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TERTIARY LIGNITES OF KEMPER AND NORTHERN LAUDERDALE COUNTIES, MISSISSIPPI

by

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Mississippi Lignites and Solid Organic
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Principal Investigator:
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University of Southern Mississippi
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Department of Geology

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ABSTRACT

Samples of lignite from thin, tabular seams ranging in thickness from a few centimeters to almost three meters in thickness in Kemper and Lauderdale counties, Mississippi were studied by proximate, petrographic, mineralogical, and grain size analyses. Proximate analysis of the samples indicates high moisture (30%), ash (63%), and volatile matter (21%), and low fixed carbon (12%) values. Grain size and mineralogical analyses indicate a predominance of sand-sized quartz in the lignite.

Petrographic analysis indicates humodetrinite (37%) and gelinite (27%) are the major organic constituent particles. The inertinite macerels (19%) (fusinite and semifusinite) are unusually high in these low-grade coal seams. The cellular macerals, textinite and ulminite, compose only 11%, and corpohuminite and exinite compose 5% of the lignite samples studied.

The values from these analyses seem to indicate that the lignite was deposited in a deltaic environment influenced by fluvial and marine processes. The paleo-environment was dominated by herbaceous plants and wood from angiosperms, and lacked significant amounts of conifers in the depositional area.

INTRODUCTION

Tertiary lignites of the Gulf Coast states may be described as porous, low rank coals, which are generally soft, friable, and brown to black in color. These lignites are an intermediate phase in the coalification process, whose characteristics are poorly understood. According to the American Association for Testing and Materials (ASTM) classification (Table 1), lignite has a heating value of less than 8,300 Btu's per pound, compared with 10,000 to 14,000 Btu's for bituminous coals (ASTM, 1976).

Commercially minable deposits of lignite comprise more than 25 percent of the coal resources of the United States, and the total reserves of Mississippi and Louisiana (Gutzler, 1979). Mississippi lignite deposits occur in many counties in exposed and subsurface seams. The Wilcox and Claiborne Groups of Mississippi contain the most extensive deposits of lignite. According to Cleaves (1980), 90 percent of the minable lignite in the state is associated with the Wilcox Group (Early Eocene) of East Central Mississippi. Wilcox seams are generally characterized as tabular, discontinuous, and irregularly shaped deposits, overlain and interbedded with unconsolidated sands, silts, and clays. These low-grade coals have high moisture (40-55%) and volatile matter contents (25-45%), and often exhibit a high ash level (20%) due to fluvial influences. Williamson (1976) concluded that a majority of Mississippi's lignite had Btu values ranging from 7,000 to 11,000 Btu's per pound;

however, thirty of the lignite samples tested in his investigation resulted in calorific values below the ASTM standard.

Lignite samples from exposed and cored seams of the early Eocene Wilcox Group of Kemper County and the late Paleocene Midway Group in northern Lauderdale County, Mississippi, were described and analyzed for this thesis. These lignite seams, some of which have been previously described, are listed in Table 2.

A proximate and petrographic analysis was performed on each sample to determine its rank and individual constituent particles, and its content of moisture, volatile matter, fixed carbon, and ash. Mineralogical and grain size analyses were performed to enhance existing and resulting data on the quality and paleoenvironment of Wilcox Group lignite. The data produced were analyzed by univariate statistical analysis using the University of Southern Mississippi's Honeywell DPS-8 computer to determine trends, correlations, or relationships in the data.

TABLE 1

CLASSIFICATION OF COALS BY RANK

[Adapted from American Society for Testing and Materials, Designation D388-66]

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

Modified from American Society for Testing and Materials (1976).

TABLE 2

LIST OF EXPOSURES EXAMINED IN THIS STUDY

K-1	NE¼, Sec. 32-T9N-R16E. 0.7 mile north of Lauderdale-Kemper County Line on Highway 39 North.	Middle Nanafalia Fm.	0.61 meters	Williamson, 1976	Ostrea thirsea beds overlying lignite seam. Lignite is dark brown and shaley.
K-2	SW¼, Sec. 20-T9N-R16E	Middle Nanafalia Fm.	0.37 meters	This study	Seam only partial exposed in a drainage ditch on the south-bound lane. Highly saturated with water.
K-3	Sec. 5-T9N-R16E	Middle Nanafalia Fm.	0.15 meters	This study	Top of seam only is exposed as a result of road construction. Seam covered in drainage ditch.
K-4	SW¼, Sec 21-T11N-R16E Approximately 300 meters west of south-bound lane of Highway 39.	Middle Nanfalia Fm.	1.98 meters	This study	Seam is located is a steep-sided stream with a high gradient. Lignite is very black and soft. Highly saturated with water.
K-5	NW¼, Sec. 33-T11N-R15E	Upper Nanafalia Fm.	1.67 meters	Williamson, 1976	Brown to black lignite with blocky partings and gypsum crystals growing in cleats.
K-7	NE¼, Sec 31-T9N-R18E 0.4 of a mile east of Highway 45 North	Lower Nanafalia FM	0.25 meters	Williamson, 1976	Poor quality lignite and car-bonaceous clays. Upper portion is very argillaceous.
K-8	NE¼, SEC 31-T9N-R18E 0.2 of a mile east of Highway 45 North.	Lower Nanafalia Fm.	0.20 meters	Williamson, 1976	Lignite is black and very fri-able.
K-9	NW¼, Sec 32-T9N-R18E	Lower Nanafalia Fm.	2.7 meters	Williamson, 1976	Poor quality lignite. Located in residential area, and exposed by construction on northern embankment. High clay content.
K-10	NE¼, Sec 32-T9N-R18E	Lower Nanafalia Fm.	2.53 meters	This study	Shaley lignite grading downward into clayey lignite and carbonaceous clay with red clay laminations.
K-11	NE¼, Sec 31-T9N-R18E	Lower Nanafalia Fm.	.61 meters	Williamson, 1976	Same as K-10.
K-12	SW¼,NE¼, Sec 4-T9N-R17E	Middle Nanafalia Fm.	0.43 meters	Stewart, 1971	Black, clayey lignite. Located in the embankment immediately above the ditch.
K-13	NE¼, Sec 27-T11N-R16E	Lower Nanafalia Fm.	2.23 meters	This study	Light to medium brown carbona-ceaus clay with interbedded layers of tan sand.
L-14	NE¼, Sec 5-T8N-R18E	Naheola Fm. Mid-way Group	2.44 meters	This study	Dark, clayey, lignite located on south embankment one-fourth of a mile east of Illinois Central Railroad line.

PURPOSE OF INVESTIGATION

At this time, there is only a limited amount of information on lignite deposits in the Gulf Coast area, and it is general and unspecific in nature. The investigation of the lignite deposits of Kemper County, Mississippi (Figure 1), was chosen because of the potentially large quantities of commercially minable lignite which exist there. Williams (1976) reported that Kemper County was an area along the Wilcox outcrop which may contain commercially exploitable lignite resources.

Kemper County was also chosen because it represents a relatively unstudied tract of lignite exposures. A lignite exposure in northern Lauderdale County was also sampled and studied, because of its similar lignite characteristics and close proximity to Kemper County lignite exposures. Utilization of the state's alternative energy sources may become essential as conventional fuels dwindle, and it is important that data on lignite deposits be made available for future analysis.

The objectives of the study of Kemper County lignite were to:

(1) Determine and document the location of lignite deposits.

(2) Determine by proximate analysis the moisture, volatile matter, fixed carbon, and ash content of

the lignite in Kemper County.

(3) Determine by petrographic analysis the macerals which compose the lignite and to measure the reflectance of important selected macerals.

(4) Determine by X-ray diffraction the major clay minerals which are present in the lignite.

(5) Determine by the pipette method the grain-size distribution of the inorganic fraction of the lignite.

(6) Determine by statistical analysis the associations and interrelationships of the laboratory data produced.

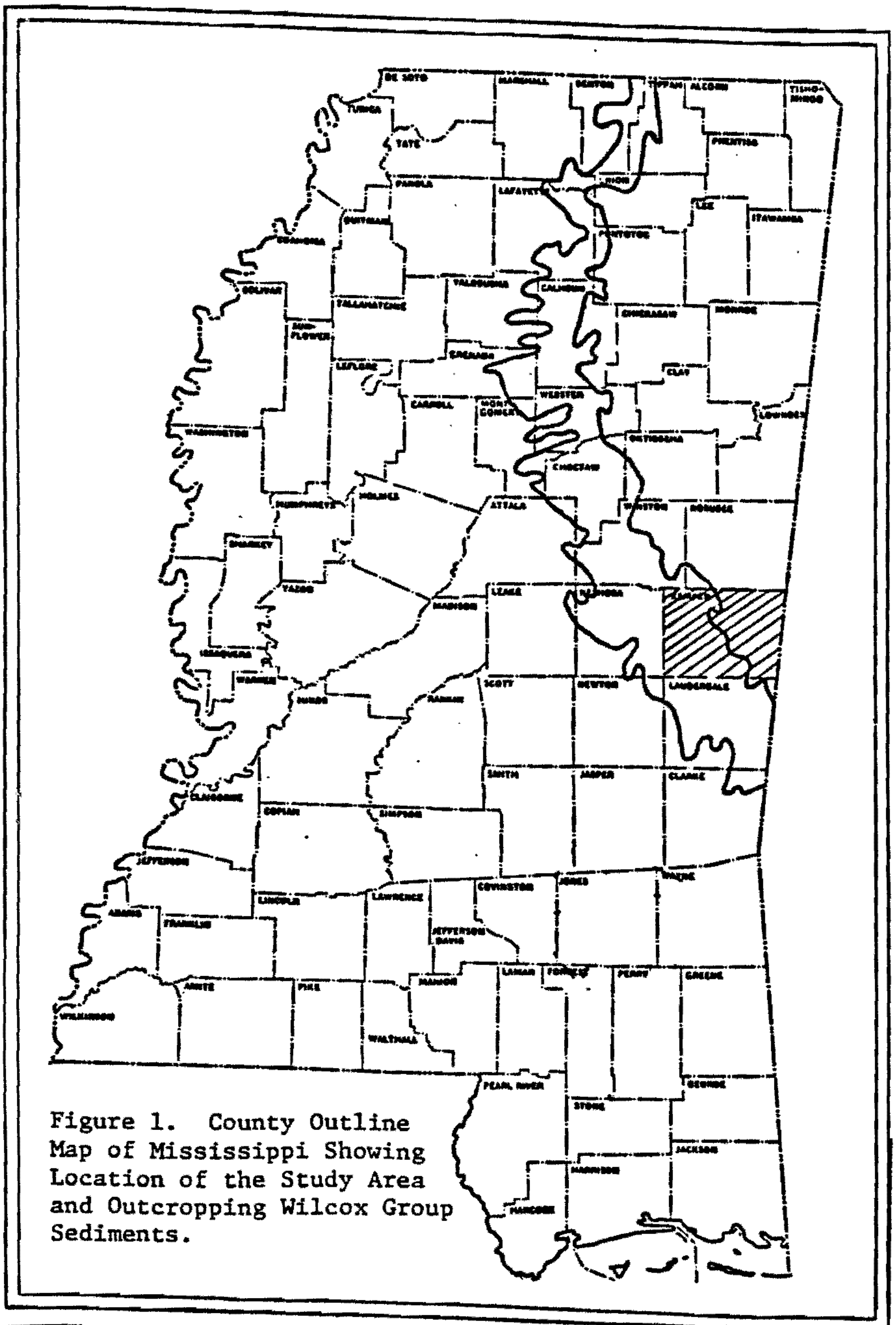


Figure 1. County Outline Map of Mississippi Showing Location of the Study Area and Outcropping Wilcox Group Sediments.

Wilcox Group Outcrop Belt

PREVIOUS INVESTIGATIONS

The occurrence of lignite in Mississippi was first documented by Millington (1852), and later by Wailes (1854). These two studies simply noted the presence of "brown coal" deposits, but did not attempt to analyze them. Brown (1907) was the first investigator to document the locations of lignite seams, and to perform proximate analyses on samples from several Mississippi counties. Although the study was a sound foundation for future studies, it contained a limited number of sample locations and poorly-documented lignite outcrop location descriptions. Mellen (1939), Foster (1940), Vestal (1943), and Parks (1961) have all briefly discussed lignite occurrences in individual studies of Mississippi counties; however, the general geology of the individual counties was the main scope of these investigators, and no scientific data on lignite were generated in these studies.

In a study of Kemper County geology, Hughes (1958) performed petrographic analyses on several thin sections of lignite. He found that the major constituents of the lignite were small quartz grains, opaque attritus, and translucent humic matter. A representative thin section of the lignite was shown to be very similar to humic attrital coal. Hughes' work constituted the total petrographic analyses performed on Mississippi lignites at that time.

A broad investigation of Mississippi lignite deposits was accomplished by Williamson (1976). This study consisted of new data from analyses on cored and exposed lignite seams in numerous counties, incorporated with existing information from previous research on the subject. This publication documented the precise locations of lignite seams, and the data from proximate and ultimate analyses on each sample. Cleaves (1980) discussed the depositional systems in the Wilcox Group of North Mississippi, and developed lignite prospecting models. Froelicher and Pescatore (1981) described the results of petrographic and chemical analyses of Wilcox lignite samples from exposed seams in Lauderdale, Choctaw, Kemper, and Calhoun counties.

Palynological investigations of Wilcox lignites of northeastern Mississippi were described in doctoral dissertations by Warter (1965) and Stewart (1971). These studies consisted of identifying microflora from lignite deposits and associated sediments. Stewart (1971) studied samples from Lauderdale, Kemper, Calhoun, and Lafayette counties, while Warter's (1965) study dealt solely with one six-inch lignite seam from Kemper County. Both investigations concluded that, based on the types of flora found, the Wilcox Formation of Kemper County was formed in a strandline area with a tropical to subtropical climate.

Detailed petrographic and proximate analyses of Wilcox lignites are being concluded by graduate students at the University of Southern Mississippi. Mike Wright is currently finalizing a study of lignites in Lauderdale County, and Darren Dueitt has recently completed an investigation of the lignite deposits of Winston and Choctaw counties. Dueitt determined that lignite from Winston and Choctaw counties formed in a fresh-water environment heavily influenced by fluvial systems, and dominated by reeds, grasses, and angiosperms.

GEOLOGIC SETTING

GULF COASTAL PLAIN GEOLOGY

The sedimentary units underlying the Gulf Coastal Plain are generally thick, undeformed deposits which dip gently to the south at 60 to 75 feet per mile. Structural features along these marginal sedimentary units alter the strike and dip direction of these formations. The Gulf Coast Geosyncline is the most important structural feature of the Gulf Coastal Plain (Figure 2). It is a thick sedimentary mass of primarily Cenozoic sediments, which forms the north-central flank of the Gulf of Mexico and thickens southward from the interior of the Gulf Coastal Plain. The axis of this structure is approximately parallel to the present coastline, and perpendicular with the axis of the Mississippi Embayment. The Mississippi Embayment (Figure 2) is also a syncline whose axis parallels the Mississippi River, and extends from the present coastline to southern Illinois (Murray, 1961). The Jackson Dome, Sabine Uplift, and Monroe Uplift are considered to be important structural features of the Mississippi Embayment.

Tertiary System

Sedimentary units of the Tertiary System form a narrow outcrop belt which extends through the lower Mississippi Valley and parallels the structural basin of the embayment. These sediments were deposited on the southern axis of the basin in a wide variety of environments. They

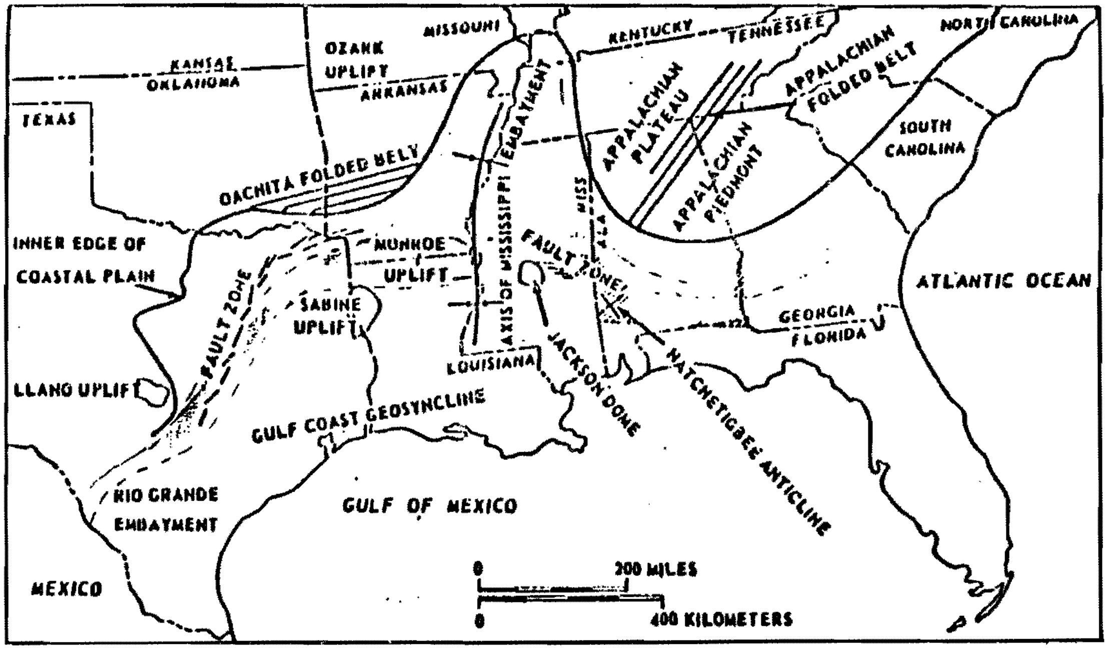


Figure 2. Paleogeography and Structural Features of the Gulf Coastal Plain During the Paleocene. Modified from Gutzler (1979).

Shallow Seas

Transitional Area

Alluvial

were then downwarped and covered by Quaternary sediments (Williamson, 1976).

The inland facies of the embayment are characterized by continental deposits of kaolinite, bauxite, and fluvial sediments. Seaward of the embayment, shoreline and open marine deposits of finer grained clastics prevail in the Gulf Coast Geosyncline. An inland extension of the Mississippi Embayment resulted from the slow subsidence of the basin during the Cretaceous and Tertiary Systems. Large rivers carried vast amounts of terrigenous sediments into the Mississippi Embayment. Remote tectonic events, regional subsidence, and differential uplifts produced major depositional cycles in the area during the Cenozoic Erathem (Lowe, 1933).

A broad coastal plain was formed at the close of the Paleocene, as the waters of the Mississippi Embayment began to recede. This low-lying coastal area was characterized by the deposition of sands, silts, and clays in intertidal and supratidal waters, which ranged from fresh to brackish. A wide variety of vegetation flourished in an environment of marshes, bays, estuaries, deltaic swamps, and bogs in this strandline area. Slow subsidence and rapid burial of organic matter in deltaic and lagoonal settings enhanced the formation of lignite. It was in this environment that the Wilcox Group lignites were deposited (Gutzler, 1979).

Micropaleontological research on Eocene flora of the southeastern United States by Berry (1930) indicates that the climate ranged from temperate to tropical. This is generally supported by the studies of Warter (1965) and Stewart (1971), which concluded that the microflora from Wilcox Group sediments represent climatic conditions similar to that of Central America, eastern Mexico, Southeast Asia, and the southwestern United States. The most common habitat of these floral assemblages is that of swamps and streamsides on a lowland coastal plain, while several plants were adapted for growth on dry, sandy soils. Stewart (1971) found numerous microfossils in the underlying carbonaceous clays of the Wilcox Group which are believed to represeent marine cysts. The presence of mollusks in the overlying marine sands reinforces the belief that East Central Mississippi occupied a low-lying, near-coastal position during the Eocene Epoch.

WILCOX GROUP OF KEMPER AND LAUDERDALE COUNTIES

The Wilcox Group of Mississippi forms a hilly, arcuate outcrop belt approximately 30 miles in width. Its exposed sediments extend from East Central Mississippi to the Mississippi-Tennessee state line (Figure 1). The Wilcox Group is approximately 700 feet thick in Lauderdale County, and thins northward (Williamson, 1976). In Kemper and northern Lauderdale counties the Wilcox Group is disconformably overlain by the Claiborne Group and underlain by the Midway Group (Figure 3).

The Wilcox Group is composed primarily of dark-colored sands, silts, and clays of fresh-water origin. Lenticular and discontinuous lignite deposits are common in the sedimentary units of the Wilcox Group. These sediments also contain trace fossils of marine origin, which become more prominent in Alabama (Hughes, 1958). The Wilcox Group of Alabama was deposited in an area bordering the open Gulf of Mexico, while in Kemper County it was deposited in an area bordering an open bay which was filling in with fluvial sediments from streams and rivers (Lowe, 1933).

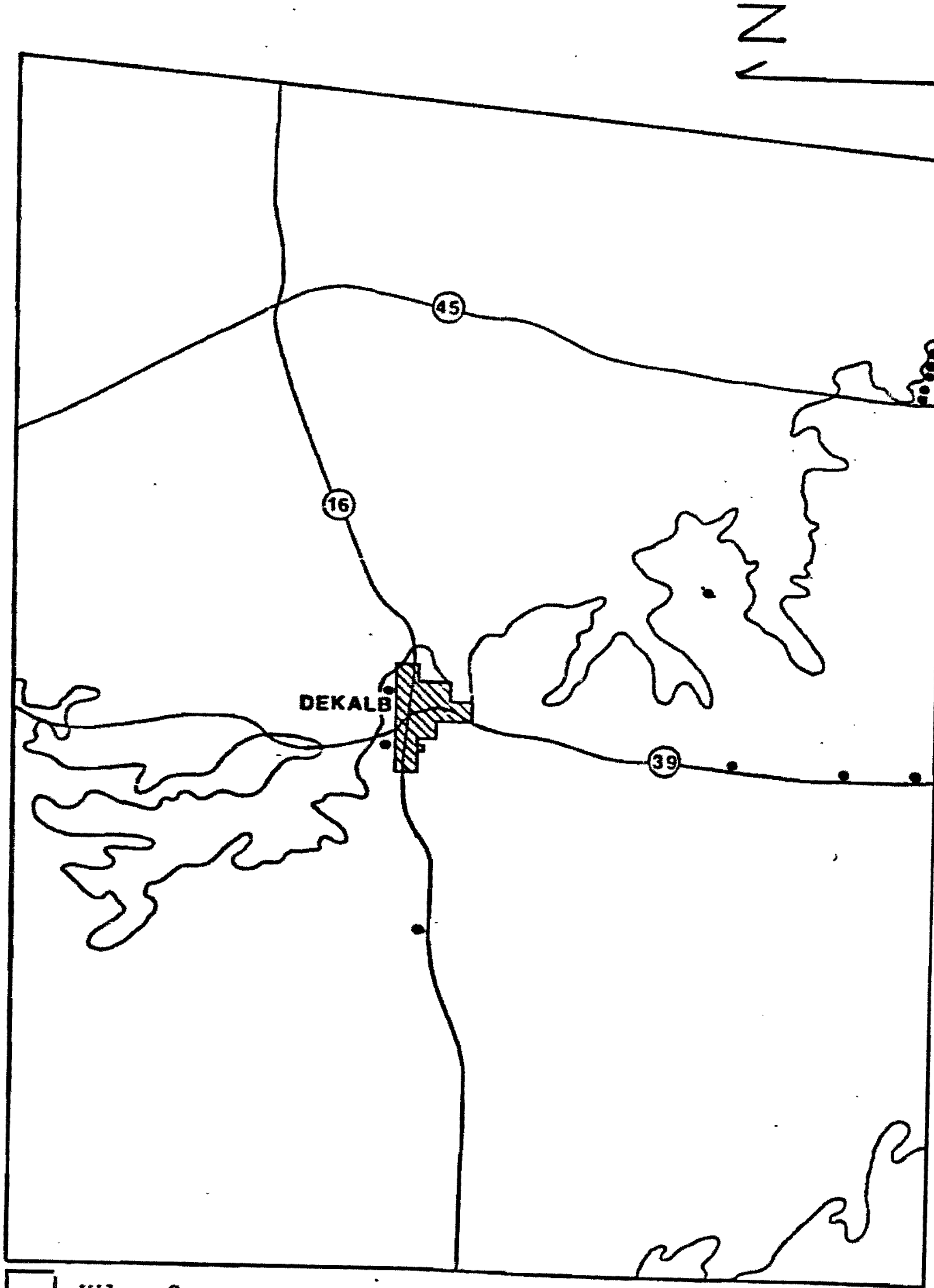
The Wilcox Group occupies almost one-half the area of Kemper County, and strikes northwest-southeast with a gentle southerly dip (Figure 4). The formations that compose the Wilcox Group of Kemper County, listed in ascending order, are the Nanafalia Formation, the Tuscahoma Formation, and the Hatchetigbee Formation.

