Petrographic Composition of Lignite from the Lake Somerville Spillway (East-central Texas)

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Abstract. In the presented paper, the macroscopic and microscopic composition of lignite from Lake Somerville Spillway has been examined. The study area is the upper part of the Manning Formation, located north-west of Somerville in the central-eastern part of Texas. There are three exposures: NE, SW and MC (Main Central) with visible parts of late-Eocene lignite seams belonging to the Jackson Group. The Manning section is divided into four marine dominated parasequences (P1 through P4). Lignite samples outlining the P1 parasequence from the MC and NE outcrops and the argillate sample from the lower part of the P2 parasequence, NE outcrop. Macroscopic characterization was carried out based on lithological classifications of humic coal. On this basis, it has been shown that the main lithotype occurring in the deposit is detritic (matrix) coal with a high share of mineral matter. The maceral composition of coal was determined according to the ICCP guidelines. The macerals from liptinite group were determined under fluorescent light. The maceral group content analysis was performed with use of 500-600 equally spaced points on the surface of the polished sections. It has been found that the examined coal is dominated by macerals from the huminite group, with a share ranging from 20.8 to 65.3% volume, including atrinite (9.8-22.8% volume, 17.5% volume on average). In the examined coal, macerals from the inertinite group (10.1 to 44.8%), especially semifusinite (max. 13.9%), fusinite (max. 9.3%) and funginite (max. 6.3%) are of particularly large share. In the liptinite group, particular attention was paid to the content of alginite (max. 4.5%) and bituminite (max. 1.3 %), which indicate the paralic sedimentation environment of the examined coal. Additionally, the variability of macerals and maceral groups within the exposures and levels of the P1 parasequence was examined. The last step was to compare lignite from Lake Somerville Spillway with other lignites belonging to the Jackson Group, namely Gibbons Creek and San Miguel lignite mines.

1. Introduction
Lignite is one of the main energy resources due to the low price per unit of generated energy and large reserves, much higher when compared to natural gas and crude oil reserves. The United States has one of the largest confirmed lignite reserves in the world and is among the leading producers of this raw material.

The aim of present paper is to determine the petrographic composition of coal from the Somerville Spillway area. Taking into account the petrographic composition of the lignite, during the evaluation of its energetic properties, is one of the new directions in the modern technological analysis of this raw material. This is due to the fact that individual maceral groups have different ranks of coal, and therefore the quantitative petrographic analysis provides additional information on their technological properties.
2. Location and geology of the Lake Somerville area
The Lake Somerville area is located north-west of Somerville in the central-eastern part of Texas, United States of America – figure 1. It is part of the Brazos River Valley area, including the upper part of the Manning strata of Late Eocene age, belonging to the Jackson Group [1][2][3]. There are three exposures with visible parts of the Manning Formation, namely NE, SW, and MC (Main Central), located SE and SW of the Lake Somerville. The examination of boreholes from the Gibbons Creek mine located north-east of the lake has shown that the Manning section is divided into 4 marine-dominated parasequences (P1 trough P4)[4][5].

![Figure 1. Location of the Lake Somerville Spillway area [5; 6]](image)

Each parasequence is characterized by different deposition style and sediment intervals created as a result of transgression and marine regression. The P1 parasequence with a thickness of 3.15 m. is composed mainly of siliciclastics with cross-beds and burrows and two lignite seams with a total thickness of 40 cm. Coal layers make up both floor and roof, defining the boundaries of the parasequence. In the case of sandstones, tidal sedimentary structures, e.g. wavy and lenticular bedding, are clearly visible. Meanwhile, the bioturbation is noticeably lower than in other fine-grained sandstones of the upper parasequences. The dark brown siltstones contain numerous trace fossils, including: *Cylindrichuns, Ophimorpha,* and *Asterosoma*[7][8]. The P2 parasequence, with a thickness of 2.35 m, is characterized by lack of coal interlayers and large amounts of muds and very fine-grained sands with storm deposits. Most likely, the entire section was formed as a result of transgression. The thickness of the contact zone with the P3 parasequence is 3.0 m. The discussed parasequence consists mainly of brown siltstones transforming into very fine-grained sandstones with the disturbed original sediment structure due to the activity of bottom-water organisms. It is covered with a layer of gravel and, most likely, lignite interlayers of unknown thickness. Above, the upper interval of the P4 parasequence, with a thickness of 1.85 m., is located. These are heavily bioturbated sandstones.
containing fossils (glossifungites), though locally the curvilinear layer is preserved. The whole area is covered by 85 centimeters of lignite [5][6][9] [10].

