Petrographic and Chemical Characterization of Selected Texas Tertiary Coals

by

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ABSTRACT

Organic petrological and chemical analysis of Tertiary coals from the Wilcox, Claiborne, and Jackson Groups of Texas revealed characteristic properties. Wilcox coals can be differentiated from Jackson coals on the basis of lower equilibrium moisture, ash and sulfur content, higher calorific value (Btu/lb), and huminite reflectance. Claiborne coal (one sample) from the Rio Grande Valley differs from most of the Wilcox and Jackson coals on the basis of the nature of liptinite or huminite macerals, calorific value, and huminite reflectance. Calorific value and mean random huminite reflectance suggest that Wilcox coals are borderline subbituminous C to lignite in rank, whereas Claiborne coals are subbituminous A and Jackson coals are lignite in rank. The decrease of calorific value (Btu/lb) and the increase of liptinite content (in volume percent) for most of the Wilcox and Jackson coals are directly related to an increase of ash content.

A maceral composition ternary diagram revealed organic facies indicative of peat-forming environments. Accordingly, the depositional environments of the sampled coals were reconstructed as follows: Wilcox coals were formed either at the junction of a lower alluvial plain and upper delta plain (northeast Texas) in the backswamp area or at the interdistributary swamp-marsh-complex basin in the upper delta plain (east-central Texas); Claiborne coal was formed in a lacustrine environment having mainly marsh and aquatic vegetation; Jackson coals were deposited either in the interdistributary basin on the lower delta plain or in a back-barrier/lagoonal basin in which conditions alternated between swamp and marsh.

INTRODUCTION

Tertiary coals of Texas occur in three stratigraphic units: the Wilcox, Claiborne, and Jackson Groups. These coals are associated with regressive sequences and are facies of ancient fluvio-deltaic sediments (Fisher and McGowen, 1967; Kaiser, 1974; Kaiser and others, 1978, 1980). They occur in an arcuate belt parallel to the present coastline of Texas, extending from Texarkana in northeast Texas to the Mexican border in the southwest, and on the semicircular Sabine Uplift of East Texas (fig. 1). The main coal seams occur in the East Texas Basin, in the Houston and Rio Grande Embayments, and on the Sabine Uplift. Depositional environments in the Wilcox, Claiborne, and Jackson Groups, as revealed by subsurface geological analysis, are shown in figure 2 (Kaiser and others, 1980; Ayers and Kaiser, 1986).

Utilization of Texas Tertiary coals began a century ago, resulting in numerous publications on the geology and depositional environments (Fisher and McGowen, 1967; Kaiser, 1974; Kaiser and others, 1978, 1980, 1986; Ayers and Kaiser, 1986; Breyer and McCabe, 1986), palynology of the peat-forming plant communities (Elsik, 1968, 1978; Nichols and Traverse, 1971; Frederikson, 1981; Gennett and others; 1986), and basic physicochemical properties (Fisher, 1963; Kaiser, 1974; Kaiser and others, 1980; Tewalt, 1986; Tewalt and others, 1986) of these coals from various parts of the basin. Studies were also done on the chemistry and utilization of Texas Tertiary coals (Selvig and others, 1950; Edgar and Kaiser, 1984; Farnum and others, 1984; Parkash and others, 1984). However, there has been no comprehensive work on organic petrography correlating maceral composition and chemical characteristics of these coals with their depositional environment as revealed by subsurface mapping (Fisher and McGowen, 1967; Kaiser, 1974; Kaiser and others, 1980; Ayers and Kaiser,

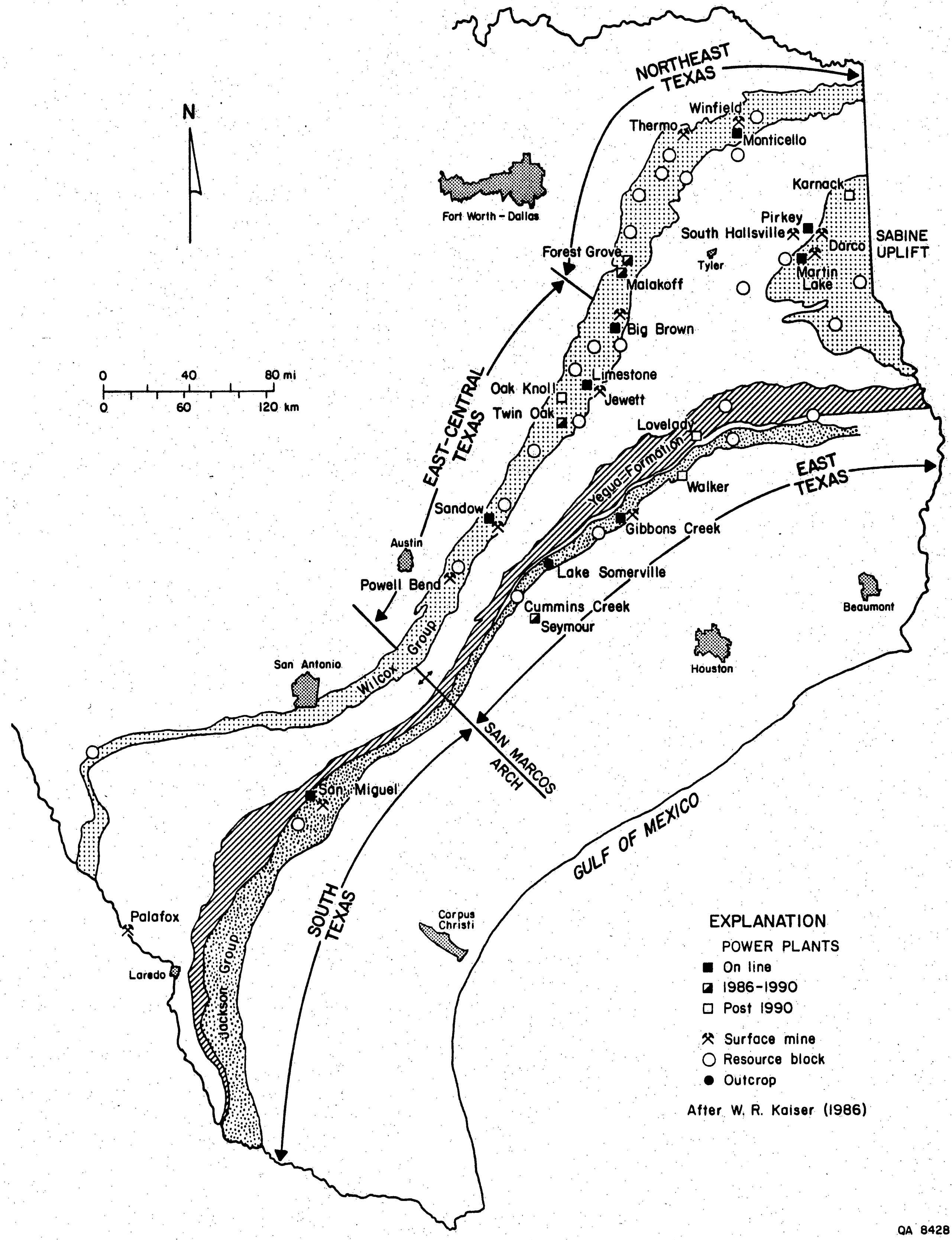

Figure 1. Outcrop of Tertiary coal-bearing units of Texas showing sample locations.

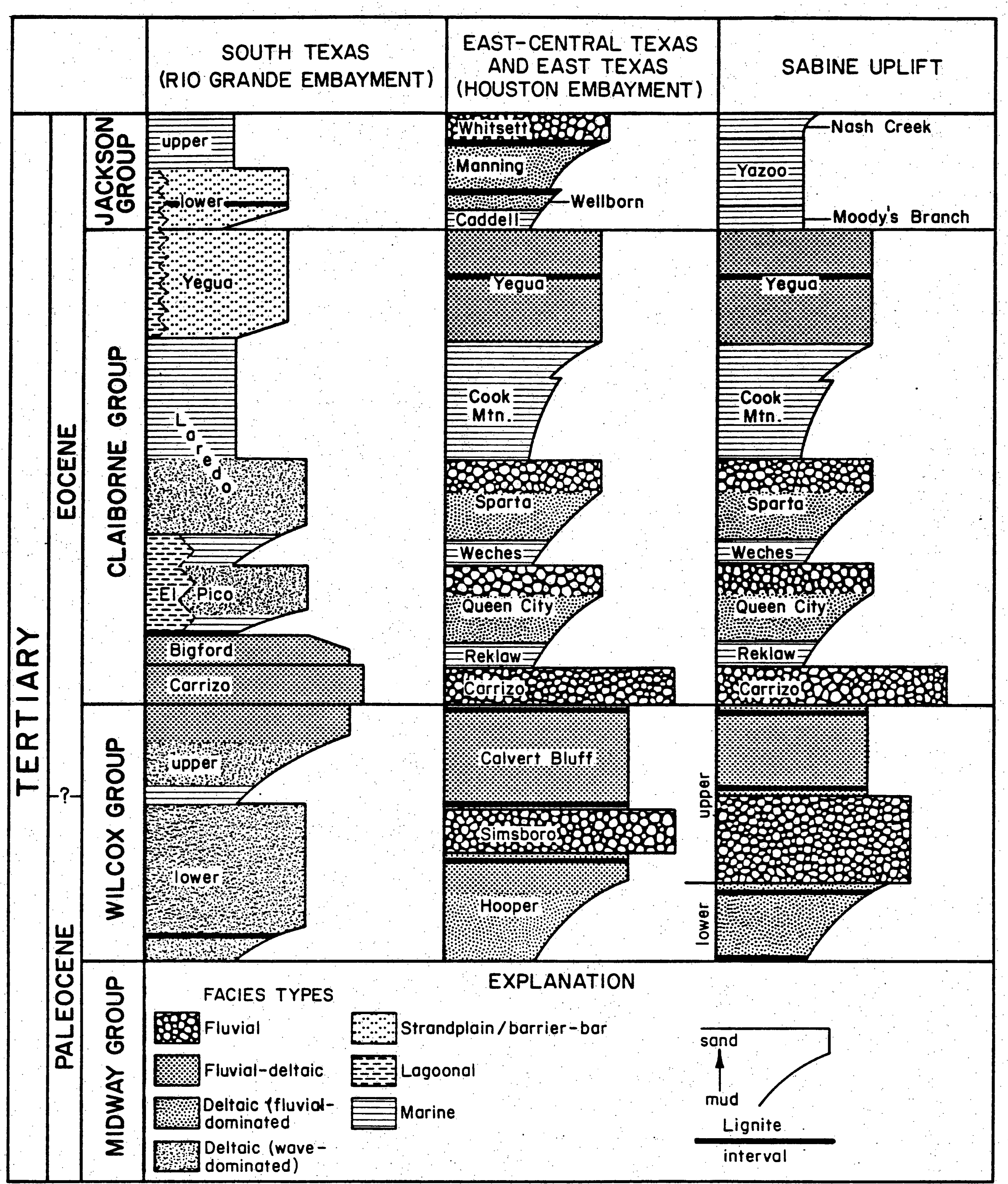

Figure 2. Early Tertiary stratigraphy, occurrence of coal, and sedimentary environments (after Kaiser and others, 1980; Ayers and Kaiser, 1986).

Organic petrography provides an additional insight into depositional environments.

This report integrates petrographic and chemical data on an initial 25 coals (chemical analyses done in 1986 by the U.S. Geological Survey) and was done as part of the Bureau's ongoing, long-term National Coal Resources Data (NCRDS) System project. This report marks a departure from resource calculation and is the first step toward coal characterization.

OBJECTIVES

Because there are no basic regional data on organic petrography of low-rank coals from the Wilcox, Claiborne, and Jackson Groups of Texas, this research was initiated to correlate petrographic parameters with chemical parameters and geological setting. The main objectives were (1) to establish a basic data base for organic petrography of Wilcox and Jackson coals, correlating lithotype and maceral composition on the basis of modern lignite petrography (Teichmuller, 1950, 1981; Jakob, 1954; Suss, 1964; International Committee for Coal Petrology [ICCP], 1971; Hagemann and Hollerbach, 1980; Stach and others, 1982; Bustin and others, 1983; Wolfram, 1984), (2) to characterize the diagenetic changes that occurred in the low-rank stage, as revealed by petrography, (3) to delineate the maturation trends, and (4) to evaluate the basic chemical data for individual near-surface coal samples.

SAMPLES

Tertiary coals from Texas were traditionally defined as Texas lignite in the literature. Because lignite is a rank term and some of these coals are not lignite in rank (Mukhopadhyay and others, 1985b), they are referred to here as Tertiary coals.

Major coal seams mainly occur in the Calvert Bluff and Hooper Formations of the Wilcox Group in east-central Texas, and their equivalent occurs in northeast Texas and on the Sabine Uplift. The Yegua, El Pico, and Bigford Formations contain the major coal seams in the Claiborne Group. In the Jackson Group, major coal seams occur in the Manning and Wellborn Formations in East Texas, and in the lower Jackson Group in South Texas.

The thickness of the coal seams in surface mines are: in northeast Texas, from 4 to 8 ft; in east-central Texas surface mines, from 6 (Elgin-Butler mine) to 15 ft (Sandow mine); on the Sabine Uplift, from 4.4 to about 16 ft (Martin Lake mine); in Jackson coals in east Texas, all thinner than 8 ft; in Jackson coals from south Texas, less than 3 ft.

Coal samples were taken from surface mines and outcrop (fig. 1). Samples were collected as lithotype and channel samples. Fifteen samples were collected for analysis from the Wilcox Group in northeast and east-central Texas and from the Sabine Uplift area (table 1). One sample was studied from the Claiborne Group (Palafox mine, Webb County, Bigford Formation) of South Texas. Nine Jackson samples from East and South Texas were analyzed.