Figure 3. Generalized Geologic Column of the Wilcox and Midway Group Stratigraphy of Mississippi

System	Series	Group	Mississippi (Northern)	Mississippi (Eastern) Formation	Mississippi (Eastern) Member	Alabama (Western) Formation	Alabama (Western) Member	Description
TERTIARY	EOCENE	WILCOX	Wilcox Group Undifferentiated	Hatchetigbee Formation		Hatchetigbee Formation		Interbedded sands, clays, carbonaceous clays, fissile shales, and lignites.
					Bashi Marl Member		Bashi Marl Member	Glauconitic, fossiliferous, sandy marl. Some lignite.
				Tuscahoma Formation		Tuscahoma Formation	Bells Landing Marl Member	Sands, thinly laminated locally, clays, and fissile shales. Lignites are common. Locally at the base are large angular to rounded blocks of bedded silt.
							Greggs Landing Marl Member	
				Nanafalia Formation		Nanafalia Formation	Grampian Hills Member	Clayey sand, silty clay, and clay - shales. Numerous lignite beds. Thin fossiliferous beds in Kemper and Lauderdale Counties near middle of section.
							Middle Member *Ostrea thirsae* Beds	
					Fearn Springs Member		Gravel Creek Sand Member	Laminated, silty, micaceous clay, and fine sand; thin lignites, and reworked bauxitic material.
	PALEOCENE	MIDWAY	Naheola Formation			Naheola Formation	Coal Bluff Marl Member	Sand, carbonaceous clay - shales, laminated silts and clays. Kaolinitic and bauxitic clay found locally near the top.
							Oak Hill Member	
			Porters Creek Formation	Porters Creek Formation	Matthews Landing Marl Member	Porters Creek Formation	Matthews Landing Marl Member	Glauconitic, sandy clay. Sparingly fossiliferous. Limonite concretions.
								Blocky clay, with slightly glauconitic, micaceous sand lenses. Siderite concretions. Tippah Sand Lentil recognized in northern Mississippi as lenticular sands, clays, and sandstones.
			Clayton Formation			Clayton Formation	McBryde Limestone Member	Glauconitic, laminated clays, marls, and sands. Locally fossiliferous.
				Chalybeate Limestone Member			Pine Barren Member	Glauconitic, fossiliferous, sandy limestone, with interbedded fossiliferous marl.

Modified from Williamson (1976).

Figure 4. Map of Study Area and Sample Locations



Wilcox Group Outcrop

Kemper County, Mississippi

Sample Locations

Nanafalia Formation

The Nanafalia Formation is the lowermost lithologic unit of the Wilcox Group in Kemper County, and consists of 125 to 150 feet of cross-bedded sands, clays, green sandy marls, and frequent lignite beds. The middle of the Nanafalia is characterized by *Ostrea thirsae* beds, which can be used as stratigraphic horizons for lithologic correlation. These pelecypods indicate a marine transgression, which occurred while the area was still uniformly subsiding. After this transgression ended, the Tuscahoma Formation was deposited (Stewart, 1971).

Tuscahoma Formation

The non-marine Tuscahoma Formation is approximately 300 feet thick. This formation represents a marine transgression in the middle portion of the Wilcox Group. It contains thinly-laminated sands, dark clays, and fissile shales, and lignite deposits are common. Sedimentation exceeded subsidence during the deposition of the Nanafalia Formation; however, subsidence began to surpass sedimentation, and a brief marine transgression occurred which deposited the lower Hatchetigbee Formation. The short transgression ended with the deposition of the upper Hatchetigbee Formation.

Hatchetigbee Formation

The Hatchetigbee Formation is approximately 200 feet thick and consists of predominantly terrigenous sediments. The lower unit of this unit consists of a sandy, glauconitic marl, which contains mollusks, foraminifera, and corals, indicating deposition in a shallow marine environment. The upper portion of the formation consists of non-marine sands, silts, and clays.

MATERIALS AND METHODS

LIGNITE OUTCROPS

Outcrops of lignite were located in Kemper County by referring to the publications of Brown (1907), Hughes (1958), and Williamson (1976), followed by a thorough reconnaissance of the area. Upon identifying a lignite seam, it was given a letter-number designator. The letter "K" stands for Kemper County, and the number represents the numerical sequence in which the seam was sampled.. A limited number of lignite samples was analyzed from one exposure in adjacent Lauderdale County. The letter "L" stands for Lauderdale County.

Sampling Procedure

The location and stratigraphic position was recorded, and the seam then prepared for sampling by horizontally excavating to a minimum of 45 cm. This process ensured that an unoxidized sample of lignite could be obtained. Exposed outcrops rarely reveal their true nature due to weathering. Tonal contrasts may be hidden by coatings of small particles, coal dust, clay films, or iron stains which may persist deep into some beds. Channeling or excavating eliminates most of these factors, and enhances accurate descriptions and thickness measurements.

After the entire thickness of the seam was channeled and cleaned, the lignite was described and divided into sampling intervals. These intervals depended upon the lithologic distinctions and continuity (Schopf, 1960). The samples were then taken, labeled, and placed in Ziploc freezer bags to ensure minimum moisture loss.

Sample Processing

The samples were prepared for analysis by crushing approximately 50 grams of lignite with a mortar and pestle until it could pass through a 0.833 millimeter mesh sieve to separate the coarse sands from the smaller fractions. The sieved sample was then stored in plastic, air-tight containers, and placed back in Ziploc bags for later use in laboratory analyses.

CORE SAMPLES

Core samples from the subsurface seams of the Wilcox Group in Kemper County were obtained from the Mississippi Bureau of Geology. The limited size of each sample restricted the use of the lignite to a petrographic analysis only.

ANALYTICAL PROCEDURES

Proximate Analysis

A proximate analysis determines moisture, volatile matter, ash, and fixed carbon of a coal sample. Moisture is basically the water content; however, some of this water may be bound in clays and not removable upon initial heating in a drying oven. Volatile matter is the gas or vapor given off by the coal exclusive of moisture. Solid residue obtained by the high-temperature heating of coal is the fixed carbon fraction, and ash is the remaining inorganic residue left after the burning of these combustible substances (Karr, 1978). Proximate analysis was performed by using an automated Fisher Coal Analyzer Model 490 and the following procedures:

(1) Place approximately one gram of each lignite sample into a pre-weighed quartz crucible, and reweigh crucible with the sample.

(2) Place crucible in a circulatory oven with lid off for 60 minutes at 107 C to drive off moisture.

(3) Reweigh samples upon completion, and place them in a cold furnace with lids on.

(4) Set furnace to heat samples at 950 C for 6 minutes to drive off volatiles. The temperature should rise approximately 30 C/minute.

(5) Reweigh samples and place in furnace with lids off, and set furnace to heat samples at 750 C for 180 minutes to ash the coal.

(6) Reweigh samples and enter data on the Fisher Coal Analyzer.

The moisture content was determined by analyzing three replicate samples, which contained the natural seam moisture. Several grams of the previously crushed and stored lignite were air-dried for 48 hours. The dried lignite was then analyzed, and the results of seven replicate samples were used to determine the volatile matter, fixed carbon, and ash content of the representative samples.

Petrographic Analysis

A petrographic analysis, consisting of a maceral count and ulminite and gelinite reflectance measurements, was performed on a representative lignite sample from each seam. Particulate pellets were made from the crushed lignite, which was previously prepared and stored. Equal amounts of the lignite from each sample were mixed with other samples from the same seam, in order to obtain a representative sample from each location. The pellet preparation consisted of adding a polyester resin and a few drops of hardener to the lignite sample. This mixture was then placed in 2mm-diameter embedding molds, and allowed to harden in a desiccator. The pellets were then removed from the molds and polished by the following method:

(1) Grind pellet for three minutes each with #200, #400, #600, #1200, and #4,000 sand paper.

(2) Polish pellet with 0.3-micron aluminum slurry for 45 minutes, and clean in ultrasonic bath for 30 seconds.

(3) Polish pellet with 0.05-micron aluminum slurry for 45 minutes, and clean in ultrasonic bath for 30 seconds.

(4) Clean pellet with distilled water.

(5) Blow dry and store in desiccator until needed.

The analysis was performed at the Kentucky Center for Energy Research Laboratory in Lexington, Kentucky. A Leitz MPV 11 reflectance and fluorescence microscope, with a 625X total magnification, was used to analyze each pellet under oil immersion. Two pellets from each seam were studied, and 500 point counts of the macerals on each sample were made for a total of 1,000 counts per seam.

Maceral Counts The actual counting was accomplished by placing each pellet on a mechanical stage with a 0.4 by 0.4mm field of view, and a 0.4mm advancement capability. The field of view contained many macerals, but only those appearing under each cross hair of the eyepiece were counted before advancing to the next field. Normally, no more than 4-8 points were counted in each field. The following macerals were recorded: textinite, ulminite, humodetrinite, gelinite, corpohuminite, fusinite, semifusinite, and exinite.

Reflectance Measurements Thirty reflectance measurements were recorded on the gelinite and ulminite contents of each pellet. This procedure was accomplished by turning the photomultiplier on and rotating the stage 720 to enhance the maximum reflectance output recorded by the instrument. Two pellets from each lignite outcrop were analyzed. Thirty measurements per pellet for a total of 60 measurements per seam were recorded.

Sedimentological Analysis

Grain Size Analysis A grain size analysis of the sands, silts, and clays was performed on the samples of lignite from seams in Kemper County. The laboratory technique of pipette analysis employed by Folk (1974) was utilized for each lignite occurrence studied for this thesis (Table 2). Fifteen grams of the crushed lignite were wet-sieved through a 230 mesh (63 micron) screen, in order to separate the sand-sized particles from the silts and clays. The sand-sized fraction was then removed, dried, and weighed. The silt and clay fractions were then prepared and run through a pipette analysis using Stokes' Law of Settling to differentiate between silt and clay-sized particles.

Mineralogical Analysis

A mineralogical analysis utilizing the General Electric X-Ray Diffractometer 700 was performed on the lignite samples. The X-ray diffractometer was used for the analysis of bulk and clay samples from the lignite. The bulk samples were prepared by placing double-sided tape on a petrographic slide, and uniformly covering the tape with lignite which had been crushed and sieved through a 0.833-millimeter sieve. In order to prepare samples for clay mineral analysis, water-suspended clay particles were placed on a petrographic slide, and allowed to dry (Folk, 1974). This technique orients the c-axis of the clay minerals normal to the slide and X-ray holder, and enhances the 001 diffraction of the clay mineral. Two clay slides were prepared, and one was solvated with ethylene glycol to determine the presence of expandable clays. After the procedure was completed, the resulting X-ray diffractograms were interpreted by the procedures outlined by Brown and Brindley (1980).

Statistical Analysis

The data from the study were analyzed using the University of Southern Mississippi Honeywell DPS-8 computer by Pearson Product-Moment correlations. A matrix was constructed in which each variable was correlated with every other variable. Correlations significant at a 50% confidence level were identified, and chosen for further analysis.

RESULTS

FIELD OBSERVATIONS

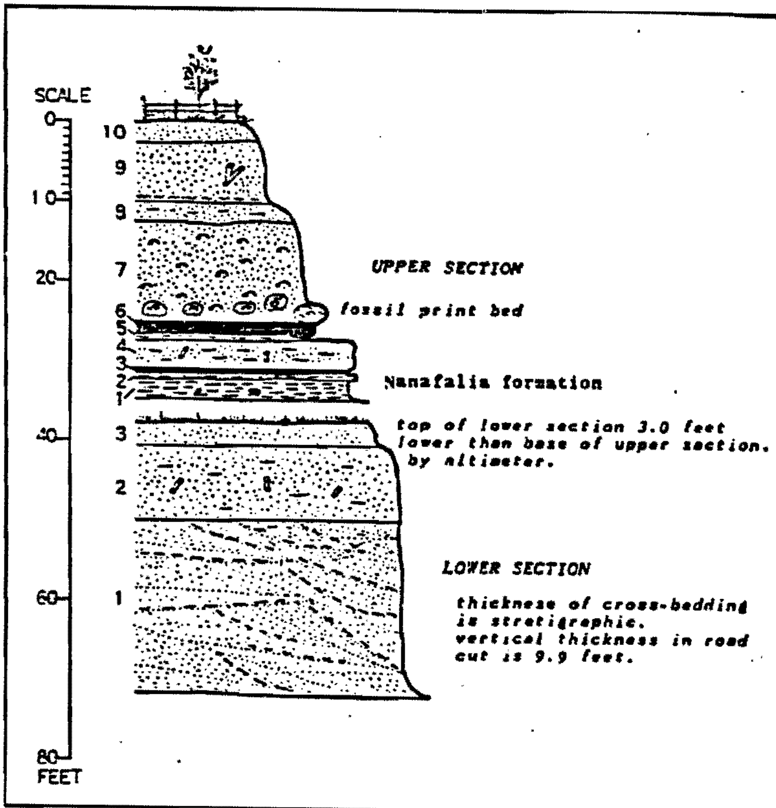
The lignite outcrops studied in this investigation are generally thin, tabular, and discontinuous (Table 2). The locations of the seams do not occur in a predictable or distinguishable pattern. All of the exposed seams investigated are from various sections of the Nanafalia Formation of Kemper County, except "L-14" which is from the Naheola Formation (late Paleocene) of northern Lauderdale County. The average seam thickness is approximately 1.2 meters, and all of the exposures have a very limited areal extent.

Locations "K-1, 2, 3, and 12" are from the Middle Nanafalia Formation (early Eocene). Hughes (1958) characterized location "K-1" as Middle Nanafalia Formation sediments, and correlated them with the Nanafalia Formation of Western Alabama through the presence of Ostrea thirsae beds at location "K-1" (Figure 5). Locations "K-2"and "K-3" are in a drainage channel along State Highway 39, and were partially exposed. Both are overlain by coarse red sands with ferruginous boulders, which is typical of the lower division of the Middle Nanafalia Formation (Hughes, 1958). The lignite deposits of the Middle Nanafalia Formation (early Eocene) are dark brown to black, shaly, and muscovitic, and contain small red to tan clay lenses. Location "K-12" consists of soft, black, and highly-weathered lignite. This seam is overlain by brown micaceous sand interbedded with carbonaceous clays. The lignite contains dark brown sand and has micaceous partings.

Locations "K-4" and "K-5" are samples from the top of the Nanafalia Formation which is early Eocene in age. These locations consist of lignite overlain by massive, gray sands and clays. The lignite from "K-4" is black, soft, micaceous, and highly weathered due to its location at the bottom of a drainage channel. Most of the seam is clayey and plastic. Location "K-5" contains a thick seam of black, blocky lignite overlain by tan to brown silty, carbonaceous shale with dark lignitic streaks. The lignite is very hard, and contains gypsum crystals and light red clay and sand in the cleats.

Locations "K-7, 8, 9, 10, 11, and 13" are from the Lower Nanafalia Formation (early Eocene), and are characterized by cross-bedded sands, micaceous clays, and sands. The lignite samples from these locations are generally poor-quality lignites interbedded with thin layers of tan to red sands and clays. Location "L-14" is from the Naheola Formation of the Midway Group (late Paleocene) of northern Lauderdale County. The lignite seam from this location is dark brown, and has a high clay content with a small areal extent.

Figure 5. Section of Middle Nanafalia Formation on State Highway 39, 0.2 to 0.4 mile north of Kemper-Lauderdale County line (SE.¼, Sec. 32, T.9 N., R.16 E).



	Feet	Feet
Top Soil		2.7
10. Buff, fine silty top soil.	2.7	
Nanfalia formation		32.2
9. Tan to brown fine to medium muscovite sand with thin platy limonite partings in lower foot and containing <u>Halymenites major</u> Lesquereux	7.4	
8. Light brown and yellow mottled argillaceous muscovitic sand. Dark gray carbonaceous clay at base.	2.3	
7. Massive olive gray fine sand containing fossil prints of the genus <u>Venericardia</u> and ferruginous boulders with fossil prints.	12.8	
6. Lignite.	1.4	
5. Dark gray carbonaceous silty clay.	0.8	

(Continued)

Figure 5. (Cont.)

	Feet	Feet
4. Gray massive firm muscovitic (large flakes) argillaceous fine sand containing limonite tubes and veinlets.	3.7	
3. Thin lignite.	0.5	
2. Dark-gray carbonaceous plastic, stiff, slightly muscovitic clay.	0.7	
1. Mottled yellow to gray plastic clay slightly carbonaceous	2.6	
Total section. . . .	34.9	

Modified from Hughes (1958).

LABORATORY ANALYSES

PROXIMATE ANALYSIS

Proximate analyses on lignite samples from sixteen locations in the study area indicated that great variation occurred both between different lignite seams, and also within individual seams. Large variations in the average values for moisture, volatile matter, fixed carbon, and ash content are seen in a seam-to-seam comparison (Appendix A).

Average moisture content of lignite in all seams is 30% (Figure 6), but six seams contain greater than 40% moisture. Volatile matter is relatively low for most seams, with an average value of 23%. Fixed carbon averages nearly 17% for all seams, but four seams contain less than 1% fixed carbon. Ash is the dominant constituent of the lignite, averaging more than 60%, and seven samples exceed 75% ash content.

PETROGRAPHIC ANALYSIS

Samples of lignite from sixteen locations were studied petrographically to determine their individual constituent particles (macerals) and the reflectance of ulminite and gelinite for each lignite sample (Appendix B). The predominant macerals are humodetrinite and gelinite, which average approximately 39% and 26%, respectively (Figure 7). However, the humodetrinite content of core samples "LS-35-1, 2, 3, and 6" from the Tuscahoma Formation is significantly lower, averaging 21%. Textinite and exinite have overall average values of 3.0%, and corpohuminite averages 2%, despite being absent in five seams. Textinite was more abundant (3.4%) in the cored samples. The inertinite macerals (fusinite and semifusinite) together comprise approximately 19% of the total count, and have generally higher values in the cored samples. The ulminite content is over 9%, but it is more abundant in the cored samples.

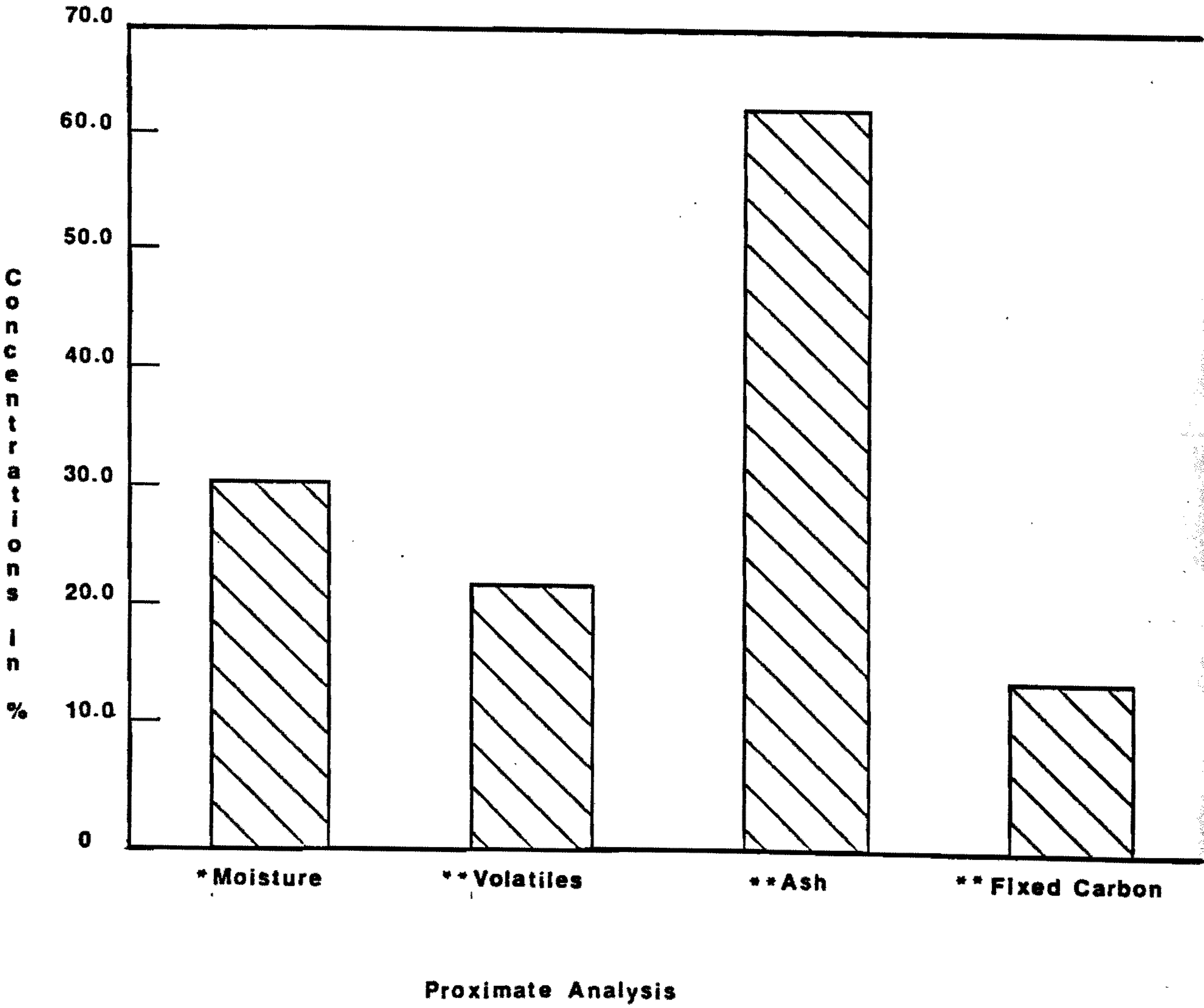
GRAIN SIZE ANALYSIS

The grain size distribution of thirteen samples from the study area is listed in Appendix C. Sand-sized quartz is the dominant grain-size fraction for all thirteen samples (Figure 8), with sand averaging almost 59% of the overall grain-size distribution, and silt and clay together constituting only 32%. Silts and clays are more abundant in the seams of the Lower Nanafalia Formation (early Eocene) and Naheola Formation (late Paleocene), while sand-sized particles are generally more abundant in the Upper and Middle Nanafalia Formation.

MINERALOGICAL ANALYSIS

A qualitative mineralogical analysis by X-ray diffraction was performed on each sample of lignite to determine which minerals were present. Kaolinite, illite, and smectite were found to be present in each sample by X-ray diffraction. In addition, petrographic analysis using reflected light revealed tan homogenous films which were

Figure 6. Graph Indicating Averages from Proximate Analysis



*Average based on samples containing "as-is" moisture.

