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Maceral Composition of the Coal in the Anambra Basin, Lower Benue Trough, Nigeria: Its Potentials for Electricity Generation.

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ABSTRACT

The petrographic composition of Cretaceous-Cenozoic-age coals from the Anambra Basin in the Lower Benue Trough of Nigeria is presented and discussed in the paleodepositional settings of the coal within Lower Benue Trough. The Anambra Basin is a failed arm of the triple junction of an inland sedimentary basin that extends in a NE-SW direction from the Gulf of Guinea in the south, to the Chad Basin in the north. A total of thirteen (13) coal samples were obtained from 12 coal localities in the Anambra Basin, Lower Benue Trough (LBT). The proximate analysis was conducted on the coal samples using a Perkin Elmer Thermogravimetric Analyzer following the procedure of ASTM D3172-13 (2013). Ultimate analysis was undertaken at Bureau Veritas, Centurion, South Africa, following SANS 17247 (2006) and ISO 17247 (2005). The data indicates the coal samples have a high volatile matter content, low ash yield, and high calorific value (28.39 MJ/Kg, areal average). Similarly, the sulphur values are generally low with an aerialaverage of 1.08 %.The vegetal matter is dominated by vitrinite, with an areal average of 48.7% by volume (mineral matter free). Petrographic analysis (macerals composition) and the thermal gravimetric analyser were conducted on the coal samples to examine the coal composite The results obtained from the coal composition and combustion behaviour pattern, it revealed that all the coals within the Anambra Basin can be used for electricpower generation.

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1. 0 Introduction

Nigeria is one of the nations in the world that requires a revolution in the energy sector. This is because the supply of energy is grossly inadequate for the growing population and development of the country. The main energy source in the country currently is hydroelectric (Ohimain 2014). The country has substantial coal assets, projected at 2.8 billion tonnes of high-quality lignite coal (Ohimain 2014), however, technical expertise and government willpower to utilize the coal resources appropriately are limited in the country. This is attributed to lack of a proper knowledge the coal quality and other application options available. However, from the Federal Government's declaration of August 2014 that 30% of Nigeria's energy generation should come from Nigeria's coal deposits (Ohimain 2014; Aliyu et al., 2015), it appeared that the nation was paying some attention to utilising the vast coal resources to meet its energy demand.

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Coal deposits, a result of mires, peat swamps and bogs, can be used to decipher coal-forming depositional environments. The petrographic assessment of coal macerals can be used to gain an understanding of the conditions prevailing during peat formation and subsequent coalification. The petrography data show coal from the Anambra Basinis rich in vitrinite macerals with variability in inertinite, and liptinite (Figures9-12).

This study reveals the petrographic composition, thecomplementary chemical data, and combustion behaviour to predict the further application of the coal within the Anambra Basin in the Lower Benue Trough, Nigeria. The maceral composition of coal samples reveals the complexity of coal in terms of its discrete microscopic organic (maceral) and inorganic (mineral) components, and their relationships. The degree of proneness to spontaneous combustion of coal increases with the increase in vitrinite macerals and prolongs with increases in inertinite. (Akande et al., 1992b; Morgan et al., 1986).

Maceral composition is a true reflection of the processes undergone as preservation, degradation and fusinization actively transformed the peat swamp (Taylor et al., 1998). A high concentration of vitrinite characterise by collotelinite, is an indication of more homogenized vitrinite layers with poorly defined structure concentration of inertinite in the Cretaceous coal suggests fluctuation of wet and dry seasons with oxygenated A Low concentration of liptinite designates humid environments of terrestrial settings (Diessel, 1992).

Chemical data (proximate and ultimate), and calorific value (CV) augment the petrographic data for an enhanced understanding of the coal facies models used.The results obtained from the coal composition and combustion behaviourrevealed that all the coal within the Anambra Basin can be used for power generation.

2. 0 Geology of the study area

The Anambra Basin is a sedimentary cover resting unconformably on the Precambrian Basement rocks (Kogbe 1976; Offodile 1976; Ajayi and Ajakaiye 1981; Peters and Ekweozor 1982; Ojoh 1992; Akande et al., 2012; Obaje 2009; Akinyemi et al., 2020, 2021a, 2022b; Mangs et al., 2022) (Figure 1). In the Anambra Basin, sediment sequences are Rift System controlled, from many episodes of tectonic events resulting in the basement fragmentation, block faulting, and subsidence that opens into the South Atlantic Ocean. The series of rift basins in the Benue Trough accumulate thick sediments ranging between 4000 and 6000 m (Ajayi 1979;Ajayi and Ajakaiye 1981).

The geology of the Benue Trough has been extensively investigated by many scholars including Carter et al. (1963); Cratchley (1965); Grant (1971); Kogbe (1976); Offodile (1976); Reyment and Mörner (1977); Petters (1978); Ofoegbu (1988); Schull (1988); Ajibade and Wright (1989); Obaje et al. (1998); Ogala et al. (2012); Akinyemi et al. (2020, 2021, 2022). With the advent of modern analytical techniques, the geology of the Benue Trough is being unpacked. The stratigraphic sequence of the Benue Trough is described in Table1, with the coal seams in the Anambra Basin indicated in red boxes. The Benue Trough is rich in coal deposits originating from organic matter (Adighije 1979; Adedosu et al., 2010). The coal seams within the Benue Trough are hosted in three different geological units.

