUS GRAINS

Morphotype: UN1

Plate: 6, Figure: J

Diagnosis: Inaperturate (?) circular bodies of unknown origin. Occur singlely or in groups of two or more. Exines dark color and finely reticulate in ornamentation. May be of fungal origin. Diameter approximately 5 microns.

Material: Sample 840357.

Remarks: Morphotype UN1 was considered an organic structure (perhaps of reproductive funtion?) of probable fungal origin. No similar forms were encountered in the literature. Frequency of occurrence: infrequent.

Morphotype: AQ1

Plate: 6, Figure: K

Diagnosis: This morphotype includes those palynomorphs which may be be representatives of the genus Aquilapollenites Rouse 1957

(Stanley, 1965, p. 132). These grains were not found whole in my preparations, but palynomorphs which appear to be pieces of angiosperm pollen with "one or both poles extended into polar protrusions: having three equatorial protrusions" (Rouse, 1957) have been included in this morphotype.

Material: Sample 840283, 72.8 x 16.7.

Remarks: The rarity and degree of preservation of morphotype AQ1 may be an indication of long-distance transport. Frequency of occurrence: infrequent. Abundance: rare.

PLATE #1

All magnifications are 1,000X.

Figure A. Perisporiacites? sp. (F12)
Material: sample 840285, 90.3 x 11.5 (p. 126).

Figure B. Polyporisporites sp. (F13)
Material: sample 840283, 80.8 x 22.2 (p. 126).

Figure C. Exesisporites sp. (F16)
Material: sample 840283, 69.1 x 21.5 (p. 127).

Figure D. Morphotype F10
Material: sample 840285, 92.2 x 7.0 (p. 127).

Figure E. Morphotype F11
Material: sample 840285, 87.8 x 7.4 (p. 127).

Figure F. Morphotype F14
Material: sample 840283, 77.3 x 24.2 (p. 128).

Figure G. Morphotype F15
Material: sample 840449, 92.3 x 15.7 (p. 128).

Figure H. Morphotype F17
Material: sample 840285, (p. 129).

Figure I. Morphotype F18
Material: sample 840448, 78.5 9.0 (p. 129).

Figure J. Morphotype FUD
Material: sample 840448, 61.5 x 20.9 (p. 129).

Figure K. and L. Ovoidites ligneolus (Pontinie), Thompson and Pflung (I10)
Material: sample 840361, 84.6 x 4.95 (p. 130).

Figure M. Stereiosporites antiquasporites (Wilson and Webster) Dettman, 1953 (L15)
Material: sample 840448P, 63.0 x 18.0 (p. 131)

Figure N. Cingulatisporites dakotaensis Stanley, 1965 (L10)
Material: sample 840285, 92.4 x 5.1 (p. 131).

Figure O. Foveosporites cyclicus Stanley, 1965 (L22)
Material: sample 840285, 83.5.x 20.3 (p. 132).

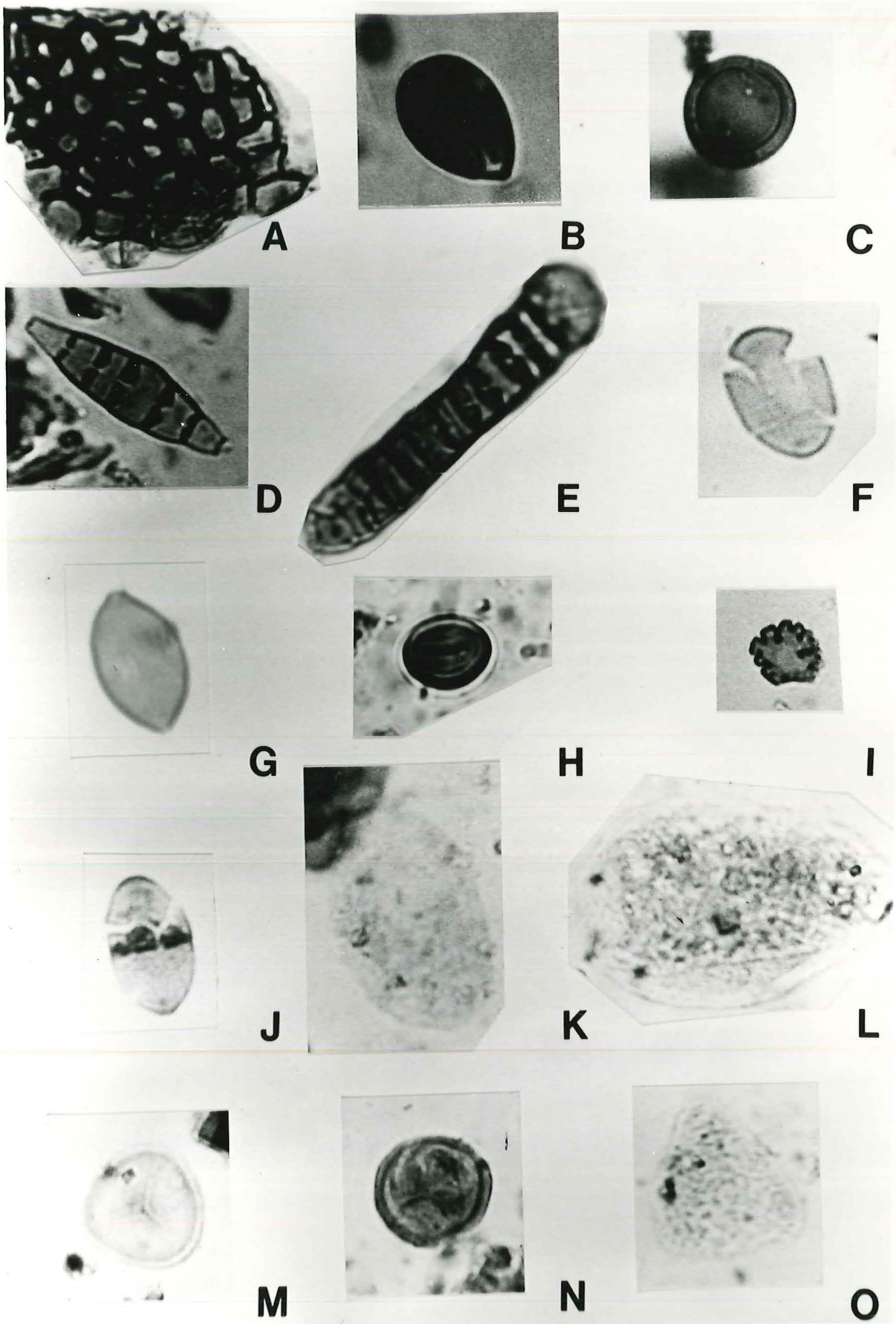

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PLATE #2

All magnifications are 1,000X.

Figure A. Cardioangulina diaphana (Wilson and Webster) Stanley, 1965 (L25)
Material: sample 840362, 86.1 x 7.4 (p. 133).

Figure B. Hymenophyllumsporites furcosus Stanley, 1965 (L19)
Material: sample 840362, 73.0 x 22.6 (p. 133).

Figure C. Osmunda comaumensis (Cookson) Stanley, 1965 (L16)
Material: sample 840362, 70.8 x 7.4 (p. 134).

Figure D. Laevigatosporites haardti (Pontinie and Venitz) Thompson and Pflung, 1953 (L13)
Material: sample 840288, 95.7 x 10.4 (p. 134).

Figure E. Laevigatosporites anomalus Norton, 1969 (L21)
Material: sample 840362, 87.8 x 8.6 (p. 135).

Figure F. Leiotriletes pseudomaximus (Pflung and Thompson) Stanley, 1965, (L24)
Material: sample 840446, 79.0 x 4.9 (p. 135).

Figure G. Schizosporis complexus Stanley, 1965 (I13)
Material: sample 840285, 79.1 x 15.7 (p. 136).

Figure H. Reticulatasporites cristatus Stanley, 1965 (I15)
Material: sample 840362, 67.8 x 8.7 (p. 137).

Figure I. Morphotype L12
Material: sample 840448P, 76.5 x 4.8 (p. 137).

Figure J. Morphotype L14
Material: sample 840283, 30.2 x 109.9 (p. 137).

Figure K. Morphotype L17
Material: sample 840362, 81.4 x 10.6 (p. 138).

Figure L. Morphotype L18
Material: sample 840446, 68.7 x 4.2 (p. 138).

Figure M. Morphotype LTU
Material: sample 840285, 89.7 x 6.7 (p. 139).

Figure O. Cycadopites giganteus Stanley, 1965 (S15)
Material: sample 840288, 84.0 x 22.7 (p. 140).

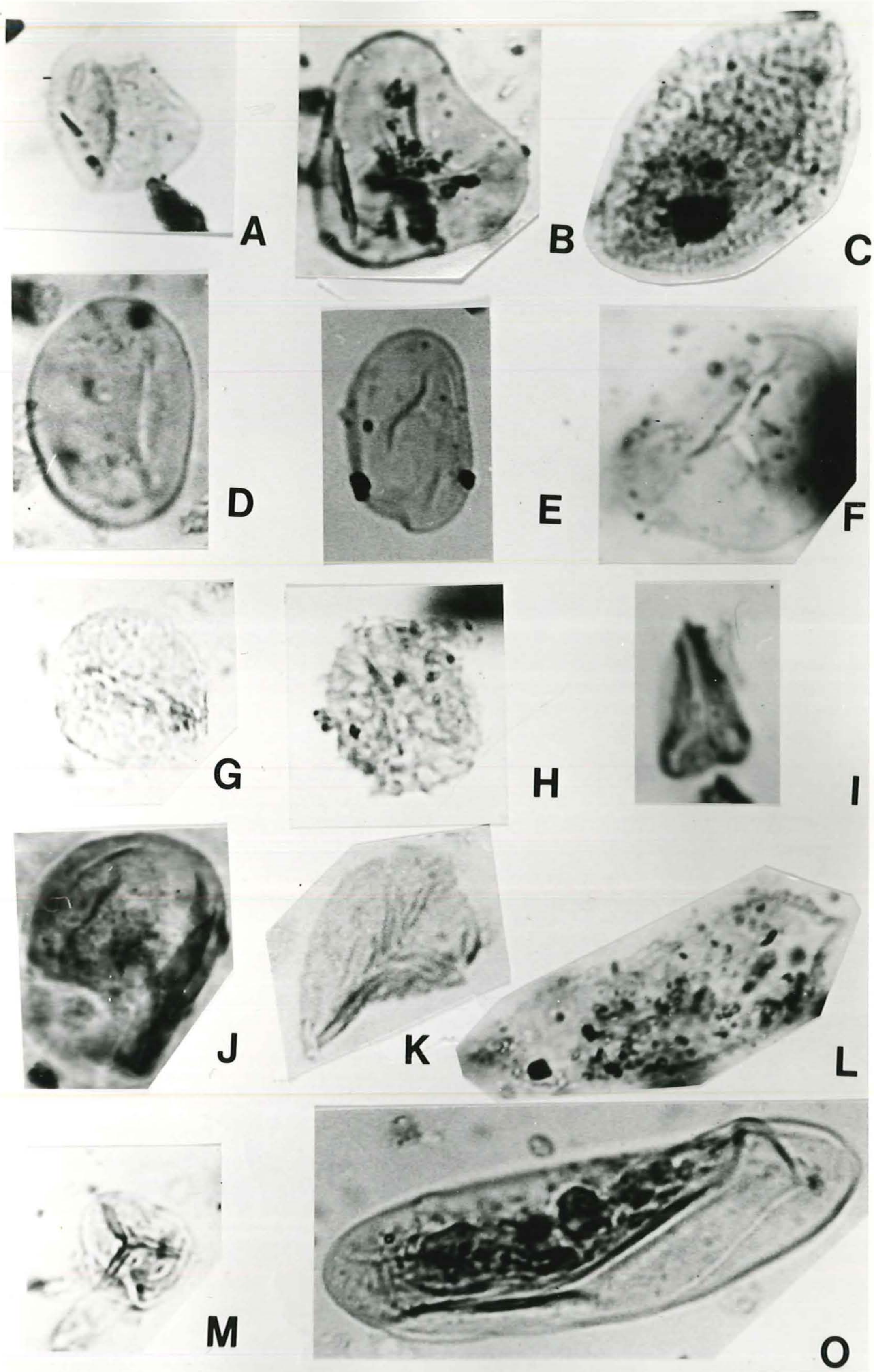

PLATE #3

All magnifications are 1,000X.

Figure A. Morphotype S11
Material: sample 840285, 30.6 x 106.8 (p. 140).

Figure B. Morphotype S12
Material: sample 840448P, 81.9 x 7.8 (p.140).

Figure C. <u>Laricoidites magnus</u> (Pontinie) Pontinie, Thompson and <u>Thiergart</u> (I08)
Material: sample 840449, 81.6 x 8.1 (p. 141).

Figure D. <u>Sequoiapollenites paleocenicus</u> Stanley, 1965 (TC3)
Material: sample 840283, 68.9 x 23.7 (p. 142).

Figure E. and F. <u>Taxodiaceaepollenites hiatus</u> (Pontinie) Kremp, 1949 (TC4)
Material: sample 840285, 86.0 x 6.9 (p. 142).

Figure G. <u>Monosulcites crescentus</u> Norton, 1969 (S10)
Material: sample 840285, 29.9 x 112.7 (p. 143).

Figure H., I. and J. Morphotype BUD
Material: sample 840448P, 61.1 x 19.0 (p. 143).

Figure K. and L. Morphotype TCU
Material: sample 840448P, 74.6 x 16.2 (p. 114).

Figure M. Morphotype I16
Material: sample 840285, 79.1 x 22.0 (p. 144).

Figure N. <u>Ginkgo shiabensis</u> Simpson (1961) (C09)
Material: sample 840448P, 61.0 x 17.6 (p. 145).

Figure O. <u>Rhoipites pisinnus</u> Stanley, 1965 (CP4)
Material: sample 840285, 98.7 x 17.1 (p. 145).