These four thin parasequences are associated with sedimentation on the small surface of a passively subsiding shelf. Lignite, on the other hand, is the result of sedimentation in a paralic environment [11].

3. Research methodology

The study was based on four channel samples of lignite and one argillate sample. They were collected from the exposed parts of the P1 parasequence in the MC and NE outcrops—figure 2. This parasite is outlined (contoured) by lignite, so the samples were collected from the lower and upper parts of the parasequence. The argillate sample was collected from the bottom part of the P2 parasequence in the NE outcrop. The lithotypes of coal and mineral partings were described according to the current classifications, including the modified determination of the xylite content [12][13][14]. The difference between individual lithotypes was related to the share in the content of detritus, xylite, fusain, and dispersed mineral matter in the petrographic composition of individual lithotypes.

![Figure 2. Sample collection points (Lithostratigraphy according to: [6])](image-url)
Microscopic characterization was carried out according to the most recent Classification of huminite – ICCP system [15]. Each sample was crushed to a grain size of about 5-15 mm, and then one-side polished petrographic preparations were made using the averaged coal. In order to determine the minerals form the liptinite group, a petrographic analysis in ordinary reflected light and fluorescent (blue) light using a Zeiss microscope has been performed. Petrographic examination was performed using a Zeiss Opton coal-petrography microscope. The quantitative petrographic composition was determined by intersection method with use of 500-600 points on the surface of each sample. The analysis has focused on determining macerals, maceral groups, and minerals. The determined macerals and minerals are summarized in four groups: huminite, liptinite, inertinite, and mineral group.

4. Macroscopic description

Petrographic examination of coal allows examining its internal structure and composition. Different petrographic compositions of different coal lithotypes are affected by a number of factors [12][13][14], including the type of organic matter, geological factors affecting the different stages of deposit formation, and the processes occurring after the formation of the deposit, being responsible for the coalification of selected lithotypes. Lignite can be divided into humic and bituminiferous (part of sapropelic series, distinguished by its characteristic yellow color and the high content of macerals from the liptinite group) varieties. In the year 1993, the ICCP proposed a general lithotype classification system for lignite [16]. In fresh state, lignite lithotypes can be recognized with the naked eye and determined on the basis of their elements and structure. Lithotype varieties can be differentiated by their degree of gelification and color. The lithotypes that can be distinguished include: xylite-rich coal, matrix coal, charcoal-rich coal, and mineral-rich coal [16]. However, it should be noted that numerous studies[12][17][18][19][20] have used a more complex classification of lignite lithotypes. Xylitic lignite, or xylite-rich coal according to the ICCP classification nomenclature, is made of a layered or lenticular concentration of xylites, with at least a 90% share of the total volume.

All fragments with well-preserved wood structure and with a diameter of at least 1 cm are classified as xylites, while smaller fragments are determined as humic detritus. There are three structural varieties of xylite: fibrous, brittle, and loose [12][18][19][21]. In contrast, detritic coal, or coal matrix according to the ICCP classification, consists of fine humic particles (detritus) forming a more or less homogeneous macroscopic mass; as a lithotype, it can contain up to 10% by volume of other components. Detro-xylitic coal and xylo-detritic coal belong to the complex lithotypes, which are built mainly of xylites and humic detritus. The former is dominated by xylites, which should account for more than half of the xylites and humic detritus in the specified layer (with at least 90% volume), while the latter is dominated by humic detritus [12]. In contrast, fusain coal is represented by charred organic matter. The abovementioned lithotype is rarely found in larger amounts in lignite deposits (coarse detritus, less charred xylites). Bituminiferous lignite is characterized by its yellow color and contains more than 70% of liptinite [22] it is usually accompanied by semi-bituminiferous lignite. Bituminous lignite is characterized by its low moisture (about 35–40 wt.%) and weight, while the carbon content is high, especially in the case of massive varieties. When coal contains 30–70% of liptinite, it is referred to as semi-bituminiferous lignite [22].