Lithotypes

Lithotypes are the megascopic components of a coal seam; they are defined by the proportions of types of vegetal debris within the coal groundmass. These lithotypes can be formed either by differences in the original plant communities and depositional environments or by biogeochemical transformation of primary plant debris during early diagenesis (Hagemann and Hollerbach, 1980). The lithotype classification was adopted from Hagemann and Hollerbach (1980; app. A). For the Tertiary coals of Texas, this classification has been modified to include two additional lithotype classes,

Table 1. Sample location, type, stratigraphy, lithotype, and huminite reflectance.

Sample no.[a]	Location, thickness, depth (ft)	Type and stratigraphy	Lithotype	Huminite reflectance R_o	St. dev.	N
	Wilcox Group	**Northeast Texas**				
2 (22500201)	Winfield south mine, Titus County, Pit G-39, top seam, 5.25′, <100′	Channel, Upper Wilcox Group	Mixed lithotypes	0.32	0.05	51
17 (11200101)	Thermo mine, Hopkins County, Pit C-14, 4th seam, 5.9′, <100′	Channel, Lower Wilcox Group	Mixed lithotypes	0.32	0.03	51
18 (11200201)	Thermo mine, Hopkins County, Pit C-14, 2nd seam, 7.5′, <100′	Channel, Lower Wilcox Group	Mixed lithotypes	0.32	0.05	56
19 (11200301)	Thermo mine, Hopkins County, Pit C-14, 1st seam, 4.59′, <100′	Channel, Lower Wilcox Group	Mixed lithotypes	0.34	0.04	61
	Wilcox Group	**East-central Texas**				
59 (16600901)	Sandow mine, E-Pit, Milam County, upper part of the seam, 6.9′, <100′	Channel, Lower Calvert Bluff Formation, Wilcox Group	Moderately to finely banded, nonxylitic, pure coal with gelified groundmass	0.31	0.03	57
60 (16600902)	Sandow mine, E-Pit, Milam County, lower part of the seam, 4.6′, <100′	Channel, Lower Calvert Bluff Formation, Wilcox Group	Unbanded, nonxylitic, pure coal with large gelified lenses	0.30	0.04	59
74 (01100201)	Elgin-Butler mine, Bastrop County, 6.23′, <100′	Channel, Lower Calvert Bluff Formation, Wilcox Group	Unbanded to finely banded, pure detrital coal	0.32	0.04	57
75 (01100101)	Powell Bend mine, Bastrop County, 7.5′, <100′	Channel, Lower Calvert Bluff Formation, Wilcox Group	Mixed lithotypes	0.30	0.04	43
78 (01100104)	Powell Bend mine, Bastrop County, lower part of the seam	Lithotype, Lower Calvert Bluff Formation, Wilcox Group	Finely banded, nonxylitic, pure coal with some gelified tissues	0.30	0.04	35
	Wilcox Group	**Sabine Uplift**				
80 (10200201)	South Hallesville mine, Harrison County, Pit A-14, Sabine Uplift area, 4.4′, <100′	Channel, Upper Wilcox	Mixed lithotypes	0.31	0.03	54
81 (10200301)	South Hallesville mine, Harrison County, Pit B-9, Sabine Uplift area, 6.1′, <100′	Channel, Upper Wilcox	Mixed lithotypes	0.30	0.04	57
82 (10200101)	Darco mine, Harrison County, upper part of the seam, Sabine Uplift area, 3.9′, <100 ′	Channel, Upper Wilcox	Mixed lithotypes	0.33	0.04	56
83 (10200102)	Darco mine, Harrison County, lower part of the seam, Sabine Uplift area, 3.94′, <100′	Channel, Upper Wilcox	Mixed lithotypes	0.32	0.03	59
87 (18300801)	Martin Lake mine, Pit A-1, Panola County, Sabine Uplift area, upper part of the seam, 7.9′, <100′	Channel, Upper Wilcox	Predominantly moderately to finely banded, pure dull coal	0.35	0.03	69
98 (18301102)	Martin Lake mine, Pit C-2, upper part of the seam	Lithotype, Upper Wilcox	Moderately banded, pure coal with alterations of charcoal; gelified tissue and spore-rich zone	0.35	0.05	52

Table 1 (cont.)

				Huminite reflectance		
Sample no.[a]	Location, thickness, depth (ft)	Type and stratigraphy	Lithotype	R_o	St. dev.	N
	Claiborne Group	**South Texas**				
118 (24000101)	Palafox mine, Webb County, <100′	Lithotype, Bigford Formation, Claiborne Group	Unbanded, nonxylitic, pure coal with clay clasts. The coal is dark brown and hard and has conchoidal fractures	0.49	0.05	59
	Jackson Group	**East Texas**				
119 (09300104)	Gibbons Creek mine, A-Pit, Grimes County, 7·5′<100′	Channel, Manning Formation, Jackson Group	Mixed lithotypes	0.24	0.03	51
120 (09300209)	Gibbons Creek mine, B-Pit, Grimes County, 8′, <100′	Channel, Manning Formation, Jackson Group	Mixed lithotypes	0.24	0.04	47
126 (23900105)	Geological section, Lake Sommerville, Washington County, surface 2′, <25′, bottom scan	Channel, Manning Formation, Jackson Group	Finely banded to unbanded, dark, impure detrital coal with pyrite	0.30	0.04	61
143 (07500305)	Borehole LCRA# 200670C1, Fayette County, 7.0′, 306.6′-313.6′	Channel, Manning Formation, Jackson Group	Light-colored, unbanded, impure detrital coal with gelified groundmass	0.30	0.06	57
	Jackson Group	**South Texas**				
147 (00700201)	San Miguel mine, Atascosa County, A-seam, Ramp 2, 1.3′, <100′	Channel, lower Jackson	Mixed lithotypes	0.30	0.02	55
148 (00700202)	San Miguel mine, Atascosa County, A-seam, Ramp 7-8, 1.3′, <100′	Channel, lower Jackson	Mixed lithotype	0.29	0.04	52
149 (00700203)	San Miguel mine, Atascosa County, B-seam, Ramp 7-8, 1.3′, <100′	Channel, lower Jackson	Mixed lithotypes	0.30	0.02	55
150 (00700204)	San Miguel mine, Atascosa County, C-seam, Ramp 7-8, 2′, <100′	Channel, lower Jackson	Mixed lithotypes	0.30	0.03	51
151 (00700205)	San Miguel mine, Atascosa County, D-seam, Ramp 7-8, 2.95′, <100′	Channel, lower Jackson	Mixed lithotypes	0.27	0.04	55

[a] Code number, first three digits = state county code, second three digits = locality in that county, last two digits = sequential number assigned at the respective locality.

termed pure and impure detrital (Mukhopadhyay, 1986; app. B). The classification used in this report therefore includes six lithotype classes. Lithotypes were defined in this classification according to megascopic morphologies on the basis of purity, thickness of bands, degree of gelification, and presence of inclusions, instead of numerical indexing (Hagemann and Hollerbach, 1980; Bustin and others, 1983), to facilitate the field definition of a lithotype. Earlier workers emphasized the color of the lithotype as an important factor (Hagemann and Hollerbach, 1980; Verheyen and others, 1984; Wolfram, 1984). The colors of different lithotypes do not vary much in Texas coals, which may be because of their slightly advanced maturity compared with German and Australian brown coals. Jackson coals show some variation in color, whereas Wilcox coals shows no variation.

Maceral Terminology

Maceral terminology used for low-rank coals, especially for the huminite (low-rank counterpart of vitrinite) group, is diverse. Terminology adopted herein (app. C) is a modified version of the classification recommended by the ICCP (1971), Teichmuller (1981), Stach and others (1982), Mukhopadhyay and others (1985a), and Cook (1986). New nomenclature for the subgroups of inertinite and liptinite groups is adopted for the first time to clarify the nature of the macerals within these subgroups. A new subgroup is introduced between huminite and liptinite groups and defined as detro-mixinite, which at this time has one maceral named mixinite. This maceral is assumed to have originated from a mixture of huminitic and liptinitic groundmasses; it may be derived either from a nonarboreal plant community or by mechanical or bacterial degradation of arboreal or nonarboreal plants. Mixinite may be equivalent to the maceral mixtinite (Ginsburg and others, 1976) used for coal microcomponents or to humosapropelinite (Mukhopadhyay and others, 1985a), which is generally observed in a type IIB and type III kerogen. Appendix C includes detailed definitions of maceral subgroups and their macerals.

ANALYTICAL METHODS

Samples for petrographic analysis were ground (+40 mesh), mounted with epoxy resin, and polished according to a modified version of the method described by Crelling and Dutcher (1980). In the maceral analysis (volume percent), 500 grains (macerals and minerals) were counted on each polished coal block or pellet using a Zeiss UMSP-30 incident-light microscope with oil-immersion objective (40X) under white- and blue-light excitation (blue-light excitation filter 450 to 490 nm, chromatic beam splitter FT 510, and barrier filter LP 515). Point counting of macerals was done using a Swift Automatic Point Counter. The maceral composition was later recalculated to a mineral-matter-free basis using the Parr formula (Cameron and others, 1984).

Reflectance of huminite, liptinite, and inertinite macerals was measured using a 546-nm filter and a sapphire (0.59 percent R_o in oil) and Leitz six-in-one glass standard of 0.3 to 1.66 percent R_o (ICCP, 1971; Stach and others, 1982). Reflectance was measured on texto-ulminite, the the eu-ulminite, gelinite, corpohuminite, sporinite, fusinite or semifusinite, and sclerotinite macerals. However, mean huminite reflectance data were taken only from the eu-ulminite maceral type (ICCP, 1971). By definition, huminites have higher reflectance than liptinites and lower reflectance than inertinites (Stach and others, 1982). Proximate and ultimate analyses and calorific value were determined by American Society for Testing and Materials (ASTM) (1981) procedures.

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RESULTS

Organic Petrography

Lithotypes

Mixed lithotypes were observed in most of the channel samples; in most cases, therefore, no specific lithotype is given (table 1). Observation of the different lithotypes indicates that Wilcox coals are mostly pure and Jackson coals are pure to impure. Wilcox coals from east-central Texas (samples 74 and 78) primarily have an unbanded to moderately banded, pure detrital and nonxylitic, pure lithotype with gelified lenses and resin or cuticle inclusions. At the Sandow mine (coal seam greater than 12 ft thick), a distinct variation in lithotypes occurs from bottom (unbanded, pure, and nonxylitic with large gelified lenses) to top (moderately banded, pure, and nonxylitic with large gelified groundmass) of the seam. Elgin-Butler coal (sample 74) has an unbanded to finely banded, pure detrital lithotype from top to bottom of the seam, with some gelified lenses and resin inclusions. At the Powell Bend mine, the lower part of the seam has a finely banded to unbanded, pure, nonxylitic lithotype with large gelified xylitic tissues, whereas the upper part of the seam is dominated by a moderately banded to finely banded, pure to impure lithotype with a few inclusions. On the Sabine Uplift, lithotypes are mixed. They vary from moderately to finely banded, pure, nonxylitic with large gelified tissue and charcoal or resin inclusions. Coals from the Darco and Martin Lake mines have a large amount of charcoal inclusions. Some thin charcoal bands (1 to 5 mm thick) also are present in these coals.

Claiborne coal (sample 118) from the Rio Grande Valley shows an unbanded, nonxylitic, pure lithotype with blue clay clasts. Hardness, uniform grain size, and unbanded, nonxylitic lithotype suggest that this coal may be sapropelic in origin.

Lithotypes in Jackson coal vary between finely banded and pure with gelified xylitic tissue and resin inclusions to unbanded or finely banded and impure detrital with fine gelified lenticles. Finely banded, impure coal has some large, lustrous, gelified bands. Some of the finely banded coal is dark gray, and some unbanded coal is light yellowish-gray.

Maceral Composition

Maceral compositions in volume percent on a mineral-matter-free basis are shown in table 2. The two far-right columns in table 2 are the volume percent of pyrite and other mineral matter that was point counted. Because sapropelinite (amorphous liptinite) content is, in general, low to absent in most of the samples, sapropelinite was point counted along with liptodetrinite.

Wilcox Group

Northeast Texas.--In general, structured macerals (humotelinite, sporinite, suberinite, and resinite) predominate over detrinitic macerals for both the huminite and liptinite groups within the different coal seams sampled at the Winfield and Thermo mines, Titus and Hopkins Counties. Humocollinite content is less than 10 percent. Eu-ulminite (fig. 3a) and texto-ulminites (fig. 3b) are the major huminite macerals; they commonly have compressed or incipient cell structures, some of which are filled with resinite or corpohuminite. Separate grains of large, oval-shaped resin bodies (fig. 3c) are common in this coal. Comparing the petrographic trend of the different seams

Table 2. Maceral composition in volume percent
(on a mineral-matter-free basis).