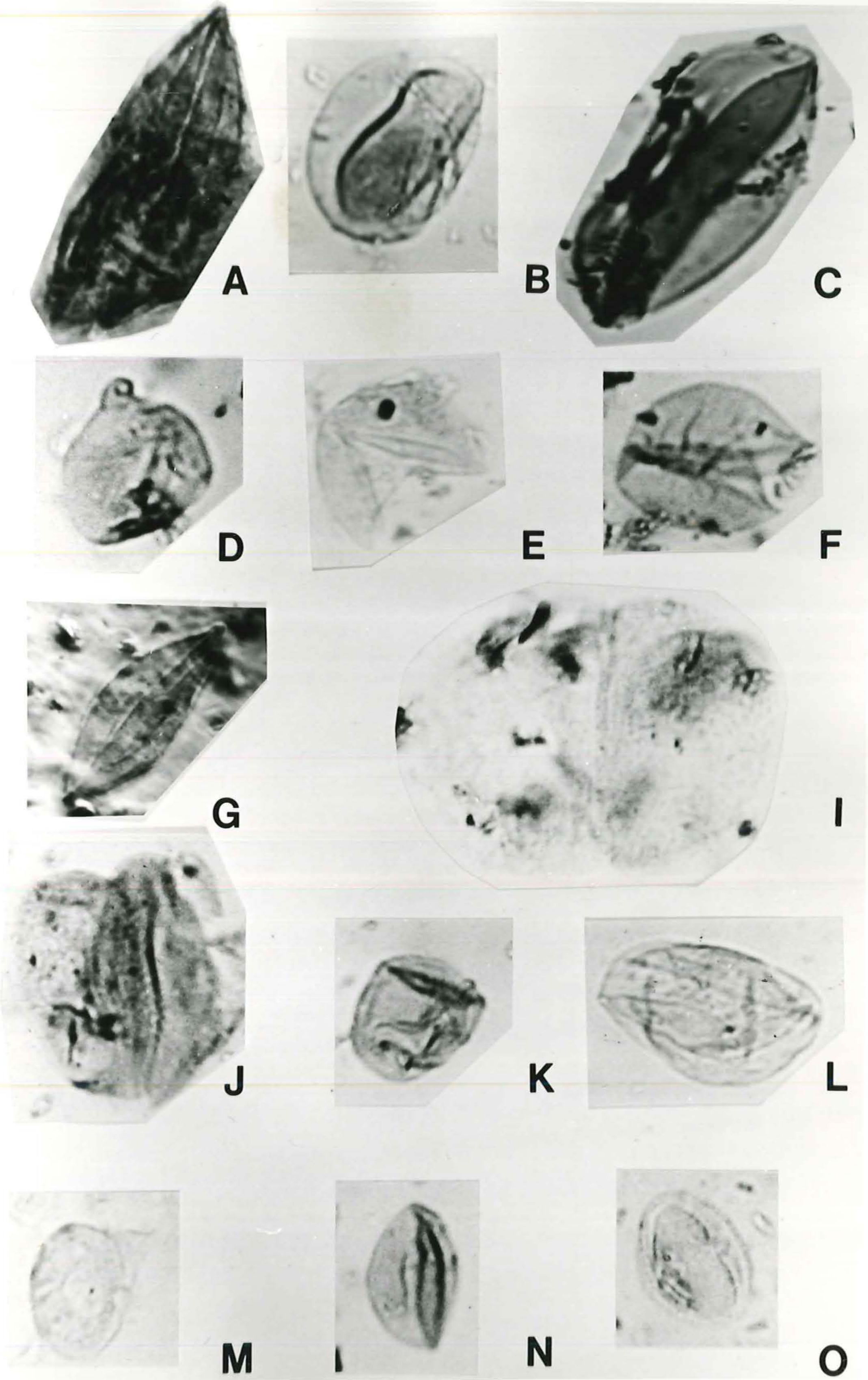
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PLATE #4

All magnifications are 1,000X.

Figure A. Rhoipites crassus Stanley, 1965 (CP5)
Material: sample 840362, 85.2 x 11.3 (p. 146).

Figure B. Betula infrequens Stanley, 1965 (P21)
Material: sample 840283, 79.7 x 17.7 (p. 147).

Figure C. Carpinus subtriangula Stanley, 1965 (P13)
Material: sample 840285, 80.5 x 11.4 (p. 147).

Figure D. Corylus granilabrata Stanley, 1965 (P15)
Material: sample 840362, 72.0 x 9.9 (p. 148).

Figure E. and F. Morphotype P20
Material: sample 840448P, 76.9 x 17.3 (p. 148).

Figure G. Ericaceoipollenites rallus Stanley, 1965 (I09)
Material: sample 840283, 73.2 x 10.0 (p. 149).

Figure H. Pterocarya levis Stanley, 1965 (P09)
Material: sample 840448P, 61.0 x 176 (p. 149).

Figure I. Engelhardtia microfoveolata Stanley, 1965 (P17)
Material: sample 840285, 43.1 x 112.6 (p. 150).

Figure J. Momipites parvus Norton, 1969 (P16)
Material: sample 840285, 45.2 x 112.6 (p. 150).

Figure K. Triporopollenites maximus Norton, 1969 (P11)
Material: sample 840449, 82.3 x 12.7 (p. 151).

Figure L. Triporopollenites plektosus Anderson, 1960 (P12)
Material: sample 840449, 88.6 x 11.4 (p. 151).

Figure M. Morphotype P20
Material: sample 840281, 77.7 x 18.2 (p. 152).

Figure N. Pseudotricolpites reticulatus Stanley, 1965 (I12)
Material: sample 840285, 35.5 x 97.2 (p. 152).

Figure O. Liliacidites variegatus Couper, 1953 (S16)
Material: sample 840285, 96.6 x 5.0 (p. 153).

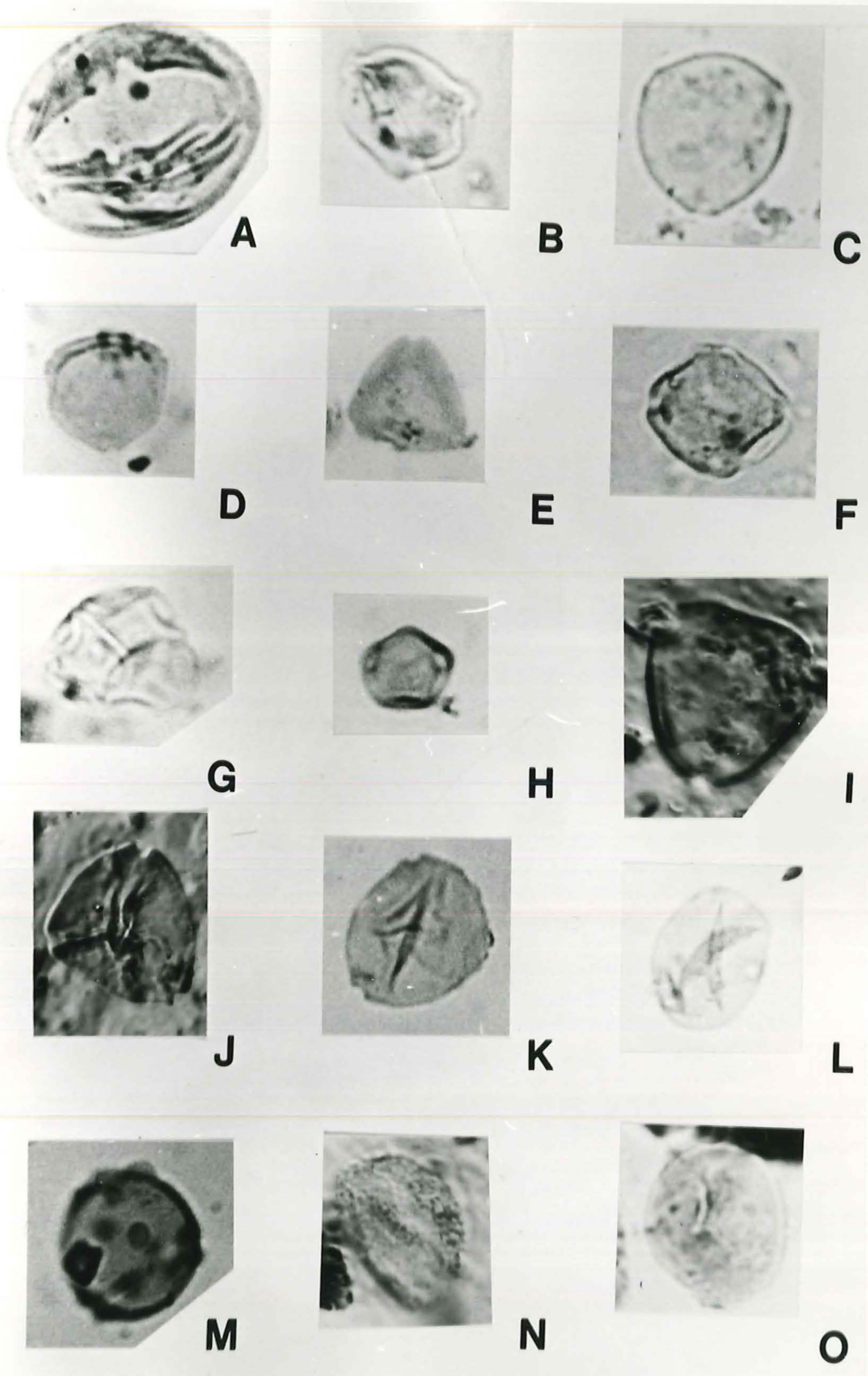
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PLATE #5

All magnifications are 1,000X.

Figure A. Pandaniidites texus Elsik, 1968 (P22)
Material: sample 840285, 96.4 x 22.1 (p. 153).

Figure B. Morphotype CP2
Material: sample 840448P, 64.1 x 16.9 (p. 154).

Figure C. Morphotype CP6
Material: sample 840448P, 73.1 x 18.0 (p. 155).

Figure D. Morphotype C13
Material: sample 840305, 95.5 x 8.2 (p. 155).

Figure E. Morphotype C16
Material: sample 840449, 76.3 x 4.6 (p. 156).

Figure F. Morphotype P14
Material: sample 840448P, 72.5 x 9.6 (p. 156).

Figure G. Morphotype P18
Material: sample 840285, 86.2 x 10.2 (p. 157).

Figure H. Morphotype P19
Material: sample 840448P, 73.2 x 9.7 (p. 157).

Figure I. Morphotype P23
Material: sample 840449, 96.0 x 11.5 (p. 157).

Figure J. and K. Morphotype PUD
Material: sample 840362, 86.7 x 6.2 (p. 158).

Figure L. Morphotype I11
Material: sample 840361, 63.4 x 24.3 (p. 158).

Figure M. Morphotype I14
Material: sample 840448P, 59.9 x 18.7 (p. 159).

Figure N. and O. Morphotype IUD
Material: sample 840447, 74.5 x 20.4 (p. 159).

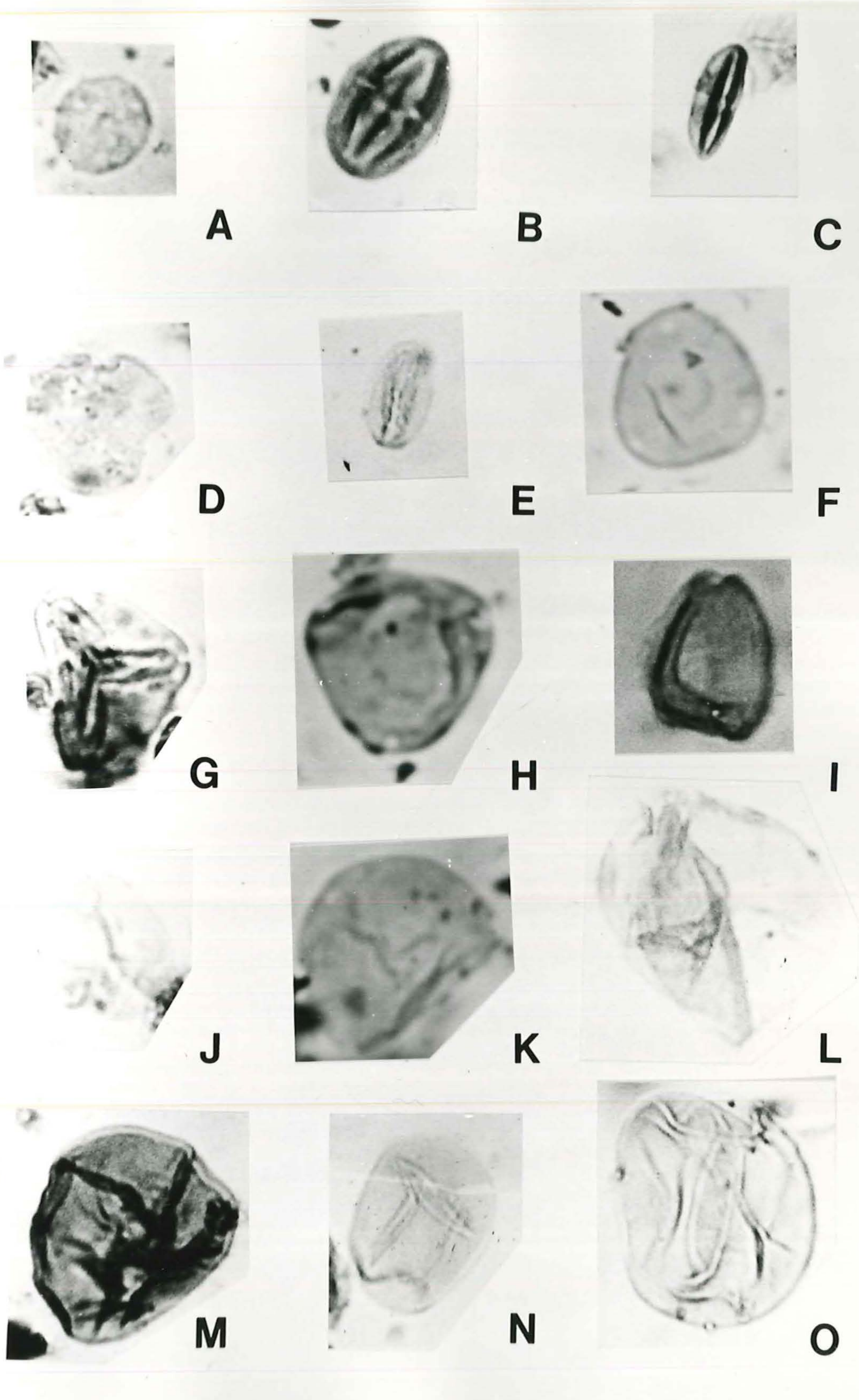
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PLATE #6

All magnifications are 1,000X.

Figure A. Morphotype C14
Material: sample 840285, 28.6 x 109.9 (p. 160).

Figure B. Morphotype C15
Material: sample 840285, 35.2 x 95.3 (p. 160).

Figure C., D. and E. Morphotype CTU
Material: sample 840283, 83.3 x 24.5 (p. 161).