**Averages based on air-dried samples.

Figure 7. Graph Indicating Averages from Petrographic Analysis

Kemper County

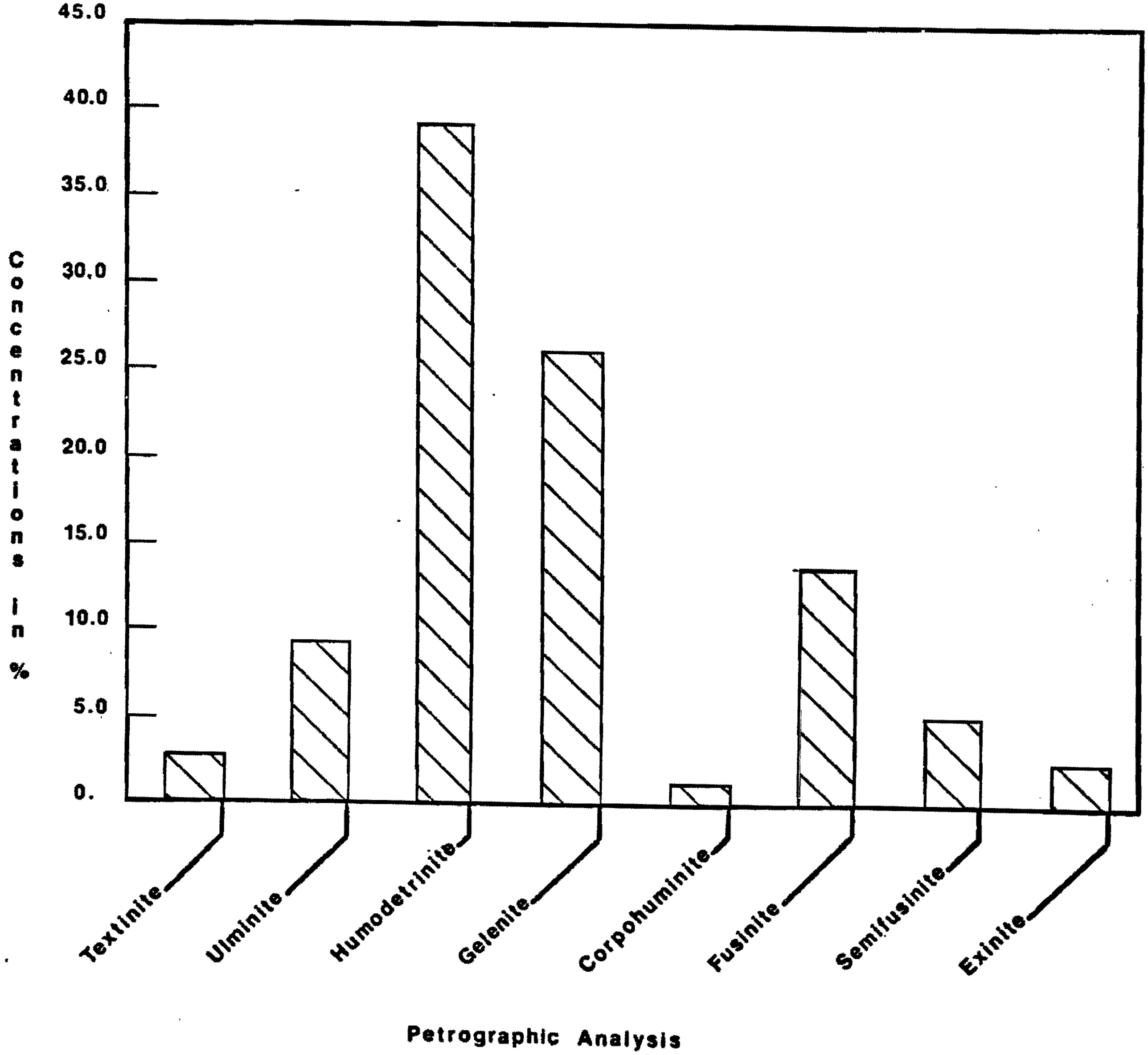
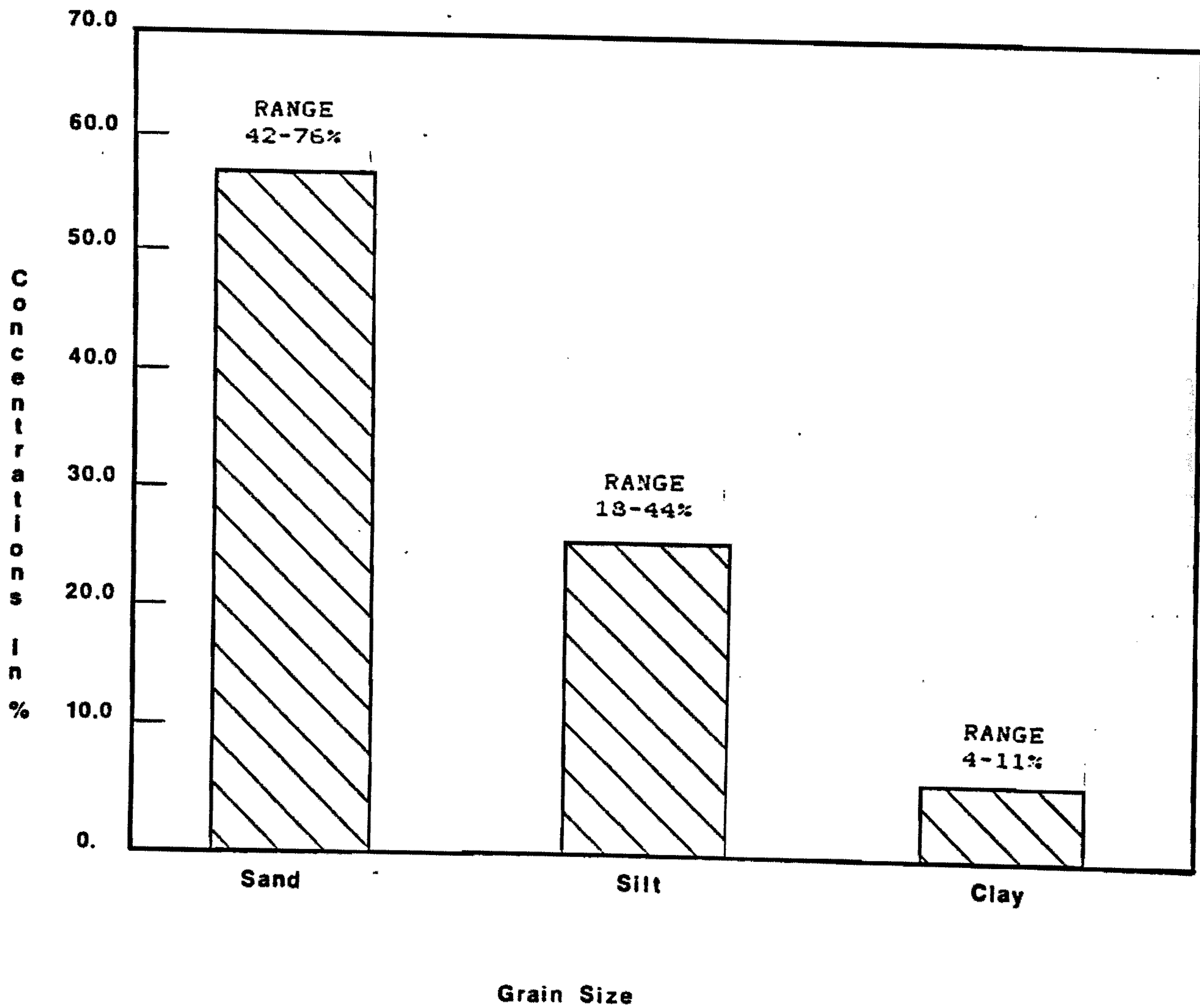


Figure 8. Graph Indicating Averages From Grain Size Analysis.



identified as indistinguishable clay minerals masking the surrounding macerals. Quartz is abundant in all samples, as evidenced by the interbedded sands and the gritty feel observed in the field, and by the abundant sand-sized grains observed in the grain-size analysis. Pyrite, glauconite, and carbonate minerals were also observed by petrographic examination of the lignite samples. Pyrite, observed in reflected light has a bright golden color, and an extremely high metallic reflectance. Carbonate minerals appear as bright white-colored, amorphous bodies, but they are not associated with the lignite in great quantities. Glauconite is present in trace amounts in lignite sample "K-1", which was seen to be overlain by glauconite sands by field observations.

Muscovite was also found to be present in most samples by field observation with a hand lens, and was observed by petrographic analysis under plane-polarized light. X-ray diffractograms also indicate the presence of muscovite in varying quantities in the lignite samples.

DATA ANALYSIS

The data from the field observations and laboratory analyses were analyzed by Pearson Product-Moment Correlation Analysis, which determines a correlation coefficient between two variables.

This correlation coefficient may be tested for significance by nonparametric statistical procedures.

Significant correlations between all variables of this study are listed in Table 3, and plots were made of some of the significant correlations between pairs of variables. Of all variables examined in this study, ash content, moisture, volatile matter, and the fixed carbon content of lignites were found to demonstrate clear relationships with other measured parameters. In addition, the macerals corpohuminite, humodetrinite, and ulminite showed significant correlations with other measured variables.

Ash Content

Ash content has a negative correlation with ulminite, exinite, and corpohuminite (Figures 9a, b and c). The correlation coefficient is lowest for ash compared to the cellular maceral ulminite, and increases with increased maceral gelification to a maximum value against corpohuminite. Ash has a strong negative correlation with moisture content (Figure 10). Ash and clay content indicate a positive correlation, but with a lower correlation coefficient (Figure 11). The relationship of ash and muscovite is significant (r=0.81) at a 50% confidence interval, but since muscovite is incombustible, it could be considered as a component of the ash content.

Moisture

Moisture shows significant correlations to three macerals and also to three components of proximate analysis. Positive relationships, with moderate correlation, occur

TABLE 3

SIGNIFICANT CORRELATIONS AMONG VARIABLES

	Kaolinite	Illite	Smectite	Moisture Content	Volatile Matter	Ash Content	Fixed Carbon
Sand	-.5616		-.6161		.4766		
Silt	.5332		.6907				
Clay	.5481				-.5168	.5282	-.5227
Textinite	.5233						
Ulminite					.5439	-.4639	
Humodetrinite				-.6423			
Corpohuminite				.7014	.7877	-.7446	.7324
Fusinite					-.4896		
Semifusinite	-.6313						
Exinite				.6367	.6547	-.7279	.7467
Ulminite Reflectance	.8139						
Quartz				-.5243	-.5104		
Muscovite				-.6862	-.7492	.8091	-.8277
Moisture					.8982	-.8737	.8435
Volatile Matter						-.9851	-.9999
Ash Content							-.9956

	Sand	Silt	Clay	Ulminite	Humo-detrinite	Gelinite
Sand		-.9847	-.9405			
Silt			.8977			
Textinite				.8313	-.7215	
Ulminite					-.8630	.6739
Humo-detrinite						-.7160

(Continued)

TABLE 3 (Cont)

	Corpo-huminite	Fusinite	Exinite	Ulminite Reflec-tance	Gelinite Reflec-tance	Muscovite
Sand	.6808		.4672	-.6874		
Silt	-.6627		-.4647	.6715		
Clay	-.6963		-.5116	.7327	.6235	
Textinite		-.5298		.5449		
Ulminite		-.7334		.6315		
Humodetri-nite	-.5417	.6635				
Gelinite		-.8891		.6175		
Corpohumi-nite			.4769			-.6397
Fusinite				-.5940		
Semi-Fusinite			.6065			
Exinite						-.6749
Ulminite Reflectance					.9002	
Quartz						.4938

with corpohuminite and exinite (Figures 12b and c), volatile matter, and fixed carbon. Moisture content shows a negative correlation with humodetrinite (Figure 12a) and ash content.

Volatile Matter

Volatile matter exhibits significant positive correlation with two highly gelified macerals, exinite and corpohuminite, and with the cellular maceral ulminite, although with a lower correlation coefficient (Figures 13a, b, and c). The correlation coefficients indicate the relationships become stronger with the greater degree of maceral gelification. Volatile matter exhibits a slight positive correlation (r=0.48) to the sand-sized fraction, and a negative correlation to the clay-sized fraction (r=-0.52) in the lignite. Fusinite (Figure 13e) and ash content (Figure 13f) are inversely related to the amount of volatile matter, and moisture has a positive relationship to volatile matter (Figure 13d).

Fixed Carbon

Fixed carbon displays a strong positive association with moisture (Figure 14a) and exinite (Figure 14f), and a weaker positive correlation with corpohuminite (Figure 14e). These may be genetically interrelated, as seen by the relationships between moisture and corpohuminite (Figure 12b), and between moisture and exinite (Figure 12c). There are very strong negative correlations between fixed carbon and volatile matter (r=-0.99) and between fixed carbon and ash content (r=-0.99) of the lignites (Figures 14c, 14d). In addition, a strong negative correlation (r=-0.98) is seen between volatile matter and ash content (Figure 13f). A slight, but statistically-significant negative correlation (r=-0.52) is seen between fixed carbon percentages and percent clay (Figure 14b), which suggests that increased clay content of sediments acts as an inhibiting factor limiting the amount of fixed carbon in lignites.

Corpohuminite

Corpohuminite displays a strong relationship to all four components of proximate analysis. A distinct positive correlation is seen between corpohuminite and moisture (Figure 15a), fixed carbon (Figure 15b), and volatile matter (Figure 15c), and a negative correlation between corpohuminite and ash (Figure 15d). A slight positive correlation (r=0.48) occurs between corpohuminite and exinite, which may be significant, since they both correlate negatively to ash and correlate positively with fixed carbon, volatile matter, and moisture. Corpohuminite and exinite are also related to the three different size classes of the grain-size distribution analysis: both are positively correlated to the sand-sized fraction, and negatively correlated to the silt and clay-sized fraction. Corpohuminite and humodetrinite show a slight negative (r=-0.54) correlation.

Humodetrinite

A common negative relationship is evident between humodetrinite and textinite (Figure 16a), ulminite (Figure 16b), gelinite (Figure 16c), and corpohuminite. The strongest negative correlations are between humodetrinite and the two most-cellular macerals, textinite and ulminite. Moisture is also negatively correlated to humodetrinite. Fusinite and the reflectance of ulminite indicate a positive correlation to humodetrinite.

Ulminite

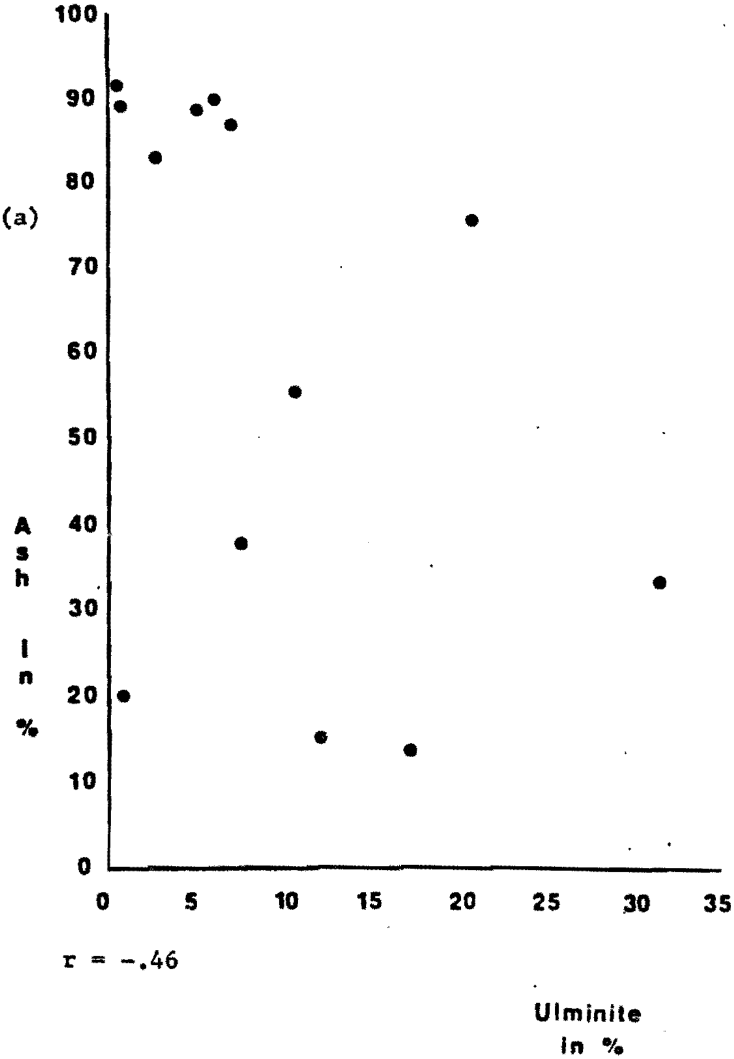
The most structured cellular maceral, textinite, exhibits a strong positive relationship ($r=0.83$) to the other highly-cellular maceral, ulminite (Figure 17a). Positive relationships are seen between ulminite and volatile matter (Figure 17b), and moisture (Figure 17d). As expected, we note a positive correlation between ulminite percentages and the reflectances due to ulminite, although the correlation coefficient ($r=0.63$) is somewhat lower than might have been expected for this relationship. Negative correlations are seen between ulminite and fusinite ($r=-0.73$) and between ulminite and ash content (Figure 17c).

Fusinite

Textinite, ulminite, and gelinite have a negative correlation to fusinite (Figures 18a, b, and c). The negative correlation increases with the degree of maceral gelification. Textinite and ulminite, which are very cellular in nature, have a lower negative correlation with fusinite, and the highly gelified maceral, gelinite, has a strong negative correlation to fusinite.

Figure 9. Correlations Between Ash Content and: (a) Ulminite, (b) Exinite, (c) Corpohuminite.

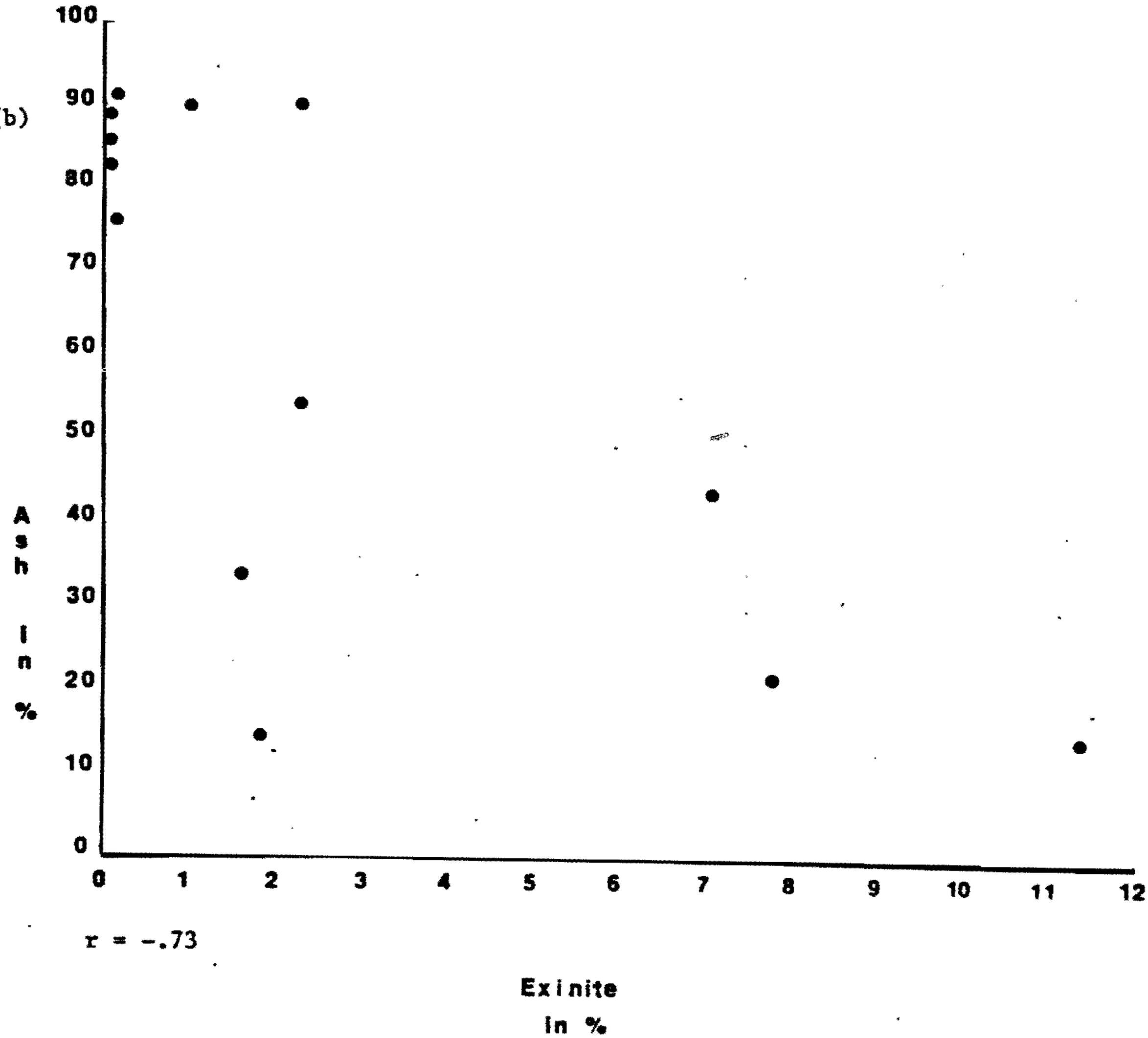
(a)



r = -.46

Figure 9. (Continued)

(b)



r = -.73

Figure 9. (Continued)

(c)

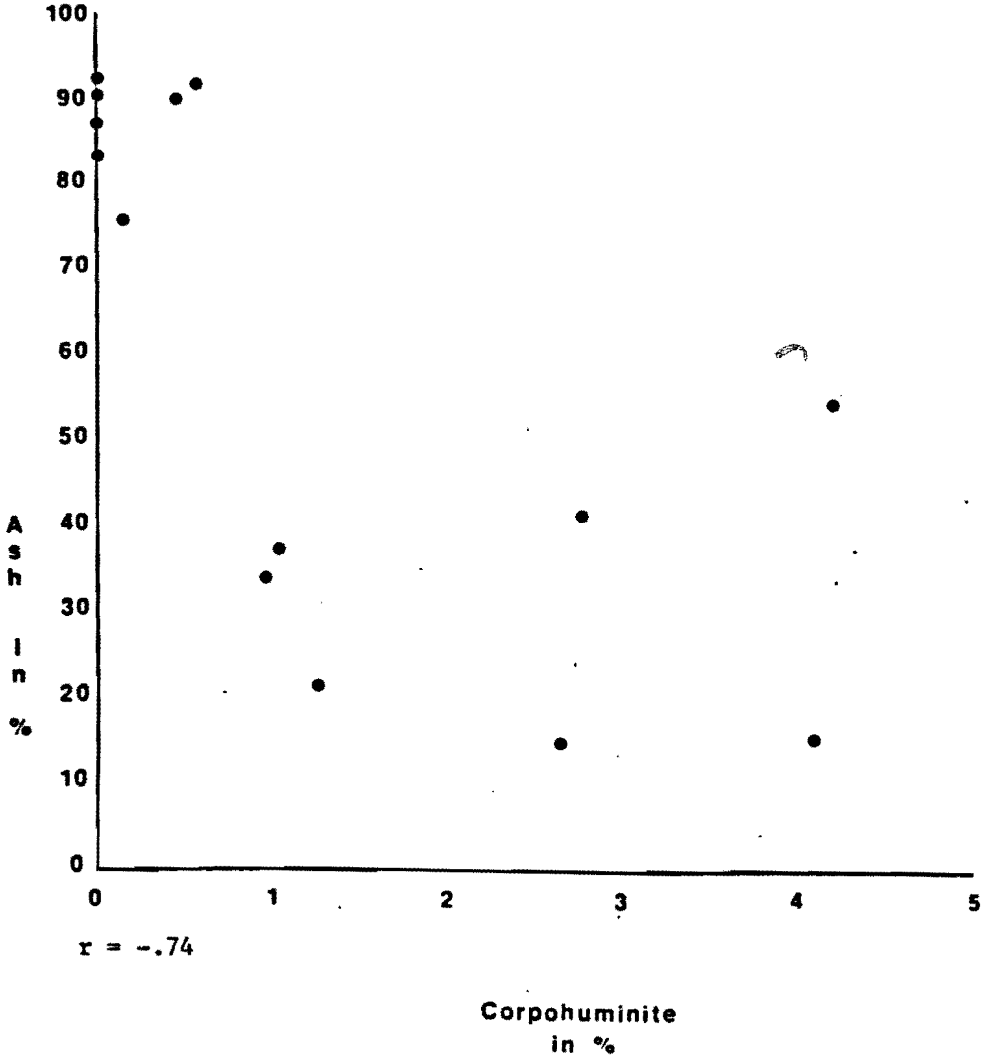
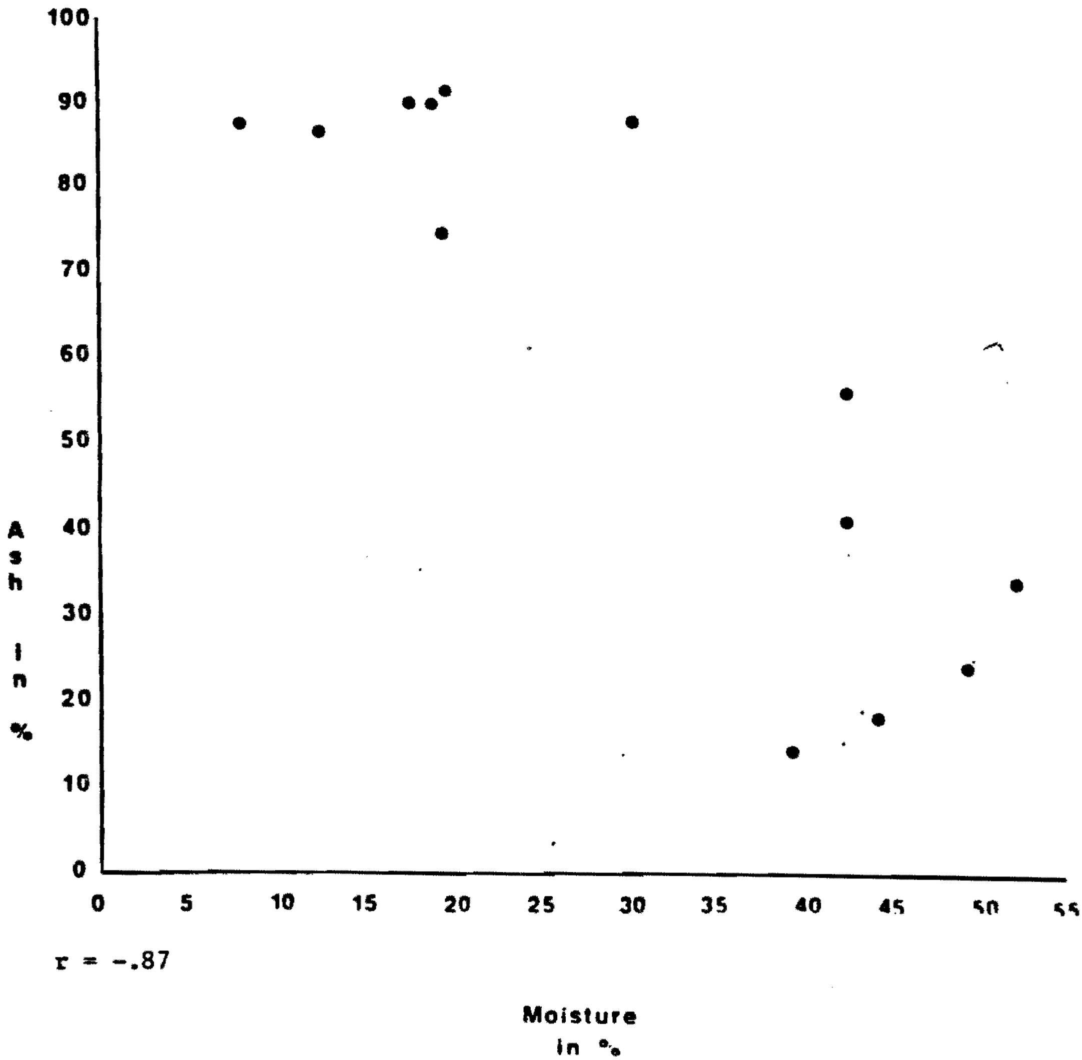


Figure 10. Correlation Between Ash and Moisture.



r = -.87

Figure 11. Correlation Between Ash and Clay.