											Macerals											Minerals	
Sample Number	Tex	Ulm	Gel Tot Hum	Cor	Att	Mix	Spo	Cut	Sub	Res	Alg Tot Lip	Algs	Lips	Phy	Exsd	Scl	Mic	Mac	Ind Tot Ine	Sem	Fus	Pyr	Otm
			Wilcox Group								**Northeast Texas**												
2	1.1	34.8	0.6 68.1	5.2	26.4	0.0	6.9	0.6	0.0	6.1	0.6 21.7	0.0	6.7	0.0	0.8	0.6	0.2	2.3	5.2 10.2	0.6	1.4	0.5	12.5
17	0.0	53.1	5.3 70.0	2.1	9.5	0.2	6.9	0.0	0.8	2.9	0.0 14.0	0.0	3.2	0.0	0.2	0.5	0.2	3.2	5.9 15.8	0.7	5.3	0.5	5.0
18	0.2	34.0	2.2 71.7	4.5	30.8	0.0	7.8	0.6	1.0	3.6	1.2 21.0	0.0	5.4	0.0	1.4	0.2	0.6	1.4	0.6 7.3	3.1	1.4	0.8	15.5
19	0.0	35.8	2.2 75.6	7.1	30.5	1.8	8.4	0.4	0.7	2.0	0.2 17.7	0.0	5.5	0.0	0.5	0.7	0.7	0.4	2.0 4.9	0.2	0.9	1.0	8.6
			Wilcox Group								**East-central Texas**												
59	0.8	35.2	3.0 60.3	3.5	17.8	0.8	5.4	1.8	2.1	4.4	1.3 27.4	0.0	8.0	0.0	4.4	0.8	0.8	2.1	4.4 11.5	0.8	2.6	1.0	23.8
60	0.8	34.6	4.2 78.7	2.2	36.9	0.6	3.8	0.2	1.2	2.4	0.0 17.7	0.0	8.1	0.0	2.0	0.6	0.2	1.4	0.8 3.0	0.0	0.0	3.9	11.4
74	0.0	12.3	8.5 57.3	0.9	35.6	0.4	7.8	1.2	1.2	9.5	4.1 38.2	0.0	12.3	0.0	2.1	0.9	0.4	1.2	0.4 4.1	0.0	1.2	5.0	14.2
75	0.0	23.8	3.9 73.5	6.2	39.6	0.3	7.6	0.7	0.0	1.3	0.7 18.6	0.0	7.6	0.0	0.7	0.7	0.7	1.0	2.3 7.6	1.0	1.9	1.5	6.6
78	0.0	14.6	1.6 60.3	3.9	40.3	0.0	5.3	0.5	0.2	2.6	1.1 20.4	0.0	9.1	0.0	1.6	1.8	1.3	3.6	4.7 19.3	2.6	5.3	0.5	6.3
			Wilcox Group								**Sabine Uplift**												
80	0.0	31.1	1.0 64.3	2.6	29.6	0.0	7.5	0.0	0.2	4.9	0.2 22.1	0.0	8.6	0.0	0.7	1.5	1.9	0.2	5.7 13.6	1.2	3.1	0.2	3.0
81	2.2	40.0	5.5 64.0	1.7	14.6	1.4	5.8	1.9	1.1	4.9	0.8 20.6	0.0	4.7	0.0	1.4	0.7	0.7	3.6	5.1 14.0	0.7	3.2	1.1	8.0
82	0.5	39.1	3.2 66.6	3.5	20.3	0.0	8.1	0.5	0.2	2.3	0.0 14.0	0.0	2.1	0.0	0.8	0.0	1.6	2.7	5.3 19.4	2.3	7.5	0.2	5.8
83	0.0	36.5	3.5 58.0	3.1	14.9	0.2	8.3	0.9	0.2	3.3	0.6 17.2	0.0	2.8	0.0	1.1	1.1	2.0	7.2	4.4 24.6	1.7	8.2	2.5	7.0
87	0.0	47.0	6.3 68.5	5.5	9.7	0.0	9.1	1.2	0.3	1.1	0.7 20.6	0.0	5.9	0.0	2.2	1.1	0.0	0.8	2.6 10.9	3.0	3.4	1.6	9.0
98	0.6	37.2	3.3 55.4	4.5	9.8	0.2	10.9	0.0	0.0	8.7	0.0 21.6	0.0	1.8	0.0	0.2	0.6	2.1	2.7	4.6 22.8	2.1	10.7	0.5	14.6

Table 2 (cont.)

Sample Number	Tex	Ulm	Gel Tot Hum	Cor	Att	Mix	Spo	Cut	Sub	Res	Macerals Alg Tot Lip	Algs	Lips	Phy	Exsd	Scl	Mic	Mac	Ind Tot Ine	Sem	Fus	Minerals Pyr	Otm
			Claiborne Group								**South Texas**												
118	0.3	14.2	1.4 58.5	20.4	22.2	0.0	6.0	2.7	0.9	7.4	7.4 40.2	0.0	16.3	0.0	3.7	0.3	0.5	0.2	0.3 1.3	0.0	0.0	0.5	7.2
			Jackson Group								**East-central Texas**												
119	1.7	11.6	5.0 50.1	2.3	29.5	4.0	7.8	1.6	4.0	4.4	3.0 33.3	0.0	9.8	0.0	2.7	4.0	0.0	5.0	0.0 12.6	0.0	3.6	2.3	23.0
120	3.0	40.5	4.5 68.4	4.9	15.5	3.2	6.5	1.3	1.6	4.9	1.0 23.1	0.0	6.2	0.0	1.6	1.3	0.6	1.3	0.2 5.3	0.6	1.3	2.5	20.2
126	0.0	12.1	6.4 55.0	4.0	32.5	0.0	8.3	0.6	0.6	7.1	3.3 41.7	0.0	19.2	1.2	1.4	1.9	1.2	0.2	0.0 3.3	0.0	0.0	0.8	15.0
143	0.0	6.7	10.4 51.3	17.5	16.7	2.0	11.0	2.2	0.0	3.0	2.2 44.0	0.0	17.8	1.0	6.8	0.8	0.3	0.8	0.0 2.7	0.0	0.8	3.5	20.5
			Jackson Group								**South Texas**												
147	3.6	19.2	3.8 73.1	4.8	41.7	0.0	5.9	1.2	1.8	3.3	0.6 23.5	0.0	9.5	0.0	1.2	2.5	0.0	0.3	0.3 3.4	0.0	0.3	4.5	12.5
148	0.7	6.9	1.8 52.5	5.5	37.6	3.7	8.5	0.9	1.6	5.9	1.4 41.2	0.0	20.8	0.0	1.4	0.7	0.0	0.0	0.3 2.6	0.0	1.6	5.0	22.0
149	1.7	43.7	3.2 84.8	1.9	34.3	0.0	2.6	0.2	0.2	2.6	0.6 11.3	0.0	4.3	0.0	0.8	0.9	0.8	0.2	0.0 3.9	0.6	1.4	4.5	6.3
150	0.0	32.7	11.0 69.5	4.6	21.2	0.0	8.2	1.3	4.6	4.1	0.0 29.2	0.0	9.8	0.0	1.2	0.9	0.4	0.0	0.0 1.3	0.0	0.0	4.0	14.7
151	0.4	16.7	7.5 68.0	4.7	38.7	0.0	4.8	1.9	1.5	2.0	3.9 28.8	0.0	10.8	0.0	3.9	1.6	0.0	0.4	0.0 3.2	0.5	0.7	5.6	15.6

Tex = Textinite; Ulm = Ulminite; Gel = Gelinite; Cor = Corpohuminite; Att = Attrinite/Densinite; Mix = Mixinite; Spo = Sporinite; Cut = Cutinite; Sub = Suberinite; Res = Resinite; Alg = Alginite; Algs = Algodetrinite I; Lips = Liptodetrinite and Sapropelinite II; Phy = Phyto- and Zooclasts; Exsd = Exsudatinite/Solid Bitumen; Scl = Sclerotinite; Mic = Micrinite; Mac = Macrinite; Ind = Inertodetrinite; Sem = Semifusinite; Fus = Fusinite; Pyr = Pyrite; Otm = Other minerals; Tot Hum = Total Huminite; Tot Lip = Total Liptinite; Tot Ine = Total Inertinite.

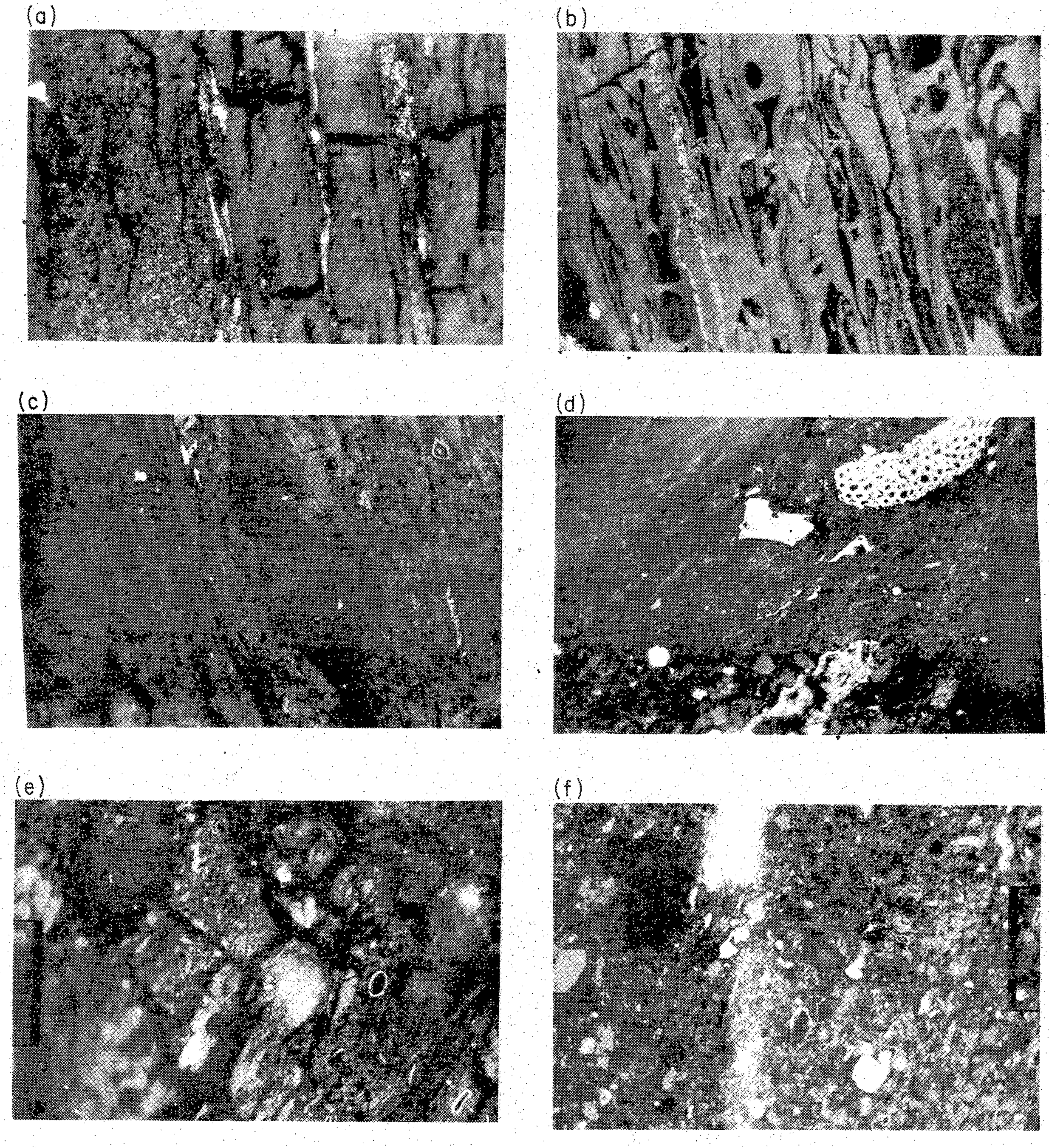

Figure 3. Photomicrographs of macerals. All photomicrographs taken in white reflected light. Scale bar 50 μm.

- **a.** Eu-ulminite, micrinite, and inertodetrinite (one grain); sample 2.
- **b.** Texto-ulminite, clay minerals, and micrinite; sample 2.
- **c.** Resinite (large oval bodies), ulminite, corpohuminite, sporinite, cutinite, suberinite, inertodetrinite, and minerals; sample 2.
- **d.** Ulminite, sporinite, fusinite, inertodetrinite, corpohuminite, attrinite, and minerals; sample 17.
- **e.** Alginite, cutinite, ulminite, attrinite, and sclerotinite; sample 18.
- **f.** Attrinite, densinite, alginite, liptodetrinite, sapropelinte, corpohuminite, and inertodetrinite; sample 74.

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- **a.** Eu-ulminite, micrinite, and inertodetrinite (one grain); sample 2.
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- **d.** Ulminite, sporinite, fusinite, inertodetrinite, corpohuminite, attrinite, and minerals; sample 17.
- **e.** Alginite, cutinite, ulminite, attrinite, and sclerotinite; sample 18.
- **f.** Attrinite, densinite, alginite, liptodetrinite, sapropelinte, corpohuminite, and inertodetrinite; sample 74.

of the Thermo mine, a distinct change in maceral composition was noticed between the top and bottom seam. At the Thermo mine, the top seam is dominated by ulminite, sporinite, and inertinite (fig. 3d), whereas the bottom seam contains mixed assemblages of huminite and liptinite macerals with a small amount of inertinite (fig. 3e). Suberinite, large resinite, and sporinite are the common liptinite macerals in all the seams. Some Botryococcus or Pediastrum(?) variety of alginites are present in the middle and lower seam of the Thermo mine (fig. 3e). The top seam of the Winfield south mine (sample 2) has a maceral composition similar to that of the middle seam of the Thermo mine. Both contain mixed huminite and liptinite macerals and a high mineral-matter content. Different varieties of sclerotinite are common in both upper and lower seams.

East-central Texas.--There is distinct variation in the type of huminite macerals from top to bottom of the main seam at the Sandow mine, Milam County. The top part of the seam, which contains more banded lithotypes than does the bottom, is dominated by humotelinite (ulminite), inertinite (fusinite), and high liptinite (mainly as liptodetrinite) content. In contrast, the bottom part of the seam contains mainly mixed huminite macerals with a dominance of humodetrinite. The middle of the seam is more liptinite rich than the top and bottom parts. This variation is reflected in the lithotype samples (Mukhopadhyay, 1986). The top part of the seam contains cutinite with two types of fluorescence. The outer part of the cuticle has yellow fluorescence, whereas the inner part has reddish-brown fluorescence. No type of inertinite maceral predominates, but fusinite and inertodetrinite are common in the top part of the seam. Framboidal pyrites are common in the bottom part.