Figure F. and G. Morphotype CPT
Material: sample 840285, 81.9 x 8.7 (p. 161).

Figure H. and I. Morphotype SMU
Material: sample 840448P, 67.0 x 8.9 (p. 161).

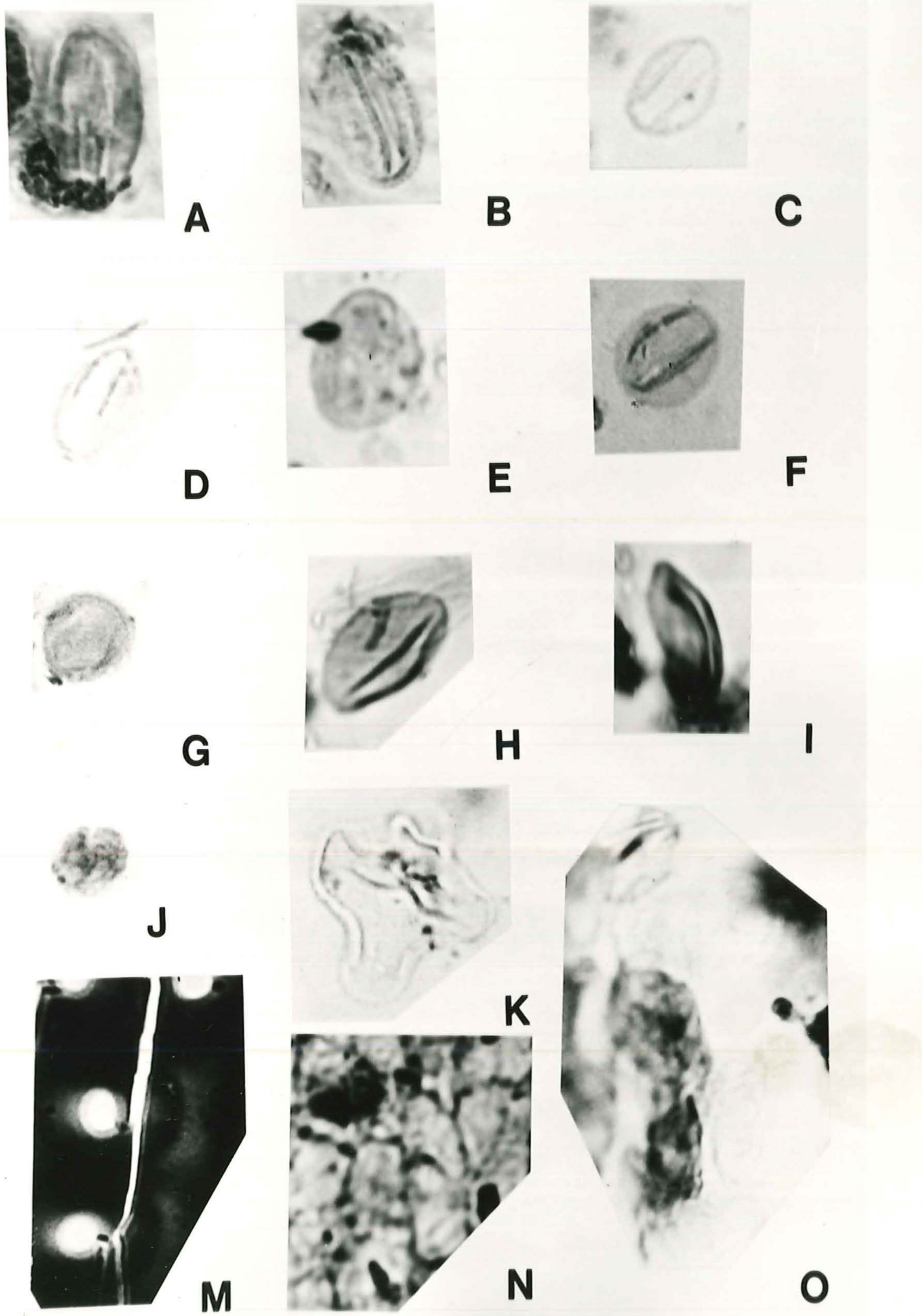
Figure J. Morphotype UN1
Material: sample 840357 (p. 162).

Figure K. Morphotype AQ1
Material: sample 840283, 72.8 x 16.7 (p. 163).

Figure M. Radial section of Coniferopsida (?) coalified wood showing bordered pits
Material: sample 840283.

Figure N. Fragment of cuticle
Material: sample 840448P.

Figure O. Sporangium of Steriosporites antiquasporites (L15)
Material: sample 840361, 74.5 x 18.4.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APPENDICES

APPENDIX A

DESCRIPTIONS OF MEASURED SECTIONS

DESCRIPTIONS OF MEASURED SECTIONS

Units described herein represent lithologic entities discerned in the field in the course of measuring the sections. Sample descriptions were done in the laboratory in the manner described on page 29. Rock color designations used are according to Goddard and others (1948). In each case, the samples are located by their position relative to the contact of lithologic units one and two. Graphic representations of the measured sections and the sample locations within them, are given in Figure 7.

Section Measured at the Falkirk Mine

Location: pit 46, Sec. 32, T.146N., R.82 W.

Unit 1 - Top of measured section.

Thickness -
Feet Meters
1.0' 0.3 m

Siltstone, poorly indurated, fine-grained, irregularly bedded.

Sample 840280 - Sample taken approximately 7.5 cm above contact with Unit 2. Poorly indurated, yellowish gray (5 Y 7/2) siltstone. Irregular laminations (discernible due to concentrations of iron-oxide staining) approximately 0.5 cm thick. Some black coalified organic clasts present.

Unit 2

Thickness -
Feet Meters
0.67' 0.20 m

Poorly indurated silty claystone. Thin (2-3 mm) regular rhythmites present.

Sample 840281 - Sample taken approximately 10 cm below the Unit-1 and Unit-2 contact. Poorly indurated, very pale orange (10 YR 8/2) silty claystone. Possesses dark, parallel rhythmites. Tabular coalified inclusions present up to 3 mm in cross section and 1.5 cm in length.

Unit 3

Thickness -
Feet Meters
3.5' 1.1 m

Lignite, banded and friable, with many xylitic structures present.

Sample 840282 - Sample taken approximately 35 cm below the Unit-1 and Unit-2 contact. Lignite, composed of thin (1-2 mm) vitrain lenses, and thin fusain bands (2-5 mm) dispersed in a durain matrix. Smooth, uniform particulate texture. Vivianite often present along fracture surfaces.

Sample 840283 - Sample taken approximately 65 cm below the Unit-1 and Unit-2 contact. Lignite, composed of thin, irregularly layered masses of vitrain (up to 5 mm thick and several centemeters long) and thin (2-5 mm) bands of fusain dispersed in a durain matrix. Coarse to fine particulate texture.

Unit 4
Thickness -
Feet Meters
3.0' 0.91 m

Lignite, massive, more competent than Unit 3, maintains a vertical slop well. Vivianite and iron-oxide staining conspicuous on fracture surfaces. Many xylitic structures present.

Sample 840284 - Sample taken approximately 1.25 m below the Unit-1 and Unit-2 contact. Lignite, well banded, vitrain lenses (approximately 2 mm thick and 1 cm long) and narrow bands of fusain. Coarse xylitic texture, fractures into small tabular sheets.

Sample 840285 - Sample taken approximately 1.8 m below the Unit-1 and Unit-2 contact. Lignite, well banded with irregular, thin (2-6 mm) bands of fusain and vitrain in a durain matrix. Fine texture some xylitic structure present. Some vitranite on fracture surfaces.

Unit 5
Thickness
Feet Meters
0.5' 0.15 m

Claystone with convoluted dark organic clasts, breaks into smooth, conchoidal fractures. Transitional over 2 cm from claystone to lignite on both top and bottom contacts.

Sample 840286 - Sample taken approximately 2.1 m below the Unit-1 and Unit-2 contact, in claystone-lignite transition zone. Claystone, very pale orange (10 YR 8/2) with dark gray (N 3) inclusions. Claystone poorly indurated and sectile. Irregular rhythmite structures and many coalified inclusions.

Sample 840287 - Sample taken approximately 2.17 m below the Unit-1 and Unit-2 contact. Claystone, pale yellowish brown (10 YR 6/2) with convoluted dark organic (coalified) inclusions causing a marbled appearance.

Sample 840288 - Sample taken approximately 2.24 m below the Unit-1 and Unit-2 contact. Claystone-lignite transition zone. Claystone, dark yellowish brown (10 YR 4/2) irregular convoluted laminae composed of dark, organic material present causing a marbled appearance. Lignite at contact bright and vitreous, lenticular masses of vitrain are dispersed in clay matrix.

Unit 6
Thickness
Feet Meters
4.5' 1.37 m

Lignite, well banded and prominantly xylitic, this seam is approximately 1.37 m thick.

Sample 840289 - Sample taken approximately 2.5 m below the Unit-1 and Unit-2 contact. Lignite, dull, well banded, xylitic structures prominant. A great deal of fusain (25 percent) present. Coarse texture.

Total thickness of measured section:
Feet Meters
13.2' 4.0 m

Bottom of measured section.

Section Measured at the Center Mine

Location

Pit 35-3, Sec. 35, T.142N., R.84W.

Unit 1
Thickness
Feet Meters
0.5' 0.15 m

Top of measured section.
Clay-rich siltstone, poorly indurated with irregular bedding and an irregular but sharp lower contact.

Sample 840352 - Sample taken approximately 7.5 cm above contact with Unit 2. Clay-rich siltstone very pale orange (10 YR 8/2) in color. Poorly indurated with irregular dark laminae present. Organic clasts composed primarily of fusinite. A micaceous sheen present along fracture surfaces.

Sample 840353 - Sample taken approximately 7.5 cm below sample 840352 (in the proximity of the Unit-1 and Unit-2 contact). Sample includes approximately 3 cm of lignite from above, and 3 cm of siltstone from below, the lignite-siltstone contact. Contact sharp but irregular. Light olive gray (5Y 6/1) with thin (0.1 mm - 1.0 mm) dark laminae present. A micaceous sheen present on fracture surfaces.

Unit 2
Thickness
Feet Meters
1.3' 0.4 m

Lignite, dull fragmental with thin (0.3 cm - 5 cm) irregular banding.

Sample 840354 - Sample taken approximately 20 cm below Unit-1 Unit-2 contact. Lignite, well banded and dull, vitrain lenses prevalent and very little fusain present. Macroscopic clay lenses present.

Unit 3	
Thickness Feet / Meters: 0.33' / 0.10 m	Claystone, thin, (0.2 mm - 1 mm) dark laminae present. Moderately indurated, sharp irregular contacts above and below.

Sample 840355 - Sample taken approximately 40 cm below the Unit-1 and Unit-2 contact. Sample includes approximately 3 cm of lignite from above and 3 cm of claystone from below the lignite-claystone contact. Claystone, light olive gray (5Y 6/1), with thin (0.2 mm - 1 mm) rhythmites dark and light laminae. Lignite finely banded and fusain rich, sometimes intercalated with the claystone.

Sample 840356 - Sample taken approximately 46 cm below the Unit-1 Unit-2 contact. Silty claystone, very pale orange (10 YR 8/2) with grayish black inclusions. Thinly laminated (as sample 840355 above) laminae seem laterally continuous for several centimeters. Friable and moderately indurated.

Unit 4	
Thickness Feet / Meters: 6.75' / 2.1 m	Lignite, massive, thinly banded. Large (1 cm - 3 cm) pyrite inclusions present along prominent right angle fractures.

Sample 840357 - Sample taken approximately 60 cm below the Unit-1 and Unit-2 contact. Lignite, bright well banded with thin (1 mm - 4 mm) planar layers of fusain and vitrain present. Fine-grained texture, vitreous fusain appears closely associated with vitrain.

Sample 840358 - Sample taken approximately 85 cm below the Unit-1 and Unit-2 contact. Lignite, well banded and dull with planar layers of fusain and vitrain. Fine particulate texture. Fractures parallel to banding.

Sample 840359 - Sample taken approximately 1.15 m below the Unit-1 and Unit-2 contact. Lignite, well banded and bright, lenticular masses of vitrain several centimeters long. Fusain present in relatively thick (3 mm) masses. Seems especially hard and competent, displays a tendency to break at right angles.

Sample 840360 - Sample taken approximately 1.45 m below the Unit-1 and Unit-2 contact. Lignite, well banded and dull. Vitrain present in isolated masses within durain matrix thin bands of fusain present as well. Masses of macroscopic resinite present.

Sample 840361 - Sample taken approximately 1.75 m below the Unit-1 and Unit-2 contact. Lignite, well banded and bright luster. An extreme amount of xylitic structures present. Lenses of vitrain present. Some brown xylitic structures along fracture planes.

Sample 840362 - Sample taken approximately 2.05 m below the Unit-1 and Unit-2 contact. Lignite, moderately banded, fine textured, moderately bright coal. Small (1 mm thick and 0.5 cm - 1 cm long) vitrain lenses dispersed in a durain matrix. Competent and fractures at right angles. Macroscopic resinite bodies common.

Sample 840363 - Sample taken approximately 2.35 m below the Unit-1 and Unit-2 contact. Lignite, well banded, moderately bright, and fine textured. Thin (0.5 mm) to thicker (3 mm) bands of vitrain present. A large amount of xylitic structrues present. Some macroscopic resenite present.

Unit 5
Thickness
Feet Meters
0.29' 0.089 m

Claystone, poorly indurated, sectile, and organic rich. Very finely laminated. Sharp contacts with overlying and underlying lignite.

Sample 840364 - Sample taken approximately 2.6 m below the Unit-1 and Unit-2 contact. Lignite-claystone contact zone. Sample includes approximately 3 cm of lignite from above and 3 cm of claystone from below the contact. Claystone displays irregular dark (organic?) clasts, color olive black (5Y 2/1). Poorly indurated and sectile sharp irregular contact with overlying lignite.

Sample 840365 - Sample taken approximately 2.66 m below the Unit-1 and Unit-2 contact. Claystone, organic rich, medium light gray (N 6) to light brownish gray. Contains irregular, thin (0.5 mm - 1 mm), wispy dark, laminae. Poorly indurated and sectile.

Unit 6
Thickness
Feet Meters
2.75' 0.84 m

Lignite, finely banded, dull, and fragmental. Grades into underlying claystone (Unit 7).