The Anambra Basin and Abakaliki Syncline constitute the Lower Benue Trough the of late Cretaceous Period. They are associated with the separation of the African and South American continents and the subsequent opening of the South Atlantic Ocean (Murat 1972;Obaje et al., 1998; Ogala et al., 2012). During the filling of the Benue-Abakaliki sector of the Trough in Albian-Santonian times, the proto-Anambra Basin was a platform (Murat 1972; Benkhelil 1989; Obaje et al., 1998; Ogala et al., 2012). The Anambra Basin contains sedimentary sequences of Cretaceous age of about 6km depthand is the structural link between the Cretaceous Benue Trough and the Tertiary Niger Delta (Mohammed 2005). Slow subsidence followed by a regression in Maastrichtian times, during which deltaic forests and floodplain developed, resulted in the coal measures of the Mamu, Ajali and Nsukka Formations, Awgu Formation and the

Agbani sandstone, Odukpani Formation and Agala sandstone (Obaje et al., 1998; Ogala et al., 2012).
The Anambra Basincoal measures/seam are hosted in the Mamu, Ajali, Odukpani, Agbani sandstone and the Nsukka Formation of Campanian- Maastrichtian age (Kogbe 1976; Petters 1982; Ojoh 1992).

3. 0 Materials and Methods.

3.1Sampling and laboratory methodology: A total of 13 grab coal samples were obtained from 12 coal localities in the Anambra Basin (Figure 2; Table 2). The samples were labelled and stored in sample bags and kept in containers analysis. A 1.0g of each of the 13 samples was milled to 212μm was used for chemical analysis usingThe ECO instrument following the TGA method described by Ogala et al., 2012.Ultimate analysis was conducted at Bureau Veritas, Centurion, South Africa, according to SANS 17247:2006/ISO 17247:2005.A 0.5g of each the of coal samples was placed into the bomb calorimeter for calorific value analysis. Similarly, 0.5g of sampleswere used for the TGA burnout test.The gas button was turned on and the combustion reactivity began to run on the samples with the corresponding heat value and recorded.The maceral, and vitrinite reflectance analyses were performed according to standard procedures: SANS/ISO 7404-3, 2016; SANS/ISO 7404-4, 2018; SANS/ISO 7404-5, 2016, respectively. The study followed the terminology recommended by the International Committee for Coal and Organic Petrology (ICCP) (ICCP,1998, 2001; Pickel et al., 2017).The calibration was checked between each sample, and a minimum of 100 readings were taken on collotelinite, avoiding poorly polished or pitted vitrinite.