Channel samples from the main coal seams at the Elgin-Butler and Powell Bend mines, Bastrop County, differ in liptinite and huminite contents (table 2). The main huminite and liptinite macerals in the Elgin-Butler mine are humodetrinite (attrinite and densinite) and liptodetrinite (fig. 3f). The amounts of resinite, sporinite, and alginite (fig. 3f) also are significant. Clay minerals and pyrite are the dominant minerals. In some samples mineral matter dominates over organic matter, and macerals float within clay minerals. Sapropelinite (fig. 3f) content is significant (about 4 percent) within this seam. Sapropelinite and liptodetrinite sometimes retain relict structures of cutinite, which may suggest that at least part of the amorphous liptinite is formed from the biodegradation of cutinite.

Coal seams at Powell Bend mine contain mixed assemblages of huminite and liptinite macerals. Attrinite, densinite, sporinite, and liptodetrinite predominate. Liptinite content of these samples is low compared with that of samples from the Elgin-Butler mine. Some grains are rich in inertinite, which is associated with attrinite, corpohuminite, and sporinite (fig. 4a). A lithotype sample (sample 78) contains higher fusinite and lower huminite. Attrinite and densinite are dominant in the lower part of the seam. Mineral matter and inertinite content show an inverse relationship at both mines.

Petrographically, the Elgin-Butler coal seam and the upper part of the seam in the Powell Bend mine are different from the coals of northeast Texas. They show a similarity to the lower part of the seam in the Sandow mine.

Sabine Uplift.--Except for the coal seam at South Hallesville mine (pit a-14, sample 80), all analyzed channel samples from the Sabine Uplift show a dominance of ulminite and different types of inertinite (fig. 4b). A coal seam from South Hallesville (pit A-14) contains mixed huminite and liptinite maceral assemblages. Inertodetrinite and macrinite are the major inertinite macerals in this coal (fig. 4c). Well-preserved suberinite is present in another seam from South Hallesville mine (sample 81) (fig. 4d). Porigelinite is common and is found within the cell walls of texto-ulminite. A few alginites (Botryococcus) and dinoflagellates (algal cyst) are seen in the coal seam

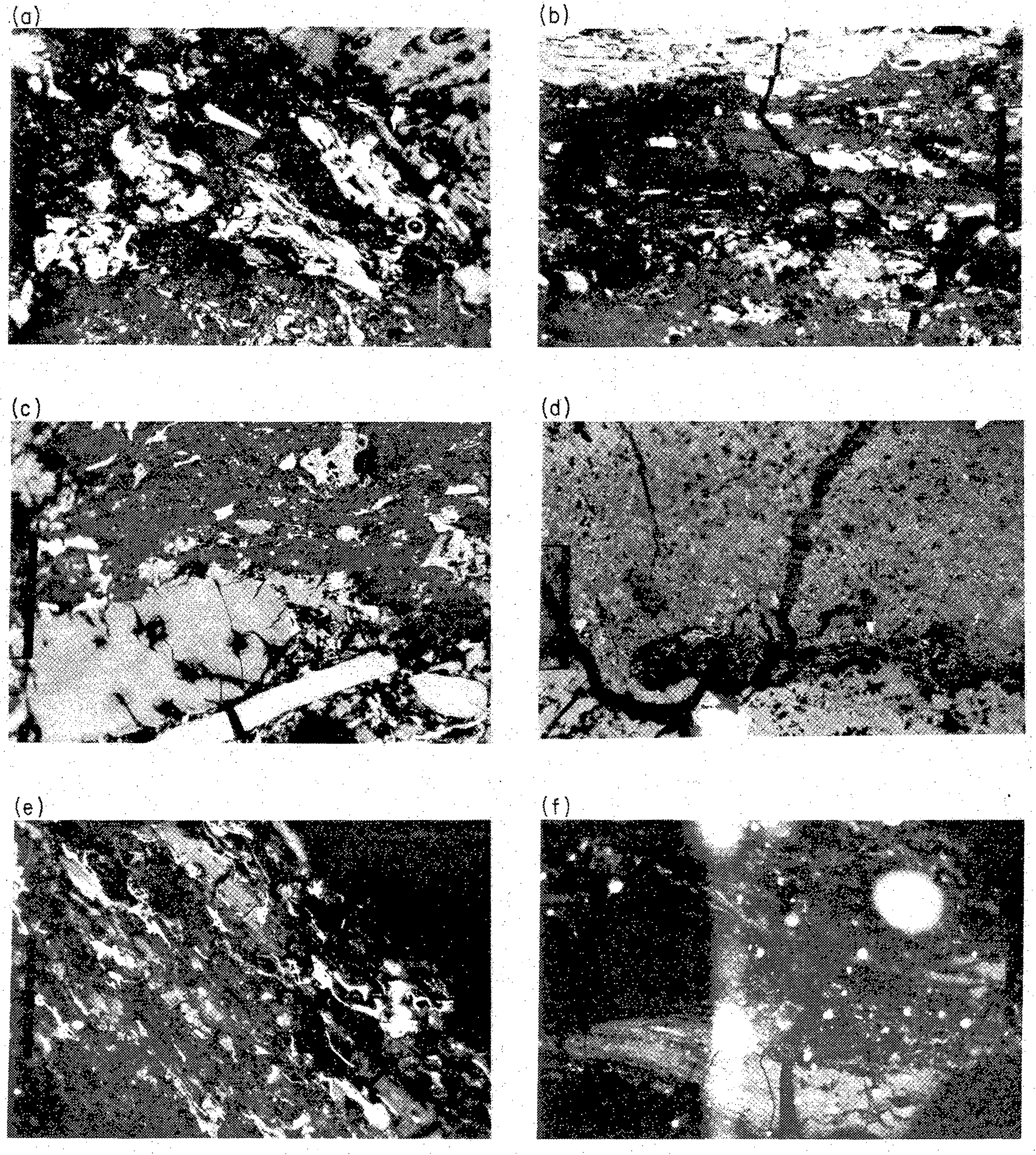


Figure 4. Photomicrographs of macerals. All photomicrographs taken in white reflected light. Scale bar 50 μm.

a. Fusinite, ulminite, attrinite, sporinite, and inertodetrinite; sample 75.
b. Fusinite, ulminite, sporinite, and inertodetrinite; sample 82.
c. Macrinite, inertodetrinite, ulminite, resinite, and attrinite; sample 81.
d. Texto-ulminite, suberinite, and sporinite; sample 81.
e. Sporinite, levigelinite, oxidized sporinite, and inertodetrinite; sample 98.
f. Ulminite, clay minerals, quartz grains, corpohuminite, and liptodetrinite; sample 83.

Figure 4. Photomicrographs of macerals. All photomicrographs taken in white reflected light. Scale bar 50 μm.

- **a**. Fusinite, ulminite, attrinite, sporinite, and inertodetrinite; sample 75.
- **b**. Fusinite, ulminite, sporinite, and inertodetrinite; sample 82.
- **c**. Macrinite, inertodetrinite, ulminite, resinite, and attrinite; sample 81.
- **d**. Texto-ulminite, suberinite, and sporinite; sample 81.
- **e**. Sporinite, levigelinite, oxidized sporinite, and inertodetrinite; sample 98.
- **f**. Ulminite, clay minerals, quartz grains, corpohuminite, and liptodetrinite; sample 83.

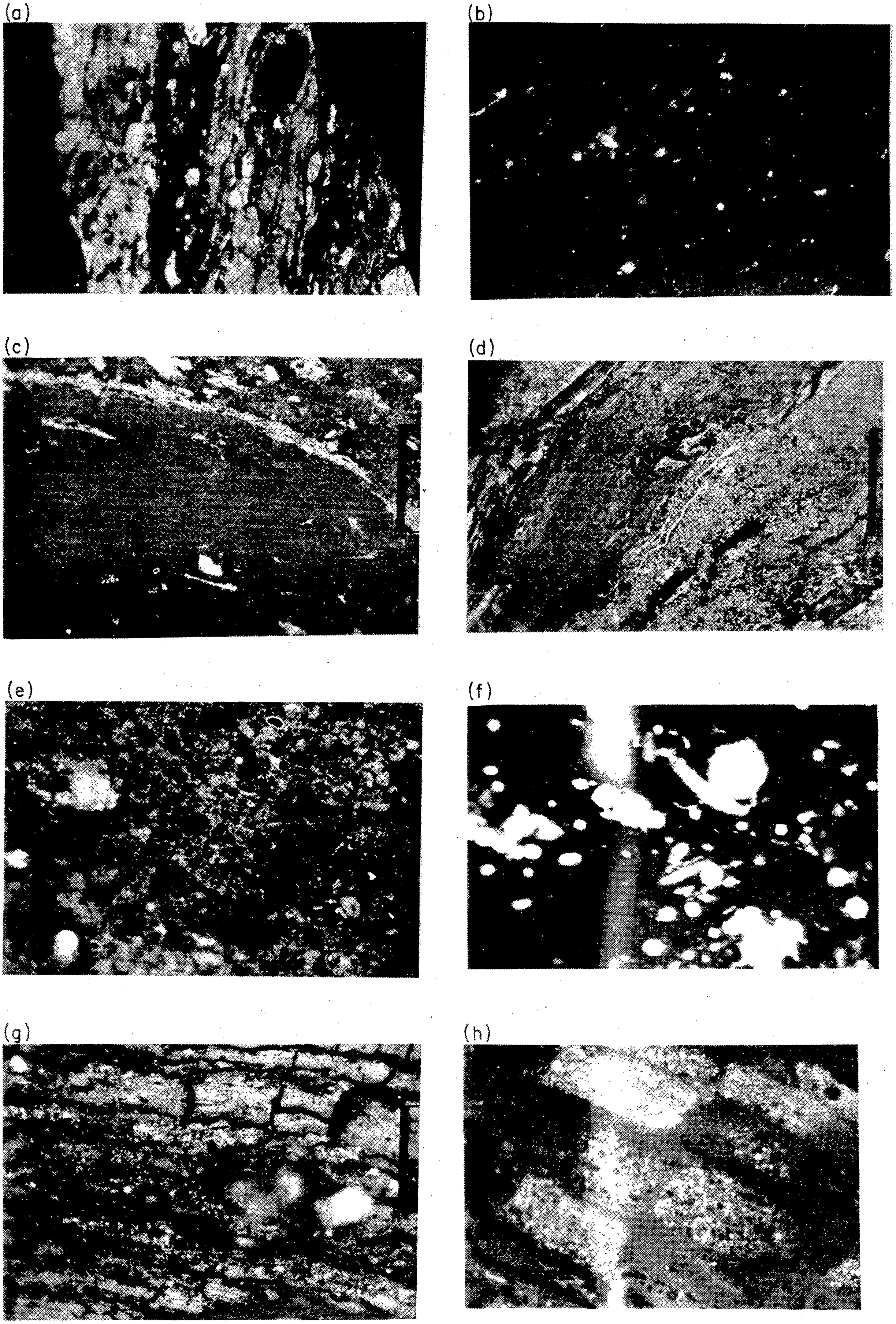
of Martin Lake mine (A-1 area). Both alginite and dinoflagellate have dark-brown fluorescence, indicating oxidation. Oxidized faunal relics are common. A lithotype sample from Martin Lake mine contains dominant ulminite, fusinite, resinite, and abundant sporinite (fig. 4e). Pyrite is rare in most of these seams. However, pyrite is abundant in the main seam from the Martin Lake mine (A-area); pyrite completely replaced texto-ulminite in some of the grains in that sample. Although not abundant, mineral matter is composed mainly of clay minerals and quartz (fig. 4f), which are often associated with texto-ulminite or attrinite.

Claiborne Group

Claiborne Group coal from the Palafox mine, Webb County (sample 118), differs from Wilcox Group coals in maceral composition as well as lithotype (discussed earlier). Attrinite or densinite and especially corpohuminite (fig. 5a) are the dominant huminite macerals. Alginite (fig. 5a), liptodetrinite, and sapropelinite (fig. 5b) are the dominant types of liptinite. The association between huminite and liptinite macerals differs from that in the coals of the Wilcox Group. Claiborne coal has separate bands of liptinite and huminite macerals, whereas in Wilcox Group coals, liptinites are intermixed with huminite macerals and rarely occur as separate layers. However, in Claiborne coal, liptinites also occur intermixed with huminite. High alginite and liptodetrinite content, lithotype, and the presence of separate distinct liptinite bands reflect subaqueous sorting of organic matter in mixed canneloid/boghead environments. However, abundant liptinite and corpohuminite may also suggest the selective oxidation of lignin-rich huminites and preservation of liptinite (fig. 5c). Low framboidal pyrite

Figure 5. Photomicrographs of macerals. All photomicrographs (except 5f) taken in white reflected light. Scale bar 50 μm.

a. Corpohuminite, attrinite, sporinite, alginite, and cutinite; sample 118.
b. Sapropelinite (amorphous liptinite), attrinite, and liptodetrinite; sample 118.
c. Sapropelinite and oxidized ulminite; sample 118.
d. Clay minerals and texto-ulminite; sample 120.
e. Attrinite, sporinite, resinite, corpohuminite, and sclerotinite; sample 126.
f. Photomicrograph taken in fluorescence reflected light. Fir needles (a variety of cutinite) and liptodetrinite; sample 143.
g. Ulminite, alginite, cutinite, and pyrite; sample 148.
h. Texto-ulminite and porigelinite; sample 150.


(a)
(b)
(c)
(d)
(e)
(f)
(g)
(h)

content supports either postdepositional oxidation or limited sulphate reduction and iron in the depositional basin.