Sample 840366 - Sample taken approximately 2.86 m below the Unit-1 and Unit-2 contact. Lignite, prominently but irregularly banded, bright and fine textured. Composed dominantly of vitrain with thick (up to 5 mm) bands of fusain present. Many xylitic structures present.

Sample 840367 - Sample taken approximately 2.16 m below the Unit-1 and Unit-2 contact. Lignite well banded, fine textured,and bright. Xylitic structures are dominant. Fusain and vitrain appear intercalated in planar bands reminiscent of wood-grain structures.

Unit 7 Thickness Feet Meters 0.5' 0.15 m	Organic-rich claystone which grades into overlying lignite seam (Unit 6). Transitional over 3 cm from lignite to underlying claystone. Waxy appearance on fracture surfaces, sectile. Sample 840368 - Sample taken approximately 2.46 m below the Unit-1 and Unit-2 contact. Claystone-lignite transition zone dark gray (N 3) to brownish black (5YR 2/1) extremely rich in coalified organic clasts. Grades almost imperceptibly into fine textured, moderately banded, dull to bright lignite above. Sample 840369 - Sample taken approximately 2.54 m below the Unit-1 and Unit-2 contact. Claystone, organic rich, medium gray (N 5) in color. Wispy, organic stringers appear to be soft-sediment deformation features. Poorly indurated and sectile.
Total Thickness of Measured Section Feet Meters 12.42 3.79 m	Bottom of measured section.

Section Measured at the Glenharold Mine

Location	27 pit, Sec. 9, T.144N., R.84W.
Unit 1 Thickness Feet Meters 0.75' 0.23 m	Top of measured section. Slightly silty claystone, massive, well consolidated, poorly indurated. Sample 840444 - Sample taken approximately 15 cm above contact with underlying lignite seam (Unit 2). Silty claystone color ranges from light brown (5 YR 5/6) to pale yellowish brown (10 YR 6/4). Displays irregular, convoluted dark colored (organic) laminations and coalified clasts. Convoluted laminae

appear to be soft-sediment deformation features. Poorly indurated and sectile.

Unit 2
Thickness
Feet Meters
1.83' 0.56 m

Lignite, dull, thinly banded, displays prominent right angle fracturing.

Sample 840445 - Sample taken approximately 30 cm below the Unit-1 and Unit-2 contact. Lignite, well banded and bright with a coarse particulate texture. Vitrain found in discrete lenses and fusain present as small sheet-like masses within durain matrix. Xylitic structures common.

Unit 3
Thickness
Feet Meters
0.25' 0.076 m

Claytone, with many coalified clasts, sharp irregular contacts above and below.

Sample 840446 - Sample taken from approximately 60 cm below the Unit-1 and Unit-2 contact. Claystone, light brownish gray (5 YR 6/1) to brownish gray (5 YR 4/1) in color. Many coalified clasts (up to 1 cm long and 3 mm in height) present in an irregular pattern. Poorly indurated and sectile.

Unit 4
Thickness
Feet Meters
3.75' 1.14 m

Lignite, dull banded coal, bands appear to increase in thickness down section.

Sample 840447 - Sample taken from approximately 78 cm below the Unit-1 and Unit-2 contact. Lignite, well banded, dull luster with a medium texture. Little vitrain or fusain present. Fusain concentrated into thin planar sheets. Some macroscopic resinite(?) present. Semiconchoidal fracture.

Sample 840448 - Sample taken from approximately 1.08 cm below the Unit-1 and Unit-2 contact. Lignite, distinctly but irregularly banded, dull luster, fine particulate to medium particulate texture. Lenticular masses of vitrain (up to 4 mm thick) often with 0.5 mm thick fusain layers associated resinite present.

Sample 840449 - Sample taken from approximately 1.38 m below the Unit-1 and Unit-2 contact. Lignite, distinctly but irregularly banded, dull luster, fine textured. Thin masses of vitrain and fusain dispersed in a durain matrix. Displays both conchoidal and bedding plain fracturing.

Sample 840450 - Sample taken from approximately 30 cm below sample 840449. Lignite, distinctly but irregularly banded, dull luster, fine, uniform texture. Banding appears wavey and gives the impression of irregularly grained wood structures.

Total Thickness of Measured Section Feet Meters 6.58' 2.01 m	Bottom of measured section.

APPENDIX B

CHEMICAL AND MINERALOGIC DATA

CHEMICAL AND MINERALOGIC DATA

Listed in Table 9 are the results of proximate and ultimate analysis expressed on a moisture fee basis. The results of proximate analysis techniques are shown in the first three columns with volatile matter, fixed carbon and ash expressed as percent. Ultimate analysis results are expressed as percent ash, hydrogen, carbon, nitrogen, sulfur, and oxygen desginated by elemental symbols. Heating values are expressed in British Thermal Units per pound (BUT) and calculated calorific values, also expressed in BTU's per pound.

Listed in Table 10 are the results of x-ray fluorescence major oxide analysis. These values are listed by sample number and the elements are designated by elemental symbols. The values are expressed in parts per million.

TABLE 9. PROXIMATE AND ULTIMATE ANALYSIS RESULTS

GFNO	VOLITILE MATTER	FIXED CARBON	ASH	H	C	N	S	O	BTU	CALORIFIC VALUE
840445	49.8	44.6	5.6	5.12	67.90	0.70	1.16	19.52	11476	10922
840447	54.1	41.1	4.8	5.58	70.98	0.49	1.10	17.04	12192	10588
840448	47.6	45.6	6.8	4.49	66.65	0.92	0.47	20.67	10915	9784
840449	47.6	45.0	7.4	4.30	67.12	0.74	0.57	19.87	10834	9642
840450	51.4	42.0	6.6	4.42	65.82	1.02	0.63	21.51	10843	9193
840282	51.1	40.1	8.8	3.95	49.66	0.84	0.92	25.26	10884	7513
840283	48.7	44.0	7.3	3.50	47.89	0.72	0.77	26.44	10817	6800
840284	47.3	46.0	6.7	3.17	45.06	0.60	0.48	28.58	10879	5982
840285	49.0	44.9	6.1	3.51	49.93	0.89	0.40	26.91	10947	7155
840289	50.6	38.5	10.9	3.89	54.98	0.76	0.41	23.50	10804	8517
840354	49.7	43.2	7.1	4.63	65.79	1.11	0.49	20.88	10798	8636
840357	45.5	45.5	9.0	3.96	67.44	1.18	0.25	18.17	10798	9182
840358	50.0	42.7	7.3	4.48	69.04	1.31	0.17	17.70	11197	8534
840359	48.4	48.0	3.6	4.74	70.04	0.77	0.28	20.58	11427	9793
840360	51.5	43.1	5.4	4.75	69.96	1.14	0.16	18.59	11354	9203
840361	54.8	40.4	4.8	4.74	69.95	1.02	0.21	19.28	11401	9780
840362	52.6	39.2	8.2	5.07	68.94	0.96	0.23	16.59	11626	9640
840363	47.5	44.0	8.5	4.92	67.35	1.13	0.32	17.78	10860	9102
840366	49.0	42.8	8.2	4.68	65.49	1.02	0.29	20.32	10823	9521
840367	46.8	48.2	5.0	4.78	67.23	0.69	0.64	21.66	11398	10148

TABLE 10. X-RAY FLUORESCENCE RESULTS
MAJOR OXIDE ANALYSIS

SAMPLE #	MINE	SIO_2	Al_2O_3	Fe_2O_3	TiO_2	P_2O_5	CaO	MgO	Na_2O	K_2O	SO_3
840444	GH	61.7	19.2	6.0	0.9	0.0	2.3	3.5	0.8	4.9	0.7
840446	GH	68.4	18.9	3.2	1.0	0.0	0.7	2.2	0.5	5.1	0.1
840280	FA	62.8	17.2	5.1	0.8	0.0	6.3	3.7	0.7	3.1	0.4
840281	FA	63.4	18.2	5.2	0.9	0.1	3.4	3.7	0.9	3.7	0.5
840286	FA	69.4	17.2	3.6	0.8	0.0	1.3	2.4	0.0	5.0	0.4
840287	FA	68.2	18.0	4.0	0.7	0.0	1.4	2.7	0.0	4.6	0.4
840288	FA	67.3	18.3	3.8	0.6	0.0	2.1	2.6	0.0	4.3	1.0
840352	CN	64.0	18.2	5.1	1.0	0.0	3.3	3.4	0.9	3.9	0.2
840353	CN	63.5	19.3	6.1	0.9	0.0	1.4	2.9	0.7	3.7	1.4
840356	CN	66.3	19.3	4.4	0.8	0.0	1.1	2.7	1.1	3.8	0.3
840355	CN	70.6	5.6	6.5	1.2	0.0	4.8	3.7	1.2	4.5	1.9
840365	CN	66.7	21.1	3.4	0.8	0.0	0.7	2.5	0.0	4.1	0.7
840369	CN	64.2	19.1	6.0	0.9	0.0	1.0	3.1	0.9	4.7	0.1
840368	CN	62.3	18.8	5.0	0.8	0.1	2.2	2.5	0.0	4.9	3.3
840364	CN	64.0	20.0	4.2	0.8	0.0	2.2	2.3	0.0	4.8	1.6

TABLE 11. X-RAY FLUORESCENCE RESULTS

MINOR ELEMENT ANALYSIS

SAMPLE NO.	Al	Si	S	K	Ca	Ti	Fe	Cl	Cr	Mn	Ni	Cu	Zn	As	Rb	Sr	Y	Zr	Ba
840444	79380	251900	1830	31830	14060	3460	34140	67	137	310	103	93	140	0	107	157	19	80	182
840446	79520	290500	398	34510	4720	3760	19290	95	122	183	15	75	71	0	107	97	14	62	151
840280	59020	242600	943	17310	35320	2660	25940	0	84	300	19	67	93	0	70	283	19	133	266
840281	63730	249100	1000	22130	20370	3240	28750	0	120	300	42	81	133	0	99	226	24	124	279
840288	72240	257500	1900	25070	12090	2070	20640	0	80	0	0	128	183	0	140	206	21	78	287
840352	73060	267700	742	23610	20060	3380	28670	57	115	252	39	237	155	0	76	164	19	101	129
840353	72940	260200	3960	23660	8870	3020	35690	38	136	280	70	82	199	32	82	225	22	139	184
840356	72430	271500	659	24770	6990	2950	26170	88	103	217	49	75	156	0	92	195	18	92	179
840355	55590	194500	2850	18010	18580	2610	20690	1550	104	175	25	89	107	0	40	345	10	65	66
840369	80270	276100	192	32950	6450	3510	37320	93	144	328	38	81	129	0	127	139	22	83	223
840365	84380	274200	1920	28830	4620	3310	22380	85	103	194	87	90	81	0	116	137	16	64	130
840286	75950	295600	492	32100	8300	2750	21230	40	107	0	21	100	57	0	208	162	31	114	362

APPENDIX C

PALYNOMORPH COUNT RESULTS

PALYNOMORPH COUNT RESULTS

The following table is the result of palynomorph counts made on each sample. "Count" refers to the actual number of grains of each morphotype identified per sample. "Percent" refers to the percentage (of the total number of grains counted) represented by each morphotype per sample.

TABLE 12. PALYNOMORPH COUNT RESULTS

Sample # 840280

Total Count 359

Type	S10	S11	S12	S15	SMU	LTU	CP2
Count	0	0	0	0	3	0	0
Percent	0.000	0.000	0.000	0.000	0.836	0.000	0.000

Type	CP4	CP5	CP6	CPT	C14	C15	C16
Count	0	0	0	0	0	2	1
Percent	0.000	0.000	0.000	0.000	0.000	0.557	0.279

Type	CTU	BUD	P09	P11	P12	P13	P14
Count	13	43	0	1	0	2	0
Percent	3.621	11.978	0.000	0.279	0.000	0.557	0.000

Type	P15	P16	P17	P19	P20	P22	P23
Count	3	0	0	0	0	0	0
Percent	0.836	0.000	0.000	0.000	0.000	0.000	0.000

Type	PUD	I16	C09	TC3	TC4	TCU	I08
Count	30	0	20	3	13	138	0
Percent	8.357	0.000	5.571	0.836	3.621	38.440	0.000

Type	I09	I10	I11	I12	I13	I14	IUD
Count	0	1	0	1	0	9	10
Percent	0.000	0.279	0.000	0.279	0.000	2.507	2.786

Type	L10	L12	L13	L14	L15	L16	L17
Count	4	2	4	2	4	1	0
Percent	1.114	0.557	1.114	0.557	1.114	0.279	0.000

Type	L18	L19	L21	L24	L25	FUD	AQ1
Count	0	0	0	0	0	20	0
Percent	0.000	0.000	0.000	0.000	0.000	5.571	0.000

Type	UN1
Count	0
Percent	0.000

TABLE 12. Continued

Sample # 840281

Total Count 321

Type	S10	S11	S12	S15	SMU	LTU	CP2
Count	0	0	0	6	6	0	0
Percent	0.000	0.000	0.000	1.869	1.869	0.000	0.000
Type	CP4	CP5	CP6	CPT	C14	C15	C16
Count	3	0	0	1	0	5	1
Percent	0.935	0.000	0.000	0.312	0.000	1.558	0.312
Type	CTU	BUD	P09	P11	P12	P13	P14
Count	28	37	0	1	0	0	0
Percent	8.723	11.526	0.000	0.312	0.000	0.000	0.000
Type	P15	P16	P17	P19	P20	P22	P23
Count	0	5	0	0	10	0	0
Percent	0.000	1.558	0.000	0.000	0.312	0.000	0.000
Type	PUD	I16	C09	TC3	TC4	TCU	I08
Count	12	0	5	1	25	106	1
Percent	3.738	0.000	1.558	0.312	7.778	33.022	0.312
Type	I09	I10	I11	I12	I13	I14	IUD
Count	0	0	2	2	0	9	19
Percent	0.000	0.000	0.623	0.000	0.000	2.804	5.919
Type	L10	L12	L13	L14	L15	L16	L17
Count	1	0	8	0	0	0	2
Percent	0.312	0.000	2.492	0.000	0.000	0.000	0.623
Type	L18	L19	L21	L24	L25	FUD	AQ1
Count	0	0	0	0	1	33	0
Percent	0.000	0.000	0.000	0.000	0.312	10.280	0.000
Type	UN1						
Count	0						
Percent	0.000						

TABLE 12. Continued

Sample # 840282

Total Count 313

Type	S10	S11	S12	S15	SMU	LTU	CP2
Count	0	0	0	0	2	0	0
Percent	0.000	0.000	0.000	0.000	0.639	0.000	0.000