The sample no. 1, collected from the bottom of the P1 parasequence in the MC outcrop, is a detritic (matrix), laminated lignite showing internal lamination- figure 3. The highly gelified layers, with a dark-brown color and black gloss, are alternating with less gelified brown layers with clearly visible detritus (ranging from 0.5 mm to a maximum of 1 mm). In addition, residual, strongly-gelified xylites, whose volume in the sample does not exceed 5%, can also be observed.
The no. 2 sample representing the upper part of the P1 parasequence in the MC outcrop contains detritic coal with a light or dark brown color, and a minor admixture of xylites and mineral matter—figure 4. It is characterized by cubic divisibility and a considerable brittleness.
The sample no. 3 was collected from the bottom of the P1 parasequence in the NE outcrop - figure 5 contains detritic, black (darker than coal from the sample 1), and strongly gelified coal with a visible conchoidal, uneven fracture. Locally, layers with noticeable very fine detritus (approx. 0.1 mm), accompanied by inclusions of heavily gelified xylites are observed. In the examined samples, about 1mm layers of fusain, with a black color and silky gloss, can also be observed.

Figure 5. Lower part of the P1 parasequence, NE outcrop (collection point of the S3 sample).

Sample no. 4, collected from the upper part of the P1 parasequence in NE outcrop, is a reddish brown, locally yellowish brown weathered coal; it is heavily clayed, while brittle xylites (clay rubble) are clearly visible-figure 6. The high share of clay minerals may be related to the occurrence over the coal seam and to the presence of tan siltstones and tree roots.

Figure 6. The upper part of the P1 parasequence, NE outcrop (collection point of the S4 sample).
The argillate sample (sample no. 5) with a very high kaolinite content—figure 7 was collected from the bottom part of the P2 parasequence in the NE outcrop. The mentioned sample is fine-grained and characterized with a cream-white color, oily gloss, and visible layering underlined by dark roots; locally, pearl gloss, most likely due to the occurrence of muscovite, can be observed.

![Figure 7](image_url)

Figure 7. Lower part of the P2 parasequence, NE outcrop (collection point of the S5 sample)

5. Microscopic description
The current petrographic classification of ortho-lignite is based on three genetic maceral groups: huminite, liptinite and inertinite group—table 1. The mentioned groups are determined on the basis of their grain morphology and optical properties.

Sample no. 1 contains the highest share (65.3 %) of macerals from the huminite group, dominated by densinite (28.4 %) and attrinite (21.6 %). The sum of these macerals indicates that these are the basic components of the examined coal—figures 8A,B,C,D. F. In addition, ulminite (9.6 %) and gelinite (5.7 %) are other macerals from this group with a relatively high share—figure 8A. The gelified layers were also visible macroscopically. In the case of macerals from the inertinite group, funginite, with a diameter of several microns, rarely up to 0.3 mm, has a dominant share (6.3%). These are mainly preserved fungal spores, less commonly parts of fungi's thallus—figure 8C. Semifusinite (2.1%), secretinite (2.6%), macrinite (1.3 %), and fusinite (0.8 %) are less commonly observed. Unrecognized, due to their large fragmentation (up to a few µm, parts of macerals from the inertinite group) were marked as inertodetrinite (3.6 %). The liptinite group has shown the highest share of alginite (3.6%), which is derived from lower plants—figure 8E, protozoa, and resinite (3.4 %), which usually occurs in the form of oval, sometimes spherical grains with a diameter ranging from 0.02 to 0.1 mm. The large amount of rare bituminite (1.3%), which is formed from the decomposition of algae, is also worth noting. Fine (less than 0.01 mm); unrecognizable particles with optical properties of macerals from the liptinite group were classified as liptodetrinite (2.6 %). The discussed sample contained a small admixture of mineral matter (2.4%), including clay minerals (1.6 %) and individual pyrites (0.8 %).
Figure 8. A- Densinite (Ds) transforming into attrinite (at) with gelinite layers (Gel); B- Semifusinite (Sf) in densinite (Ds); C- Funginites (Fg) in densinite (Ds); D- Fusinite (Fs), Part of semifusinite (Sf) and inertodetrinite (Id) in attrinite (At); E- Alginite (Alg) in blue light; F- Attrinite (At) and clayed attrinite (At+caly) with semifusinite (Sf)