Jackson Group

East Texas.--Two channel samples (samples 119 and 120, table 2) from two different pits at the Gibbons Creek mine, Grimes County, have distinctly different maceral compositions. The sample from pit A has dominant attrinite, sporinite, liptodetrinite, and inertinite, whereas a channel sample from pit B has dominant ulminite and texto-ulminite (fig. 5d). Sporinite, cutinite, suberinite, and mixinite are more common than in Wilcox coals. Most of the alginite (*Botryococcus*), however, is associated with ulminite. Clay minerals are the major component in this coal (fig. 5d), and they show mostly dark-brown fluorescence because of the absorbance of bitumen on the surface of clay. These bitumen-saturated clay minerals associated with liptodetrinite form a highly fluorescent groundmass.

The lowest seam (sample 126) from an outcrop at Lake Somerville, Washington County, contains mainly attrinite or densinite, sporinite, liptodetrinite (fig. 5e), and rare inertinite. A coal sample from the Cummins Creek deposit, Fayette County, contains mixed huminite macerals and abundant liptodetrinite. Liptinites from this sample are mostly liptodetrinite, sporinite, cutinite, and a new maceral, fir needle (a variety of cutinite). Fir needle (fig. 5f) is octagonal in shape, dark gray in normal reflected light, and has golden yellow fluorescence. Suberinite is common and occurs in two forms: (a) as compressed cell walls, filled with some waxy materials, having yellow fluorescence, and (b) as open cell lumens, filled with corpohuminite, which are nonfluorescent.

South Texas.--Channel samples of five thin coal seams from San Miguel mine, Atascosa County, were analyzed. These seams are separated by thin (1 to 3 ft thick) clay splits. There is a major variation in maceral composition from top (seam A) to bottom (seam D). Both samples from seam A in two different pits have high attrinite or densinite and liptodetrinite. Seam A in Ramp 7-8 has more alginite, resinite, cutinite, and liptodetrinite (fig. 5g). There is an abundance of framboidal pyrite in seam A, which sometimes replaces attrinite. Sapropelinite is abundant in sample 148. In contrast to seam A, seams B and C contain mixed huminite macerals and a predominance of liptodetrinite (associated with mineral matter). However, the liptinite content of seam B is higher than that of seam C. Ulminite is abundant in both seams B and C (fig. 5h). Sapropelinite is common in seam B. Some of the attrinite or densinite is fluorescent in seam C. Seam D (sample 151), in contrast, contains more attrinite or densinite than ulminite. Resinite, liptodetrinite, sapropelinite, and large pieces of alginite are the common liptinites associated with abundant attrinite. Seam D also contains a few dinoflagellates (phytoclasts) that have greenish-yellow fluorescence. Different varieties of sclerotinite are common. Framboidal and fine granular pyrite is common in this seam.

Early Diagenesis

Porigelinite, levigelinite, and corpohuminite are generally formed during early diagenetic transformation of ulminite and textinite. Early diagenetic transformation of attrinite resulted the formation of densinite. Preliminary chemical analysis of xylitic (contains textinite and ulminite) and gelified (corpohuminite and levigelinite) parts of two lithotype samples (unpublished data) show that the gelified part has a lower H/C and higher O/C ratio than the xylitic part. Similarly, some densinite-rich coals (sample 37) contain lower H/C ratios than do the attrinite-rich samples (sample 22). Previous studies may support the interpretation that the gelification process may be caused by oxidation (Hatcher and others, 1982; Russell, 1984). Two maceral associations are common. Discrete corpohuminite is associated with high liptinite and attrinite (sample 118), whereas porigelinite is generally associated with ulminite, inertinite, and rare liptinite (sample 17).

Maturation

Huminite/Vitrinite Reflectance

The mean of the random huminite reflectance is one of the maturation parameters used to determine the rank of Texas tertiary coals. Mean huminite reflectance is assumed to be an unreliable parameter for determining coal rank at a low coalification stage (below 0.5 percent R_o; Stach and others, 1982). One of the main reasons for the unreliability of huminite reflectance at this low rank is the diverse nature of the huminite maceral types. Figure 6 shows the variability of huminite reflectance of four different huminite maceral types from a single sample (sample 78). A progressive increase of mean huminite reflectance from texto-ulminite, to eu-ulminite, to gelinite, to corpohuminite (fig. 6) was observed. Between texto-ulminite and corpohuminite, a difference of 0.1 percent R_o was observed. The standard deviation of mean random huminite reflectance for any of these maceral types does not exceed 0.02. This type of variability in huminite reflectance of different maceral types has also been observed by other workers (Valceva, 1979; Russell, 1984). The measured reflectance values from attrinite or densinite maceral types are not considered because of their fine granular texture, impregnation by bitumens of these maceral types, and complication of measurement due to internal reflection. To determine the rank of these coals, only

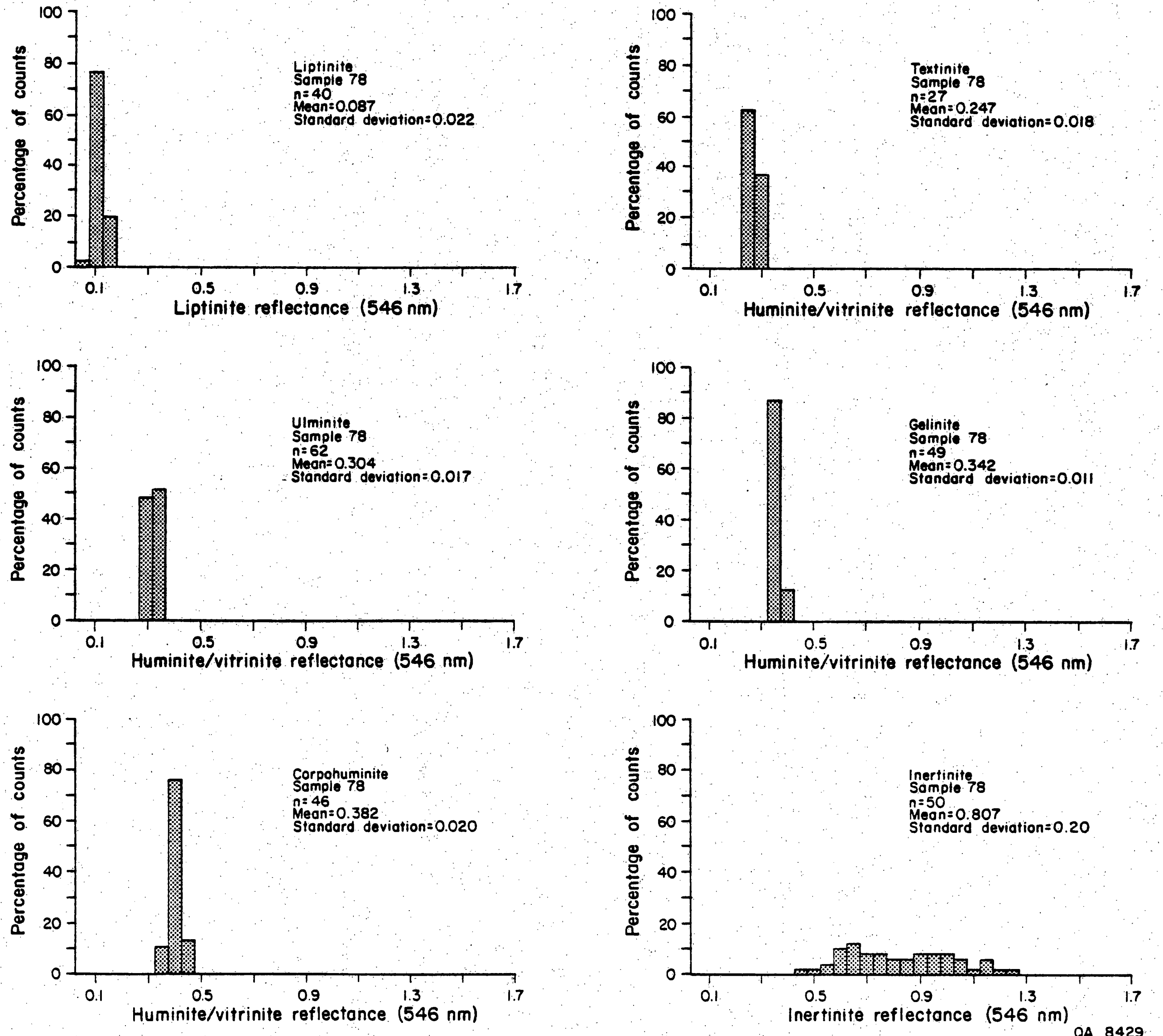


Figure 6. Reflectance histograms for huminite, liptinite, and inertinite macerals; sample 78.

eu-ulminites are measured. Texto-ulminites are not considered because they are often impregnated with resinite or they have little uniform space available for measurement. A similar problem arises when reflectance is measured on porigelinite grains. Levigelinite and corpohuminite are considered to be partly formed because of early diagenetic oxidation; therefore, these maceral types also are not considered. The reflectance of liptinite is lower than the reflectance of any of the macerals of the huminite group (fig. 6). Similarly, inertinite macerals have higher reflectance than do macerals of the huminite group (fig. 6).

The mean of the random reflectance, number of points measured, and standard deviation of mean reflectance for eu-ulminite (huminite) maceral type are given in table 1. Mean huminite reflectance for the sampled near-surface Wilcox Group coals in northeast Texas lies between 0.32 and 0.34 percent for Sabine Uplift coals, between 0.30 and 0.35 percent, and for east-central Texas coals, between 0.30 and 0.32 percent. The boundary between lignite and subbituminous C coals is at 0.35 to 0.38 percent R_o. Most of the near-surface coals are borderline lignite to subbituminous C in rank.

One Claiborne coal (sample 118, table 1) from South Texas has a much higher rank (subbituminous A) compared with Wilcox coals. Because the stratigraphic position of the Claiborne Group is above the Wilcox Group, it is assumed that this coal has been subjected either to higher heat flow than the Wilcox Group coals or to oxidation during early diagenesis.

Mean huminite reflectance of the Jackson coals from Gibbons Creek mine is 0.24 percent R_o. Coal seams from the Cummins Creek deposit, Fayette County, and from the outcrop sample at Lake Sommerville, Washington County, have R_o values of 0.30 percent. Coal seams in the San Miguel mine in South Texas have a mean huminite reflectance between 0.27 and 0.31 percent R_o. All these coals are lignite in rank.

PHYSICOCHEMICAL PROPERTIES

Tables 3 and 4 include the proximate and ultimate analyses of Wilcox, Claiborne, and Jackson coals. Equilibrium moisture (ASTM, 1981) of these coals was not determined during these analyses. Most of the available data represent average moisture content of individual seams from various mine reports or from previous studies (Kaiser, 1985; Tewalt, 1986). These data of equilibrium moisture content from different near-surface coals are not included in table 3 or 4. Equilibrium moisture values for the individual mines are: Winfield and Thermo, average 32 percent; Big Brown, 31.5 percent (values between 30 and 34 percent); Powell Bend, Sandow, and Elgin-Butler, average 33 percent (values between 29 and 35 percent); Sabine Uplift area, 33.5 percent; Gibbons Creek, average 42 percent; Cummins Creek, average 44 percent; and San Miguel, average 37.5 percent. Because moist, ash-free calorific value (Btu/lb) is the major rank parameter at this level of maturation (Stach and others, 1982), average equilibrium moisture was used for the calculation of calorific value. The average moist, ash-free calorific value for Wilcox coals is highest in east-central Texas (table 5) and lowest on the Sabine Uplift. The coals from the Sabine Uplift also have the lowest average ash, volatile matter, sulfur, and H/C ratio among all the analyzed Wilcox coals (table 5). Jackson coals from East Texas have higher average volatile matter content and H/C ratio, and lower ash, sulfur, and calorific value (Btu/lb) than Jackson coals from South Texas. Basically, Wilcox and Jackson coals (east-central Texas) are different in average calorific value, equilibrium moisture, and ash and sulfur content. Wilcox coals have average ash content (dry) of less than 17 percent, and Btu/lb (moist, ash-free) of more than 8300, whereas Jackson coals (East Texas) have an average ash content (dry) higher

Table 3. Proximate analysis and calorific value (Btu/lb) on dry basis.

Sample Number	Ash (%)	Volatile Matter (%)	Fixed Carbon (%)	Calorific value (Btu/lb)*
Wilcox Group			Northeast Texas	
2	22.05	41.77 (53.59)	36.18 (46.41)	9,553 (8,328) [7,327]
17	16.05	42.77 (50.95)	41.18 (49.05)	10,592 (8,574) [8,096]
18	24.96	40.68 (54.21)	34.36 (45.79)	9,233 (8,371) [7,248]
19	13.20	45.35 (52.24)	41.45 (47.76)	10,784 (8,429) [8,798]
Wilcox Group			East-central Texas	
59	24.15	38.83 (51.19)	37.02 (48.81)	9,537 (8,550) [7,597]
60	16.00	43.65 (51.96)	40.35 (48.04)	10,468 (8,474) [8,157]
74	20.11	46.93 (58.75)	32.96 (41.25)	10,513 (8,936) [8,796]
75	12.90	44.17 (50.71)	42.93 (49.29)	11,070 (8,652) [9,508]
78	10.69	44.81 (50.14)	44.50 (49.83)	11,632 (8,887) [9,729]
Wilcox Group			Sabine Uplift	
80	11.99	45.55 (51.76)	42.46 (48.24)	11,093 (8,445) [8,846]
81	12.04	42.61 (48.44)	45.35 (51.56)	11,165 (8,500) [8,449]
82	10.40	43.27 (48.29)	46.33 (51.71)	10,974 (8,206) [8,702]
83	11.36	45.37 (51.18)	43.37 (48.82)	11,214 (8,537) [9,323]
87	9.44	44.69 (49.35)	45.87 (50.65)	11,139 (8,237) [8,740]
98	28.06	37.47 (52.08)	34.47 (47.92)	9,071 (8,441) [7,522]
Claiborne Group			South Texas	
118	14.62	48.51 (56.82)	36.87 (43.18)	12,692 (12,600) [12,282]
Jackson Group			East Texas	
119	41.06	35.99 (61.06)	22.95 (38.94)	7,406 (7,270) [6,206]
120	36.63	38.83 (61.28)	24.54 (38.72)	8,019 (8,094) [6,622]
126	9.68	52.64 (58.28)	37.64 (41.72)	10,630 (7,441) [9,298]
143	20.60	50.80 (60.29)	28.60 (39.71)	7,310 (5,660) [6,680]
Jackson Group			South Texas	
147	29.62	38.99 (55.40)	31.39 (44.60)	8,859 (8,108) [6,369]
148	48.98	32.26 (63.23)	18.76 (36.77)	6,287 (7,938) [5,695]
149	25.14	40.09 (53.56)	34.77 (46.44)	9,369 (8,059) [7,620]
150	24.60	40.90 (54.24)	34.50 (45.76)	9,531 (8,140) [6,524]
151	26.58	38.96 (53.07)	34.46 (46.93)	9,260 (8,124) [7,676]

Data in square brackets are on as-received basis.
Data in parentheses for calorific value are calculated on moist, ash-free basis.
Data in parentheses for volatile matter and fixed carbon are calculated on dry, ash-free basis.