Type	CP4	CP5	CP6	CPT	C14	C15	C16
Count	3	3	0	1	0	3	1
Percent	0.958	0.958	0.000	0.319	0.000	0.958	0.319

Type	CTU	BUD	P09	P11	P12	P13	P14
Count	14	38	0	4	0	0	0
Percent	4.473	12.141	0.000	1.278	0.000	0.000	0.000

Type	P15	P16	P17	P19	P20	P22	P23
Count	3	2	0	0	2	0	0
Percent	0.958	0.639	0.000	0.000	0.639	0.000	0.000

Type	PUD	I16	C09	TC3	TC4	TCU	I08
Count	13	0	9	4	20	136	0
Percent	4.153	0.000	2.875	1.278	6.390	43.450	0.000

Type	I09	I10	I11	I12	I13	I14	IUD
Count	0	1	0	3	0	8	4
Percent	0.000	0.319	0.000	0.958	0.000	2.556	1.278

Type	L10	L12	L13	L14	L15	L16	L17
Count	0	0	2	6	1	0	0
Percent	0.000	0.000	0.639	1.917	0.319	0.000	0.000

Type	L18	L19	L21	L24	L25	FUD	AQ1
Count	0	0	1	0	0	28	1
Percent	0.000	0.000	0.319	0.000	0.000	8.946	0.319

Type	UN1
Count	0
Percent	0.000

TABLE 12. Continued

Sample # 840283

Total Count 320

Type	S10	S11	S12	S15	SMU	LTU	CP2
Count	5	0	0	0	4	0	0
Percent	1.563	0.000	0.000	0.000	1.250	0.000	0.000
Type	CP4	CP5	CP6	CPT	C14	C15	C16
Count	0	0	0	0	0	5	0
Percent	0.000	0.000	0.000	0.000	0.000	1.563	0.000
Type	CTU	BUD	P09	P11	P12	P13	P14
Count	18	10	0	2	0	1	0
Percent	5.625	3.125	0.000	0.625	0.000	0.313	0.000
Type	P15	P16	P17	P19	P20	P22	P23
Count	1	2	0	0	3	0	0
Percent	0.313	0.625	0.000	0.000	0.938	0.000	0.000
Type	PUD	I16	C09	TC3	TC4	TCU	I08
Count	18	0	23	2	28	139	0
Percent	5.625	0.000	7.188	0.625	8.750	43.438	0.000
Type	I09	I10	I11	I12	I13	I14	IUD
Count	0	0	1	0	0	9	9
Percent	0.000	0.000	0.313	0.000	0.000	2.813	2.813
Type	L10	L12	L13	L14	L15	L16	L17
Count	0	0	3	0	1	0	0
Percent	0.000	0.000	0.938	0.000	0.313	0.000	0.000
Type	L18	L19	L21	L24	L25	FUD	AQ1
Count	0	0	0	0	0	36	0
Percent	0.000	0.000	0.000	0.000	0.000	11.250	0.000
Type	UN1						
Count	0						
Percent	0.000						

TABLE 12. Continued

Sample # 840285

Total Count 322

Type	S10	S11	S12	S15	SMU	LTU	CP2
Count	0	0	1	2	3	0	0
Percent	0.000	0.000	0.311	0.621	0.932	0.000	0.000
Type	CP4	CP5	CP6	CPT	C14	C15	C16
Count	2	2	0	0	0	3	0
Percent	0.621	0.621	0.000	0.000	0.000	0.932	0.000
Type	CTU	BUD	P09	P11	P12	P13	P14
Count	6	52	0	4	0	6	0
Percent	1.863	16.149	0.000	1.242	0.000	0.000	0.000
Type	P15	P16	P17	P19	P20	P22	P23
Count	4	7	0	0	0	0	0
Percent	1.242	2.174	0.000	0.000	0.000	0.000	0.000
Type	PUD	I16	C09	TC3	TC4	TCU	I08
Count	17	0	9	1	30	126	0
Percent	5.280	0.000	2.795	0.311	9.317	39.130	0.000
Type	I09	I10	I11	I12	I13	I14	IUD
Count	0	0	0	1	0	0	0
Percent	0.000	0.000	0.000	0.311	0.000	0.000	0.000
Type	L10	L12	L13	L14	L15	L16	L17
Count	0	0	2	4	6	0	0
Percent	0.000	0.000	0.621	1.242	1.863	0.000	0.000
Type	L18	L19	L21	L24	L25	FUD	AQ1
Count	0	0	0	0	0	34	0
Percent	0.000	0.000	0.000	0.000	0.000	10.559	0.000
Type	UN1						
Count	0						
Percent	0.000						

TABLE 12. Continued

Sample # 840286

Total Count 315

Type	S10	S11	S12	S15	SMU	LTU	CP2
Count	4	0	0	2	10	0	0
Percent	1.270	0.000	0.000	0.635	3.175	0.000	0.000
Type	CP4	CP5	CP6	CPT	C14	C15	C16
Count	0	0	2	0	0	0	0
Percent	0.000	0.000	0.635	0.000	0.000	0.000	0.000
Type	CTU	BUD	P09	P11	P12	P13	P14
Count	14	5	0	0	0	0	0
Percent	4.444	1.587	0.000	0.000	0.000	0.000	0.000
Type	P15	P16	P17	P19	P20	P22	P23
Count	0	0	0	0	1	0	0
Percent	0.000	0.000	0.000	0.000	0.317	0.000	0.000
Type	PUD	I16	C09	TC3	TC4	TCU	I08
Count	21	0	6	0	23	130	0
Percent	6.667	0.000	1.905	0.000	7.302	41.270	0.000
Type	I09	I10	I11	I12	I13	I14	IUD
Count	0	0	1	0	0	22	31
Percent	0.000	0.000	0.317	0.000	0.000	6.984	9.841
Type	L10	L12	L13	L14	L15	L16	L17
Count	0	0	0	0	1	0	0
Percent	0.000	0.000	0.000	0.000	0.317	0.000	0.000
Type	L18	L19	L21	L24	L25	FUD	AQ1
Count	0	0	0	0	0	42	0
Percent	0.000	0.000	0.000	0.000	0.000	13.333	0.000
Type	UN1						
Count	0						
Percent	0.000						

TABLE 12. Continued

Sample # 840287

Total Count 306

Type	S10	S11	S12	S15	SMU	LTU	CP2
Count	0	0	0	2	4	0	0
Percent	0.000	0.000	0.000	0.654	1.307	0.000	0.000
Type	CP4	CP5	CP6	CPT	C14	C15	C16
Count	0	0	0	0	0	3	0
Percent	0.000	0.000	0.000	0.000	0.000	0.980	0.000
Type	CTU	BUD	P09	P11	P12	P13	P14
Count	29	14	0	0	0	0	0
Percent	9.477	4.575	0.000	0.000	0.000	0.000	0.000
Type	P15	P16	P17	P19	P20	P22	P23
Count	0	0	0	0	5	0	0
Percent	0.000	0.000	0.000	0.000	1.634	0.000	0.000
Type	PUD	I16	C09	TC3	TC4	TCU	I08
Count	35	0	5	0	16	128	0
Percent	11.438	0.000	1.634	0.000	5.229	41.830	0.000
Type	I09	I10	I11	I12	I13	I14	IUD
Count	0	0	0	0	0	0	30
Percent	0.000	0.000	0.000	0.000	0.000	0.000	9.804
Type	L10	L12	L13	L14	L15	L16	L17
Count	0	0	0	0	0	0	0
Percent	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Type	L18	L19	L21	L24	L25	FUD	AQ1
Count	21	0	0	0	0	10	4
Percent	6.863	0.000	0.000	0.000	0.000	3.268	1.307
Type	UN1						
Count	0						
Percent	0.000						

TABLE 12. Continued

Sample # 840288

Total Count 310

Type	S10	S11	S12	S15	SMU	LTU	CP2
Count	1	0	0	2	5	1	0
Percent	0.323	0.000	0.000	0.645	1.613	0.323	0.000

Type	CP4	CP5	CP6	CPT	C14	C15	C16
Count	1	0	0	0	0	2	1
Percent	0.323	0.000	0.000	0.000	0.000	0.645	0.323

Type	CTU	BUD	P09	P11	P12	P13	P14
Count	25	29	0	2	0	0	0
Percent	8.065	9.355	0.000	0.645	0.000	0.000	0.000

Type	P15	P16	P17	P19	P20	P22	P23
Count	1	3	0	0	0	0	0
Percent	0.323	0.968	0.000	0.000	0.000	0.000	0.000

Type	PUD	I16	C09	TC3	TC4	TCU	I08
Count	25	0	2	0	29	137	0
Percent	8.065	0.000	0.645	0.000	9.355	44.194	0.000

Type	I09	I10	I11	I12	I13	I14	IUD
Count	0	0	0	0	0	2	16
Percent	0.000	0.000	0.000	0.000	0.000	0.645	5.161

Type	L10	L12	L13	L14	L15	L16	L17
Count	0	0	8	3	0	4	0
Percent	0.000	0.000	2.581	0.968	0.000	1.290	0.000

Type	L18	L19	L21	L24	L25	FUD	AQ1
Count	0	0	0	2	1	8	0
Percent	0.000	0.000	0.000	0.645	0.323	2.581	0.000

Type	UN1
Count	0
Percent	0.000

TABLE 12. Continued

Sample # 840289

Total Count 316

Type	S10	S11	S12	S15	SMU	LTU	CP2
Count	0	0	0	0	1	0	0
Percent	0.000	0.000	0.000	0.000	0.316	0.000	0.000
Type	CP4	CP5	CP6	CPT	C14	C15	C16
Count	0	0	0	0	0	5	1
Percent	0.000	0.000	0.000	0.000	0.000	1.582	0.316
Type	CTU	BUD	P09	P11	P12	P13	P14
Count	29	33	0	2	0	1	0
Percent	9.177	10.443	0.000	0.633	0.000	0.316	0.000
Type	P15	P16	P17	P19	P20	P22	P23
Count	10	9	1	0	1	0	0
Percent	3.165	2.848	0.316	0.000	0.316	0.000	0.000
Type	PUD	I16	C09	TC3	TC4	TCU	I08
Count	47	0	3	0	10	134	0
Percent	14.873	0.000	0.949	0.000	3.165	42.405	0.000
Type	I09	I10	I11	I12	I13	I14	IUD
Count	0	0	0	0	0	7	8
Percent	0.000	0.000	0.000	0.000	0.000	2.215	2.532
Type	L10	L12	L13	L14	L15	L16	L17
Count	0	0	8	0	1	0	0
Percent	0.000	0.000	2.532	0.000	0.316	0.000	0.000
Type	L18	L19	L21	L24	L25	FUD	AQ1
Count	3	0	0	0	0	2	0
Percent	0.949	0.000	0.000	0.000	0.000	0.633	0.000
Type	UN1						
Count	0						
Percent	0.000						

TABLE 12. Continued

Sample # 840444

Total Count 307

Type	S10	S11	S12	S15	SMU	LTU	CP2
Count	5	0	0	0	0	0	0
Percent	1.629	0.000	0.000	0.000	0.000	0.000	0.000

Type	CP4	CP5	CP6	CPT	C14	C15	C16
Count	0	0	0	0	0	0	0
Percent	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Type	CTU	BUD	P09	P11	P12	P13	P14
Count	15	6	0	0	0	0	0
Percent	4.886	1.954	0.000	0.000	0.000	0.000	0.000

Type	P15	P16	P17	P19	P20	P22	P23
Count	0	0	1	0	1	0	0
Percent	0.000	0.000	0.326	0.000	0.326	0.000	0.000

Type	PUD	I16	C09	TC3	TC4	TCU	I08
Count	3	2	9	1	38	129	0
Percent	0.977	0.651	2.932	0.326	12.378	42.020	0.000

Type	I09	I10	I11	I12	I13	I14	IUD
Count	0	1	1	0	0	7	14
Percent	0.000	0.326	0.326	0.000	0.000	2.280	4.560

Type	L10	L12	L13	L14	L15	L16	L17
Oount	0	1	3	10	6	0	0
Percent	0.000	0.326	0.977	3.257	1.954	0.000	0.000

Type	L18	L19	L21	L24	L25	FUD	AQ1
Count	0	0	0	1	0	53	0
Percent	0.000	0.000	0.000	0.326	0.000	17.264	0.000

Type	UN1
Count	0
Percent	0.000

TABLE 12. Continued

Sample # 840445

Total Count 317

Type	S10	S11	S12	S15	SMU	LTU	CP2
Count	1	0	0	0	8	0	1
Percent	0.315	0.000	0.000	0.000	2.524	0.000	0.315
Type	CP4	CP5	CP6	CPT	C14	C15	C16
Count	3	10	0	0	0	1	1
Percent	0.946	3.155	0.000	0.000	0.000	0.315	0.315
Type	CTU	BUD	P09	P11	P12	P13	P14
Count	12	56	0	2	0	2	2
Percent	3.785	17.666	0.000	0.631	0.000	0.631	0.631
Type	P15	P16	P17	P19	P20	P22	P23
Count	0	4	3	1	0	0	0
Percent	0.000	1.262	0.946	0.315	0.000	0.000	0.000
Type	PUD	I16	C09	TC3	TC4	TCU	I08
Count	4	0	9	4	8	72	0
Percent	1.262	0.000	2.839	1.262	2.524	22.713	0.000
Type	I09	I10	I11	I12	I13	I14	IUD
Count	0	2	1	0	0	4	6
Percent	0.000	0.631	0.315	0.000	0.000	1.262	1.893
Type	L10	L12	L13	L14	L15	L16	L17
Oount	0	0	0	0	0	0	0
Percent	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Type	L18	L19	L21	L24	L25	FUD	AQ1
Count	0	0	0	0	0	100	0
Percent	0.000	0.000	0.000	0.000	0.000	31.546	0.000
Type	UN1						
Count	0						
Percent	0.000						

TABLE 12. Continued

Sample # 840446

Total Count 315

Type	S10	S11	S12	S15	SMU	LTU	CP2
Count	3	0	0	13	10	2	0
Percent	0.952	0.000	0.000	4.127	3.175	0.635	0.000

Type	CP4	CP5	CP6	CPT	C14	C15	C16
Count	0	1	0	3	0	5	0
Percent	0.000	0.317	0.000	0.952	0.000	1.587	0.000

Type	CTU	BUD	P09	P11	P12	P13	P14
Count	43	12	3	0	0	0	0
Percent	13.651	3.810	0.952	0.000	0.000	0.000	0.000