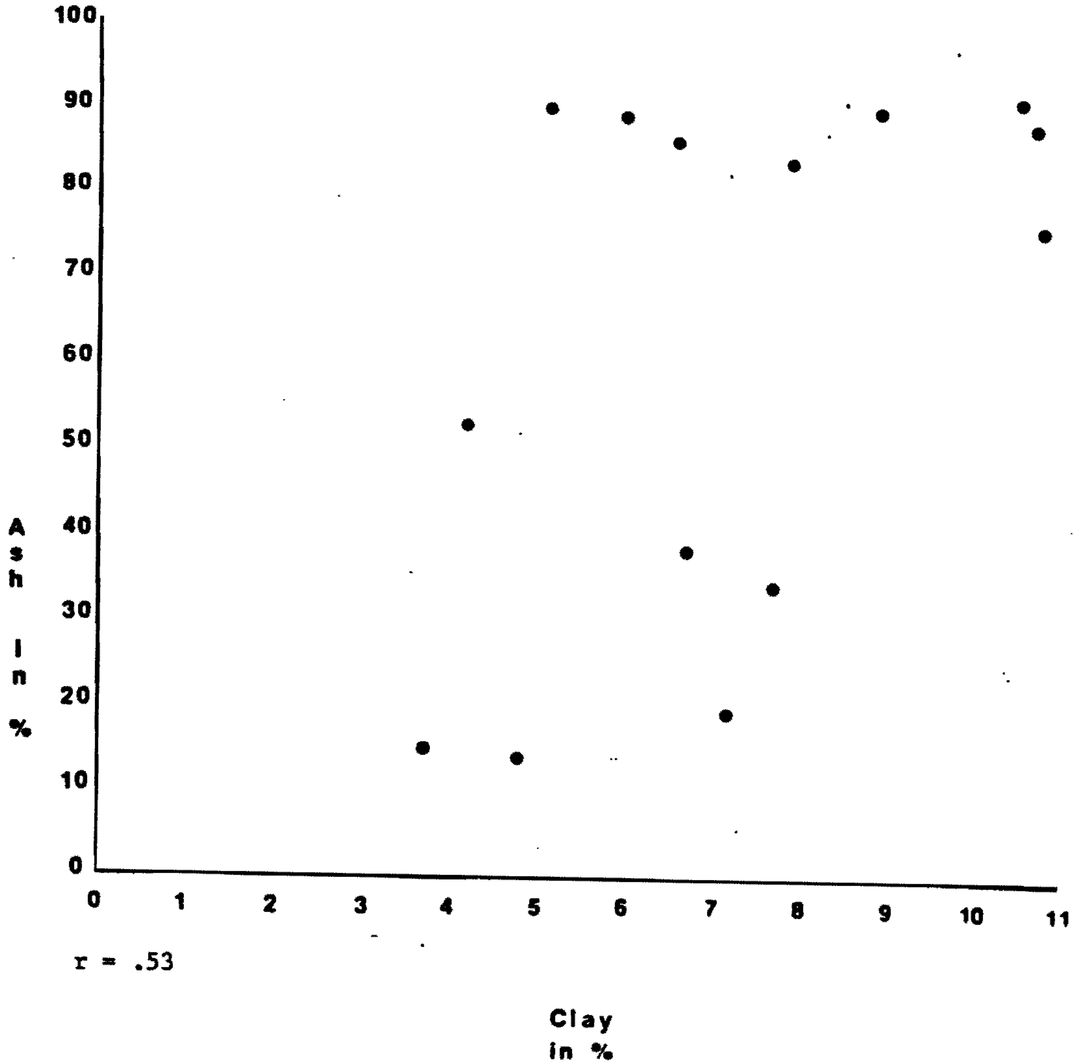


Figure 12. Correlations Between Moisture Content and: (a) Humodetrinite, (b) Corpohuminite, (c) Exinite.

(a)

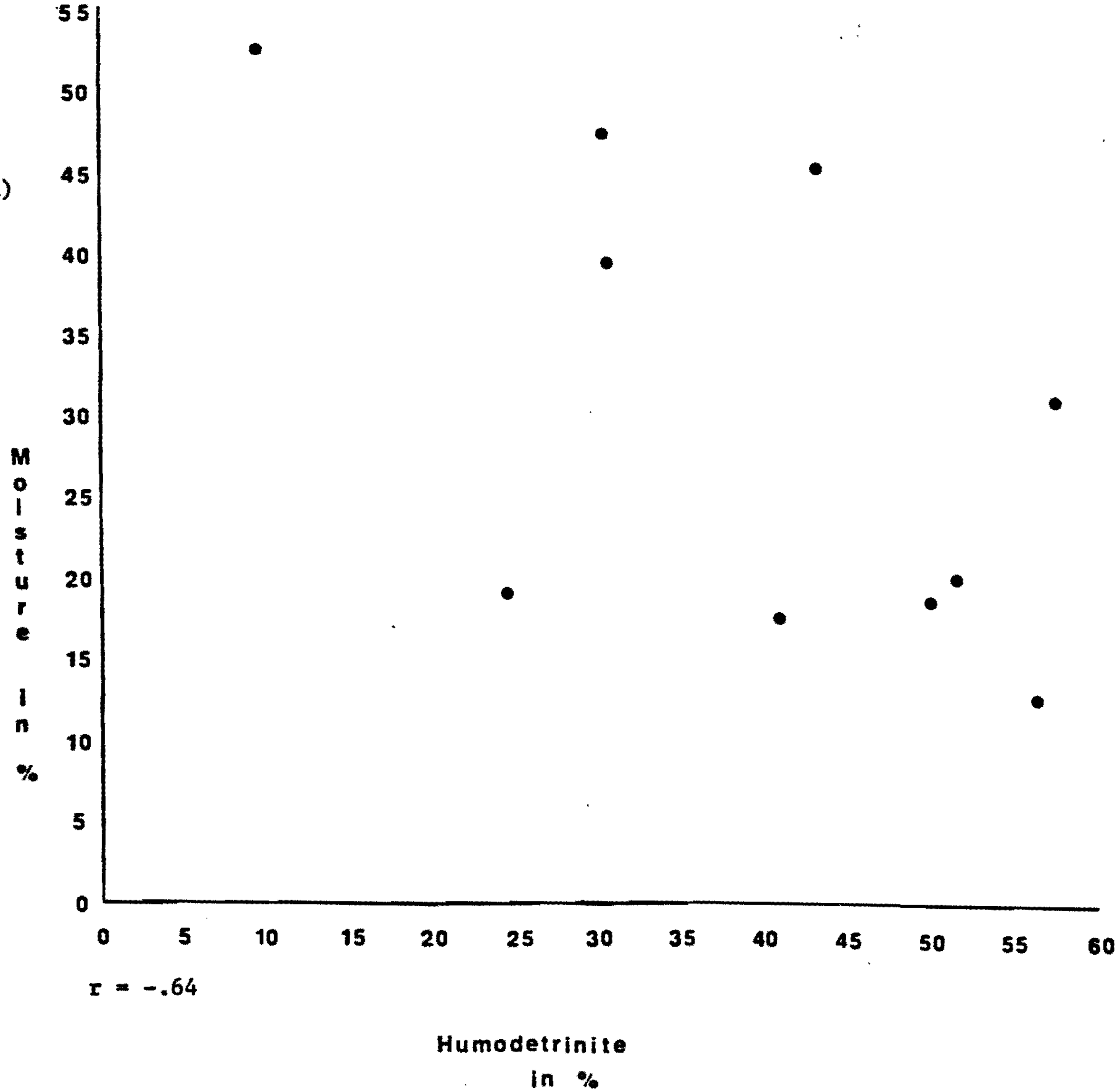
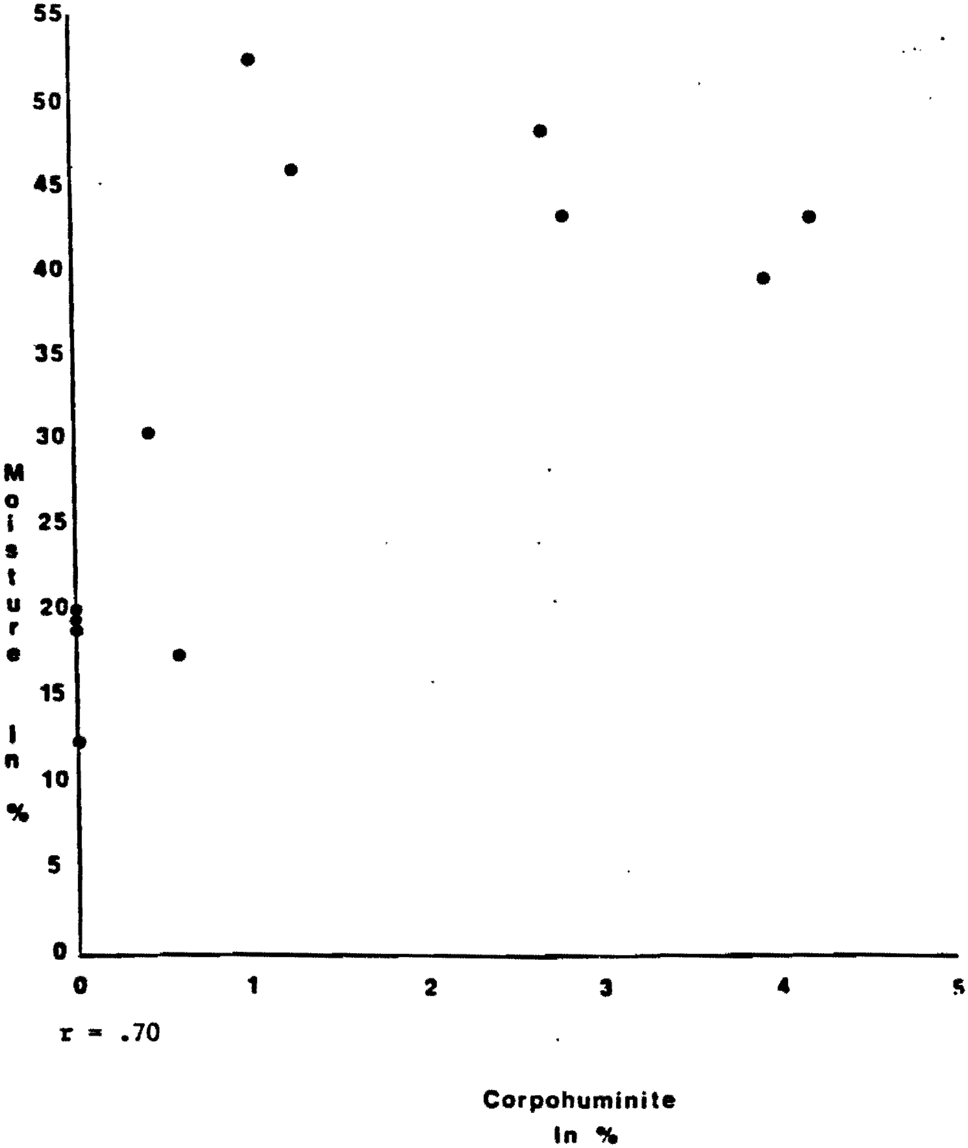


Figure 12. (Continued)

(b)



r = .70

Figure 12. (Continued)

(c)

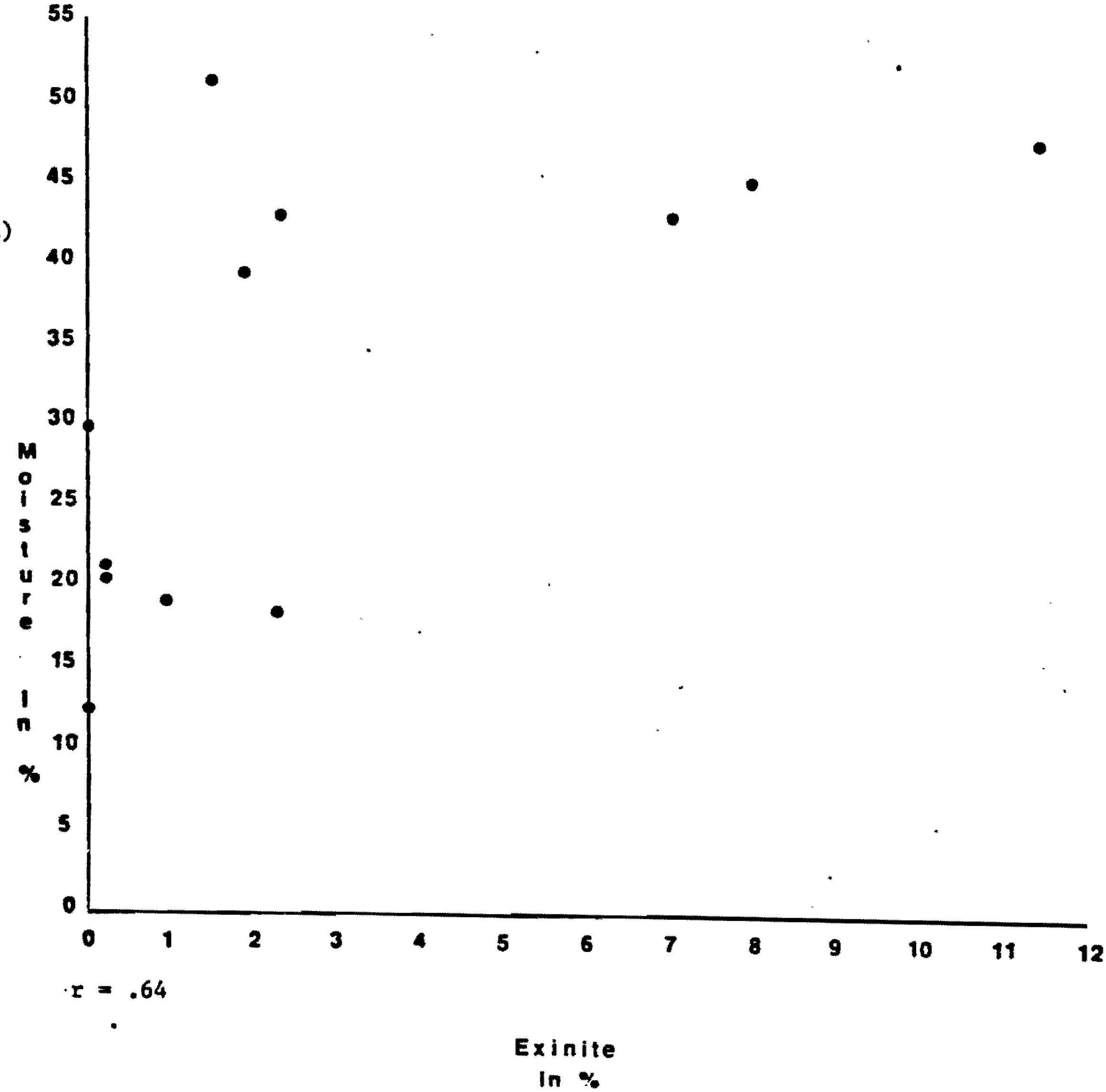
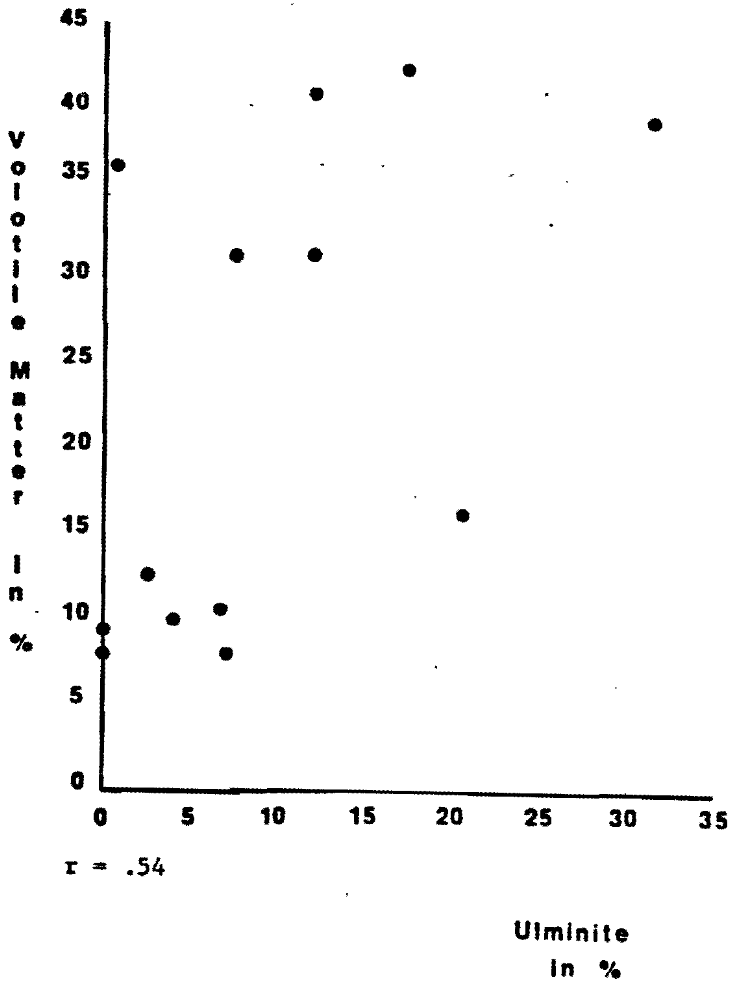


Figure 13. Correlations Between Volatile Matter and: (a) Ulminite, (b) Exinite, (c) Corpohuminite, (d) Moisture, (e) Fusinite, (f) Ash.

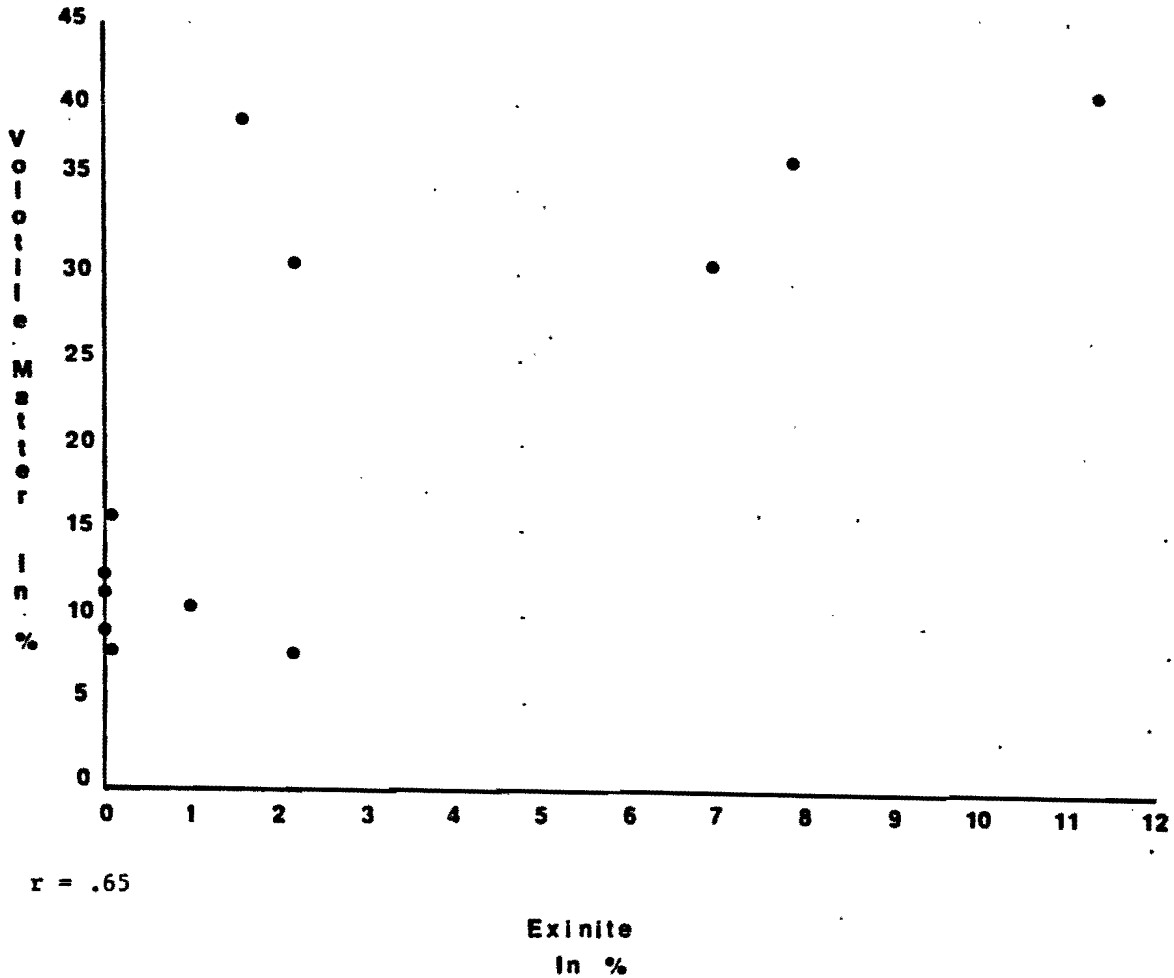
(a)



r = .54

Figure 13. (Continued)

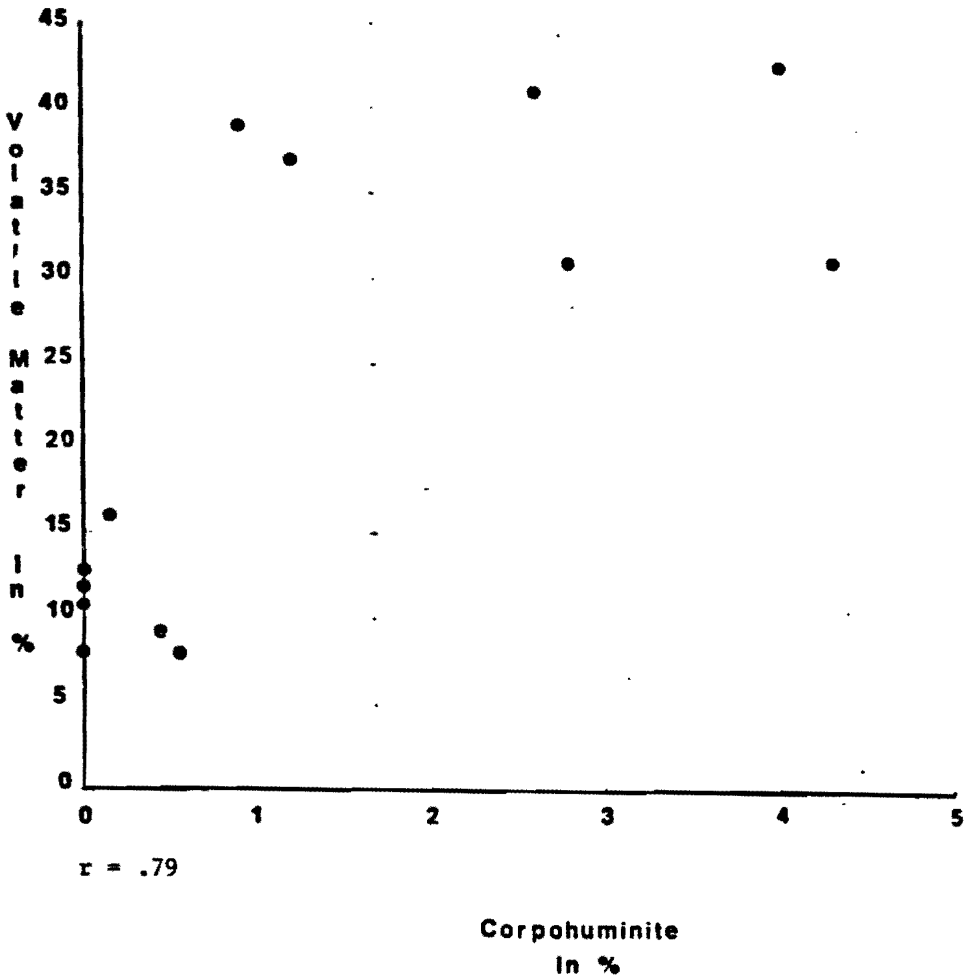
(b)



r = .65

Figure 13. (Continued)