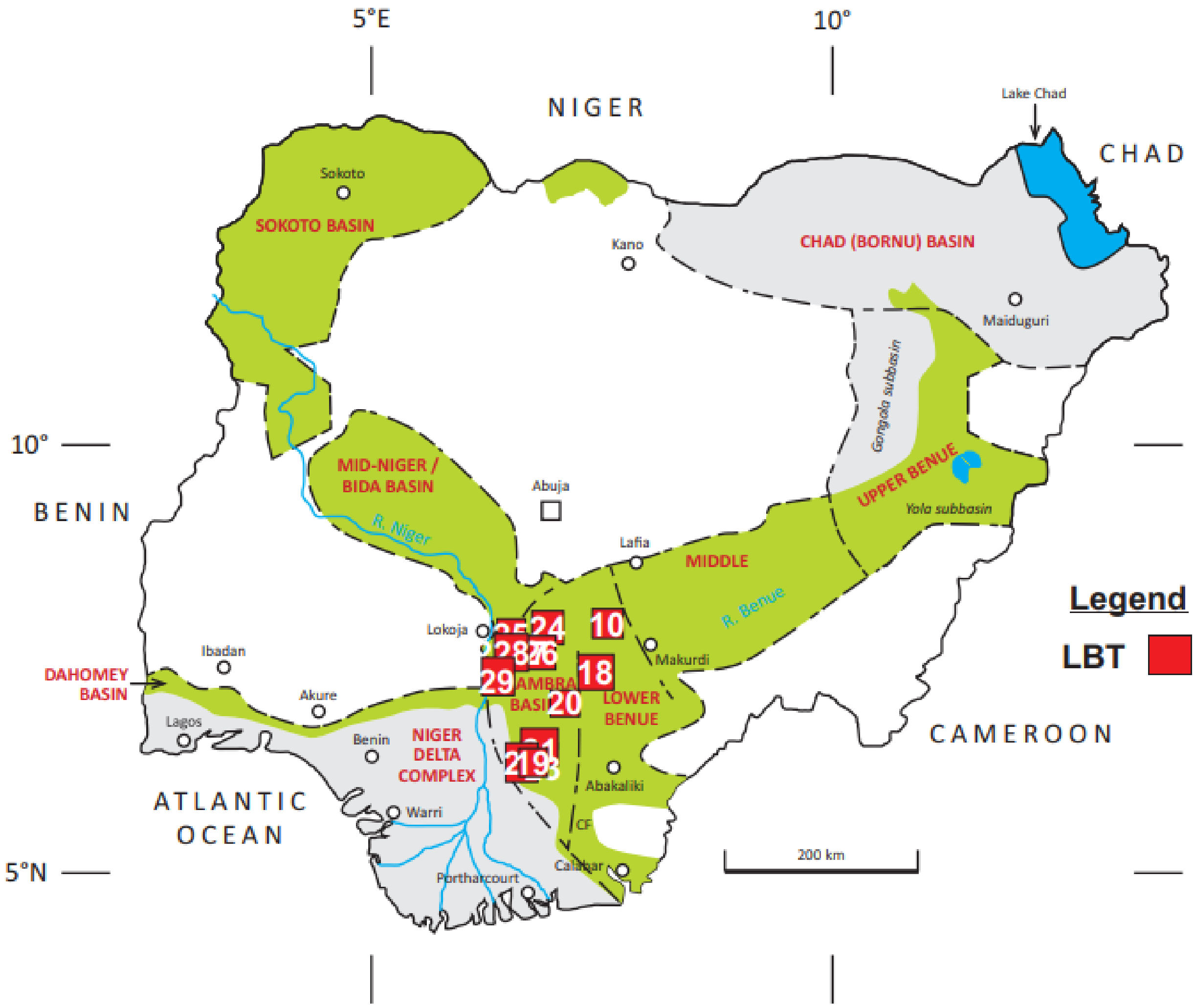


Figure 1. Sample locations identified as indicated on the map of Benue Trough (modified after Pearson and Obaje 1999).

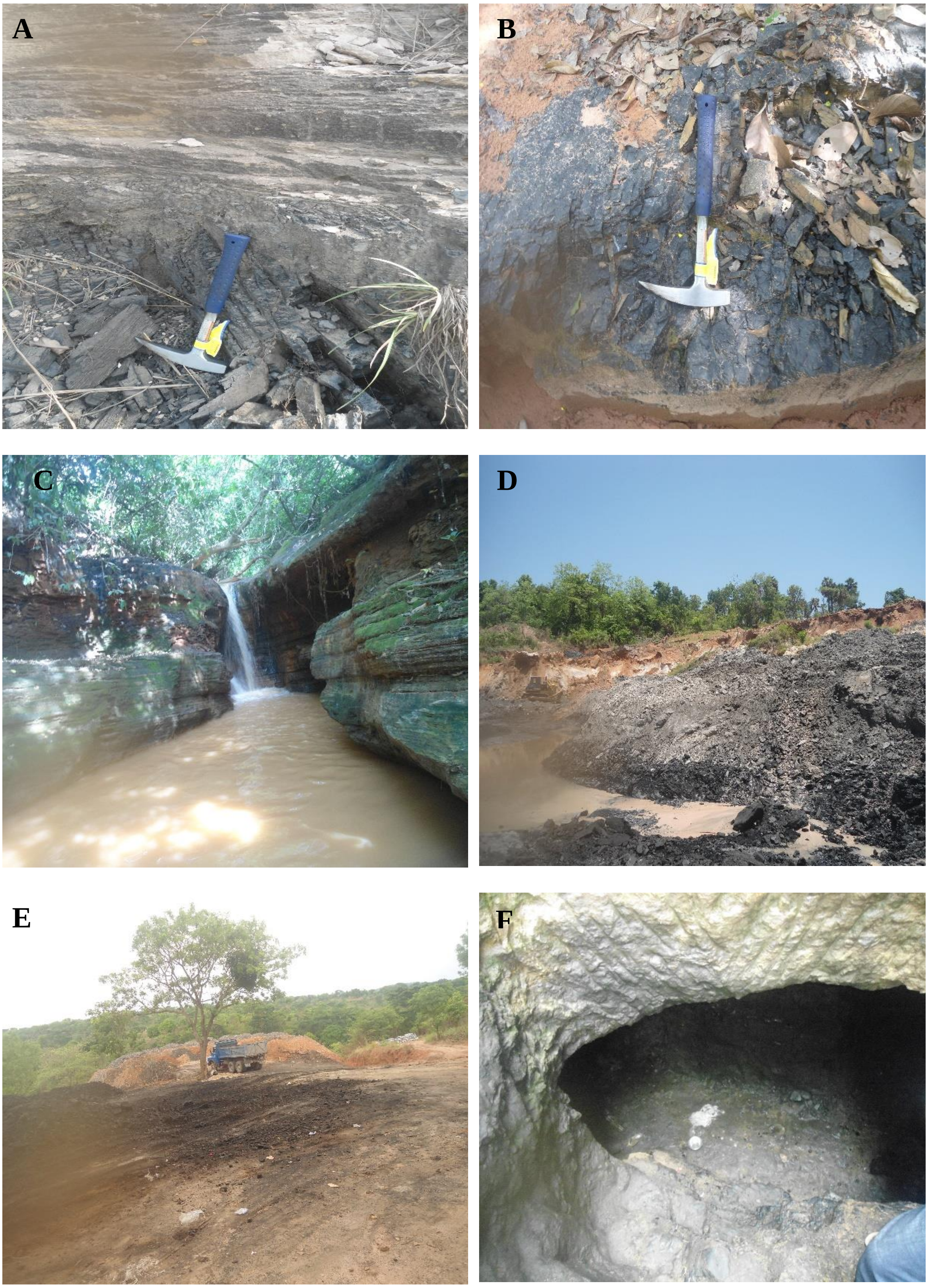


Figure2. Sampling at, Enugu and Kogi States. Sample 21 A Ngwo, Samples 22 & 23 B and C Onyeama Mine, Enugu State, Sample 24 D Imani village, Sample 27 E Ofogu village, Sample 28 at Odokpuno Village F, Kogi State, in the Anambra Basin.