The inertinite group has the highest share (44.8%) in the sample no. 2. This may indicate paleo-peat bog fires and the high content of fungi. Semifusinite (13.9 %) and fusinite (9.3 %) are the most common macerals in this group - figures 8B,D, F. These are partially or completely charred plant (mainly trees and bushes) tissues. Their impregnation with gelinite and pyrite are less commonly observed. In addition, a significant share of funginite (5.7%) and inertodetrinite (8.7%) dispersed in attrinite can be observed. Macrinite (3.3 %) is composed of massive organic particles of different size, presumably charred fragments of humic gels. The huminite group (35.4 %) is mainly represented by attrinite (22.8 %), which is the background for the very large inertinite group – figure 8D. Locally, attrinite transforms into more condensed densinite (6.6%). Ulminite (3.9 %) and gelinite (2.1 %) can also be observed. In the liptinite group, sporinite (3.0%), occurring in the porous, compacted form with a diameter from 0.02 to 0.06 mm, and resinite (3.9 %), are the most widely distributed. There is no alginite, while the share of bituminite is marginal (0.6 %). The mineral matter accounts for 9.9 % of the total content of the examined sample and is represented by clay minerals (7.8 %), sulphides(1.2 %), and individual quartz grains (0.9 %).

The sample no. 3 contains 56.8 % of macerals from the huminite group. Densinite (17.6 %) and attrinite (16.0 %), forming a background for the examined coal, have a dominant share. The share of ulminite, which occurs in the sample in the form of two subgeneric textoulminite and eulminite (dominant) macerals, has also been shown to be high. Gelinite (7.8%) is a non-porous humic matter present in the form of isolated bodies with a diameter of up to 0.1 mm, mainly in attrinite -figure 8A. Textinite (1.4 %) is filled with corpohuminite (1.1 %) in the form of small plates or spherical grains with a diameter of about 30-90 µm. The liptinite group (22.4%), dominated by resinite (8.4 %), has also a significant share in the discussed sample. It fills the cell spaces in textinite and usually occurs in the massive form. Kutinite (2.2 %) occurs in the form of elongated coats; in the polished sections they are visible as thin, thinbands with a complex structure. In the examined sample, alginite (4.5 %) occurs in the form of lamalginite (fossil colonies) and, less commonly, in isolated forms (telalginite) (Fig. 8E). Sporinite (2.5 %) is a pollen plant and spore residue. The inertinite group (15.4 %) is dominated by inertodetrinite (5.6 %) and secretinit (3.9 %) in spherical form with very irregular pores. Large parts of semifusinite (2.5%), slightly darker than fusinite and characterized by thick walls and a full-
body shape, which is the effect of the so-called gelification, can also be observed. The mineral admixture (5.5%) in the sample includes clay minerals (4.5%), sulphides (0.8%), and (with the marginal share) quartz (0.8%).

In the no. 4 sample, more than half of the composition is mineral matter (60.2% ), and therefore it can be considered as a carbon rock. Clay minerals (59.3%), sulphides (0.7%), and (marginally) quartz (0.3%) have a dominant share in the discussed sample. The organic matter in the sample is 39.8%. The huminite group (20.8 %) is dominated by atrinite (9.8 %) and textinite (8.0 %), which is filled with clay minerals and marginally with corpohuminite (1.5 %). The inertinite group (10.1 %) is mainly represented by the heavily dispersed inertodetrinite (7.1 %), secretinite (1.8 %), micrinite (0.9 %), and funginite (0.3 %). In the liptinite group, which has the lowest share (8.9 %) in the discussed sample, the most widely distributed are resinite (5.6 %) and liptodetrinite (2.4 %). Resinite is slightly weathered, which is reflected in brighter, less fluorescent coats.