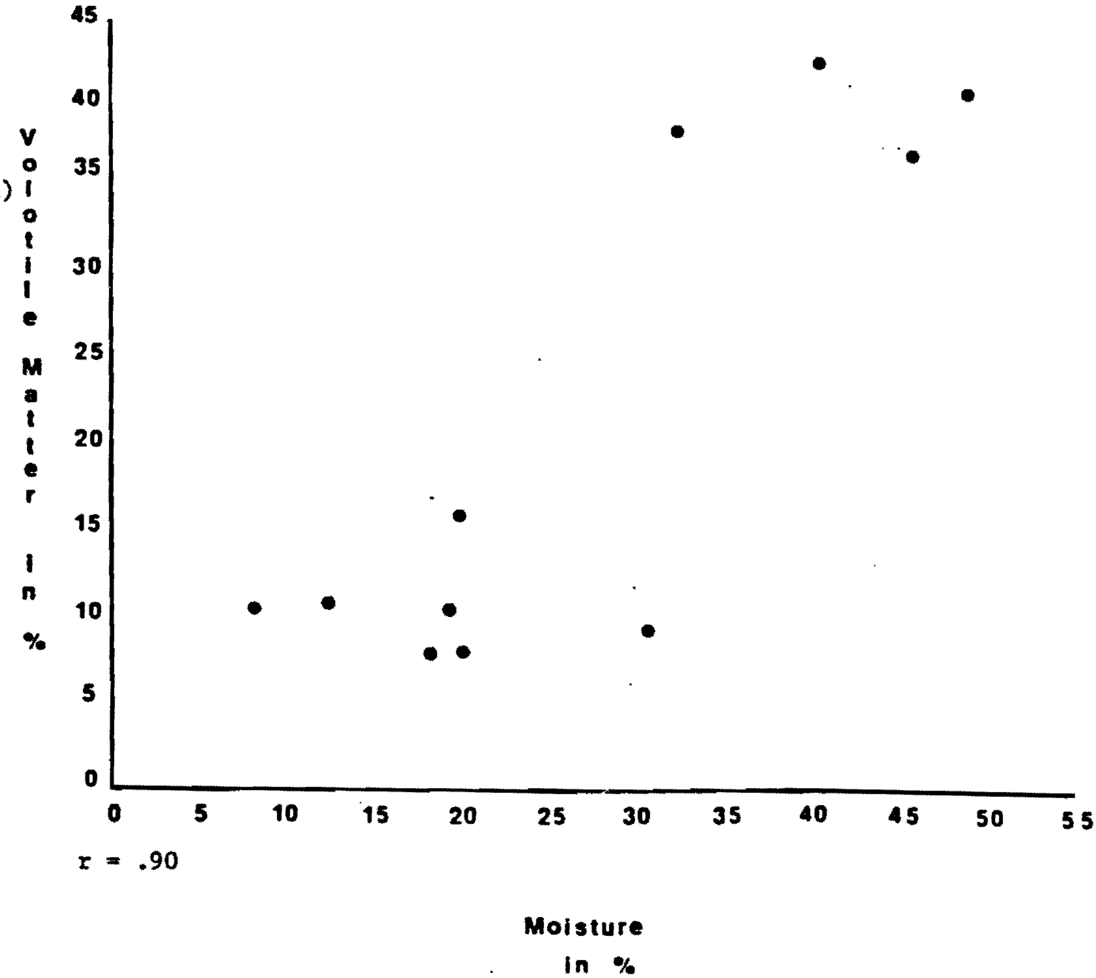
(c)



r = .79

Figure 13. (Continued)

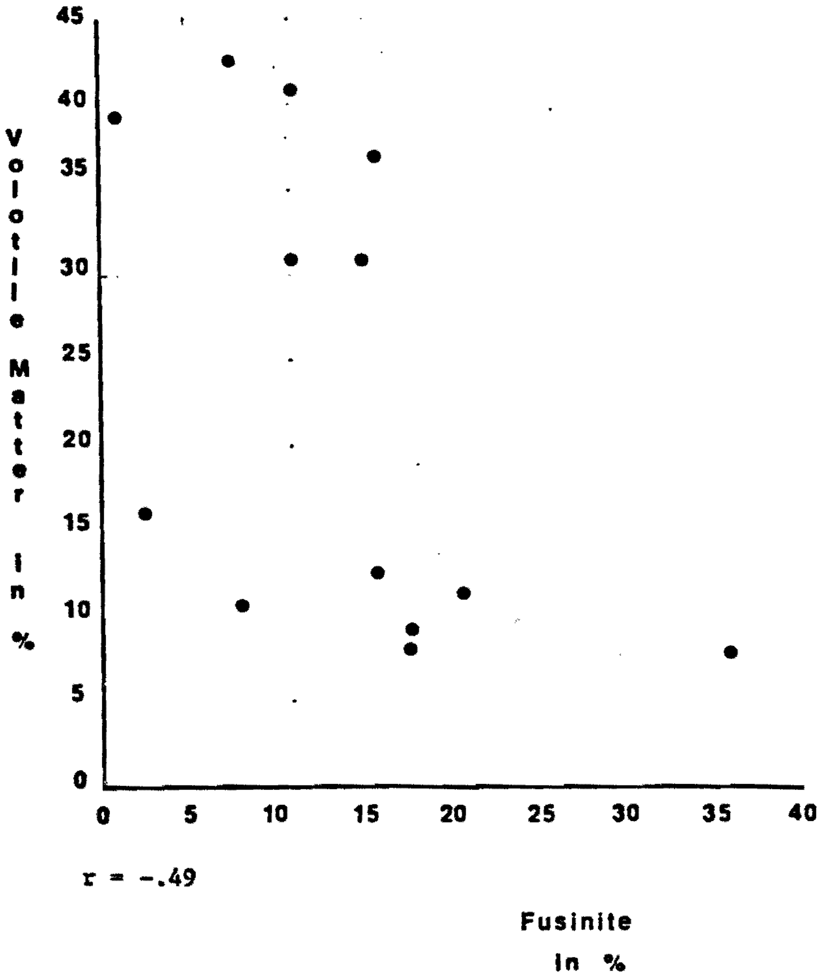
(d)



r = .90

Figure 13. (Continued)

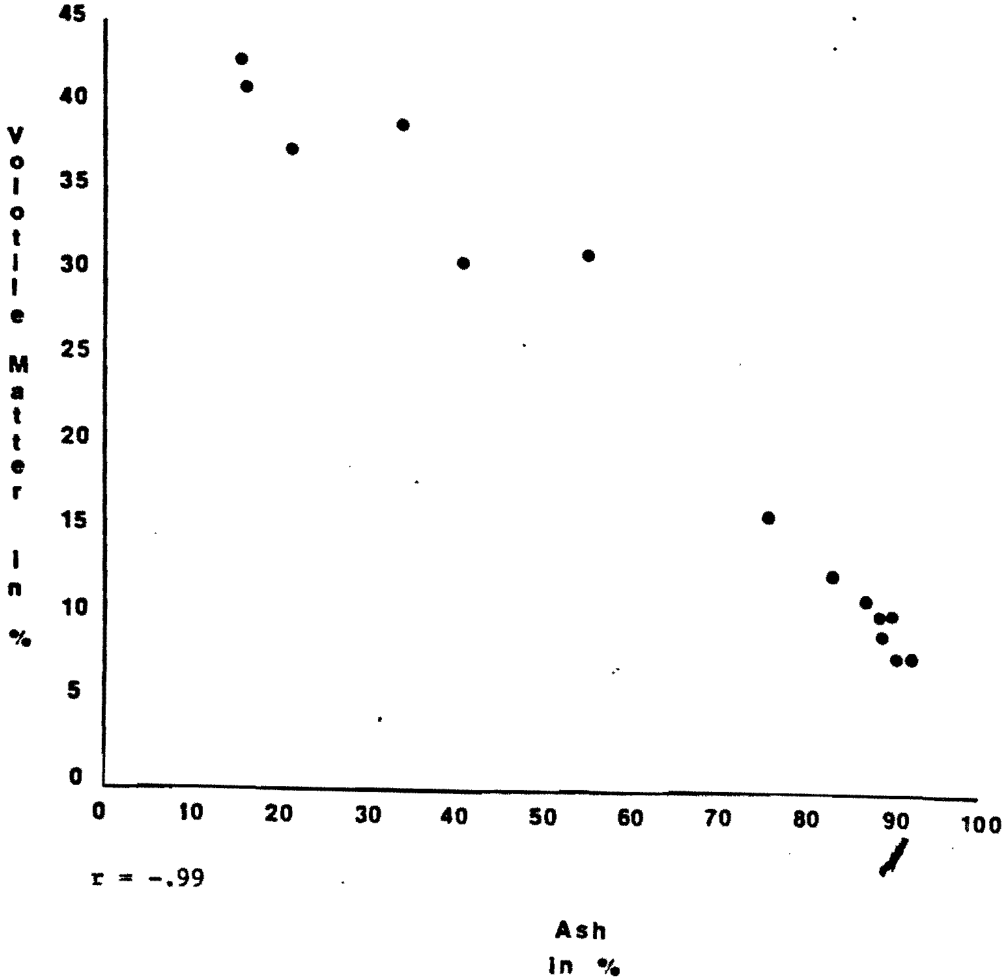
(e)



r = -.49

Figure 13. (Continued)

(f)



r = -.99

Figure 14. Correlations Between Fixed Carbon and: (a) Moisture, (b) Clay, (c) Ash Content, (d) Volatile Matter, (e) Corpohuminite, (f) Exinite.

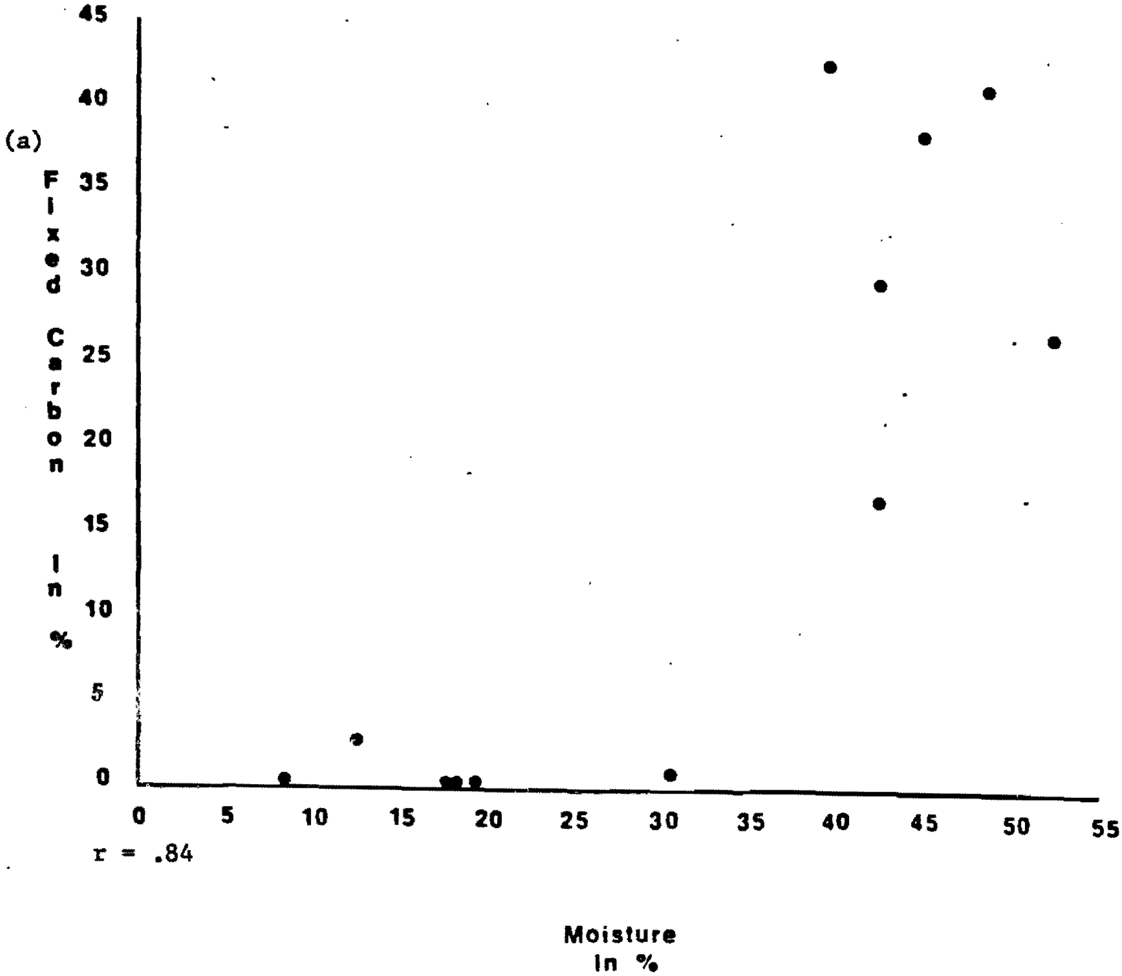
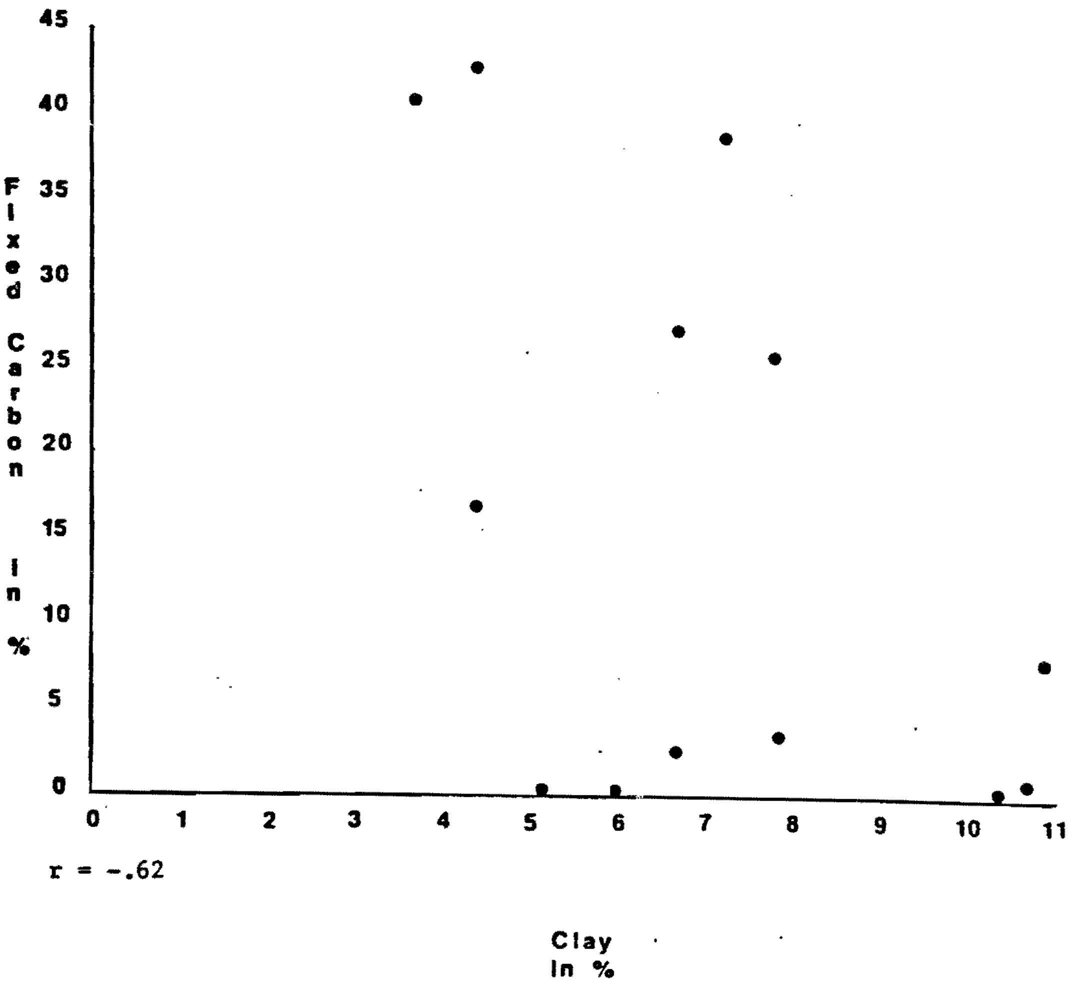


Figure 14. (Continued).

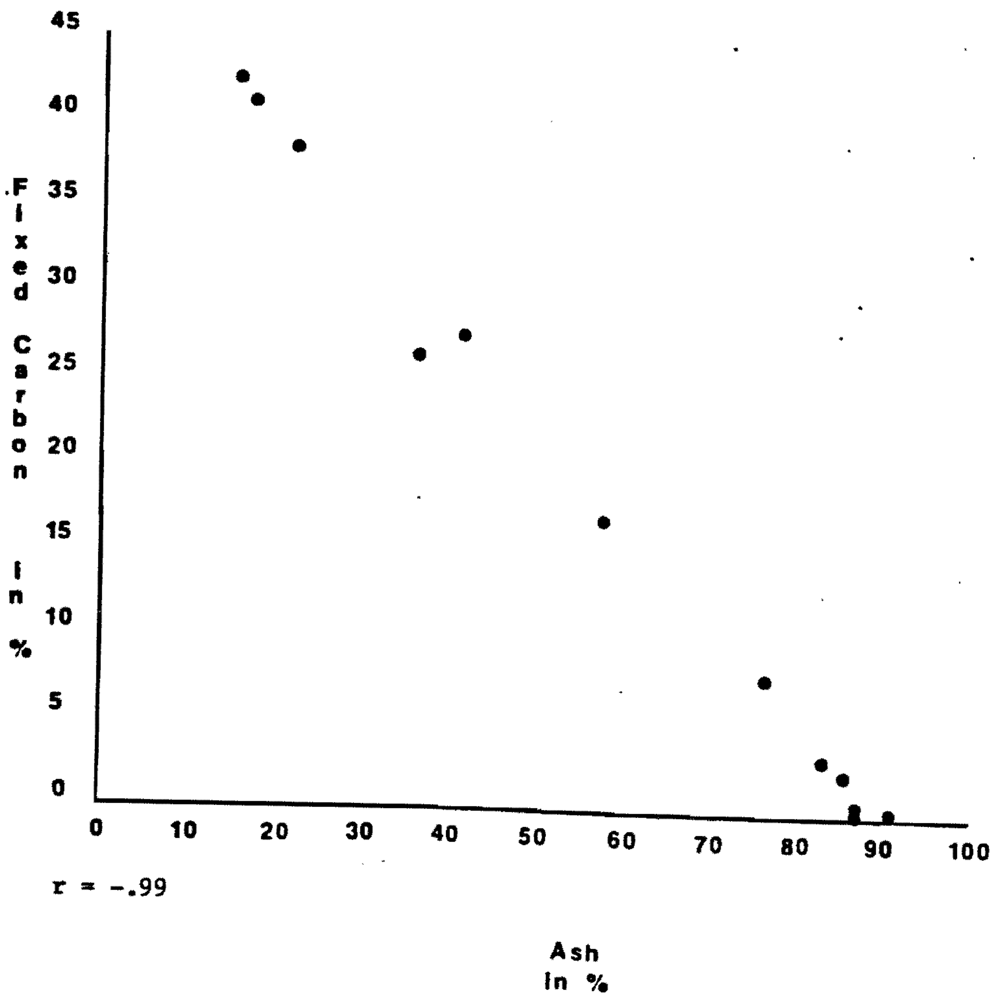
(b)



r = -.62

Figure 14. (Continued).

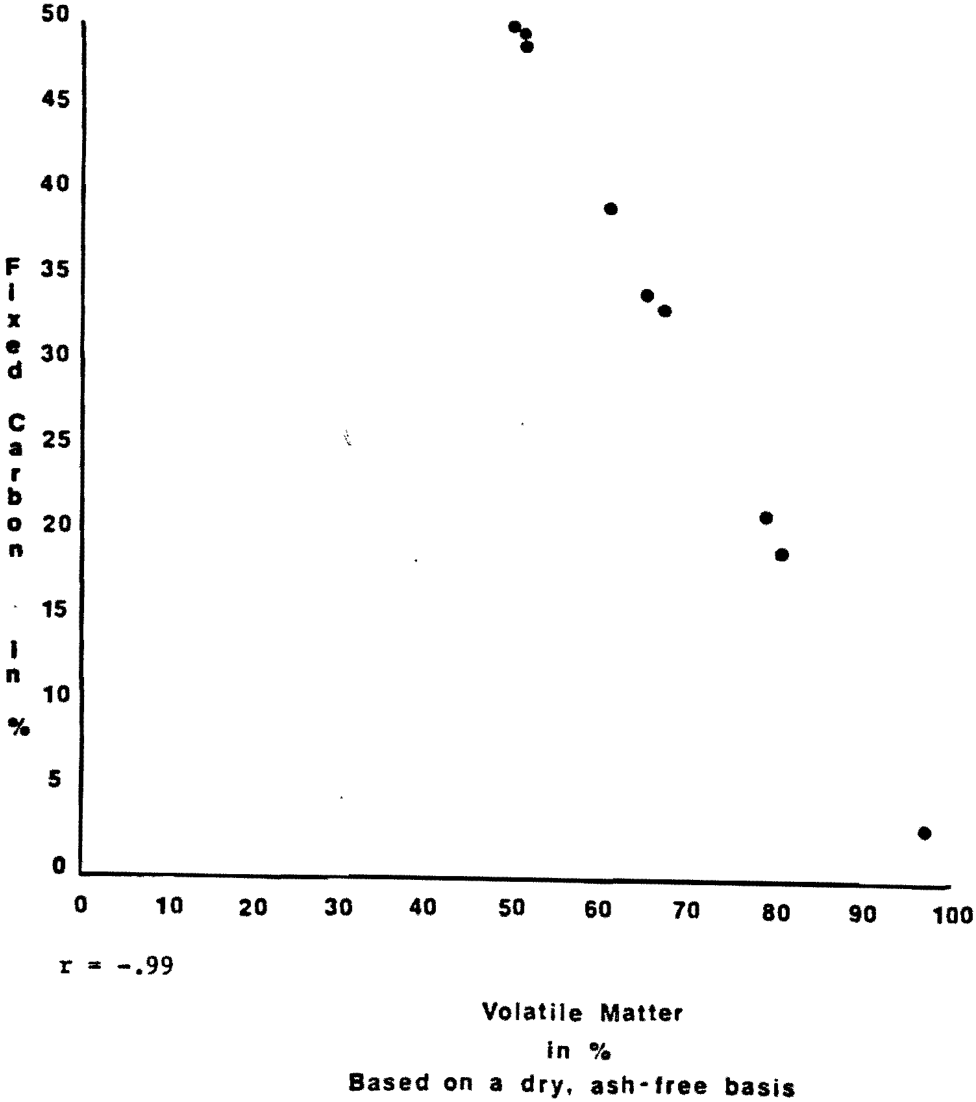
(c)



r = -.99

Figure 14. (Continued).

(d)



r = -.99

Figure 14. (Continued).