Table 1. Sample Localities and Identification Numbers.

S/ID	Locality name	Sample type	Seam	Stratigraphic Formation	Local Gov't Area (LGA)	State
10	Owukpa	Old mine	NA	Mamu FM	Ogbadibo	Benue
18	Awha-Ndiago	Old mine	NA	Mamu FM	Enugu	Enugu
19	Inyi	Old mine	NA	Mamu FM	Oji River	Enugu
20	Ezimo	Old mine	NA	Nsukka FM	Udenu	Enugu
21	Ngwo	Old mine	NA	Nsukka FM	Udi	Enugu
22	Onyeama mine	Old mine	NA	Nsukka FM	Udi	Enugu
23	Onyeama mine	Old mine	NA	Nsukka FM	Udi	Enugu
24	Omelewu	Excavated surface	NA	Mamu FM	Olamaboro	Kogi
25	Okobo	Open mine	NA	Mamu FM	Ankpa	Kogi
26	Awo Akpali	Open mine	NA	Mamu FM	Ankpa	Kogi
27	Ofagu-Ikah	Open mine	NA	Odukpani FM	Ankpa	Kogi
28	Odokpuno	Underground mine	NA	Odukpani FM	Ankpa	Kogi
29	Ejinya Efofe	Open surface	NA	Odukpani FM	Ankpa	Kogi

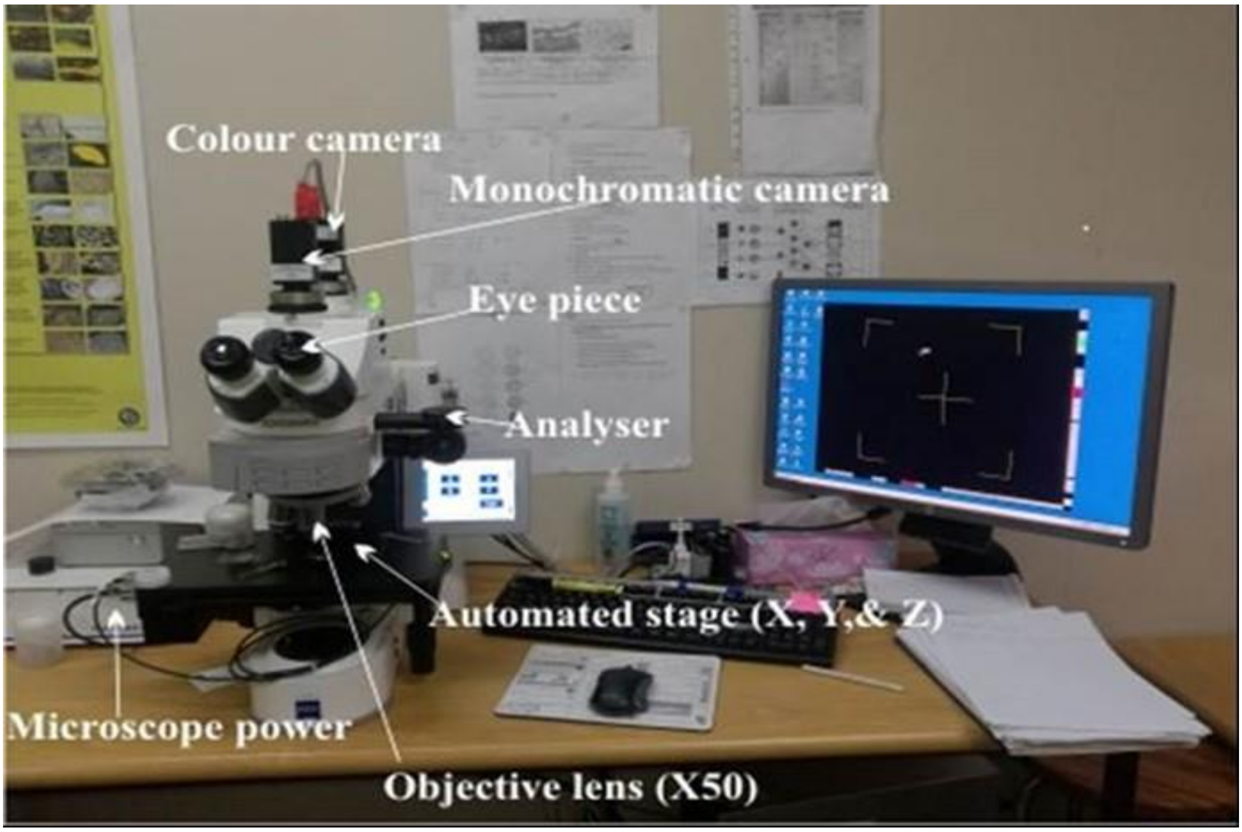


Figure 3. Reflected light microscope (Zeiss Axio Imager M2m) showing component(Mangs et al., 2022)

4.0 Presentation of Results

4.1 Chemical analyses: The proximate and ultimate data are presented in Table 3 and Figures5-7. The relatively low ashyields observed in the coal samples agree with data presented by Ogala et al. (2012) in the same Basin. The CV values for the samples are high, representing high high-grades. The moisture content was high in samples 27, 28 and 29, and it could signifylow-rank coal, possibly lignite to sub-bituminous coals. The ultimate analysis is reported in (daf) presented in Table 3 and represented in Figure 6 to contain high carbon, while the sulphur is low in most samples, except for samples18 and 20, due to iron content. Despite being grab samples, proximate and ultimate data indicated that the samples generally represented coals of high quality (ISO11760, 2005).The trends observed in the proximate data (Figure 6) suggested good good-quality coals.