Type	P15	P16	P17	P19	P20	P22	P23
Count	2	5	0	0	3	0	0
Percent	0.635	1.587	0.000	0.000	0.952	0.000	0.000

Type	PUD	I16	C09	TC3	TC4	TCU	I08
Count	8	0	5	0	25	100	1
Percent	2.540	0.000	1.587	0.000	7.937	31.746	0.317

Type	I09	I10	I11	I12	I13	I14	IUD
Count	0	0	3	13	0	5	19
Percent	0.000	0.000	0.952	4.127	0.000	1.587	6.032

Type	L10	L12	L13	L14	L15	L16	L17
Count	0	0	13	2	2	0	0
Percent	0.000	0.000	4.127	0.635	0.635	0.000	0.000

Type	L18	L19	L21	L24	L25	FUD	AQ1
Count	1	4	1	5	0	2	1
Percent	0.317	1.270	0.317	1.587	0.000	0.635	0.317

Type	UN1
Count	0
Percent	0.000

TABLE 12. Continued

Sample # 840447

Total Count 303

Type	S10	S11	S12	S15	SMU	LTU	CP2
Count	2	0	0	0	7	0	0
Percent	0.660	0.000	0.000	0.000	2.310	0.000	0.000
Type	CP4	CP5	CP6	CPT	C14	C15	C16
Count	0	0	0	0	0	2	2
Percent	0.000	0.000	0.000	0.000	0.000	0.660	0.660
Type	CTU	BUD	P09	P11	P12	P13	P14
Count	6	2	0	0	0	0	0
Percent	1.980	0.660	0.000	0.000	0.000	0.000	0.000
Type	P15	P16	P17	P19	P20	P22	P23
Count	0	5	0	0	0	2	0
Percent	0.000	1.650	0.000	0.000	0.000	0.660	0.000
Type	PUD	I16	C09	TC3	TC4	TCU	I08
Count	9	0	13	3	4	52	0
Percent	2.970	0.000	4.290	0.990	1.320	17.162	0.000
Type	I09	I10	I11	I12	I13	I14	IUD
Count	0	1	0	3	0	12	53
Percent	0.000	0.330	0.000	0.990	0.000	3.960	17.492
Type	L10	L12	L13	L14	L15	L16	L17
Count	0	0	1	2	0	0	0
Percent	0.000	0.000	0.330	0.660	0.000	0.000	0.000
Type	L18	L19	L21	L24	L25	FUD	AQ1
Count	0	0	0	0	0	121	0
Percent	0.000	0.000	0.000	0.000	0.000	39.934	0.000
Type	UN1						
Count	1						
Percent	0.330						

TABLE 12. Continued

Sample # 840448

Total Count 305

Type	S10	S11	S12	S15	SMU	LTU	CP2
Count	3	2	1	0	7	0	0
Percent	0.984	0.656	0.328	0.000	2.295	0.000	0.000

Type	CP4	CP5	CP6	CPT	C14	C15	C16
Count	0	0	1	0	0	0	1
Percent	0.000	0.000	0.328	0.000	0.000	0.000	0.328

Type	CTU	BUD	P09	P11	P12	P13	P14
Count	7	14	0	0	1	0	1
Percent	2.295	4.590	0.000	0.000	0.328	0.000	0.328

Type	P15	P16	P17	P19	P20	P22	P23
Count	0	2	1	0	2	0	0
Percent	0.000	0.656	0.328	0.000	0.656	0.000	0.000

Type	PUD	I16	C09	TC3	TC4	TCU	I08
Count	0	0	19	1	17	118	0
Percent	0.000	0.000	6.230	0.328	5.574	38.689	0.000

Type	I09	I10	I11	I12	I13	I14	IUD
Count	0	0	2	0	1	20	17
Percent	0.000	0.000	0.656	0.000	0.328	6.557	5.574

Type	L10	L12	L13	L14	L15	L16	L17
Count	0	0	4	2	2	0	0
Percent	0.000	0.000	1.311	0.656	0.656	0.000	0.000

Type	L18	L19	L21	L24	L25	FUD	AQ1
Count	0	0	0	0	0	59	0
Percent	0.000	0.000	0.000	0.000	0.000	19.344	0.000

Type	UN1
Count	0
Percent	0.000

TABLE 12. Continued

Sample # 840449

Total Count 298

Type	S10	S11	S12	S15	SMU	LTU	CP2
Count	2	0	1	0	8	2	0
Percent	0.671	0.000	0.336	0.000	2.685	0.671	0.000
Type	CP4	CP5	CP6	CPT	C14	C15	C16
Count	1	0	0	1	0	1	0
Percent	0.336	0.000	0.000	0.336	0.000	0.336	0.000
Type	CTU	BUD	P09	P11	P12	P13	P14
Count	3	30	0	3	0	0	0
Percent	1.007	10.067	0.000	1.007	0.000	0.000	0.000
Type	P15	P16	P17	P19	P20	P22	P23
Count	2	0	0	0	1	1	2
Percent	0.671	0.000	0.000	0.000	0.336	0.336	0.671
Type	PUD	I16	C09	TC3	TC4	TCU	I08
Count	5	2	26	2	21	90	0
Percent	1.678	0.671	8.725	0.671	7.047	30.201	0.000
Type	I09	I10	I11	I12	I13	I14	IUD
Count	0	0	4	2	2	25	23
Percent	0.000	0.000	1.342	0.671	0.671	8.389	7.718
Type	L10	L12	L13	L14	L15	L16	L17
Count	0	0	1	4	1	0	0
Percent	0.000	0.000	0.336	1.342	0.336	0.000	0.000
Type	L18	L19	L21	L24	L25	FUD	AQ1
Count	0	0	0	0	0	31	0
Percent	0.000	0.000	0.000	0.000	0.000	10.403	0.000
Type	UN1						
Count	1						
Percent	0.336						

TABLE 12. Continued

Sample # 840450

Total Count 311

Type	S10	S11	S12	S15	SMU	LTU	CP2
Count	3	0	1	0	4	3	0
Percent	0.965	0.000	0.322	0.000	1.286	0.965	0.000
Type	CP4	CP5	CP6	CPT	C14	C15	C16
Count	0	0	0	2	0	1	0
Percent	0.000	0.000	0.000	0.643	0.000	0.322	0.000
Type	CTU	BUD	P09	P11	P12	P13	P14
Count	4	42	0	1	2	0	0
Percent	1.286	13.505	0.000	0.322	0.643	0.000	0.000
Type	P15	P16	P17	P19	P20	P22	P23
Count	0	4	0	0	5	6	0
Percent	0.000	1.286	0.000	0.000	1.608	1.929	0.000
Type	PUD	I16	C09	TC3	TC4	TCU	I08
Count	15	0	30	4	19	102	0
Percent	4.823	0.000	9.646	1.286	6.109	32.797	0.000
Type	I09	I10	I11	I12	I13	I14	IUD
Count	0	2	3	0	0	12	28
Percent	0.000	0.642	0.965	0.000	0.000	3.859	9.003
Type	L10	L12	L13	L14	L15	L16	L17
Count	0	0	2	5	0	1	0
Percent	0.000	0.000	0.643	1.608	0.000	0.322	0.000
Type	L18	L19	L21	L24	L25	FUD	AQ1
Count	0	0	0	4	0	6	0
Percent	0.000	0.000	0.000	1.286	0.000	1.929	0.000
Type	UN1						
Count	0						
Percent	0.000						

TABLE 12. Continued

Sample # 840352

Total Count 312

Type	S10	S11	S12	S15	SMU	LTU	CP2
Count	2	0	0	1	4	0	0
Percent	0.641	0.000	0.000	0.321	1.282	0.000	0.000
Type	CP4	CP5	CP6	CPT	C14	C15	C16
Count	0	0	0	1	0	0	1
Percent	0.000	0.000	0.000	0.321	0.000	0.000	0.321
Type	CTU	BUD	P09	P11	P12	P13	P14
Count	23	22	0	1	0	0	0
Percent	7.372	7.051	0.000	0.321	0.000	0.000	0.000
Type	P15	P16	P17	P19	P20	P22	P23
Count	0	0	0	0	0	0	0
Percent	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Type	PUD	I16	C09	TC3	TC4	TCU	I08
Count	16	0	8	6	40	144	0
Percent	5.128	0.000	2.564	1.923	12.821	46.154	0.000
Type	I09	I10	I11	I12	I13	I14	IUD
Count	1	0	0	1	0	12	23
Percent	0.321	0.000	0.000	0.321	0.000	3.846	7.372
Type	L10	L12	L13	L14	L15	L16	L17
Count	0	0	0	2	1	0	0
Percent	0.000	0.000	0.000	0.641	0.321	0.000	0.000
Type	L18	L19	L21	L24	L25	FUD	AQ1
Count	0	0	0	1	0	2	0
Percent	0.000	0.000	0.000	0.321	0.000	0.641	0.000
Type	UN1						
Count	0						
Percent	0.000						

TABLE 12. Continued

Sample # 840253

Total Count 326

Type	S10	S11	S12	S15	SMU	LTU	CP2
Count	4	0	0	0	0	0	8
Percent	1.183	0.000	0.000	0.000	0.000	0.000	2.237

Type	CP4	CP5	CP6	CPT	C14	C15	C16
Count	2	0	0	0	1	6	0
Percent	0.600	0.000	0.000	0.000	0.300	1.780	0.000

Type	CTU	BUD	P09	P11	P12	P13	P14
Count	34	15	0	0	1	0	0
Percent	10.100	4.440	0.000	0.000	0.300	0.000	0.000

Type	P15	P16	P17	P19	P20	P22	P23
Count	2	1	0	0	3	0	0
Percent	0.600	0.300	0.000	0.000	0.890	0.000	0.000

Type	PUD	I16	C09	TC3	TC4	TCU	I08
Count	22	0	11	1	23	132	1
Percent	6.510	0.000	5.621	0.300	6.805	39.053	0.300

Type	I09	I10	I11	I12	I13	I14	IUD
Count	0	0	3	0	0	11	11
Percent	0.000	0.000	0.890	0.000	0.000	5.621	5.621

Type	L10	L12	L13	L14	L15	L16	L17
Count	0	0	0	4	11	0	0
Percent	0.000	0.000	0.000	1.183	5.621	0.000	0.000

Type	L18	L19	L21	L24	L25	FUD	AQ1
Count	0	0	0	0	0	19	0
Percent	0.000	0.000	0.000	0.000	0.000	5.621	0.000

Type	UN1
Count	0
Percent	0.000

TABLE 12. Continued

Sample # 840354

Total Count 332

Type	S10	S11	S12	S15	SMU	LTU	CP2
Count	5	0	0	0	2	0	1
Percent	1.506	0.000	0.000	0.000	0.602	0.000	0.301

Type	CP4	CP5	CP6	CPT	C14	C15	C16
Count	1	0	0	0	0	1	1
Percent	0.301	0.000	0.000	0.000	0.000	0.301	0.301

Type	CTU	BUD	P09	P11	P12	P13	P14
Count	20	8	0	0	0	0	0
Percent	6.024	2.410	0.000	0.000	0.000	0.000	0.000

Type	P15	P16	P17	P19	P20	P22	P23
Count	2	0	0	1	0	0	0
Percent	0.602	0.000	0.000	0.301	0.000	0.000	0.000

Type	PUD	I16	C09	TC3	TC4	TCU	I08
Count	11	0	20	0	16	120	0
Percent	3.313	0.000	6.024	0.000	4.819	36.145	0.000

Type	I09	I10	I11	I12	I13	I14	IUD
Count	0	0	1	4	0	19	11
Percent	0.000	0.000	0.301	1.205	0.000	5.723	3.313

Type	L10	L12	L13	L14	L15	L16	L17
Count	0	0	0	0	4	5	0
Percent	0.000	0.000	0.000	0.000	1.205	1.506	0.000

Type	L18	L19	L21	L24	L25	FUD	AQ1
Count	0	0	0	0	0	79	0
Percent	0.000	0.000	0.000	0.000	0.000	23.795	0.000

Type	UN1
Count	0
Percent	0.000

TABLE 12. Continued

Sample # 840355

Total Count 336

Type	S10	S11	S12	S15	SMU	LTU	CP2
Count	0	0	0	0	1	0	0
Percent	0.000	0.000	0.000	0.000	0.298	0.000	0.000

Type	CP4	CP5	CP6	CPT	C14	C15	C16
Count	0	3	0	0	0	3	0
Percent	0.000	0.893	0.000	0.000	0.000	0.893	0.000

Type	CTU	BUD	P09	P11	P12	P13	P14
Count	38	22	0	0	0	1	0
Percent	11.310	6.548	0.000	0.000	0.000	0.298	0.000

Type	P15	P16	P17	P19	P20	P22	P23
Count	2	3	0	0	0	0	0
Percent	0.595	0.893	0.000	0.000	0.000	0.000	0.000

Type	PUD	I16	C09	TC3	TC4	TCU	I08
Count	45	0	10	3	7	136	0
Percent	13.393	0.000	2.976	0.893	2.083	40.476	0.000

Type	I09	I10	I11	I12	I13	I14	IUD
Count	0	3	0	1	0	10	6
Percent	0.000	0.893	0.000	0.298	0.000	2.976	1.786

Type	L10	L12	L13	L14	L15	L16	L17
Count	0	0	0	7	1	0	0
Percent	0.000	0.000	0.000	2.083	1.298	0.000	0.000

Type	L18	L19	L21	L24	L25	FUD	AQ1
Count	0	0	0	1	0	33	0
Percent	0.000	0.000	0.000	0.298	0.000	9.821	0.000

Type	UN1
Count	0
Percent	0.000

TABLE 12. Continued

Sample # 840356

Total Count 316

Type	S10	S11	S12	S15	SMU	LTU	CP2
Count	0	0	0	1	1	0	0
Percent	0.000	0.000	0.000	0.316	0.316	0.000	0.000
Type	CP4	CP5	CP6	CPT	C14	C15	C16
Count	0	2	0	0	0	5	3
Percent	0.000	0.633	0.000	0.000	0.000	1.582	0.949
Type	CTU	BUD	P09	P11	P12	P13	P14
Count	63	8	0	0	0	1	0
Percent	19.937	2.532	0.000	0.000	0.000	0.316	0.000
Type	P15	P16	P17	P19	P20	P22	P23
Count	1	0	1	0	1	0	0
Percent	0.316	0.000	0.316	0.000	0.316	0.000	0.000
Type	PUD	I16	C09	TC3	TC4	TCU	I08
Count	29	0	6	2	12	139	1
Percent	9.177	0.000	1.899	0.633	3.797	43.987	0.316
Type	I09	I10	I11	I12	I13	I14	IUD
Count	0	1	1	2	0	3	13
Percent	0.000	0.316	0.316	0.633	0.000	0.949	4.114
Type	L10	L12	L13	L14	L15	L16	L17
Count	0	0	3	0	3	0	0
Percent	0.000	0.000	0.949	0.000	0.949	0.000	0.000
Type	L18	L19	L21	L24	L25	FUD	AQ1
Count	0	0	0	2	2	10	0
Percent	0.000	0.000	0.000	0.633	0.633	3.165	0.000
Type	UN1						
Count	0						
Percent	0.000						