### Table 1. Petrographic composition of the examined lignite.

| Sample number |  S1 | S2 | S3 | S4 | S5 |
|---------------|-----|----|----|----|----|
| textinite     | 0.0 | 0.0| 1.4| 8.0| 1.3|
| ulminite      | 9.6 | 3.9| 12.9|0.0| 0.0|
| atrinite      | 21.6| 22.8|16.0| 9.8| 5.5|
| densinite     | 28.4| 6.6| 17.6| 1.5| 0.0|
| corpohuminite | 0.0 | 0.0| 1.1| 1.5| 0.0|
| gelinite      | 5.7 | 2.1| 7.8| 0.0| 0.0|
| ∑ humunite    | 65.3| 35.4|56.8|20.8| 6.9|
| ∑ humunitemmd | 66.9| 39.3|60.0|52.3|45.1|
| fusinite      | 0.8 | 9.3| 0.8| 0.0| 0.0|
| semifusinite  | 2.1 | 13.9| 2.5| 0.0| 0.0|
| funginite     | 6.3 | 5.7| 2.0| 0.3| 1.6|
| secretinite   | 2.6 | 3.9| 3.9| 1.8| 0.3|
| macrinite     | 1.3 | 3.3| 0.6| 0.9| 0.0|
| inertodetrinite| 3.6| 8.7| 5.6| 7.1| 5.2|
| ∑ inertinite  | 15.4| 44.8|15.4|10.1| 7.1|
| ∑ inertinitemmd| 15.8| 49.7|16.3|25.4|46.4|
| sporinite     | 1.6 | 3.9| 2.5| 0.0| 0.0|
| kutinite      | 1.8 | 0.9| 2.2| 0.9| 0.0|
| resinite      | 3.4 | 3.0| 8.4| 5.6| 1.3|
| alginate      | 3.6 | 0.0| 4.5| 0.0| 0.0|
| bituminite    | 1.3 | 0.6| 0.0| 0.0| 0.0|
| suberinite    | 1.0 | 0.0| 1.4| 0.0| 0.0|
| liptodetrinite| 2.6 | 1.5| 3.4| 2.4| 0.0|
| ∑ liptinite   | 16.9| 9.9|22.4|8.9| 1.3|
| ∑ liptinitemmd| 17.3| 11.0|23.7|22.3| 8.5|
| ∑ carbonaceous substance | 97.6 | 90.1 | 94.6 | 39.8 | 15.3 |
| quartz        | 0.0 | 0.9| 0.1| 0.0| 0.3|
| sulphides     | 0.8 | 1.2| 0.8| 0.9| 0.7|
| clay minerals | 1.6 | 7.8| 4.5| 59.3|83.7|
| ∑ minerals    | 2.4 | 9.9| 5.4|60.2| 84.7|

*maceral analysis (without organic substance)
The sample no. 5 is a typical gangue. The share of mineral matter is 84.7%, including 83.7% of clay minerals, most probably kaolinite, 0.7% sulphides, and 0.3% of quartz. The organic matter in the sample is only 15.3%. The inertinite group (7.1%), dominated by bituminodetrinite (5.2%) and funginite (1.6%), has the dominant share in the sample. The liptinite group is represented by weathered resinite (1.3%), while the huminite group by textinite (1.3%) filled with argillaceous matter and heavily clayed attrinite (5.5%) with a highly variable proportion of these components. It forms transitional forms to (lenses, nests, and laminae) clay aggregates.

The least variable group in the examined coal is the liptinite group, particularly liptodetrinite that occurs in each sample at similar levels. Alginites, bituminites, and suberinites have shown a very high variability in this group. Alginite occurs only in lignite samples collected from the lower part of the P1 parasequence (both exposures), whereas the bituminite is observed in the upper and lower parts, but only in the main exposure (MC outcrop).