Table 4. Elemental composition, or ultimate analysis.
(dry basis)

Sample No.	Hydrogen (%)	Carbon (%)	Nitrogen (%)	Oxygen (%)	Sulfur (%)				Ash (%)	H/C	O/C
					A	a	b	c			
	Wilcox Group					Northeast Texas					
2	3.91 (5.00)	56.12 (72.00)	1.05 (1.35)	16.23 (21.01)	0.64	0.00	0.04	0.60	22.05	0.84	0.22
17	4.29 (4.99)	61.19 (74.08)	0.92 (1.10)	14.75 (17.57)	1.90	0.08	0.37	1.45	16.05	0.81	0.18
18	3.92 (5.22)	54.03 (72.00)	0.92 (1.23)	15.51 (20.67)	0.66	0.08	0.37	1.45	24.96	0.81	0.18
19	4.58 (5.28)	62.85 (72.41)	1.19 (1.37)	17.33 (19.96)	0.85	0.03	0.05	0.77	13.20	0.87	0.21
	Wilcox Group					East-central Texas					
59	4.07 (5.37)	55.27 (72.86)	0.99 (1.31)	13.96 (18.40)	1.56	0.08	0.22	1.26	24.15	0.88	0.19
60	4.38 (5.21)	60.87 (72.46)	0.94 (1.12)	16.17 (19.26)	1.64	0.09	0.45	1.10	16.00	0.86	0.20
74	4.68 (5.86)	59.25 (74.17)	0.93 (1.16)	13.27 (10.61)	1.76	0.04	0.73	0.99	20.11	0.98	0.17
75	4.58 (5.26)	64.19 (73.70)	1.21 (1.39)	14.95 (17.16)	2.17	0.06	0.81	1.32	12.90	0.86	0.17
78	4.70 (5.26)	66.69 (74.67)	1.16 (1.30)	15.40 (16.28)	1.36	0.06	0.10	1.20	10.69	0.85	0.17
	Wilcox Group					Sabine Uplift					
80	4.50 (5.11)	64.65 (73.46)	1.04 (1.18)	16.04 (18.25)	1.78	0.08	0.71	0.99	11.99	0.83	0.19
81	4.34 (4.93)	65.03 (73.93)	1.06 (1.21)	15.84 (18.01)	1.69	0.07	0.79	0.83	12.04	0.80	0.18
82	4.41 (4.92)	64.97 (72.51)	1.19 (1.33)	18.31 (20.49)	0.72	0.01	0.07	0.64	10.40	0.82	0.21
83	4.35 (4.91)	65.50 (73.89)	1.15 (1.30)	16.41 (18.81)	1.23	0.06	0.44	0.73	11.36	0.80	0.19
87	4.60 (5.08)	67.35 (74.37)	1.33 (1.47)	16.21 (17.91)	1.07	0.04	0.17	0.86	9.44	0.82	0.18
98	3.83 (5.32)	52.36 (72.78)	0.88 (1.22)	13.69 (19.69)	1.18	0.08	0.09	1.01	28.06	0.88	0.20
	Claiborne Group					South Texas					
118	5.84 (6.84)	68.18 (29.86)	1.03 (1.21)	9.50 (11.12)	0.83	0.01	0.07	0.75	14.62	1.03	0.10
	Jackson Group					East Texas					
119	3.32 (5.63)	42.28 (71.74)	0.69 (1.17)	11.55 (19.84)	1.10	0.01	0.05	1.04	41.06	0.94	0.21
120	3.62 (5.71)	45.22 (71.36)	0.68 (1.07)	12.41 (19.59)	1.44	0.02	0.14	1.28	36.63	0.96	0.21
126	4.71 (5.23)	60.92 (67.45)	0.79 (0.87)	20.71 (22.90)	3.19	0.01	0.02	3.16	9.68	0.93	0.25
143	4.7 (5.34)	57.14 (70.10)	0.77 (0.94)	13.84 (20.25)	2.95	0.10	0.11	2.74	20.6	0.99	0.18
	Jackson Group					South Texas					
147	3.80 (5.40)	50.95 (72.34)	0.71 (1.01)	11.99 (17.04)	2.93	0.04	0.54	2.35	29.62	0.90	0.18
148	3.35 (6.57)	36.03 (70.62)	0.48 (0.94)	8.85 (17.34)	2.31	0.07	0.49	1.75	48.98	1.11	0.18
149	4.04 (5.40)	53.75 (71.81)	0.64 (0.85)	13.92 (18.59)	2.51	0.03	0.34	2.14	25.14	0.90	0.19
150	3.86 (5.12)	54.51 (72.30)	0.75 (0.99)	13.78 (18.27)	2.50	0.05	0.42	2.03	24.60	0.85	0.19
151	4.10 (5.58)	52.78 (71.89)	0.78 (1.06)	12.86 (17.52)	2.90	0.06	0.82	2.02	26.58	0.93	0.18

A = total sulfur
a = sulfate sulfur
b = pyritic sulfur
c = organic sulfur
Data in square brackets are calculated on dry, ash-free basis.

Table 5. Average chemical composition of sampled coals.

Ash (++)	Volatile Matter (*)	Fixed Carbon (*)	Calorific Value (+)	Sulfur (++)	H/C	O/C
Wilcox Group, northeast Texas (four samples)						
19.1	52.8	47.2	8,425	1.30	0.83	0.20
Wilcox Group, east-central Texas (five samples)						
16.8	52.6	47.4	8,700	1.70	0.89	0.18
Wilcox Group, Sabine Uplift (six samples)						
13.9	50.1	49.9	8,394	1.28	0.82	0.19
Claiborne Group, South Texas (one sample)						
14.6	56.8	43.2	12,000	0.83	1.03	0.10
Jackson Group, East Texas (four samples)						
27.0	60.2	39.8	7,116	2.17	0.96	0.21
Jackson Group, South Texas (five samples)						
31.0	55.9	44.1	8,073	2.63	0.94	0.18

(++) - Percentage on dry basis
(+) - Btu/lb on moist, ash-free basis
(*) - Percentage on dry, ash-free basis

than 25 percent, Btu/lb of less than 8100, and higher H/C ratio. According to calorific value, Wilcox coals are borderline subbituminous C or lignite in rank, whereas Jackson coals are lignite in rank. This corroborates the rank of Wilcox and Jackson coals determined by mean huminite reflectance.

DISCUSSION

Depositional Environments

The constituents of a brown coal are controlled by geological setting, vegetation, nutrient supply to the vegetation, level of ground water, acidity of the ground water, and early diagenetic changes. Four depositional conditions may result in the formation of peat (Stach and others, 1982) in a fluvio-deltaic environment: (1) A forest swamp, which generally occurs in the fluvial interchannel backswamp area that consists mainly of arboreal vegetation. This type of deposit may form on the alluvial plain or at the junction of alluvial and upper delta plains. (2) A forested swamp-marsh complex or swamp vegetation mixed with floatant marsh, which consists of a mixture of arboreal and reed-marsh vegetation and is deposited in an interdistributary basin or abandoned-distributary area away from the major channel at the transition of the upper delta plain and lower alluvial plain or on the upper delta plain (Kosters and others, 1987). (3) Fresh-water or brackish marshes with sedges, reeds, and herbaceous vegetation, which forms at the upper or lower delta plain. (4) Open aquatic conditions where peat forms subaqueously from a mixture of algae, other subaquatic plants, and allochthonous plant materials; these conditions may form in a delta plain where the peat swamp is drowned by an expanding lake and the lake is surrounded by vegetation of types (1), (2), or (3).

These four generalized depositional settings should be reflected in maceral compositions of brown coal that is not geochemically homogenized. Peat containing more than 80 percent well-preserved humotelinite (textinite) and highly banded, xylitic lithotype with resin inclusions suggests that organic accumulation may have been formed from arboreal vegetation (*Sequoia* type vegetation) and stagnant water having acidic pH. These coals contain abundant gelified lenses. Impure xylitic, highly banded lithotype indicates intermittent flooding of the swamp. Peat containing more than 60 percent poorly preserved humotelinite and moderately to finely banded, nonxylitic, pure lithotype indicates shrub vegetation (not truly arboreal) deposited in a swamp environment. The absence of textinite and abundance of ulminite (better preserved tissue mainly from stems and barks) suggests the possibility of a *Nyssa*-*Taxodium* type vegetation, perhaps slightly lower on the alluvial plain or at the transition of the upper delta plain and alluvial plain but deposited under acidic (pH less than 4) conditions that prevent bacterial degradation, allowing the retention of well-preserved ulminite. The influx of ulminite instead of textinite may also be attributed to homogenization due to humification during the early and late diagenetic stages. Abundance of humodetrinite mixed with humotelinite (ulminite) and finely banded to unbanded, nonxylitic, pure lithotype may indicate accumulation at the transition of the lower alluvial plain and upper delta plain or at the upper delta plain, typical of a swamp-marsh complex described for the Barataria basin by Kosters and others (1987). Huminite having more than 80 percent humodetrinite, coupled with sporinite, cutinite, and liptodetrinite and finely banded to unbanded, detrital or nonxylitic, pure lithotype, suggests that accumulation took place mainly from reed-marsh vegetation lower on the upper delta plain under a neutral pH, allowing maximal bacterial degradation. Finely banded to unbanded, detrital or nonxylitic, impure lithotype may indicate rapid delta-lobe switching and foundering. Coal containing abundant humodetrinite and corpohuminite with abundant amorphous liptinite (sapropelinite), liptodetrinite, sporinite, and/or alginite and hard, unbanded, nonxylitic, pure lithotype indicates accumulation in lacustrine and subaquatic conditions on the delta plain under mildly acidic to mildly basic conditions to sustain active bacterial degradation.

The high and low stand of the ground-water table in swamp, reed-marsh, and lacustrine environments can be determined by the amount of fusinite. The abundance of gelo-inertinite may be related to degradation of plants by aerobic bacteria and fungi. Abundance of inertinite may indicate drying of the peat surface, periods of low water table, and swamp fires due to drought. The nature of liptinites may also provide some useful clues to the recognition of depositional environment. Coal having less than 25 percent liptinite, mainly as resinite and terrestrial exinite (sporinite, cutinite, and suberinite), and high ulminite indicates deposition in a forested swamp. Coal having greater than 30 percent liptinite, mainly as liptodetrinite, sporinite, and cutinite with abundant humodetrinite, indicates reed-marsh vegetation. Coal having more than 35 percent liptinite and abundant alginite and sapropelinite may indicate lacustrine conditions. The presence of dinoflagellates (phytoclasts) may indicate an influx of marine or brackish water into the peat-forming environment. Study of the petrography of recent peats from three different depositional environments in the Frazer River Delta revealed different maceral composition in three different environments (Styan and Bustin, 1983). Accordingly, gyttja peat at the transition of the upper and lower delta plains contains liptodetrinite, alginite, cutinite, and humodetrinite. Sphagnum peat includes macerals like telinite, resinite, and telocollinite. Alluvial peat contains more inertinite macerals.

According to the interpretation from subsurface geologic analysis, lignites in the Calvert Bluff Formation of east-central Texas and equivalent formations on the Sabine

Uplift occur in sand-poor interchannel facies between major channels (Kaiser and others, 1978, 1980). Lignites within these areas are derived from a hardwood swamp in a subtropical, humid paleolatitude on the alluvial plain (Kaiser and others, 1978). Hooper lignites are considered fluvial at the near-surface. On the basis of subsurface mapping, the major fluvial channels have a northwest-southeast trend in east-central Texas, whereas channels have a north-south trend in northeast Texas and a northeast-southwest trend on the Sabine Uplift (W. R. Kaiser, personal communication, 1986). Lobate and digitate sand bodies (Kaiser and others, 1978) of the Jackson Group in East Texas reflect the Fayette delta system (Fisher and others, 1970); lignites were deposited in marshes within the lower delta plain. Lignite geometry and occurrence in South Texas coincide well with the buildup of strike-oriented strandplain/barrier-bar sands. Lignites accumulated mainly as swamp-marsh vegetation in a strandplain/barrier-bar complex (Ayers and Kaiser, 1986; Mukhopadhyay, 1986).