TABLE 12. Continued

Sample # 840357

Total Count 316

Type	S10	S11	S12	S15	SMU	LTU	CP2
Count	2	0	0	0	2	0	0
Percent	0.633	0.000	0.000	0.000	0.633	0.000	0.000
Type	CP4	CP5	CP6	CPT	C14	C15	C16
Count	0	0	0	0	0	0	0
Percent	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Type	CTU	BUD	P09	P11	P12	P13	P14
Count	17	18	0	0	0	3	0
Percent	5.380	5.696	0.000	0.000	0.000	0.949	0.000
Type	P15	P16	P17	P19	P20	P22	P23
Count	1	0	2	0	0	0	0
Percent	0.316	0.000	0.633	0.000	0.000	0.000	0.000
Type	PUD	I16	C09	TC3	TC4	TCU	I08
Count	4	0	1	0	2	46	0
Percent	1.266	0.000	0.316	0.000	0.633	14.557	0.000
Type	I09	I10	I11	I12	I13	I14	IUD
Count	6	0	0	0	0	4	5
Percent	1.899	0.000	0.000	0.000	0.000	1.266	1.582
Type	L10	L12	L13	L14	L15	L16	L17
Count	0	0	1	1	0	0	0
Percent	0.000	0.000	0.316	0.316	0.000	0.000	0.000
Type	L18	L19	L21	L24	L25	FUD	AQ1
Count	0	0	0	2	0	183	0
Percent	0.000	0.000	0.000	0.633	0.000	57.911	0.000
Type	UN1						
Count	16						
Percent	5.063						

TABLE 12. Continued

Sample # 840358

Total Count 323

Type	S10	S11	S12	S15	SMU	LTU	CP2
Count	2	0	0	0	0	0	1
Percent	0.619	0.000	0.000	0.000	0.000	0.000	0.310
Type	CP4	CP5	CP6	CPT	C14	C15	C16
Count	0	0	0	0	0	0	0
Percent	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Type	CTU	BUD	P09	P11	P12	P13	P14
Count	11	12	0	3	0	0	0
Percent	3.406	3.715	0.000	0.929	0.000	0.000	0.000
Type	P15	P16	P17	P19	P20	P22	P23
Count	1	0	0	0	0	0	0
Percent	0.310	0.000	0.000	0.000	0.000	0.000	0.000
Type	PUD	I16	C09	TC3	TC4	TCU	I08
Count	12	0	9	0	1	46	1
Percent	3.715	0.000	2.786	0.000	0.310	14.241	0.310
Type	I09	I10	I11	I12	I13	I14	IUD
Count	3	0	0	0	0	2	9
Percent	0.929	0.000	0.000	0.000	0.000	0.619	2.786
Type	L10	L12	L13	L14	L15	L16	L17
Count	0	0	0	3	0	0	0
Percent	0.000	0.000	0.000	0.929	0.000	0.000	0.000
Type	L18	L19	L21	L24	L25	FUD	AQ1
Count	0	0	0	0	0	207	0
Percent	0.000	0.000	0.000	0.000	0.000	64.087	0.000
Type	UN1						
Count	0						
Percent	0.000						

TABLE 12. Continued

Sample # 840359

Total Count 307

Type	S10	S11	S12	S15	SMU	LTU	CP2
Count	0	0	0	0	2	1	0
Percent	0.000	0.000	0.000	0.000	0.651	0.326	0.000
Type	CP4	CP5	CP6	CPT	C14	C15	C16
Count	0	0	0	2	0	0	6
Percent	0.000	0.000	0.000	0.651	0.000	0.000	1.954
Type	CTU	BUD	P09	P11	P12	P13	P14
Count	5	36	0	0	0	0	0
Percent	1.629	11.726	0.000	0.000	0.000	0.000	0.000
Type	P15	P16	P17	P19	P20	P22	P23
Count	0	2	0	0	0	0	0
Percent	0.000	0.651	0.000	0.000	0.000	0.000	0.000
Type	PUD	I16	C09	TC3	TC4	TCU	I08
Count	3	0	6	0	3	122	0
Percent	0.977	0.000	1.954	0.000	0.977	39.739	0.000
Type	I09	I10	I11	I12	I13	I14	IUD
Count	0	0	2	0	1	13	9
Percent	0.000	0.000	0.651	0.000	0.326	4.235	2.932
Type	L10	L12	L13	L14	L15	L16	L17
Count	0	0	1	3	0	0	0
Percent	0.000	0.000	0.326	0.977	0.000	0.000	0.000
Type	L18	L19	L21	L24	L25	FUD	AQ1
Count	0	0	0	0	0	90	0
Percent	0.000	0.000	0.000	0.000	0.000	29.316	0.000
Type	UN1						
Count	0						
Percent	0.000						

TABLE 12. Continued

Sample # 840360

Total Count 337

Type	S10	S11	S12	S15	SMU	LTU	CP2
Count	2	0	0	0	0	0	1
Percent	0.593	0.000	0.000	0.000	0.000	0.000	0.297
Type	CP4	CP5	CP6	CPT	C14	C15	C16
Count	4	0	0	0	0	2	1
Percent	1.187	0.000	0.000	0.000	0.000	0.593	0.297
Type	CTU	BUD	P09	P11	P12	P13	P14
Count	16	46	0	0	0	0	1
Percent	4.748	13.650	0.000	0.000	0.000	0.000	0.297
Type	P15	P16	P17	P19	P20	P22	P23
Count	0	2	0	0	0	0	0
Percent	0.000	0.593	0.000	0.000	0.000	0.000	0.000
Type	PUD	I16	C09	TC3	TC4	TCU	I08
Count	3	0	9	2	7	116	0
Percent	0.890	0.000	2.671	0.593	2.077	34.421	0.000
Type	I09	I10	I11	I12	I13	I14	IUD
Count	0	0	0	8	0	16	11
Percent	0.000	0.000	0.000	2.374	0.000	4.748	3.264
Type	L10	L12	L13	L14	L15	L16	L17
Count	0	6	1	1	1	0	0
Percent	0.000	1.780	0.297	0.297	0.297	0.000	0.000
Type	L18	L19	L21	L24	L25	FUD	AQ1
Count	0	0	0	0	0	81	0
Percent	0.000	0.000	0.000	0.000	0.000	24.036	0.000
Type	UN1						
Count	0						
Percent	0.000						

TABLE 12. Continued

Sample # 840361

Total Count 314

Type	S10	S11	S12	S15	SMU	LTU	CP2
Count	4	0	0	0	1	0	0
Percent	1.274	0.000	0.000	0.000	0.318	0.000	0.000
Type	CP4	CP5	CP6	CPT	C14	C15	C16
Count	1	0	0	1	0	0	0
Percent	0.318	0.000	0.000	0.318	0.000	0.000	0.000
Type	CTU	BUD	P09	P11	P12	P13	P14
Count	6	31	0	0	0	0	1
Percent	1.911	9.873	0.000	0.000	0.000	0.000	0.318
Type	P15	P16	P17	P19	P20	P22	P23
Count	1	1	0	0	0	0	0
Percent	0.318	0.318	0.000	0.000	0.000	0.000	0.000
Type	PUD	I16	C09	TC3	TC4	TCU	I08
Count	7	0	8	2	4	114	0
Percent	2.229	0.000	2.548	0.637	1.911	36.306	0.000
Type	I09	I10	I11	I12	I13	I14	IUD
Count	0	0	0	2	2	6	10
Percent	0.000	0.000	0.000	0.637	0.637	1.911	3.185
Type	L10	L12	L13	L14	L15	L16	L17
Count	0	2	2	6	8	1	0
Percent	0.000	0.637	0.637	1.911	2.548	0.318	0.000
Type	L18	L19	L21	L24	L25	FUD	AQ1
Count	0	0	0	0	0	99	0
Percent	0.000	0.000	0.000	0.000	0.000	31.529	0.000
Type	UN1						
Count	0						
Percent	0.000						

TABLE 12. Continued

Sample # 840362

Total Count 310

Type	S10	S11	S12	S15	SMU	LTU	CP2
Count	0	0	0	1	3	0	0
Percent	0.000	0.000	0.000	0.323	0.968	0.000	0.000
Type	CP4	CP5	CP6	CPT	C14	C15	C16
Count	0	0	0	1	0	5	0
Percent	0.000	0.000	0.000	0.323	0.000	1.613	0.000
Type	CTU	BUD	P09	P11	P12	P13	P14
Count	35	42	0	3	0	0	0
Percent	11.290	13.548	0.000	0.968	0.000	0.000	0.000
Type	P15	P16	P17	P19	P20	P22	P23
Count	5	7	0	0	1	0	0
Percent	1.613	2.258	0.000	0.000	0.323	0.000	0.000
Type	PUD	I16	C09	TC3	TC4	TCU	I08
Count	11	1	13	1	11	130	0
Percent	3.548	0.323	4.194	0.323	3.548	41.935	0.000
Type	I09	I10	I11	I12	I13	I14	IUD
Count	0	1	0	2	0	6	3
Percent	0.000	0.323	0.000	0.645	0.000	1.935	0.968
Type	L10	L12	L13	L14	L15	L16	L17
Count	0	0	4	2	6	0	0
Percent	0.000	0.000	1.290	0.645	1.935	0.000	0.000
Type	L18	L19	L21	L24	L25	FUD	AQ1
Count	0	1	2	0	0	13	0
Percent	0.000	0.323	0.645	0.000	0.000	4.194	0.000
Type	UN1						
Count	0						
Percent	0.000						

TABLE 12. Continued

Sample # 840363

Total Count 319

Type	S10	S11	S12	S15	SMU	LTU	CP2
Count	1	0	0	1	0	0	0
Percent	0.313	0.000	0.000	0.313	0.000	0.000	0.000
Type	CP4	CP5	CP6	CPT	C14	C15	C16
Count	0	0	0	0	0	2	1
Percent	0.000	0.000	0.000	0.000	0.000	0.627	0.313
Type	CTU	BUD	P09	P11	P12	P13	P14
Count	18	20	0	0	0	0	0
Percent	5.643	6.270	0.000	0.000	0.000	0.000	0.000
Type	P15	P16	P17	P19	P20	P22	P23
Count	1	4	0	0	0	0	0
Percent	0.313	1.254	0.000	0.000	0.000	0.000	0.000
Type	PUD	I16	C09	TC3	TC4	TCU	I08
Count	9	0	4	0	12	139	0
Percent	2.821	0.000	1.254	0.000	3.762	43.574	0.000
Type	I09	I10	I11	I12	I13	I14	IUD
Count	0	0	1	1	0	3	16
Percent	0.000	0.000	0.313	0.313	0.000	0.940	5.016
Type	L10	L12	L13	L14	L15	L16	L17
Count	0	0	23	3	0	0	0
Percent	0.000	0.000	7.210	0.940	0.000	0.000	0.000
Type	L18	L19	L21	L24	L25	FUD	AQ1
Count	0	0	0	1	0	59	0
Percent	0.000	0.000	0.000	0.313	0.000	18.495	0.000
Type	UN1						
Count	0						
Percent	0.000						

TABLE 12. Continued

Sample # 840364

Total Count 325

Type	S10	S11	S12	S15	SMU	LTU	CP2
Count	2	0	0	7	0	0	0
Percent	0.615	0.000	0.000	2.154	0.000	0.000	0.000

Type	CP4	CP5	CP6	CPT	C14	C15	C16
Count	0	0	0	0	0	2	0
Percent	0.000	0.000	0.000	0.000	0.000	0.615	0.000

Type	CTU	BUD	P09	P11	P12	P13	P14
Count	13	0	0	0	0	0	0
Percent	4.000	0.000	0.000	0.000	0.000	0.000	0.000

Type	P15	P16	P17	P19	P20	P22	P23
Count	0	5	0	0	0	0	0
Percent	0.000	1.538	0.000	0.000	0.000	0.000	0.000

Type	PUD	I16	C09	TC3	TC4	TCU	I08
Count	7	0	0	0	14	53	28
Percent	2.154	0.000	0.000	0.000	4.308	16.308	8.615

Type	I09	I10	I11	I12	I13	I14	IUD
Count	0	0	1	0	0	2	13
Percent	0.000	0.000	0.308	0.000	0.000	0.615	4.000

Type	L10	L12	L13	L14	L15	L16	L17
Count	0	0	98	2	1	0	0
Percent	0.000	0.000	30.154	0.615	0.308	0.000	0.000

Type	L18	L19	L21	L24	L25	FUD	AQ1
Count	0	0	2	12	5	58	0
Percent	0.000	0.000	0.615	3.962	1.518	17.846	0.000

Type	UN1
Count	0
Percent	0.000

TABLE 12. Continued

Sample # 840365

Total Count 320

Type	S10	S11	S12	S15	SMU	LTU	CP2
Count	2	1	0	0	9	4	0
Percent	0.625	0.313	0.000	0.000	2.813	1.250	0.000
Type	CP4	CP5	CP6	CPT	C14	C15	C16
Count	0	0	0	0	0	0	2
Percent	0.000	0.000	0.000	0.000	0.000	0.000	0.625
Type	CTU	BUD	P09	P11	P12	P13	P14
Count	20	7	0	1	0	1	0
Percent	6.250	2.188	0.000	0.313	0.000	0.313	0.000
Type	P15	P16	P17	P19	P20	P22	P23
Count	1	1	0	0	0	0	0
Percent	0.313	0.313	0.000	0.000	0.000	0.000	0.000
Type	PUD	I16	C09	TC3	TC4	TCU	I08
Count	14	0	14	1	38	139	0
Percent	4.375	0.000	4.375	0.313	11.875	43.438	0.000
Type	I09	I10	I11	I12	I13	I14	IUD
Count	0	0	2	0	0	14	28
Percent	0.000	0.000	0.625	0.000	0.000	4.375	8.750
Type	L10	L12	L13	L14	L15	L16	L17
Count	0	0	3	0	2	0	0
Percent	0.000	0.000	0.938	0.000	0.625	0.000	0.000
Type	L18	L19	L21	L24	L25	FUD	AQ1
Count	0	0	0	3	1	11	1
Percent	0.000	0.000	0.000	0.938	0.313	3.438	0.313
Type	UN1						
Count	0						
Percent	0.000						