(e)

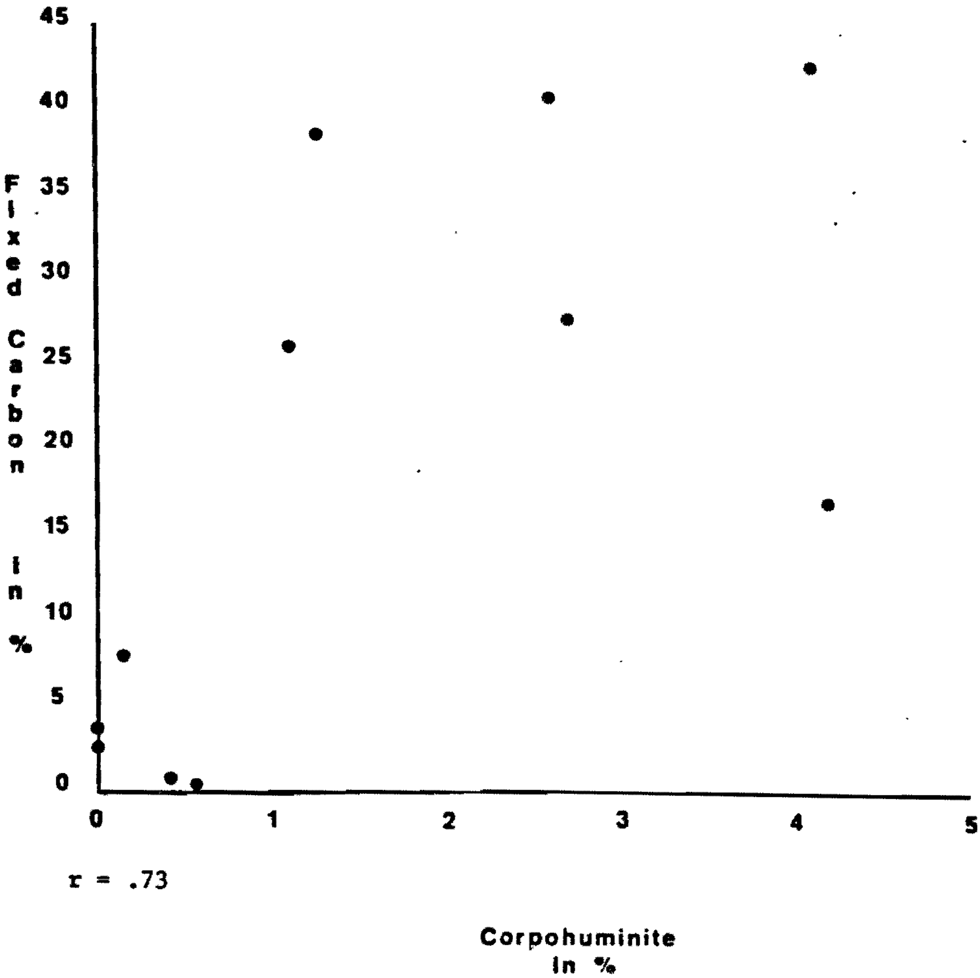
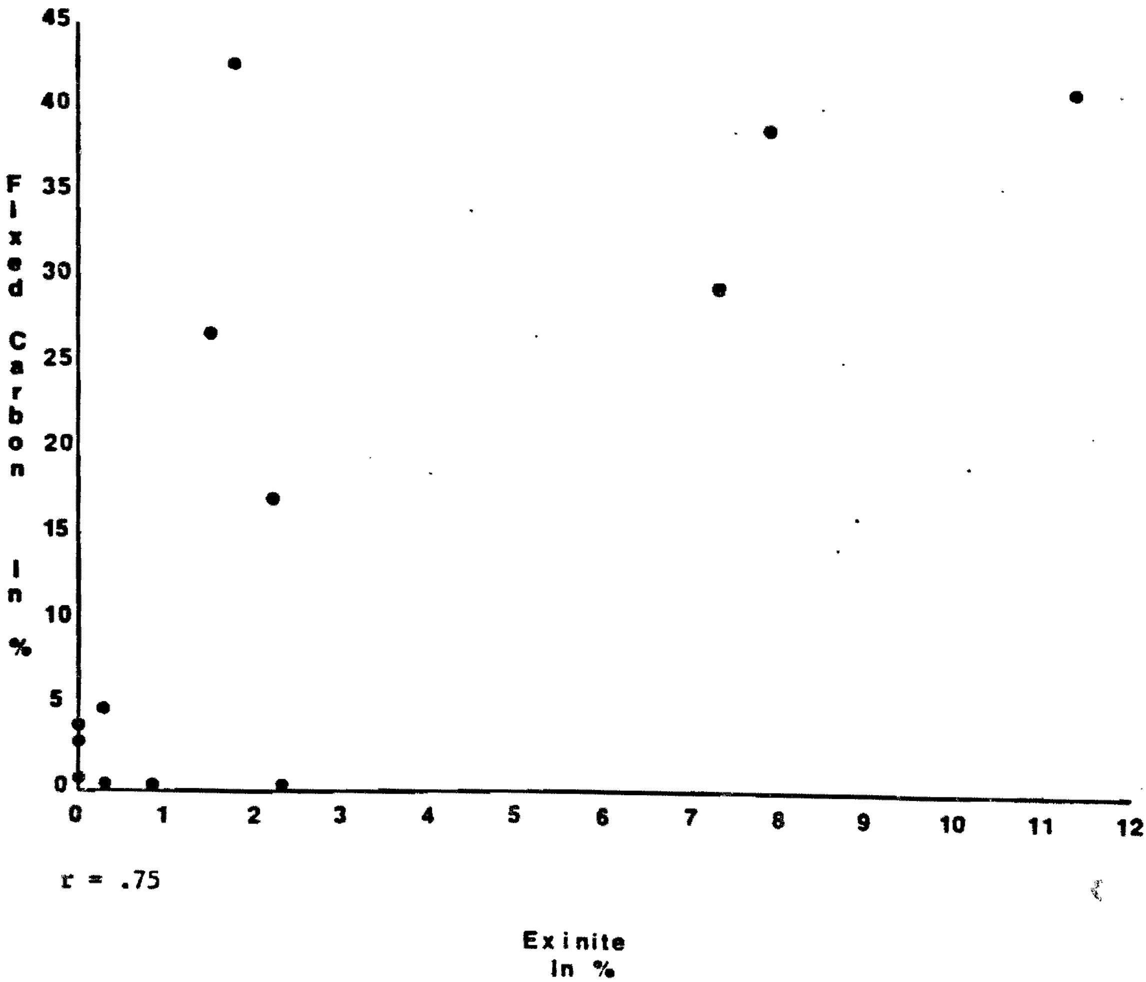


Figure 14. (Continued).

(f)



r = .75

Figure 15. Correlations Between Corpohuminite and: (a) Moisture, (b) Fixed Carbon, (c) Volatile Matter, (d) Ash.

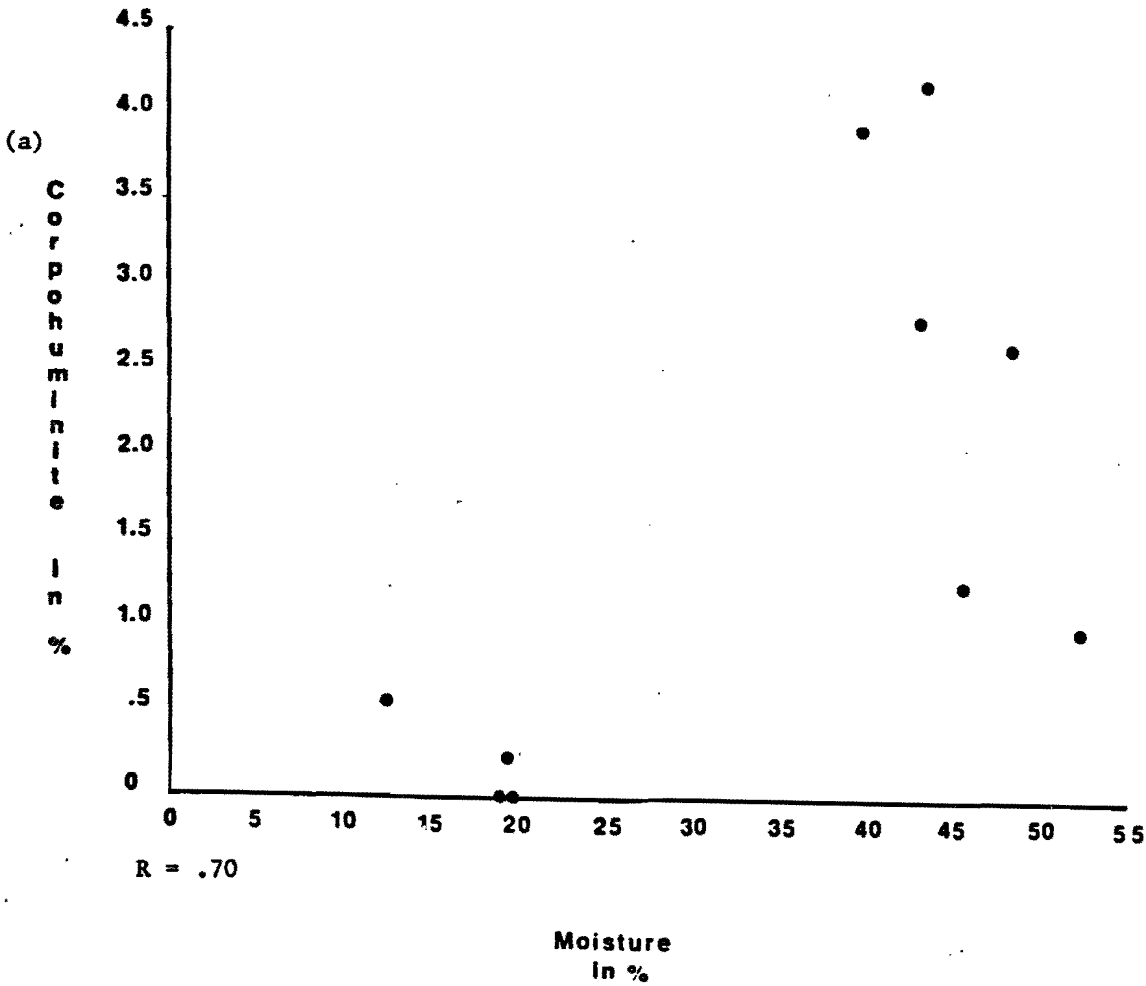
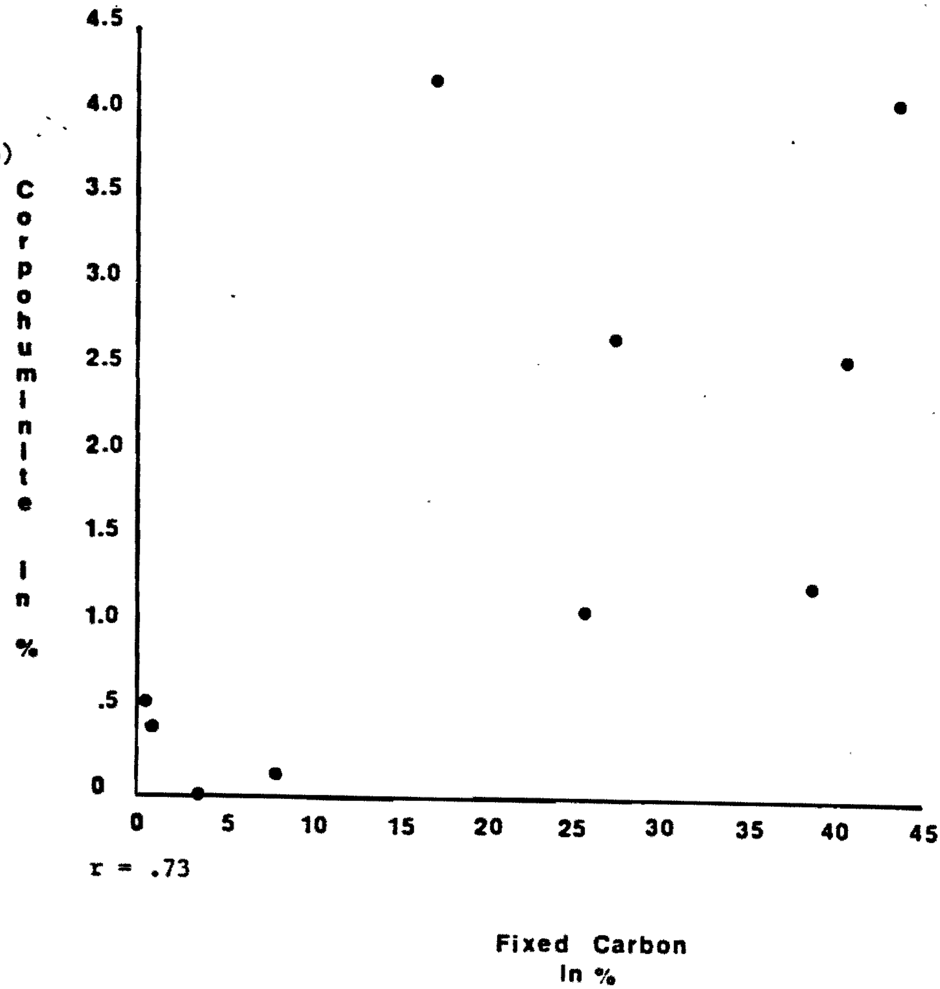


Figure 15. (Continued).

(b)



r = .73

Figure 15. (Continued).

(c)

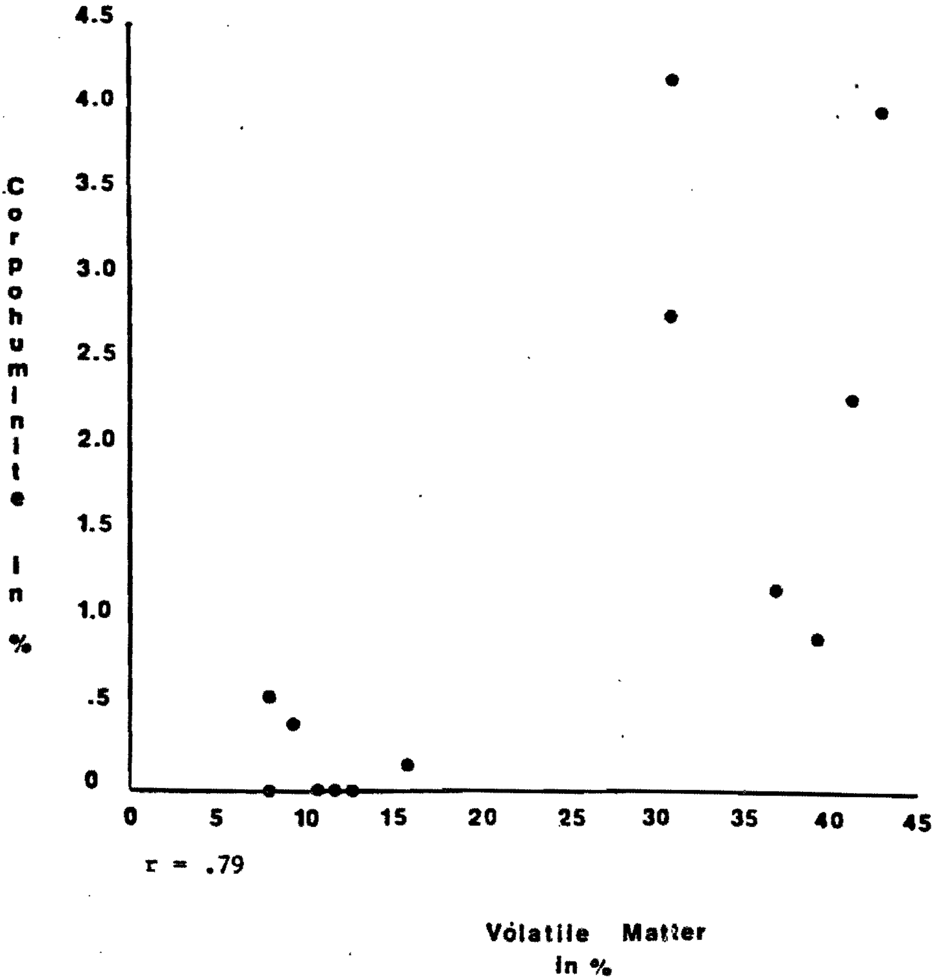
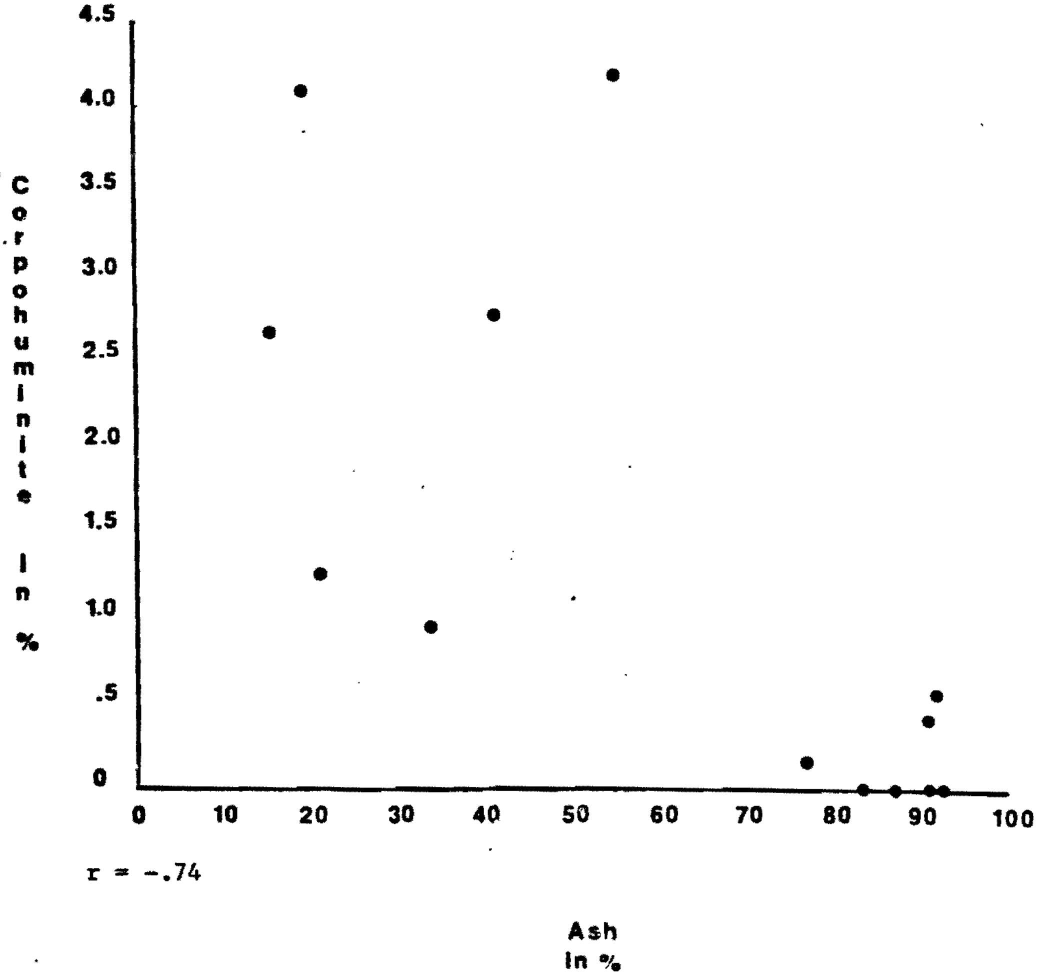


Figure 15. (Continued).

(d)



r = -.74

Figure 16. Correlations Between Humodetrinite and: (a) Textinite, (b) Ulminite, and (c) gelinite.

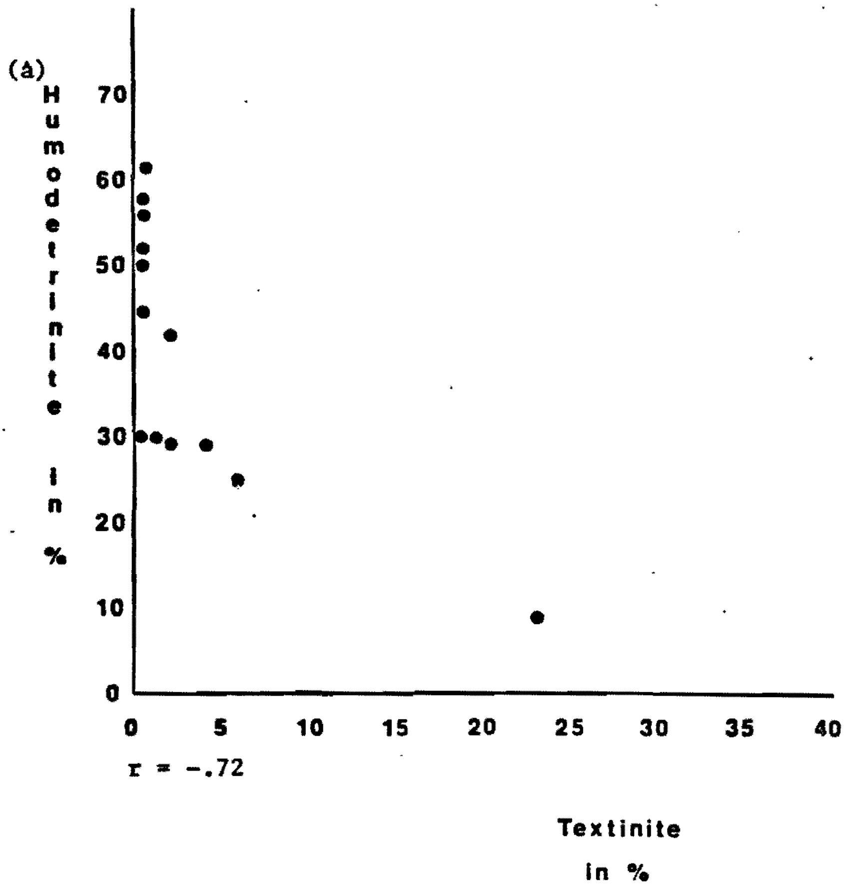
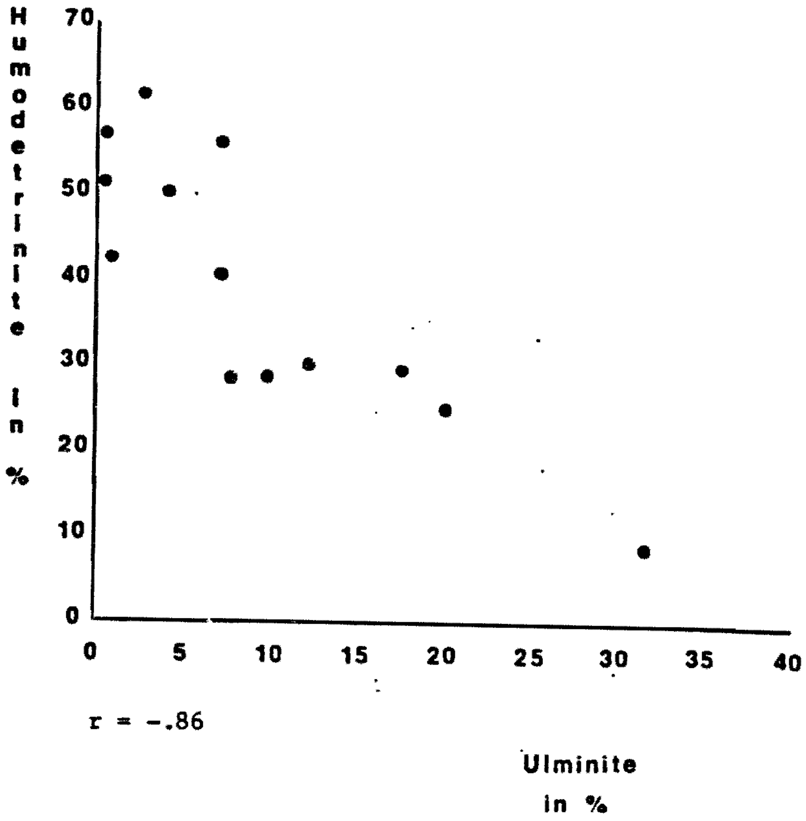


Figure 16. (Continued).

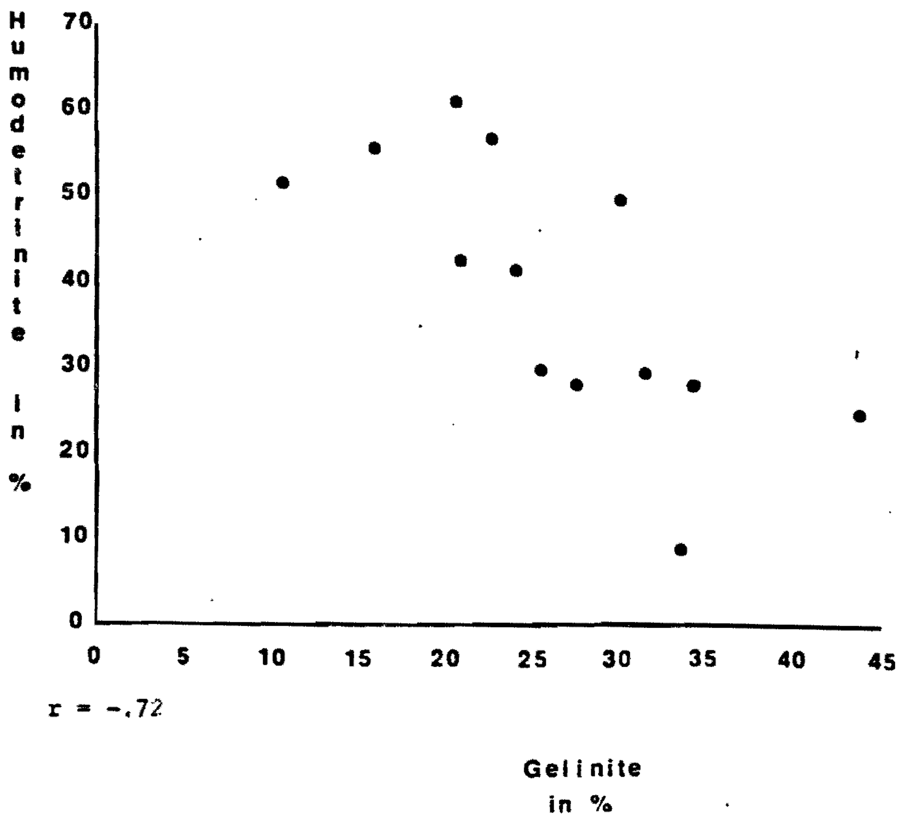
(b)



r = -.86

Figure 16. (Continued).