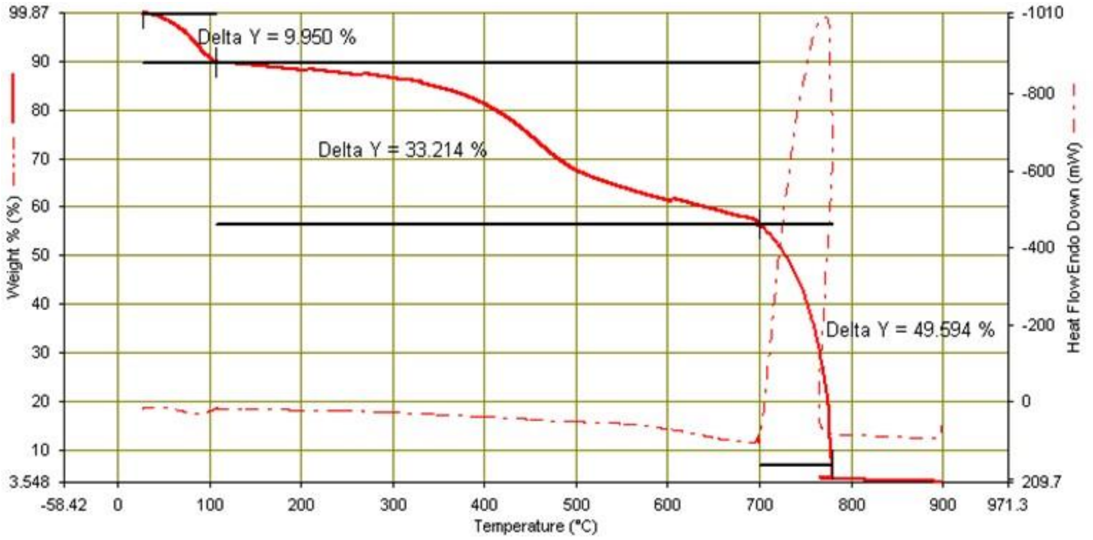


Figure 4. Typical TGA Graph from which the proximate data is determined

NOTE (moisture, Delta y = 9.950%; volatile matter, Delta y = 33.214%; and fixed carbon, Delta y = 49.594%).

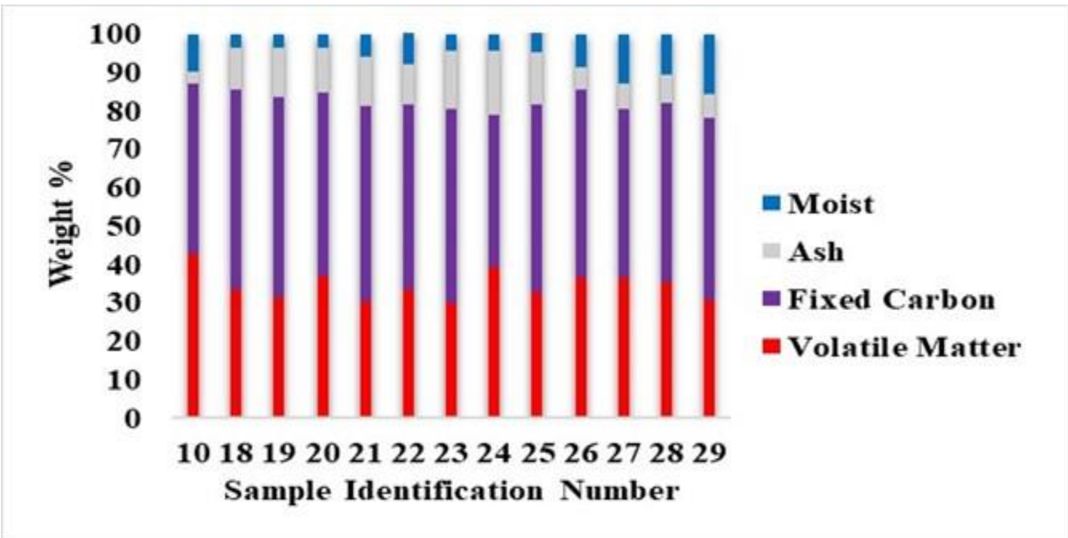


Figure 5. An overview of the proximate data as presented in histogram.