The huminite group in a non-mineral state is only moderately variable, but with the mineral matter, the mentioned variability is high. The samples collected from the lower parts of the P1 parasequence contain about 60% of macerals from this group, while in the case of samples collected from the upper parts this share is much lower - the MC and NE exposures are dominated by macerals from the inertinite group and mineral matter, respectively. Textinite and corpohuminite, which occur only in samples collected from the NE outcrop, are characterized by the greatest variability in this group. On the other hand, the moderate variability (the lowest in this group) has been found for attrinite, which formed a background for each of the analysed sample.

The majority of macerals from the inertinite group has shown a high variability. Secretinite and inertodetrinite, which were present in all samples, have shown the average variability. In the discussed area, fusinite is highly variable. While it is widely distributed in the upper part of the P1 parasequence in the MC outcrop, it is practically nonexistent in the upper part of the NE outcrop.

The variability in the mineral matter content of the examined samples is high due to the very high content of clay minerals in the sample no. 4. However, the highest variability in this group has been shown for quartz, which occurrence in the samples was rather sporadic. The sulphides, with approx. 1% share in all samples, are characterized by moderate variability.

6. Results and discussions

The petrographic composition of lignite from the Somerville Spillway area is different than in the case of other deposits previously described in the literature - table 2. The inertinite group, which is the most widely distributed, deserves special attention. Its relatively high share may indicate the diagenesis of paleo-peat bog due to fires or chemical oxidation of coal under dry conditions prevailing in a subtropical peat bog and affecting the deposited plants. In addition, in the examined coal the dominant macerals in the discussed group are: semifusinite, funginite, and secretinite, while in other deposits, the most commonly observed are fusinite and macrinite.

![Table 2. Comparison of the average content of maceral groups (nonmineral state) in lignite deposits belonging to the Jackson Group.](image)

| Lignite occurrence area          | Macerals from the huminite group | Macerals from the liptinite group | Macerals from the inertinite group |
|----------------------------------|----------------------------------|----------------------------------|----------------------------------|
| Gibbons Creek Mine [3]           | 92%                              | 7%                               | 1%                               |
| San Miguel lignite [23]          | 89%                              | 10%                              | 1%                               |
| Lake Somerville Spillway         | 54%                              | 19%                              | 27%                              |

In other deposits, the huminite group is present, on average, in an amount of 90% weight percent, while in the examined deposit its share is much lower and amounts to approx. 50% by weight. This is due to the domination of humotelinite macerals (textinite + eulminite) in the Gibbons Creek and San
Miguel mines. In the examined coal, the discussed subgroup is less numerous, while attrinite and densinite, which are the primary components of the discussed coal, have the dominant share. Gelinite is the only component occurring at similar levels in all the examined areas.

In the Gibbons Creek and San Miguel mines, the liptinite group amounts to about 10%, while in the examined coal its share is almost twice as high. Liptodetrinite has a dominant share in all of the examined deposits. The analysis has focused on the occurrence of alginite and bituminite in the Lake Somerville area, alginite in the San Miguel mine, and bituminite in the Gibbons Creek mine.

7. Summary and conclusions
The lignite from the Somerville Spillway area was formed in a paralic environment. This is evidenced by the presence of thin but numerous (in the P1, P3, and P4 sequences) coal seams highly contaminated with mineral matter. Coal seams are symmetrically distributed in the profile. In addition, the detritic grains in the coal are of similar size. In the discussed area, fine grained sandy layers with angular stratification, characteristic for this environment, can also be observed. Microscopic examination of coal has shown the presence of alginite, originating from plants or microorganisms, i.e. marine algae, and bituminite, formed as a result of decomposition of algae with the increasing rank of coal.

The examined lignite samples are highly variable depending on the part of the P1 parasequence and the outcrop (MC outcrop, NE outcrop). In addition, lignite from the Somerville Spillway area is significantly different from other coals belonging to the same Jackson Group. This may indicate a significant impact of tides on sedimentation.

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