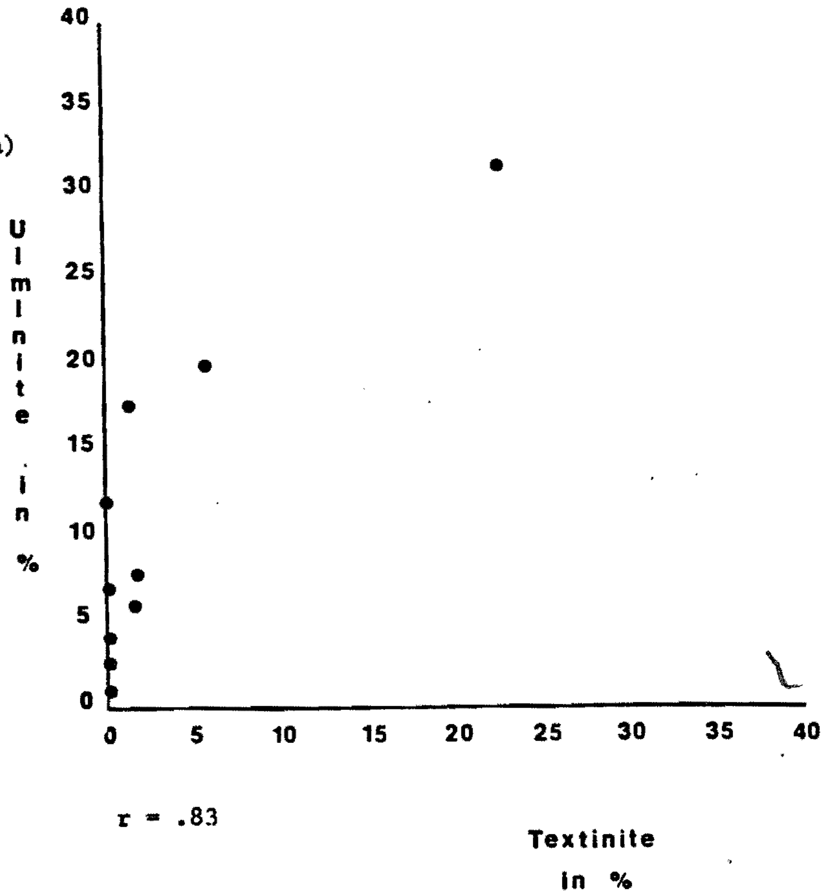
(c)



r = -.72

Figure 17. Correlation Between Ulminite and: (a) Textinite, (b) Volatile matter, (c) Ash, and (d) Moisture.

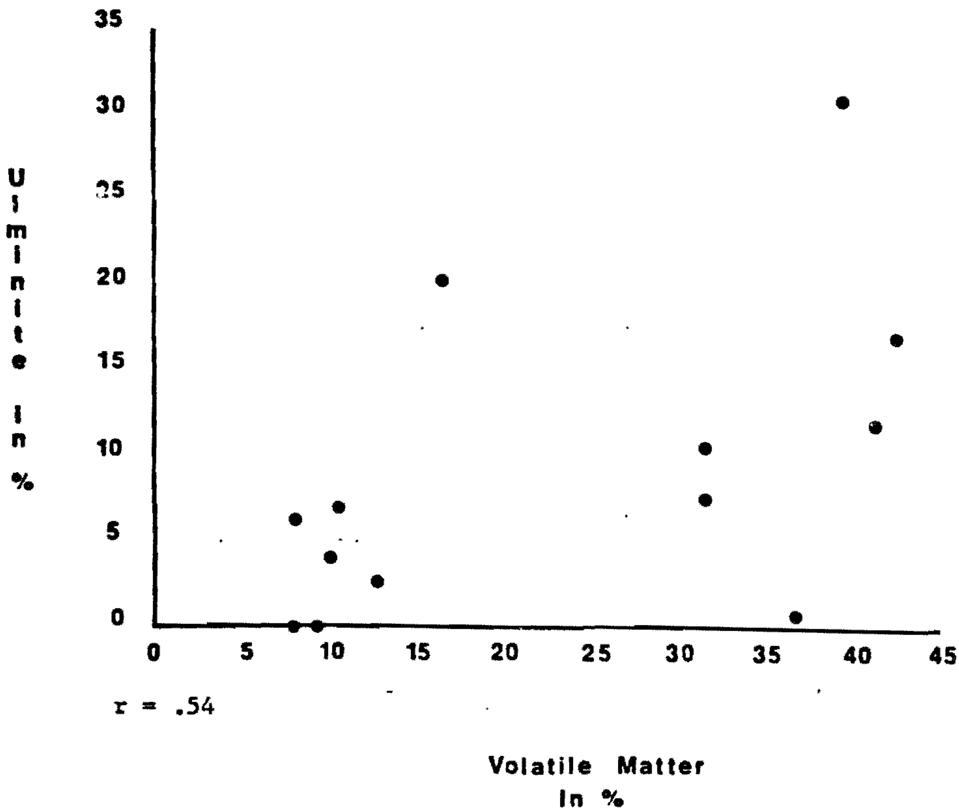
(a)



r = .83

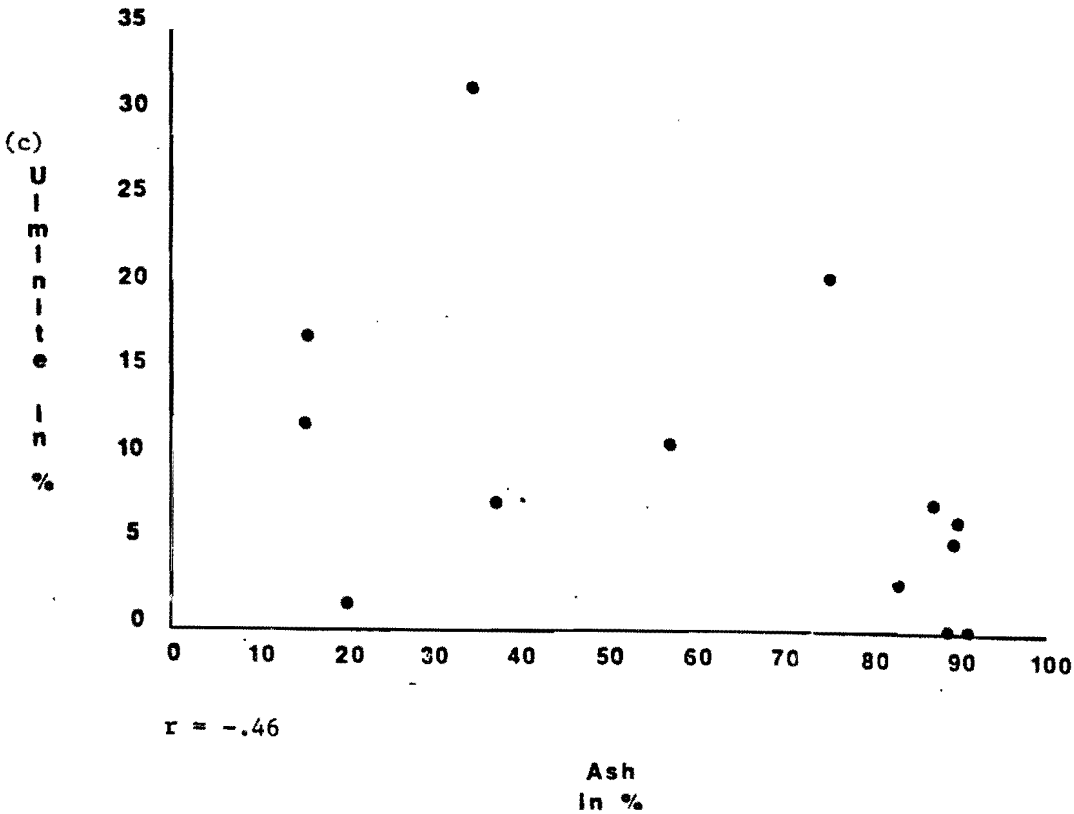
Figure 17. (Continued).

(b)



r = .54

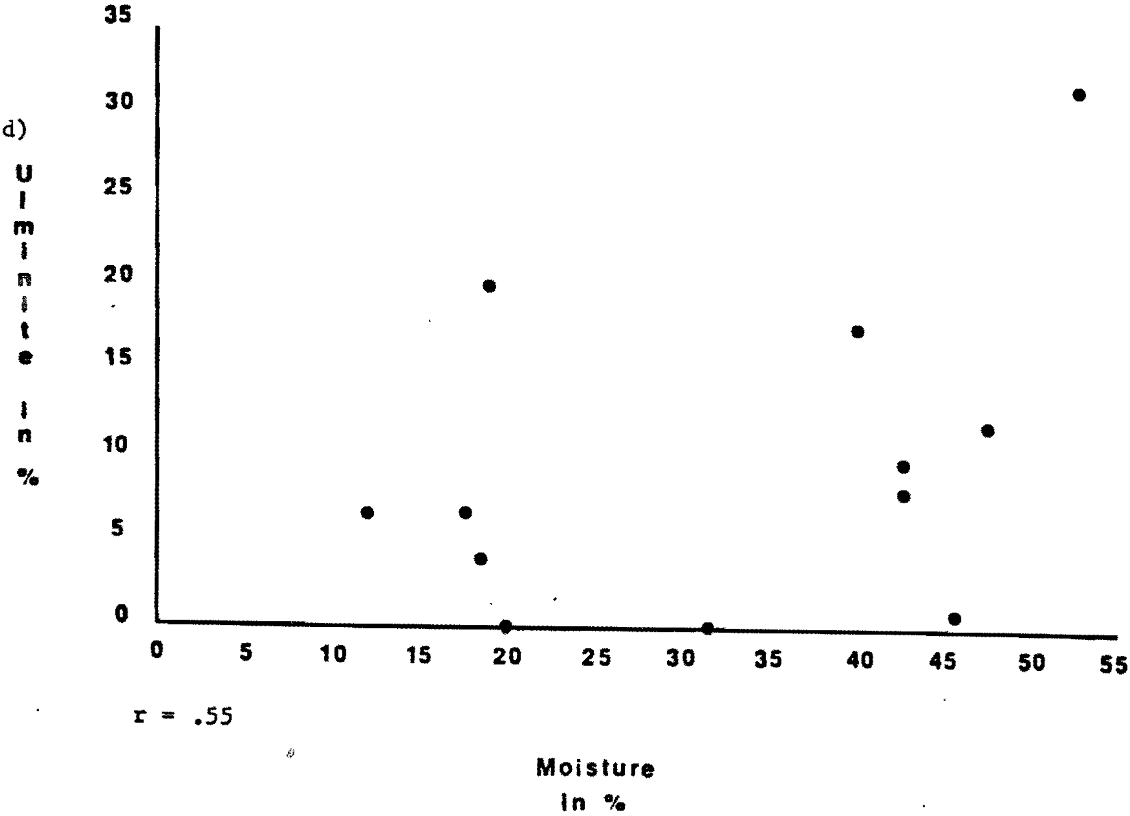
Figure 17. (Continued).



r = -.46

Figure 17. (Continued).

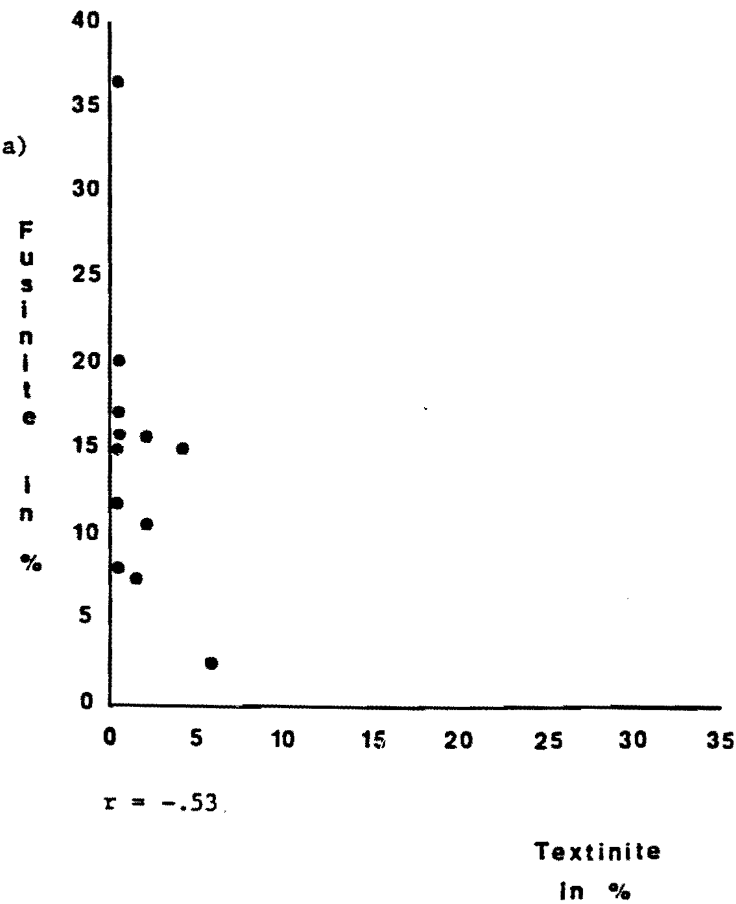
(d)



r = .55

Figure 18. Correlation Between Fusinite and: (a) Textinite, (b) Ulminite, (c) Gelinite.

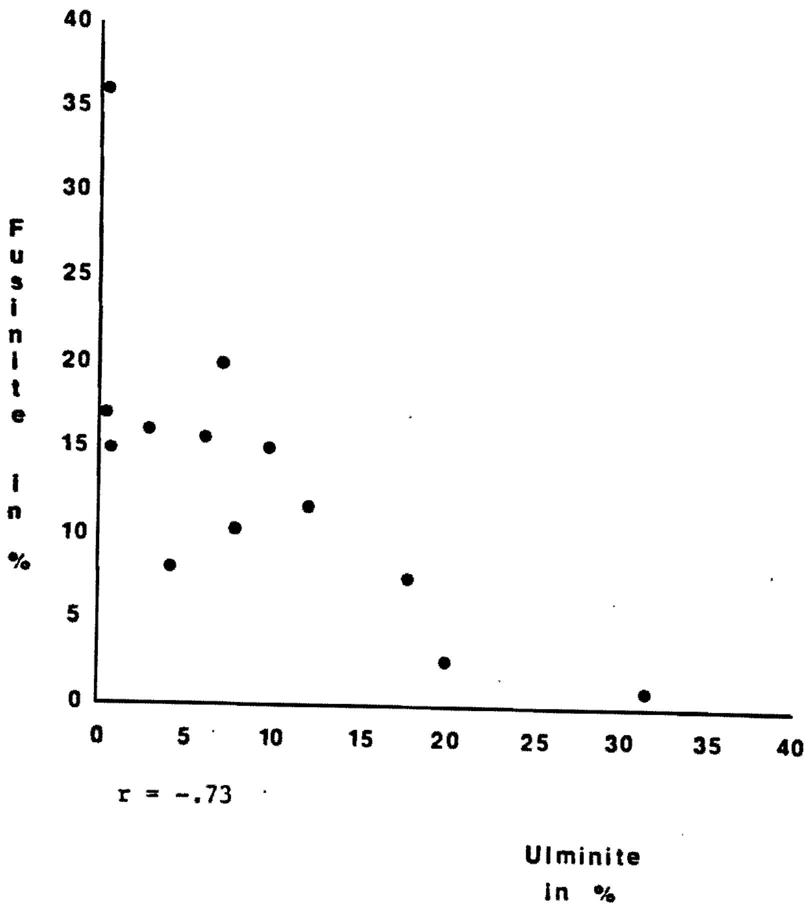
(a)



r = -.53

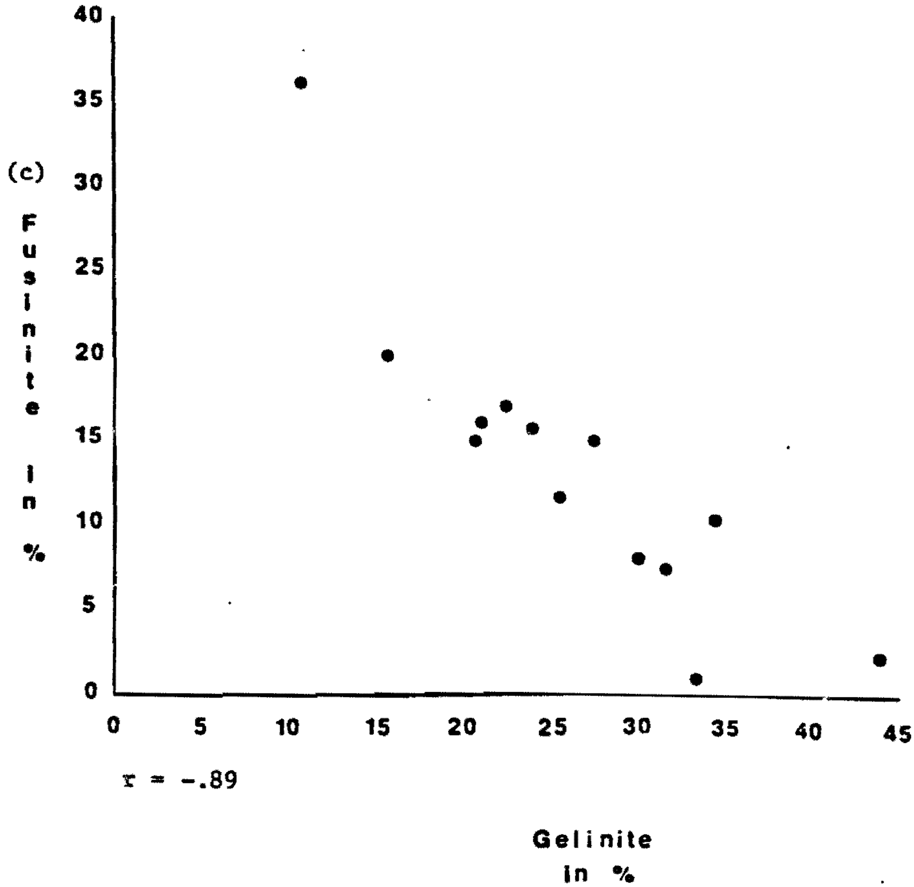
Figure 18. (Continued).

(b)



r = -.73

Figure 18. (Continued).



DISCUSSION

WILCOX GROUP LIGNITE DEPOSITION AND SEA-LEVEL

During the Early Eocene, many delta systems lined the Gulf Coastal Plain, due to the deposition of large quantities of terrigenous materials brought to the edge of the continent from erosion of the uplifted Appalachian region, concurrent with slow, steady subsidence of the Mississippi Embayment. In the Gulf Coastal Plain region, backswamps and interdistributary environments on broad lowland plains bordering a restricted shelf, were favorable sites for deposition and development of peat (Lowe, 1933).

Most of the Wilcox Group of Mississippi was deposited during a major marine regression during the Early Eocene. However, the Nanafalia Formation of the Lower Wilcox Group and the Bashi Marl Member of the Hatchetigbee Formation (Upper Wilcox Group) were deposited during marine transgressions. The Upper and Lower Nanafalia Formation were deposited in beach, delta fringe, and restricted shallow-marine environments, while the Middle Nanafalia Formation was deposited in an inner neritic environment (Mellen, 1964). Sediments overlying lignite at location "K-1" contain small marine oysters, <u>Ostrea thirsae</u>, and glauconitic marine sands, which indicate a shallow marine depositional environment for this sample location. Transgressive marine sediments and possible facies relationships analogous to Wilcox Group sediments in the study area are shown in Figure 19. As marine waters

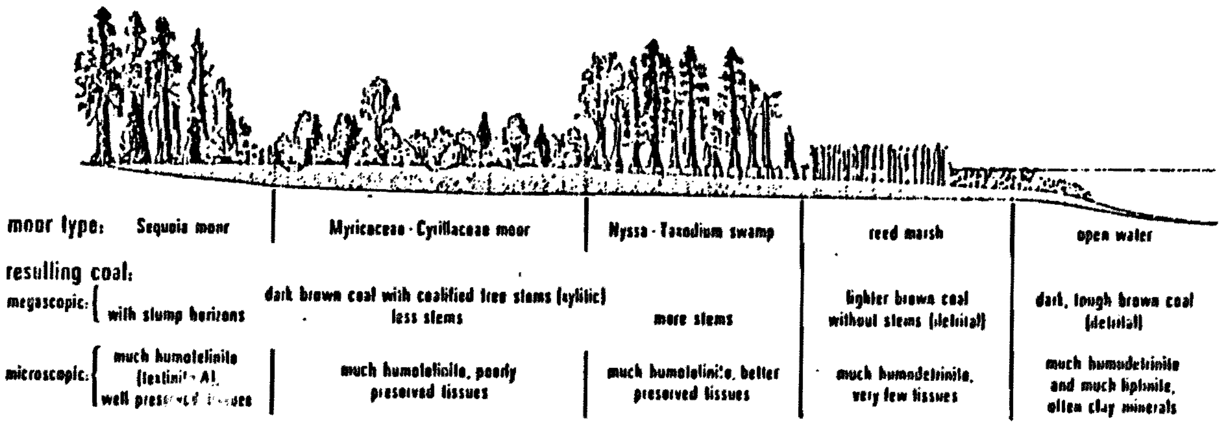


Figure 19. Expected coal macerals produced by decomposition of various plant communities (from Stach and others, 1982, p. 287).

transgress and the delta slowly subsides, peat deposits are buried and preserved. Marsh environments then continue to increase landward and produce favorable environments for plant accumulation. Hughes (1958) has stated that marine sediments outcrop only in the southwestern portion of Kemper County. All other lignite outcrops examined in this study are associated with terrigenous sediments, so this could indicate that Location "K-1" marks the northernmost extension of transgressive shallow seas. However, this may not necessarily be the case, as subsequent erosion of marine sediments by a fluvially-dominated environment could have reworked sediments during the later (Middle Eocene) marine regression that led to the deposition of the Tuscahoma Formation.

DEPOSITIONAL PALEOENVIRONMENT

Favorable conditions for organic accumulation and peat formation probably occurred in depressions between interdistributary channels of a destructive prograding delta lobe (Figure 19). Organic-rich sediments accumulating in such an environment would have been isolated in depressions on a slightly higher terrain in deltaic areas. Peats resulting from this depositional model would be thinly-bedded, limited in lateral extent, and contain large quantities of sand (Cleaves, 1980), which agrees with the results of this study. In Kemper County, lignite exposures are thin, tabular deposits with limited areal extent, which were formed in an area influenced by fluvial sedimentation, as seen by the large amounts of sand-sized material and high ash contents of the lignites and associated sediments (Figures 6 and 8, Appendix A).

Palynological studies on Lower Eocene Wilcox Group lignites of East Central Mississippi (Warter, 1965) indicate the presence of a warm, temperate to tropical climate. Pollen of plants characteristic of swamps and streamside environments were commonly found in these lignites, along with pollen from plants adapted to dry, sandy soils. Dinoflagellate cysts from marine plankton were present in underclays of the Nanafalia Formation (Stewart, 1971), which reinforces the conclusion that a low-lying, near-coastal environment was present in Kemper County during the Early to Middle Eocene.

PROXIMATE ANALYSIS

Proximate analysis on lignite samples examined in this study indicates that ash is the dominant constituent of these low-rank coals (Figure 6). Most of this ash appears to be sand-sized quartz grains, which may be seen by field observation to be interbedded with lignite laminae, a conclusion that is reinforced by grain-size analyses of individual lignite seams (Figure 8). Another important constituent of the ash is muscovite, which can be seen to be evenly dispersed throughout the lignite, and is also identifiable by X-ray diffraction of bulk sediment samples.