In view of the previously discussed relationship between maceral type, vegetal precursors, and depositional environment, maceral type was correlated with environment of deposition, as interpreted from sand-body geometry (Fisher and others, 1970; Kaiser and others, 1978, 1980; Ayers and Kaiser, 1986). The macerals are represented in a ternary diagram (fig. 7) whose apexes represent the different combinations or affinities of maceral types formed under similar conditions. Apexes of this diagram represent (A) humotelinite + terrestrial exinite (sporinite + cutinite + suberinite) + resinite, (B) humodetrinite + liptodetrinite + sapropelinite + alginite, and (C) inertinite. In the ternary diagram, amounts of humocollinites are excluded because it is assumed they formed in part during the early to late diagenetic stage. The interpreted depositional conditions of these three apexes on the ternary diagram are: (A) Forested swamp on the alluvial plain or at the junction of alluvial plain and upper delta plain

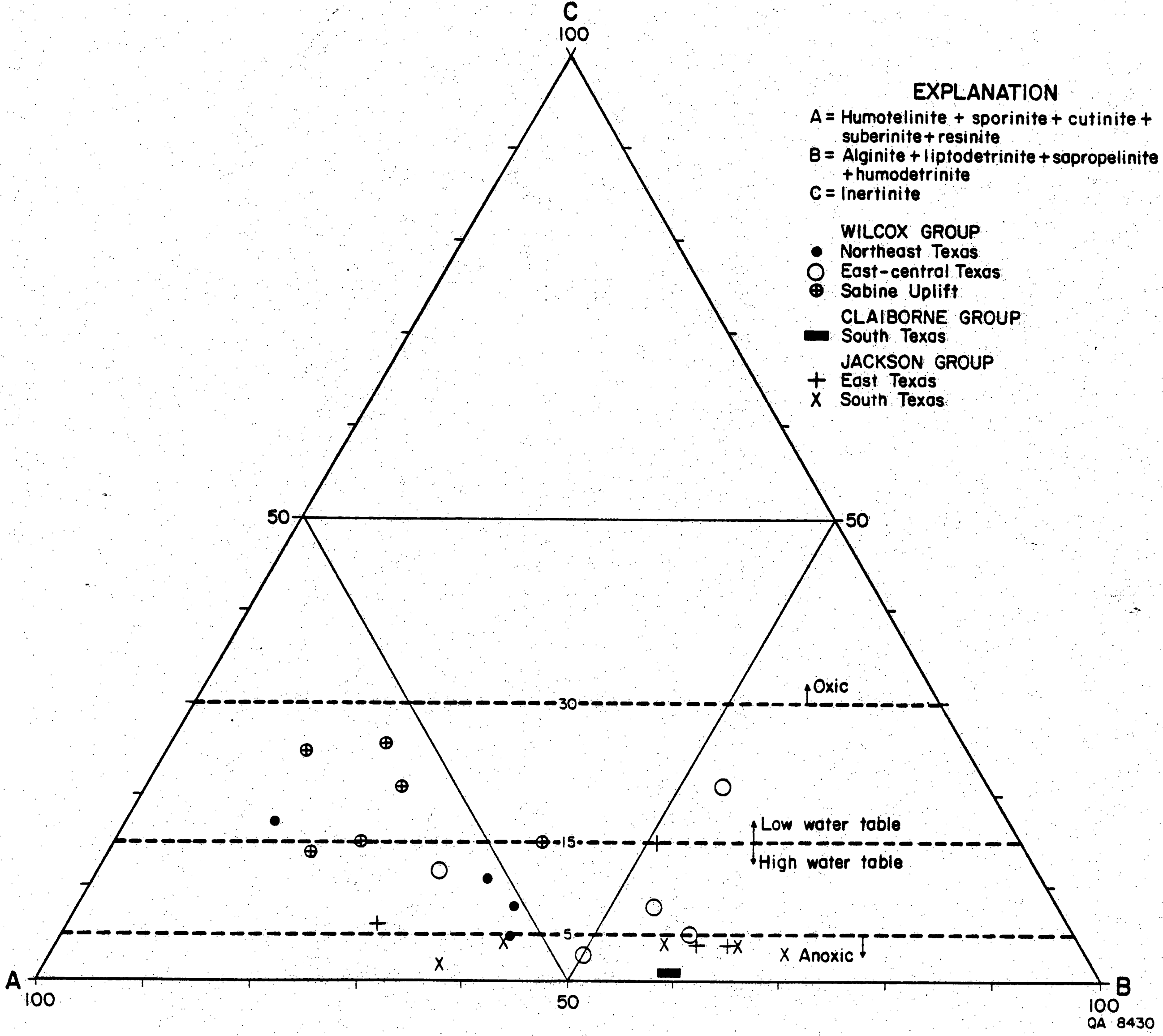


Figure 7. Ternary diagram combining macerals of similar affinity at three apexes and the position of coals from the Wilcox, Claiborne, and Jackson Groups.

A = Humotelinite, terrestrial exinite (sporinite, cutinite, and suberinite), and resinite. Probable depositional environment is mildly oxic to mildly anoxic alluvial swamp with well-preserved cell structure.

B = Humodetrinite, liptodetrinite, sapropelinite, and alginite. Probable depositional environment is delta plain, lacustrine, and back-barrier/strandplain marsh and subaquatic with increasing maceration, bacterial activity, and more anoxic conditions than A.

C = Inertinite. Probable depositional environment is oxic swamp on alluvial plain or delta plain or tidal flat.

having mildly oxic to mildly anoxic conditions and well-preserved cell structure. (B) Swamp-marsh complex or subaquatic lakes on the delta plain or barrier bar/strandplain having more anoxic conditions than apex A, dominant reed-marsh or aquatic vegetation, and increasing maceration and bacterial activity. (C) Swamp on the alluvial plain, delta plain, or tidal flat having highly oxic conditions affected by mouldering process. Arbitrary percentages of inertinite (5, 15, and 30 percent) have been chosen to indicate fluctuation of the water table during the peat-forming period (fig. 7) because inertinites are considered to be formed as a result of the oxidation process. A coal having more than 30 percent inertinite is considered to have been affected by the mouldering process. In such a case, resistant parts of the plants are mostly preserved. A coal that has less than 15 percent but greater than 5 percent inertinite is considered to be formed as the result of an optimum peatification process (mildly oxidizing and mildly reducing), resulting in huminite-rich coal. A coal having less than 5 percent inertinite is considered to be deposited in a combination of peatification and putrefaction processes (Stach and others, 1982) in a subaquatic condition. Abundant framboidal pyrite is generally associated with this type of coal. The interpretations of the depositional condition as revealed by sand-body geometry and coal petrography may not be identical because there may have been a time lag between the deposition of peat and clastics.

The position of the coals in the ternary diagram (fig. 7) suggests a distinct trend for different Wilcox and Jackson coals. Most of the coals from northeast Texas lie between apexes A and C. These samples are banded, nonxylitic, pure coal that contain abundant ulminite and sporinite and rare inertinite. It is therefore assumed that the upper seams (Thermo mine, Hopkins County) were deposited in a swamp environment under relatively low energy and high water-table conditions. However, high mineral content in some samples from the Winfield mine suggest intermittent flooding of the swamp. Presence of the Pediastrum type of alginite and influx of detrinite in the lower seam of this region suggests that deposition started with mixed swamp-marsh and aquatic vegetation under lacustrine conditions in an upper delta plain and culminated in floodbasin swamp deposition of the upper seam in a fluvial system. Abundant organic sulfur in the upper seams at the Thermo mine may indicate marine deposits above this coal.

Compared with coals in northeast Texas, those from the surface mines of east-central Texas (except some samples from the Sandow mine) have more humodetrinite and liptodetrinite. On the basis of maceral composition, these coals may have been deposited in interchannel basins as swamp-marsh vegetation on the upper delta plain (comparable to the Barataria basin in the Mississippi River Delta; Kosters and others, 1987).

Claiborne coal contains abundant detrinitic and aquatic macerals (fig. 7). The depositional environment may have been lacustrine in the lower delta plain, or it may have been a marsh environment. After the formation of peat, oxidizing ground water may have leached most of the lignin-rich huminites and selectively preserved the algal and other resistant liptinites to form a biodegraded mass (P. G. Hatcher, personal communication, 1987); corpohuminites were formed during early diagenesis. High huminite reflectance may be caused by secondary oxidation by ground-water movement. It probably does not represent a true sapropelic marsh environment undergoing extensive biodegradation by anoxic bacteria under neutral or alkaline conditions. Fairly low ash and sulfur content coupled with alginite and biodegraded macerals suggests that this coal was shielded during deposition by a marginal remnant of arborescent vegetation that inhibited influx of sediment-laden water from the margins of the marsh or was simply isolated from clastic influx by the bypassing of sediment. It may be possible that minerals are leached out along with the lignin fraction of the peat during early diagenesis.

Jackson coals in East Texas have abundant detrinitic macerals and palynologically overwhelming marsh-dominated populations (Arecipites and Momipites; Genett and others, 1986). However, marked variation in maceral composition was noticed in the upper and lower parts of the coal seam in the Gibbons Creek mine (8-ft-thick seam with several thin partings). The channel samples had low ash and sulfur content. This may suggest that early progradation of the delta led to a marsh-dominated blanket peat away from the main trunk stream. The peat was deposited at the transition of the upper and lower delta plain, which eventually changed to a swamp-marsh complex in an upper deltaic environment. The position of these coal seams in the ternary diagram (fig. 7) indicates that the peat-forming environment had a high ground-water table, resulting in coal with very low inertinite content. A similar depositional model is predicted for Lake Somerville coals, which may have been deposited at the transition of the upper and lower delta plain as a blanket peat. Compared with Lake Somerville coals, low sulfur content of the seams from the Gibbons Creek mine suggests lower influx of sulphide and ferrous iron within the depositional basin. Alternatively, mudstones on top of the seam may be impervious to the flow of sulphates from seawater.

According to sand-body geometry (discussed earlier), coal seams in the Cummins Creek deposit, Fayette County, were deposited in the lower delta plain within the Fayette delta system. The analyzed coal seam has distinct abundant marsh-dominated (table 2) macerals. Fir needles may have been transported into the depositional basin. It is therefore assumed that this coal seam may have been deposited on the lower delta plain or on an embayment within the lower delta plain having marsh-dominated plant communities. However, no brackish-marsh plant communities were encountered. High sulfur and ash contents indicate frequent marine inundation of fresh-water peat by delta-lobe switching and/or foundering. Because the Jackson delta was much smaller than the Wilcox, a seaward, lower delta plain location of the peat would subject it to more frequent marine transgression.

The depositional environment of coal seams at the San Miguel mine, Atascosa County, lower Jackson Group, should be complex back-barrier to lagoonal according to sand-body geometry (Kaiser and others, 1978; Ayers, 1986). Petrological data imply that at least some seams were deposited in swamp environments. In seam D (the lowest seam), humodetrinite, liptodetrinite, abundant amorphous liptinite, and a few marine phytoclasts (dinoflagellates?) are more abundant than swamp pollens and ulminite. This may indicate that the peat formed in a filled lagoonal environment behind a barrier bar. Seams B and C have more swamp pollen than seam D. Abundant ulminite and rare humodetrinite and liptodetrinite may indicate a swamp-dominated back-barrier-bar environment (Cohen, 1984). Abundant ulminite and terrestrial exinites in seam C indicate a fresh-water, swamp-dominated coal. However, abundant liptodetrinite and fluorescent attrinite in seam B suggest active biodegradation and mixing with bacterial lipid in a marsh-plant-dominated swamp environment behind a barrier bar. Seam A may have been deposited in a reducing, filled lagoonal environment with abundant detrinitic and amorphous macerals formed in reed-marsh plant communities (*Momipites*, *Caprifoliipites*-*Salixipollenites*; Genett and others, 1986). High mineral-matter content (mainly clay minerals and pyrite occurring as bands or within macerals) and the presence of oxidized textinite may suggest postdepositional inundation by seawater along an active shoreline. The evidence cited previously suggests rapid changes in depositional regime owing to a nearby and active marine shoreline.

Correlation between Lithotype, Maceral Composition, and Chemical Properties

In both Wilcox and Jackson coals, lithotypes and maceral composition can be correlated. Moderately to highly banded, nonxylitic, pure coal has humotelinite and inertinite-rich macerals. Finely banded coal contains a mixture of humotelinite- and humodetrinite-rich macerals. Unbanded coal shows either dominant detrinite-rich coal or a mixture of detrinite- and collinite-rich macerals. However, most detrital pure or impure coal contains abundant humodetrinite- and liptodetrinite-rich macerals. Color is not an important factor in recognizing liptinite-rich or liptinite-poor coals in the Wilcox Group because of slightly more advanced maturation than previously studied coals (Hagemann and Hollerbach, 1980; Verheyen and others, 1984; Wolfram, 1984). Most of the detrital coal in the Jackson Group is more liptinite- or hydrogen-rich than the unbanded, nonxylitic Wilcox coals.

Two plots were used to establish the relation between chemical parameters and maceral composition at the rank range studied (fig. 8). Calorific value (Btu/lb) is inversely related to dry ash content (percent) for most of the Wilcox and Jackson coals (fig. 8a), meaning that higher ash content lowers the calorific value. Most of the Wilcox and Jackson coals show some correlation between the liptinite content (volume percent from the maceral composition) and dry ash percent (fig. 8b). A similar relationship exists between sulfur and liptinite content, which may indicate sulfur is mainly organic and tied to liptinites. Claiborne coal deviates from the trend line of both the plots, which may suggest a different organic facies than most of the Wilcox and Jackson coals.