TABLE 12. Continued

Sample # 840366

Total Count 311

Type	S10	S11	S12	S15	SMU	LTU	CP2
Count	0	1	0	0	1	2	0
Percent	0.000	0.322	0.000	0.000	0.322	0.643	0.000

Type	CP4	CP5	CP6	CPT	C14	C15	C16
Count	2	0	0	1	0	4	0
Percent	0.643	0.000	0.000	0.322	0.000	1.286	0.000

Type	CTU	BUD	P09	P11	P12	P13	P14
Count	19	6	0	2	0	0	0
Percent	6.109	1.929	0.000	0.643	0.000	0.000	0.000

Type	P15	P16	P17	P19	P20	P22	P23
Count	2	2	0	0	2	0	0
Percent	0.643	0.643	0.000	0.000	0.643	0.000	0.000

Type	PUD	I16	C09	TC3	TC4	TCU	I08
Count	14	0	20	2	27	152	0
Percent	4.502	0.000	6.431	0.643	8.682	48.875	0.000

Type	I09	I10	I11	I12	I13	I14	IUD
Count	0	0	0	7	1	11	9
Percent	0.000	0.000	0.000	2.251	0/322	3.537	2.894

Type	L10	L12	L13	L14	L15	L16	L17
Count	0	0	11	0	2	3	0
Percent	0.000	0.000	3.537	0.000	0.643	0.965	0.000

Type	L18	L19	L21	L24	L25	FUD	AQ1
Count	0	0	0	0	0	5	3
Percent	0.000	0.000	0.000	0.000	0.000	1.608	0.965

Type	UN1
Count	0
Percent	0.000

TABLE 12. Continued

Sample # 840367

Total Count 319

Type	S10	S11	S12	S15	SMU	LTU	CP2
Count	2	0	0	0	3	0	0
Percent	0.627	0.000	0.000	0.000	0.940	0.000	0.000

Type	CP4	CP5	CP6	CPT	C14	C15	C16
Count	0	0	0	0	0	1	0
Percent	0.000	0.000	0.000	0.000	0.000	0.313	0.000

Type	CTU	BUD	P09	P11	P12	P13	P14
Count	11	27	0	0	0	0	0
Percent	3.448	8.464	0.000	0.000	0.000	0.000	0.000

Type	P15	P16	P17	P19	P20	P22	P23
Count	0	3	1	0	0	0	0
Percent	0.000	0.940	0.313	0.000	0.000	0.000	0.000

Type	PUD	I16	C09	TC3	TC4	TCU	I08
Count	7	0	7	1	21	133	0
Percent	2.194	0.000	2.194	0.313	6.583	41.693	0.000

Type	I09	I10	I11	I12	I13	I14	IUD
Count	0	0	1	1	0	9	4
Percent	0.000	0.000	0.313	0.313	0.000	2.821	1.254

Type	L10	L12	L13	L14	L15	L16	L17
Count	0	0	18	1	0	1	0
Percent	0.000	0.000	5.643	0.313	0.000	0.313	0.000

Type	L18	L19	L21	L24	L25	FUD	AQ1
Count	0	0	0	0	0	66	1
Percent	0.000	0.000	0.000	0.000	0.000	20.960	0.313

Type	UN1
Count	0
Percent	0.000

TABLE 12. Continued

Sample # 840368

Total Count 319

Type	S10	S11	S12	S15	SMU	LTU	CP2
Count	0	0	0	1	2	0	0
Percent	0.000	0.000	0.000	0.313	0.627	0.000	0.000
Type	CP4	CP5	CP6	CPT	C14	C15	C16
Count	0	0	0	0	0	6	2
Percent	0.000	0.000	0.000	0.000	0.000	1.881	0.627
Type	CTU	BUD	P09	P11	P12	P13	P14
Count	62	17	0	0	1	1	0
Percent	19.436	5.329	0.000	0.000	0.313	0.313	0.000
Type	P15	P16	P17	P19	P20	P22	P23
Count	0	2	2	0	1	1	2
Percent	0.000	0.627	0.627	0.000	0.313	0.313	0.627
Type	PUD	I16	C09	TC3	TC4	TCU	I08
Count	30	0	4	2	18	113	0
Percent	9.404	0.000	1.254	0.627	5.643	35.423	0.000
Type	I09	I10	I11	I12	I13	I14	IUD
Count	0	0	2	5	3	0	11
Percent	0.000	0.000	0.627	1.567	0.940	0.000	3.448
Type	L10	L12	L13	L14	L15	L16	L17
Count	0	0	4	0	0	0	0
Percent	0.000	0.000	1.254	0.000	0.000	0.000	0.000
Type	L18	L19	L21	L24	L25	FUD	AQ1
Count	0	0	0	0	0	27	0
Percent	0.000	0.000	0.000	0.000	0.000	8.464	0.000
Type	UN1						
Count	0						
Percent	0.000						

TABLE 12. Continued

Sample # 840369

Total Count 317

Type	S10	S11	S12	S15	SMU	LTU	CP2
Count	0	0	0	2	0	0	0
Percent	0.000	0.000	0.000	0.631	0.000	0.000	0.000

Type	CP4	CP5	CP6	CPT	C14	C15	C16
Count	0	0	0	0	1	1	3
Percent	0.000	0.000	0.000	0.000	0.315	0.315	0.946

Type	CTU	BUD	P09	P11	P12	P13	P14
Count	32	12	0	2	1	1	0
Percent	10.095	3.785	0.000	0.631	0.315	0.315	0.000

Type	P15	P16	P17	P19	P20	P22	P23
Count	0	0	0	0	40	0	0
Percent	0.000	0.000	0.000	0.000	12.618	0.000	0.000

Type	PUD	I16	C09	TC3	TC4	TCU	I08
Count	62	0	4	0	28	100	0
Percent	19.558	0.000	1.262	0.000	8.833	31.546	0.000

Type	I09	I10	I11	I12	I13	I14	IUD
Count	0	0	0	1	0	6	8
Percent	0.000	0.000	0.000	0.315	0.000	1.893	2.524

Type	L10	L12	L13	L14	L15	L16	L17
Count	0	0	7	1	0	0	0
Percent	0.000	0.000	2.208	0.315	0.000	0.000	0.000

Type	L18	L19	L21	L24	L25	FUD	AQ1
Count	0	0	0	1	0	4	0
Percent	0.000	0.000	0.000	0.315	0.000	1.262	0.000

Type	UN1
Count	0
Percent	0.000

APPENDIX D

RESULTS OF PEARSON PRODUCT-MOMENT CORRELATIONS OF PALYNOMORPH COUNTS WITH X-RAY FLUORESCENCE MAJOR OXIDES AND MINOR ELEMENTS, AND PROXIMATE-ULTIMATE ANALYSIS RESULTS

PEARSON PRODUCT-MOMENT CORRELATION RESULTS

The correlation results presented here were derived by using the Statistical Analysis System correlation procedure (Sall and Delong, 1982, p. 501-508). This procedure computes the correlation coefficients (Pearson product-moment and weighted product-moment) between variables.

The top value given for each variable represents the true Pearson product-moment correlation. This is a measure of the variables' predictive abilities for one another as well as their tendancies to fall on or near a line of fit. If the variables can be expressed exactly as linear functions of one another, then the correlation value is 1 or -1 (1 indicates a direct correlation, -1 indicates an inverse correlation). A value of 0 for this correlation means that the variables are completely independent of one another.

The bottom value given for each variable represent probability values for the Pearson correlation. This value represents the probability that the correlation is not significant. Only correlations with probability values of less than 0.1 (0.0 represents the best probability that the correlation is significant) are given for each variable.

TABLE 13. PALYNOMORPHS CORRELATED WITH PROXIMATE AND ULTIMATE ANALYSIS DATA

VARIABLE	TYPES							
	L15	TC3	UN1	I10				
Volatile	0.44	-0.44	-0.41	0.39				
Matter	0.060	0.062	0.078	0.095				
	P15	PUD	C15	CTU	L21	L18	I11	P16
Fixed	-0.58	-0.56	-0.52	-0.48	-0.47	-0.43	-0.43	-0.40
C%	0.009	0.013	0.023	0.036	0.042	0.064	0.67	0.090
	P15	CTU	PUD	L18	C15	C16	P11	
Ash %	0.69	0.65	0.60	0.54	0.51	0.43	-0.39	
	0.001	0.003	0.007	0.018	0.026	0.067	0.097	
	P13	TC4	IUD	P11	PUD	P15		
H %	-0.53	-0.50	-0.47	-0.46	-0.44	-0.40		
	0.020	0.030	0.045	0.045	0.056	0.095		
	TC4	C15	P11	PUD	P15	P13	FUD	TCU
C %	-0.64	-0.60	-0.59	-0.57	-0.48	-0.46	-0.45	0.43
	0.0032	0.0068	0.0075	0.010	0.037	0.047	0.051	0.063
	SMU	I09	I08					
N %	-0.66	0.49	0.45					
	0.0023	0.035	0.051					
	SMU	TC3	I10	CP5	IUD			
S %	0.69	0.69	0.62	0.59	0.40			
	0.0010	0.0010	0.0043	0.008	0.090			

TABLE 13. Continued PALYNOMORPHS CORRELATED WITH PROXIMATE AND ULTIMATE ANALYSIS DATA

VARIABLE	TYPES					
	TC4	TCU	FUD	PUD	P13	P11
O %	0.71	0.50	-0.49	0.46	0.44	0.43
	0.0006	0.031	0.034	0.050	0.060	0.063
	TC4	P20	IUD			
BTU	-0.50	-0.42	0.40			
	0.028	0.076	0.094			
	P11	TC4	PUD	C15	P14	P17
CALO	-0.50	-0.49	-0.46	-0.45	0.45	0.39
	0.028	0.035	0.047	0.052	0.055	0.095

TABLE 14. CORRELATED WITH X-RAY FLUORESCENCE

XRF VARIABLE	TYPES			
	BUD	TC4	I10	S10
Al	-0.75	0.71	-0.65	0.54
	0.005	0.0090	0.023	0.068
	I10	IUD	L14	
Si	-0.83	0.63	-0.57	
	0.0009	0.028	0.051	
	CP2	L15	L14	
S	0.71	0.64	0.53	
	0.0093	0.025	0.076	
	BUD	TC3	S10	TC4
K	-0.74	-0.60	0.55	0.52
	0.006	0.037	0.066	0.083
	BUD	TC3	TC2	L24
Ca	0.83	0.59	0.55	-0.53
	0.0008	0.046	0.062	0.074
	L16	TCU	CPT	
Ti	-0.71	-0.55	0.55	
	0.0091	0.062	0.064	
	P12	SMU	P20	
Fe	0.73	0.70	0.55	
	0.0074	0.001	0.064	

TABLE 14. Continued CORRELATED WITH X-RAY FLUORESCENCE

XRF VARIABLE	TYPES				
	CP5	BUD	I10	CP4	
Cl	0.73	-0.56	0.56	-0.55	
	0.0075	0.060	0.061	0.067	
	C14	P12	L16	TCU	P20
Cr	0.63	0.63	-0.62	-0.57	0.54
	0.028	0.028	0.030	0.053	0.070
	CP6	SMU	L16		
Mn	-0.60	-0.56	-0.53		
	0.041	0.059	0.077		
	TC1	L12	L15	P17	
Ni	0.62	0.62	0.54	0.51	
	0.031	0.031	0.068	0.089	
	I09	TC3	TC4		
Cu	0.94	0.65	0.53		
	0.001	0.021	0.075		
	SMU	CP2	AQ1		
Zn	-0.65	0.52	-0.52		
	0.021	0.083	0.085		
	L15	P12	C14	I11	
As	0.83	0.67	0.67	0.52	
	0.0009	0.0016	0.016	0.084	

TABLE 14. Continued CORRELATED WITH X-RAY FLUORESCENCE

XRF VARIABLE	TYPES				
	CP6	IUD	TC3	I10	
Rb	0.77	0.63	-0.63	-0.58	
	0.0035	0.027	0.027	0.048	
	I10	TC4	BUD		
Sr	0.74	-0.70	0.60		
	0.065	0.011	0.038		
	CP6	CP5	I10	L24	P15
Y	0.69	-0.65	-0.60	-0.55	-0.51
	0.014	0.022	0.038	0.065	0.087
	L24	STU	AQ1	CP4	CP2
Zr	-0.76	-0.55	-0.54	0.53	0.51
	0.0041	0.066	0.070	0.074	0.089
	CP6	CP5			
Ba	0.60	-0.56			
	0.039	0.059			
	CP5				
SiO_2	0.60				
	0.040				
	I10	CP5	TC4		
Al_2O_3	-0.85	-0.73	0.61		
	0.004	0.0072	0.036		

TABLE 14. Continued CORRELATED WITH X-RAY FLUORESCENCE

XRF VARIABLE	TYPES					
	SMU	IUD	STU	AQ1	L24	L14
Fe_2O_3	-0.86	-0.73	-0.65	-0.63	-0.61	0.58
	0.0003	0.0072	0.023	0.023	0.036	0.047
	L16	CP5	I10			
TiO_2	-0.65	0.56	0.55			
	0.023	0.060	0.065			
	L10	L17	CP4	P16		
P_2O_5	1.0	1.0	0.79	0.56		
	0.00	0.00	0.0024	0.060		
	BUD	TC3	I10	TC2		
CaO	0.79	0.59	0.56	0.55		
	0.0021	0.044	0.057	0.067		
	L24	BUD	SMU			
MgO	-0.63	0.59	-0.58			
	0.029	0.043	0.049			
	SMU	IUD	STU	I10	CP5	
Na_2O	-0.71	-0.68	-0.60	0.55	0.52	
	0.01	0.014	0.040	0.062	0.08	
	BUD	TC2				
K_2O	-0.66	-0.55				
	0.021	0.063				

TABLE 14. Continued CORRELATED WITH X-RAY FLUORESCENCE

XRF VARIABLE	TYPES	
	I10	L14
SO_3	0.59	0.56
	0.042	0.060

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