Proximate Data (Wt. %)					CV	Ultimate Data (%) (Daf)				
S/ ID	VM	FC	Ash	Moist	(MJ/Kg)	S	C	H	N	O[a]
10	42.9	44.0	03.2	09.8	30.02	0.61	73.86	7.02	1.94	16.57
18	33.7	51.8	11.0	03.5	29.36	4.02	80.00	5.84	1.71	08.43
19	31.7	52.0	12.6	03.6	28.39	0.84	78.20	6.36	2.13	12.47
20	37.0	47.7	11.5	03.7	28.93	2.03	78.33	6.32	1.76	11.55
21	30.6	50.8	12.8	05.8	26.11	0.66	72.26	5.97	1.93	19.17
22	33.4	48.3	10.5	07.9	28.63	0.71	78.64	6.27	1.97	12.40
23	30.0	50.5	15.2	04.3	28.52	0.86	80.09	6.80	2.17	10.08
24	39.4	39.5	16.6	04.4	26.11	0.77	72.19	7.80	1.52	17.71
25	32.8	48.9	13.4	07.9	26.85	0.79	74.33	6.86	1.83	16.19
26	36.6	48.9	05.8	08.7	28.58	0.61	73.79	6.19	1.64	17.78
27	36.5	44.0	06.5	13.0	29.42	0.70	74.23	7.46	1.66	15.95
28	35.3	46.8	07.3	10.6	27.79	0.74	71.59	6.49	1.64	19.54
29	30.9	47.4	05.9	15.8	30.33	0.73	74.97	8.47	1.95	13.88
Areal Ave	34.7	47.7	10.2	07.6	28.39	1.08	75.58	6.76	1.83	14.75

Table 2. Proximate, CV, and Ultimate data

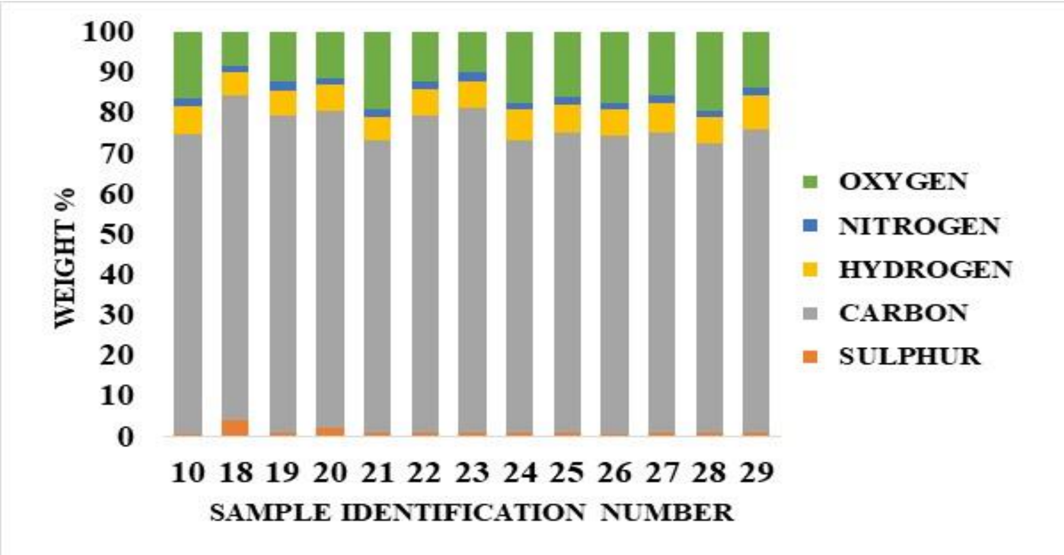


Figure 6. Ultimate Analysis (daf) presented in histogram

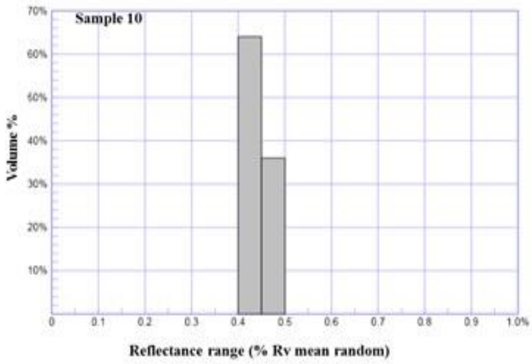
4.2. Vitrinite reflectance measurement

The reflectance values, on areal average, characterize the coal samples into Low-Rank A sub-bituminous category, (Table 4), although there was some variation within the basin (Figure 8). Sample 09 is classified as a lignite. All the samples in the Anambra Basin are classified as low rank. Thus, implying differing coalification processes between the basin. Based on the histograms of the typical vitrinite reflectance measurement for each sample as displayed in Figures 13, 14and Table 4 show samples28 and 29 are classified as lignite with RoV values of 0.39 and 0.37 % respectively.

Table 3. Vitrinite reflectance data (RoV. % mean random)

S/ ID	RoV_{mr} (%)	St. dev	Min. %	Max. %	Coal Rank	Coal Type
10	0.45	0.02	0.41	0.49	Low-Rank A	Sub-Bituminous
18	0.43	0.02	0.40	0.47	Low-Rank A	Sub-Bituminous
19	0.46	0.04	0.37	0.57	Low-Rank A	Sub-Bituminous
20	0.42	0.02	0.33	0.46	Low-Rank A	Sub-Bituminous
21	0.52	0.06	0.42	0.70	Med- Rank D	Bituminous
22	0.45	0.32	0.40	0.54	Low-Rank A	Sub-Bituminous
23	0.53	0.04	0.42	0.63	Med. Rank D	Bituminous
24	0.49	0.03	0.41	0.57	Low-Rank A	Sub-Bituminous
25	0.43	0.04	0.31	0.54	Low-Rank A	Sub-Bituminous
26	0.42	0.02	0.37	0.48	Low-Rank A	Sub-Bituminous
27	0.45	0.03	0.39	0.55	Low-Rank A	Sub-Bituminous
28	0.39	0.03	0.33	0.47	Low-Rank B	Lignite
29	0.37	0.04	0.26	0.50	Low-Rank B	Lignite
Areal Ave	0.45	0.05	0.37	0.54		