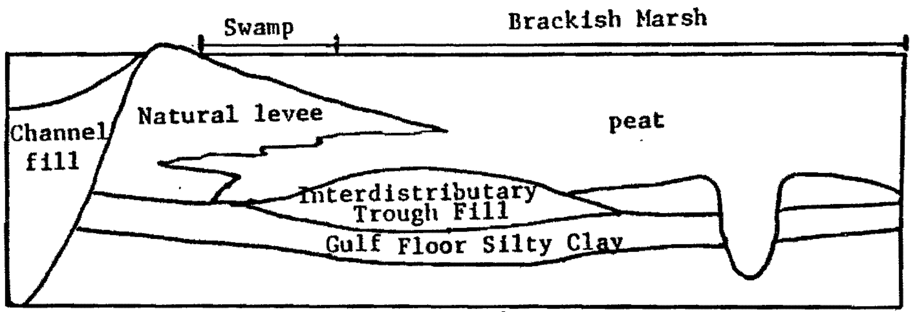
Volatile Matter Content

The volatile matter of Kemper County lignite has an average value of 21% (Figure 6), and fixed carbon has an average value of 12% (Figure 8). This is in agreement with Stach and others (1982), who indicate that volatile matter decreases and fixed carbon increases with an increase in the coal rank (Figure 20), so lignites should be characterized by high volatile matter content and low fixed carbon content.

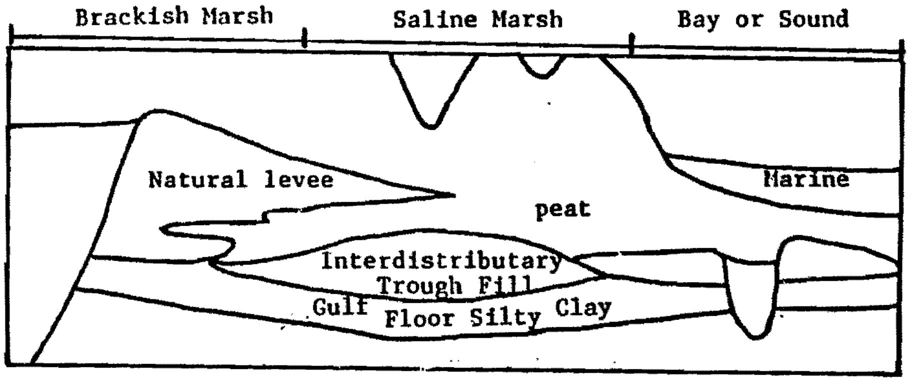
The greater the quantities of more-gelified macerals, the higher the volatile matter content of the lignite. For example, volatile matter shows positive correlation with ulminite (Figure 13a), exinite (Figure 13b), and corpohuminite (Figure 13c). The strong positive correlation between volatile matter and exinite is explained by the high hydrogen content of exinites (International Committee for Coal Petrology, 1971). The relationships between volatile matter and corpohuminite and ulminite may be explained by the degree of coalification of the lignite. Corpohuminite is relatively resistant to change during early stages of coalification, and ulminite may be considered a maceral which has not undergone much physical or biochemical alteration (ICCP, 1971).

Volatile matter is higher in low-rank coals (Stach and others, 1982), so the positive correlations between these variables may be related to the relative rank of the lignites, which in turn may be related to the

Figure 20. Facies Relationships in subsidizing deltaic deposits.



1. Swamp advances over subsiding levee.



2. Continued subsidence with transgression by marine deposits.

From Gutzler (1979).

depositional environment. A lower-energy environment would be more favorable to the presence of ulminite, exinite, and corpohuminite, which would tend to increase the volatile matter content. A negative correlation between volatile matter and fusinite (Figure 13e) is due to the high-carbon, low-hydrogen content of this maceral.

Fixed Carbon Content

A positive correlation exists between fixed carbon and moisture content of Kemper County lignites. Both variables correlate negatively to the ash content in the lignite. High ash content results in a low moisture content due to the low-moisture, non-combustible nature of ash and the environment which is favorable for its deposition. Fixed carbon would also be negatively correlated due to the lack of constituent particles which contain carbon (macerals), due to a high-enery environment and high ash content.

In addition, a strong negative correlation is seen between fixed carbon and ash content, due to the high-energy depositional environment hypothesized for these lignites. Higher-energy environments are less favorable for preservation of gelified macerals, which would in turn lead to higher ash content. This is substantiated by the negative correlations between ash and ulminite (Figure 9a), exinite (Figure 9b), and corpohuminite (Figure 9c). The negative correlation between fixed carbon and clay-sized particles (Figure 14b) is due to the high ash content in the clay size-fraction, which will be discussed later in this chapter. Positive correlations are seen between the fixed carbon content and the concentrations of corpohuminite (Figure 14e) and of exinite (Figure 14f). An increase in these macerals would result in a higher carbon content and a lower ash content, which would translate into higher measured values of fixed carbon.

Perhaps the strongest correlation seen in this study is the negative relationship between fixed carbon and volatile matter (Figure 14d), which is due to the decrease in volatile matter concurrent with an increase in fixed carbon content, during progressive coalification (Stach and others, 1982) (see Figure 21).

Ash Content

Volatile matter and fixed carbon components of proximate analysis are dependent upon the presence of macerals with high hydrogen content (fusinites) and high carbon content (exinites), which are deposited primarily in low-energy environments. The high-energy paleoenvironment of deposition of Kemper County lignites would be more favorable for the formation of macerated maceral components, and the deposition of lignites with higher ash contents. This would account for the strong negative correlation between ash and volatile matter, and between ash and fixed carbon content (Table 3; FIGURE 14c).

A slight positive correlation between ash content and percent clay (Figure 11) could indicate that most of the ash content of these lignites originated as

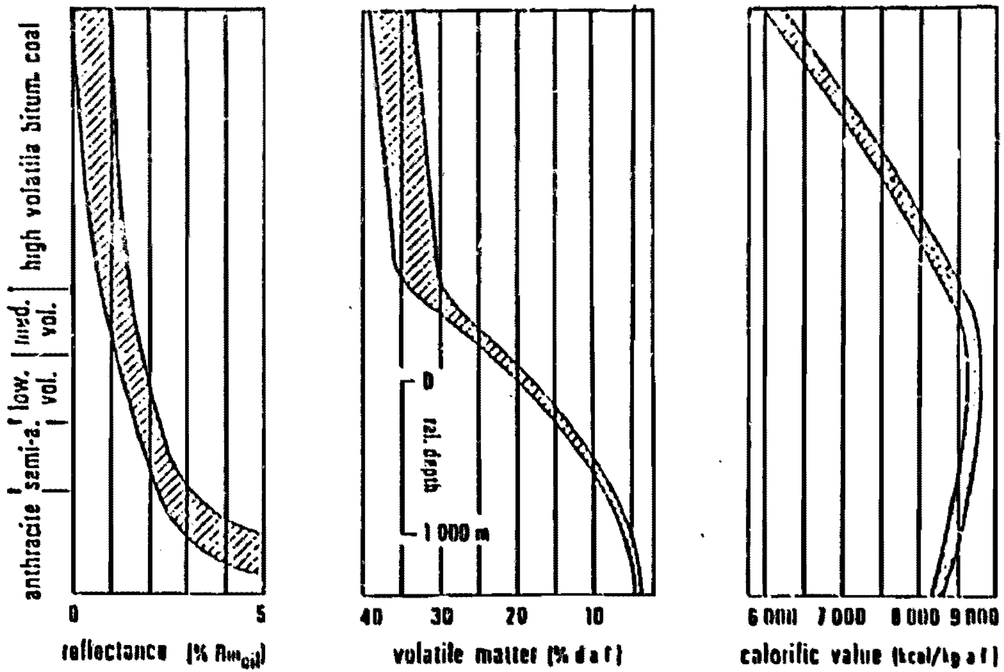


Figure 21. Plots of various parameters of coal showing their changes as compared with increasing coal rank (from Stach and others, 1982, p. 41).

clay-sized particles. Inorganic matter in coal may be introduced into the seam by several methods (Gutzler, 1976):

1) Inorganic matter from the original plant material.
2) Inorganic minerals formed during organic accumulation and peatification.
3) Inorganic minerals introduced by wind and streams during organic accumulation and peatification.
4) Minerals introduced after consolidation of organic matter, by percolation through cracks and fissures.

One or all of these processes could account for the positive correlation between ash content and clay-sized fraction of the lignites. However, greater study of this relationship is needed to validate this hypothesis.

The conditions hypothesized for the accumulation and preservation of organic matter would also enhance the ash content of lignites. Streams provide a means of transport and burial of organic sediments in depressions of the delta plain, but they may also have eroded previously-deposited organic material and peat, while depositing sand-sized quartz and other non-combustible sediment particles.

The negative correlations between ash content and ulminite content (Figure 9a), exinite content (Figure 9b), and corpohuminite content (Figure 9c) are in agreement with this depositional model. All three of these macerals would be physically macerated, biochemically transformed, and/or transported away from depocenters in a high-energy, well-oxygenated environment. The low values and limited distribution of these macerals in the study area could indicate an environment with moderately high energy input, but with insufficient energy to completely destroy or transport these organic deposits.

Components of ash, such as quartz, muscovite, and inorganic sedimentary particles, contain little or no moisture. The high concentrations of these inorganic particles are responsible for the negative correlation between ash content and moisture content (Figure 10).

Moisture Content

In general, Wilcox Group lignites of Mississippi have high (approximately 40-45%) moisture content and volatile content (Williamson, 1976), while Kemper County lignites contain relatively low quantities of volatile matter, and have a lower average moisture content (30%). In these samples, moisture content appears to be lower than normal due to the high ash concentrations, and volatile matter and fixed carbon are lower due to the small amounts of important macerals.

Moisture content has a negative correlation with humodetrinite (Figure 12a). Humodetrinite is composed primarily of macerated humic substances, and appears to be associated with high-energy environments which would be favorable for the deposition of low-moisture inorganic materials (such as quartz and muscovite). In fact, ash, quartz, and muscovite are all negatively correlated to moisture content (Table 3). Moisture has a moderately strong positive correlation with the corpohuminite (Figure 12b) and exinite (Figure 12c) contents of the lignites. An environment favorable to the existence of humodetrinite would be unfavorable to the existence of corpohuminite and exinite, as a well-oxygenated, high-energy environment could break down or transform corpohuminite in the transformation from peat to lignite (Gutzler, 1979). The majority of the exinites in Kemper County lignites are sporinites, or outer membranes of spores and pollen grains, which are resistant to physical and chemical degradation. However, sporinites may be transported away from the sites of organic accumulation during the early states of consolidation and coalification.

Volatile matter (Figure 13d) and fixed carbon (Figure 14a) demonstrate strong positive correlations to moisture content. Volatile matter and fixed carbon values are directly dependent upon the presence of certain macerals, which contain adequate amounts of hydrogen and carbon, as discussed previously.

If the lignite components are dominated by humodetrinite and ash, due to a destructive paleo-environment, then volatile matter and fixed carbon contents will be lower. This relationship is seen by the negative correlation between ash and humodetrinite (Figure 12a) and by the negative correlation between ash and moisture content (Figure 13f) previously discussed.

MACERAL CONTENT

Petrographic analyses indicate that humodetrinite and gelinite are the most abundant macerals present in Kemper County lignites. Humodetrinite results from the decomposition of humic substances during the peat stage (ICCP, 1971), and is probably derived from herbaceous plants and wood of angiosperms which contain little cellulose or lignin. Gelinite consists primarily of precipitated humic gels, and may be formed syngenetically during the latter stages of peat formation by the gelification of humodetrinite (Stach and others,1982). Gelinite could be formed by increased microbial activity in turbulent, oxygenated waters with the hydrologic potential for transportation of sand-sized quartz grains. In such an environment, rapid chemical reduction of plant material to amorphous substances could occur, with subsequent precipitation into gelinite (Gutzler, 1979).

Minor maceral components of lignites examined in this study include textinite, ulminite, corpohuminite, fusinite, and semifusinite. These macerals are generally derived from the wood and bark of conifers (ICCP, 1971). However, the small amount of these macerals in Kemper County lignites indicates either a sparse distribution or an absence of large trees in the depositional area. Very few plant remains were found in lignites in this study area, but Dueitt (1985) reported several preserved tree stumps in Wilcox Group lignites in Calhoun County, Mississippi, to the northwest of this study area. Dueitt concluded that his study area of Winston and Choctaw counties was dominated by deposition of grasses, reeds, and angiosperms, a conclusion that is in agreement with the depositional environment of Kemper County.

Large quantities of humodetrinite and gelinite, along with a high ash content and large amounts of sand-sized material, indicate that the sites of organic accumulation and peat formation in Kemper County were high-energy, low-lying deltaic environments dominated by reeds, grasses, and angiosperm wood (Figure 21). These types of plants are high in cellulose, and low in lignins which are resistant to decomposition.

Humodetrinite

Humodetrinite is negatively correlated to textinite (Figure 16a), ulminite (Figure 16b), and corpohuminite. Textinite originates from resistant plant tissues of conifers, and ulminite from bark, parenchyma, and sclerenchyma which may be impregnated by resins and tannins (ICCP, 1971). In contrast, humodetrinite consists of materials from herbaceous plants and angiosperms that are non-resistant to physical and biochemical transformation. A moderately-high depositional conditions relative to a deltaic enviornment with an abundance of grasses and reeds would favor the formation of humodetrinite, while textinite and ulminite formation would occur in more-wooded, lower-energy environments.

Humodetrinite has a negative correlation with gelinite. Gelinite consists primarily of precipitated humic gels, which may originate from humodetrinite in the later stages of coal formation. Gelinite is abundant in brown coals, and is associated with sandy sediments (Gutzler, 1979). The negative correlation between these two macerals may be due to the direct transformation of humodetrinite to gelinite. Environments favorable to humodetrinite would have a low rate of coalification, and thus a low gelinite content. The formation of gelinite from humodetrinite during coalification would produce an inverse relationship.

Fusinite is positively correlated to humodetrinite content (Table 3). Fusinites may be formed by fire or by oxidation during the coalification process. They are very light and porous, and are susceptible to transportation by wind and air. In an open depositional system, carbonaceous matter may be transported into, and deposited within depressions with high oxygen content. Such a system could have redeposited fusinites, and the oxidative degradation of plant materials would be favorable to the formation of humodetrinite. In addition, microbial activity in such an environment could transform other macerals to fusinite (Gutzler, 1979), which may also explain the correlation between fusinites and humodetrinites.

Corpohuminite and Exinite

Corpohuminite demonstrates positive correlations with moisture (Figure 15a), fixed carbon

(Figure 15b), and volatile matter (Figure 15c), and a negative correlation with ash content (Figure 14d). These associations have all been previously discussed in the Proximate Analysis section. Both corpohuminite and exinite show positive correlations with moisture, volatile matter, and fixed carbon, and negative correlations with ash content (Table 3). Despite their similar trends, these macerals show only a slight (r=0.48) positive correlation to each other. The low correlation between corpohuminite and exinite may be due to the fact that while both macerals originate from the same materials and share the same environment during the early stages of coalification, they are not directly related to each other. Corpohuminite originates from tannin-rich cell excretions, such as lichens, algae, and fungi, while exinites originate from slightly-altered algal cell walls, spores, and cuticles (ICCP, 1971). Despite their different origins, both macerals tend to be preserved in similar depositional paleoenvironments.

Ulminite

A strong positive correlation between ulminite and textinite (Figure 17a) is due to the similarity of origin of these two macerals. Both textinite and ulminite are composed of cell wall material from woody tissues of conifers. (Despite their strong correlation, only small amounts of these macerals were found in Kemper County lignite samples examined in this study, which also points to the general lack of woody materials in the Early Eocene source areas for Wilcox Group lignites.) The correlations between ulminite and volatile matter (Figure 17b), ash (Figure 17c) and humodetrinite (Figure 16b) have all been previously discussed. A positive correlation between ulminite and moisture (Figure 17d) is seen.

Fusinite

Fusinites consist of highly reflective cell walls of lignin and cellulose, which originate primarily from conifers. They may be formed from peat fires in laterally extensive fusain horizons, or during the coalification process from textinite and exinite. Fusinites are high in carbon content and exinites have high hydrogen content (ICCP, 1971), so the presence of large quantities of these macerals would be indicated by higher fixed carbon and volatile matter contents, respectively. The characteristics of Kemper County lignites, as determined by proximate analysis, are summarized in Table 4.

Fusinite has a negative relationship to textinite (Figure 18a), ulminite (Figure 18b), and gelinite (Figure 18c). Textinite and ulminite are composed of cell wall material from woody tissues, and are basically absent from Kemper County lignites due to the lack of large trees in the depocenter and to the high-energy environment of coalification. The negative correlation between fusinite and gelinite is a complicated relationship, since both macerals may occur in identical environments. A well-oxygenated, aerobic environment is favorable for gelinite and fusinite formation, but fusinite is more easily reworked and transported due to its high porosity, so this may explain the negative gelinite-fusinite correlation. If fusinite is formed from textinite and ulminite during coalification, then the low occurrence of these two macerals would limit the presence of fusinite.

TABLE 4

GENERAL SUMMARY OF KEMPER COUNTY TERTIARY LIGNITES

Characteristics	Nanafalia Formation
Geometry	Tabular, limited areal extent, single seams.
Thickness of Seams	Thin to moderately thick
Geologic Setting	
Tectonics	Slowly subsiding delta
Regional	Sand-size clastics
Partings	Sandy clays
Composition	
Moisture	Moderately high
Ash	Very high
Volatile matter	Moderately low
Fixed carbon	Low
Petrology	
Textinite	Very low
Ulminite	Low
Humodetrinite	Very high
Gelinite	High
Corpohuminite	Very low
Fusinite	Moderately high
Semifusinite	Low
Exinite	Very low

SUMMARY

Samples of lignite from the Wilcox Group (Lower Eocene) of Kemper County, Mississippi were subjected to proximate, petrographic, mineralogical, and grain size analyses. The results of these analyses indicate that these poor-quality lignites were deposited in small depressions and channels in a deltaic area dominated by herbaceous plants, and heavily influenced by fluvial processes.

The dominant ash content of the lignite is composed primarily of sand-sized quartz. The moisture content is lower than expected, because the non-combustible components of the ash retain little or no moisture. Ash content is negatively correlated to ulminite, exinite, and corpohuminite, which appears to indicate that fixed carbon and volatile matter values are low in these lignites due to the lack of macerals that supply hydrogen and carbon. Moisture has a positive relationship with exinite, corpohuminite, volatile matter, and fixed carbon, and a negative correlation with ash. This interrelationship among these sets of variables indicates a causal effect as a direct result of a high-energy environment in which large amounts of ash were deposited. This environment would be unfavorable for the deposition and coalification of plant material, and would result in lower production of macerals,

thus lowering fixed carbon and volatile matter values. The inorganic sand-sized fraction of the lignite is quite large, and reinforces the conclusion that the lignites were deposited in a high-energy environment.

The dominance of humodetrinite and the small amount of ulminite and textinite indicates the plant community consisted primarily of herbaceous plants (grass-like plants, reeds, and wood from angiosperms), and lacked a significan number of conifers. Gelinite, which is associated with sandy sediments and well-oxygenated waters, is also abundant in the lignite, and appears to indicate a high-energy environment with elevated aerobic processes. These aerobic processes might also be responsible for the moderately-high amount of fusinite, since the fusinite in this area is not considered to be a result of peat fires. The aerobic activity and biochemical processes possibly caused the fusinization of textinite and ulminite,leading to the negative correlation fusinite has with these two cellular macerals.

CONCLUSIONS

1. Volatile matter has an average value of 21%, and fixed carbon has an average value of 12%. Volatile matter is strongly negatively correlated to fixed carbon. Fixed carbon increases and volatile matter decreases as the degree of coalification increases.
2. The dominance of ash and sand-sized quartz indicates the lignite was deposited in moderately-high energy depositional environment in a deltaic area influenced by fluvial processes.
3. The abundance of humodetrinite indicates the paleo-environment was dominated by herbaceous plants and wood from angiosperms.
4. The lack of macerals formed from woody plants indicates a lack of conifers in the depositional area.
5. Moisture is negatively correlated to ash content. As ash increases, exinite and corpohuminite decrease, also causing a drop in the moisture content. The absence of necessary macerals with hydrogen and carbon results in a decrease in volatile matter and fixed carbon.
6. Concave seam geometry indicates deposition was in isolated, shallow depressions.
7. Volatile matter and fixed carbon have low values, and are negatively correlated to each other.

APPENDIX A

PROXIMATE ANALYSIS DATA

PROXIMATE ANALYSIS (In Percent)

Seam	Moisture Average/Range	Volatile Matter Average/Range	Fixed Carbon Average/Range	Ash Average/Range
K-1	45.32/40.22-48.76	37.05/35.78-40.28	38.77/37.46-40.64	21.34/19.31-25.92
K-2	42.67/40.29-45.92	31.29/28.41-35.30	28.43/18.89-35.30	40.65/29.91-50.83
K-3	42.80/41.13-44.60	31.51/28.84-39.65	16.78/14.15-21.81	54.59/44.72-59.87
K-4	39.81/38.64-40.97	42.88/40.76-43.51	42.87/40.86-43.75	14.99/12.91-20.05
K-5	48.5/45.2-51.35	41.3/37.31-46.84	41.33/35.88-42.83	16.0/10.51-23.93
K-7	8.15/5.61-9.23	10.89/10.41-12.23	.33/.19-.40	88.73/87.54-89.43
K-8	52.47/49.9-53.88	39.43/38.12-39.67	26.78/26.40-26.99	33.99/33.51-34.19
K-9	18.91/16.99-22.03	10.46/8.63-11.95	.49/.42-.67	89.75/87.34-91.02
K-10	30.32/28.2-31.41	9.63/8.57-10.42	.71/.67-.99	89.12/88.32-89.9
K-11	12.29/10.17-15.13	11.31/10.92-11.75	2.89/1.14-2.17	87.10/85.0-88.11
K-12	40.7/39.5-41.23	12.57/12.12-12.89	3.67/3.51-3.94	84.27/84.14-85.32
K-13	19.51/17.35-21.69	16.38/16.11-16.88	8.00/7.98-8.32	75.62/74.0-76.11
L-14	20.07/17.32-22.81	8.01/6.09-10.70	.44/.03-.56	91.63/88.17-94.19
LS-35-2	NA	NA	NA	NA
LS-35-3	NA	NA	NA	NA
LS-35-1	NA	NA	NA	NA
LS-35-6	NA	NA	NA	NA
K101C JMV-8	25.5/8.4-42.6	33.77/17.4-59.5	23.02/11.9-40.5	40.6/28.1-48.9
K101C [illegible]-9	32.65/15.3-50.0	38.4/21.6-52.4	34.97/19.7-39.3	13.66/8.7-17.5
K-Mine-1	2.13/NA	46.82/NA	41.83/NA	7.9/NA
K-Mine-2	NA	41.48/NA	40.80/NA	17.6/NA

APPENDIX B

PETROGRAPHIC ANALYSIS DATA

PETROGRAPHIC ANALYSIS (In Percent)

Seam	Textinite	Ulminite	Gelinite	Humo-detrinite	Corpo-huminite	Fusinite	Semi-fusinite	Exinite	Ulminite Reflectance	Gelinite Reflectance
K-1	0.0	0.9	20.8	42.3	1.3	15.4	11.4	7.9	NA	.365
K-2	2.0	7.8	34.4	28.6	2.8	10.6	6.2	7.6	.25	.36
K-3	4.4	9.8	27.3	28.4	4.2	15.2	8.4	2.3	.26	.358
K-4	1.3	17.7	31.4	30.0	4.1	7.5	6.1	1.9	.241	.352
K-5	0.0	13.6	25.0	29.1	2.6	11.0	7.3	11.4	.254	.374
K-8	22.6	31.4	33.0	8.8	1.2	1.0	0.4	1.6	.34	.40
K-9	0.0	4.6	30.0	49.6	0.0	8.2	6.7	0.9	.22	.31
K-10	0.0	0.0	22.3	57.3	0.4	16.6	3.4	0.0	NA	.444
K-11	0.0	6.7	15.5	55.8	0.0	20.2	1.8	0.0	.25	.387
K-12	0.0	2.7	20.3	61.1	0.0	15.9	0.0	0.0	.281	.354
K-13	5.6	20.1	43.8	23.0	0.1	2.2	4.9	0.3	.42	.48
L-14	0.0	0.0	10.1	51.6	0.0	36.0	2.0	0.3	NA	.394
LS-35-1	9.8	33.0	18.6	25.0	3.0	1.6	4.0	5.0	.26	.371
LS-35-2	3.8	12.0	23.0	21.0	7.4	14.8	13.8	4.2	.278	.389
LS-35-3	5.4	24.8	14.2	14.6	4.2	16.2	11.6	9.0	.253	.37
LS-35-6	1.0	10.0	27.0	25.0	0.0	31.0	3.0	3.0	.258	.38
Average Error (%)	± .33	±1.0	± 2.55	± 2.7	± .27	± 0.83	± 0.6	± 0.32	NA	NA

APPENDIX C

GRAIN SIZE ANALYSIS DATA

GRAIN SIZE ANALYSES (In Percent)

Seam			
K-1	58	33	7
K-2	68	23	7
K-3	76	18	4
K-4	74	20	5
K-5	81	14	4
K-7	74	20	6
K-8	57	34	8
K-9	73	20	5
K-10	56	31	11
K-11	67	27	7
K-12	55	37	8
K-13	44	44	11
K-14	42	41	11

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