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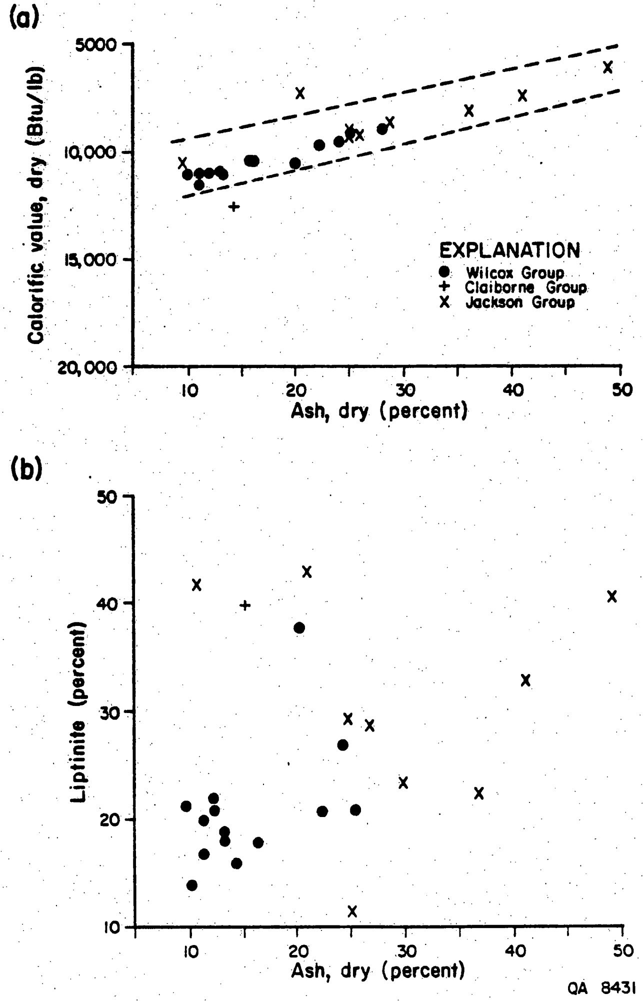

Figure 8. Plots of (a) Btu/lb (dry) versus ash content (dry); (b) liptinite percent versus ash content (dry) for all coals analyzed.

SUMMARY

Tertiary coals from existing surface mines and exposures of Wilcox (northeast and east-central Texas), Claiborne (South Texas, one sample), and Jackson (East and South Texas) Groups were characterized by organic petrography (lithotype, maceral composition, and huminite reflectance) and chemical analyses. Maceral composition, when plotted on a ternary diagram having apexes with macerals of similar affinity, demonstrates the variability of peat-forming depositional environments. These results, when correlated with the chemical data, suggest the following:

(1) Wilcox and Jackson coals can be differentiated on the basis of volatile matter (average Wilcox 51.8 percent; average Jackson 58 percent), ash content (average Wilcox 16.6 percent; average Jackson 29 percent), calorific value (average Wilcox 8510 Btu/lb; average Jackson 7594 Btu/lb), sulfur (average Wilcox 1.43 percent dry; average Jackson 2.40 percent dry), R_o (average Wilcox 0.32 percent; average Jackson 0.28 percent), H/C (average Wilcox 0.85; average Jackson 0.95), and liptinite content (average Wilcox 21 percent, average Jackson 30 percent).

(2) Wilcox coals (except lower seams) from the surface mines of northeast Texas (Titus and Hopkins Counties) and the Sabine Uplift (Panola and Harrison Counties) are banded, nonxylitic, pure coal having high ulminite, sporinite, and resinite content, indicating deposition within an alluvial plain backswamp having arboreal vegetation, intermittent flooding, and acidic conditions. The main differences between these two areas are the presence of charcoal lenses (as inclusion within lithotype) and more inertinite in coals

from the Sabine Uplift. The lower seam in northeast Texas was deposited in a lacustrine environment having abundant marsh and aquatic vegetation. Recycled alginite, poorly preserved and recycled dinoflagellate, and oxidized faunal relics within the coals from the Sabine Uplift suggest transportation of palynomorphs from nearby brackish bays and inundation of the peat surface by marine trangression. Coals from the Sabine Uplift have lowest calorific value (less than 8400 Btu/lb, moist, ash-free basis), ash (less than 14 percent) and sulfur content (1.28 percent) within the Wilcox coals from different areas.

(3) A mixed maceral assemblage having a slight dominance of humodetrinite and liptodetrinite and the presence of mixed swamp and marsh pollen in Wilcox Group surface mines of east-central Texas (Freestone, Bastrop, and Milam Counties) indicate that the coals were deposited within the upper delta plain as swamp-marsh complex vegetation similar to the present Barataria basin of the Mississippi River Delta. Chemical properties are: average calorific value (moist, ash-free) 8,700 Btu/lb, volatile matter (daf) 52.6 percent, ash (dry) 16.8 percent, and sulfur (dry) 1.70 percent.

(4) Claiborne coal is a distinct lithotype that contains mixtures of corpohuminite, alginite, liptodetrinite, and sapropelinite. These data suggest that this coal was deposited either in a lacustrine environment as a mixed cannel and boghead type or in a marsh environment within a lower delta plain that was later subjected to ground-water movement and selective enrichment of liptinite macerals by oxidation during early diagenesis. Chemical properties are: calorific value 12,600 Btu/lb, R_o 0.5 percent, volatile matter (daf) 56.8 percent, ash (dry) 14.6 percent, and sulfur 0.9 percent.

(5) Abundant detrinitic and amorphous macerals, high-sulfur and mineral-matter content, and low inertinite content of the coals of the East Texas Jackson Group suggest deposition at the transition of the upper and lower delta plain marsh with a high ground-water table and intermittent marine transgression. Fir needles (a variety of cutinite?), which are dominant in these coals, may be transported. Chemical characteristics of these coals are: average calorific value (moist, ash-free) 7,116 Btu/lb, volatile matter (daf) 60.2 percent, ash (dry) 27 percent, sulfur (dry) 2.17 percent.

(6) As in East Texas Jackson coals, marsh pollen, humodetrinite, liptodetrinite, and amorphous liptinite dominate seams A and D of the San Miguel mine in the South Texas Jackson Group. Seams B and C have swamp-dominated pollens and humotelinite. Presence of dinoflagellates (not recycled), mixture of swamp and marsh vegetation, abundant biodegradation, and sand-body geometry may indicate a barrier-bar environment behind an active shoreline. Chemical properties are: average calorific value 8,073 Btu/lb, volatile matter (daf) 55.9 percent, ash (dry) 31 percent, and sulfur (dry) 2.63 percent.

(7) According to calorific value (moist, ash-free) and R_o, Wilcox coals are borderline lignite to subbituminous C in rank, Claiborne coal is subbituminous A, and Jackson coals are lignite in rank.

(8) Decrease of calorific value (Btu/lb) and increase of liptinite content are related to increase of ash content for most of the coals.

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Appendix A. Macropetrographic (lithotype) classification of soft, brown coals (after Hagemann and Hollerbach, 1980).

Categories	Lithotype classes	Lithotypes	Lithotype varieties			
Reading column matrix	01	02	03	04	05	
Quality parameter	Structure: presence of xylite and/or contamination by mineral matter	Texture: ratio between groundmass and plant remains	Intensity and hue of color	Evidence of gelification	Inclusions	Additional features
Macropetrographic description	① *pure coal, nonxylitic*	① *unbanded coal*	① *pale yellow*	① *gelified groundmass* (+, + +, + + +)	① *resin bodies* (+, + +, + + +)	(1) *surface texture* extensive cracking moderate cracking no cracking
	② *pure coal, xyl.* fibrous xylite tree stumps tree trunks etc.	② *moderately banded coal*	② *medium light-yellow*	② *gelified tissues* (+, + +, + + +)	② *cuticles* (+, + +, + + +)	(2) *fracture* even imbricated
	③ *impure coal, nonxylitic* clayey coal sandy coal calcerous coal etc.	③ *banded coal*	③ *pale brown*	③ *microgranular humic gel particles* (+, + +, + + +)	③ *charcoal* (+, + +, + + +)	(3) *size degradation* coarse fragmentation fine fragmentation crumbling
	④ *impure coal, xylitic*	④ *highly banded coal*	④ *medium light-brown* ⑤ *dark brown* ⑥ *dark black*	④	④	

Appendix B. Lithotype classification of lignite and subbituminous coals (modified after Hagemann and Hollerbach, 1980; Mukhopadhyay, 1986).

Lithotype classes	Lithotypes	Gelification/inclusions
1. Pure coal, detrital	Unbanded	Gelified particles and lenses, cuticles and minor resin
2. Pure coal, nonxylitic	Unbanded Finely banded (less than 2 mm) Moderately banded (greater than 2 mm and less than 5 mm)	Gelified groundmass, resin bodies, charcoal, etc.
3. Pure coal, xylitic	Moderately banded Highly banded (greater than 5 mm)	Gelified tissues, cuticles
4. Impure coal, detrital	Unbanded	Gelified particles and lenses, resin bodies and cuticles
5. Impure coal, nonxylitic	Unbanded Finely banded Moderately banded	Gelified groundmass, charcoal, resin bodies
6. Impure coal, xylitic	Highly banded Moderately banded	Charcoal, etc.

Appendix C. Petrographic nomenclature for low-rank coals (reflected light) (modified after ICCP, 1971, 1975; Teichmüller, 1981; Stach and others, 1982).

Primary macerals

Group	Subgroup	Maceral	Maceral type
Huminite	Humotelinite	Textinite	
		Ulminite	Texto-ulminite Eu-ulminite
	Humodetrinite	Attrinite Densinite	
	Humocollinite	Gelinite	Levigelinite Porigelinite
		Corpo-huminite	Phlobaphinite Pseudo-phlobaphinite
	Detro-Mixinite		Mixinite (humo-liptinitic groundmass)
Liptinite	Morpho-liptinite	Sporinite Cutinite Suberinite Resinite Fluorinite Chlorophyllinite Phyto- and zooclasts Alginite	
	Detro-liptinite	Algodetrinite Liptodetrinite	
	Amorpho-liptinite	Sapropelinite (≈Bituminite)	
Inertinite	Telo-inertinite	Fusinite Semifusinite Sclerolinite	

Appendix C (cont.)

Group	Subgroup	Maceral	Maceral type
	Detro-inertinite	Inertodetrinite Micrinite	
	Gelo-inertinite	Macrinite	
		Faunal Relics(?)	
		Secondary maceral	
Liptinite		Exsudatinite or Bitumen	
Inertinite		Micrinite	

Macerals

Huminite Group

Huminite:	Mainly composed of ligno-cellulose plant remains; sometimes mixed with some lipids. This maceral group is the counterpart of vitrinite below a maturation level of $0.55\%R_o$.
Humotelinite:	Structured huminite macerals.
a) Textinite:	Ungelified plant tissue with open cell lumens.
b) Texto-ulminite:	Partly gelified, cell lumens partly closed.
c) Ulminite or Eu-ulminite:	Completely gelified huminite but shows faint traces of cell walls.
Humodetrinite:	Macerated huminite macerals.
a) Attrinite:	Finely macerated humic particles, granular and porous appearance.
b) Densinite:	Same as attrinite but more clustered.
Humocollinite:	Gelified huminite macerals.
a) Porigelinite:	Granular, colloidal, porous particles, mainly fills the cell lumens.

b) Levigelinite:	Massive, structureless, smooth appearance. Sometimes fluorescent (dark brown), often shows dehydration cracks filled with exsudatinite.
c) Corpohuminite:	Oval, rounded, and tubular bodies with reflectivity higher than or equal to gelinite or ulminite. These are either liberated as excretion from living-plant cell walls (phlobaphinite) or are produced as secondary cell fillings from humic gels (pseudo-phlobaphinite; Stach and others, 1982). Other corpohuminite bodies similar in shape and reflectivity to phlobaphinite but not occurring in clearly defined cell structure (Cameron and others, 1984). Therefore, these macerals do not fall into the two categories cited above.
Detro-mixinite: subgroup	Macerals that are fragmented to smaller particles by destroying their identity. However, according to fluorescence, these macerals are mixtures of huminite and liptinite.
Mixinite:	In normal reflected light, has a grainy, gray color with occasional framboidal pyrite. In blue-light excitation is dark-brown fluorescent to nonfluorescent. It is assumed that this maceral originated from the biodegradation or mechanical mixing of fine-grained (<5 µ) humic and liptinitic components of unknown origin.

Liptinite Group

Liptinite:	Mainly composed of exinitic and lipid components of plants and zooplankton. It is also called exinite.
Phyto- and zooclasts	These macerals are the fragments or clasts (more than 10µ in size) of dinoflagellates, acritarchs, chitinozea, fishes, and foraminifera, etc., and mostly contain lipid-rich substances that have yellow to brown substances.
Algodetrinite:	Constitutes the particulate liptinites that are mechanically degraded or biodegraded to less than 10 µ in size. In most cases, their morphologies are destroyed. Algodetrinite can only be differentiated from liptodetrinite by their remnant morphology.
Sapropelinite: (≈Bituminite)	Amorphous liptinite. In normal reflected light, these macerals are grainy and brown and often associated with framboidal pyrite. It is assumed that this maceral originated from the biodegradation of phyto- and zooplanktons and sometimes from terrestrial exinite (Mukhopadhyay and others, 1985).

Morpholiptinite	Macerals that retained original structure of the parent parts of the plant.
Detroliptinite	Macerals that are fragmented to smaller particles by destroying their identity (Mukhopadhyay and others, 1985).
Amorpholiptinite	Fluffy, granular mass showing fluorescent colors. Original components are difficult to identify in normal microscopic methods.

For descriptions of other macerals in the liptinite group, see Stach and others (1982) and Cameron and others (1984).

Inertinite Group

Telo-, detro-, and gelo- inertinites are interpreted as those macerals retaining the original plant structures, fragmented inertinite, and gelified, amorphous inertinites. For descriptions of all the macerals in this group, see ICCP (1971), Stach and others (1982), and Cameron and others (1984).