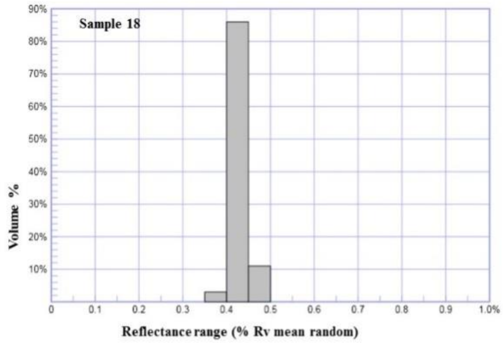
Foot Note: min. = minimum reading obtained; max. = maximum reading obtained



Measure count = 96
Reflectance Rr = 0.446 %
s = 0.021 %
Date 8/25/2018 02:59 PM
Operator
Printed 4/12/2019

0.40 - 0.45 % R 64 %
0.45 - 0.50 % R 36 %

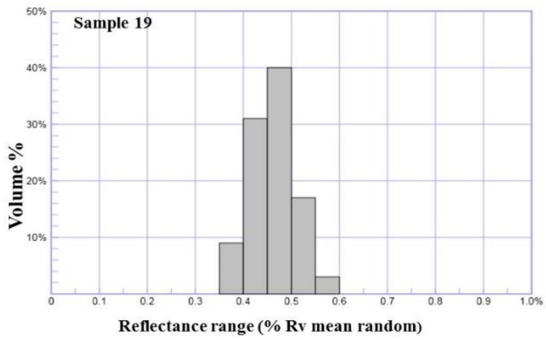
F=3.0.8251 D=4.81.2682



Measure count = 117
Reflectance Rr = 0.427 %
s = 0.016 %
Date 9/15/2018 11:08 AM
Operator
Printed 4/18/2019

0.35 - 0.40 % R 3 %
0.40 - 0.45 % R 86 %
0.45 - 0.50 % R 11 %

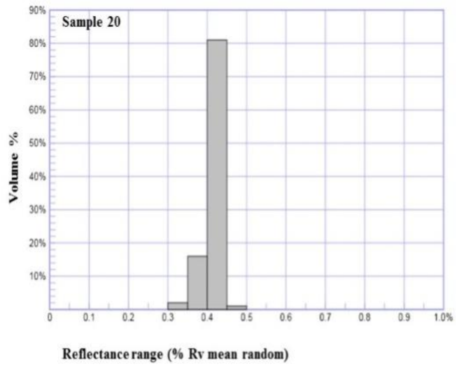
F=3.0.8251 D=4.81.2682



Measure count = 109
Reflectance Rr = 0.462 %
s = 0.044 %
Date 6/15/2018 12:46 PM
Operator
Printed 4/18/2019

0.35 - 0.40 % R 9 %
0.40 - 0.45 % R 31 %
0.45 - 0.50 % R 40 %
0.50 - 0.55 % R 17 %
0.55 - 0.60 % R 3 %

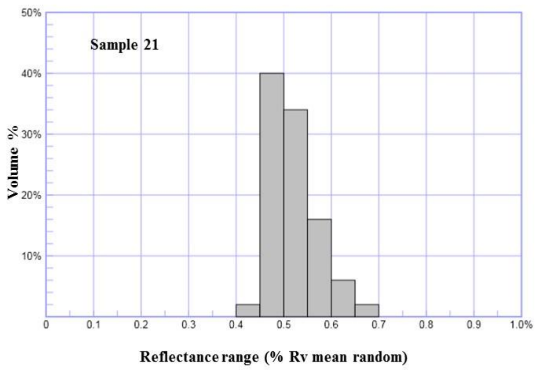
F=3.0.8251 D=4.81.2682



Measure count = 103
Reflectance Rr = 0.415 %
s = 0.020 %
Date 3/19/2019 11:31 AM
Operator
Printed 4/18/2019

0.30 - 0.35 % R 2 %
0.35 - 0.40 % R 16 %
0.40 - 0.45 % R 81 %
0.45 - 0.50 % R 1 %

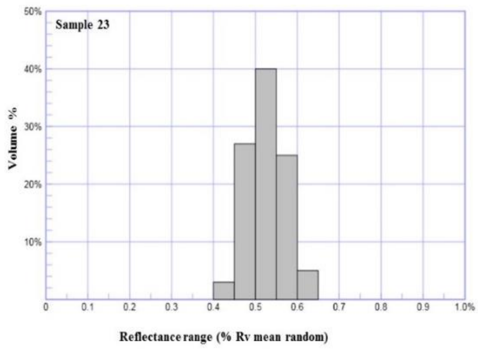
F=3.0.8251 D=4.81.2682



Measure count = 131
Reflectance Rr = 0.519 %
s = 0.055 %
Date 4/18/2018 04:26 PM
Operator
Printed 4/18/2019

0.40 - 0.45 % R 2 %
0.45 - 0.50 % R 40 %
0.50 - 0.55 % R 34 %
0.55 - 0.60 % R 16 %
0.60 - 0.65 % R 6 %
0.65 - 0.70 % R 2 %

F=3.0.8251 D=4.81.2682



Measure count = 150
Reflectance Rr = 0.526 %
s = 0.042 %
Date 4/19/2018 11:22 AM
Operator
Printed 4/18/2019

0.40 - 0.45 % R 3 %
0.45 - 0.50 % R 27 %
0.50 - 0.55 % R 40 %
0.55 - 0.60 % R 25 %
0.60 - 0.65 % R 5 %

F=3.0.8251 D=4.81.2682

Figure 7. Vitrinite reflectance histograms (10, 18, 19, 20, 21, 23) (Mangs 2023)

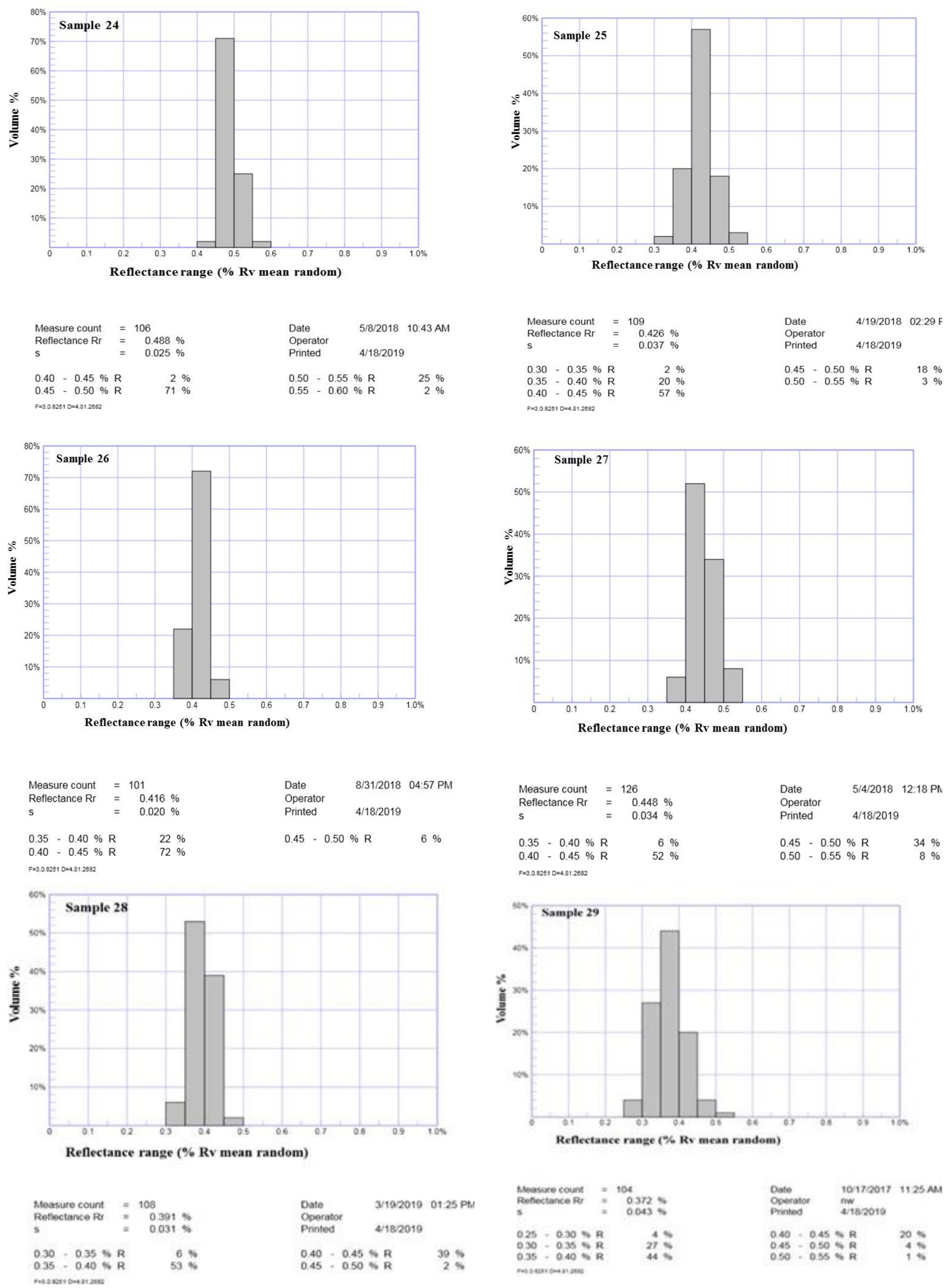


Figure 8. Vitrinite reflectance histograms Samples: 24, 25, 26, 27, 28, 29 (Mangs 2023)

4.3. Maceral composition of coals within the Anambra Basin

The maceral composition is displayed in Table 5 and Figures9-12 andshows variations through the Basin with dominance in vitrinite, with variation in the inertinite and liptinite. Samples 10, 19, 23, 24, 25, 27, 29 are dominated by vitrinite as shown in Figures 9-12, which is a precursor of collodetrinite, the dominant maceral type in the higher rank coal samples.

Samples18, 20, 21, 25,and 26 are dominated by inertinite as indicated in Figures9 - 12. Liptinite macerals across the samples are poorly distributed generally.Petrographically, the mineral matter shows a similar trend to the ash yield, the dominant minerals observed are clay and quartz, with pyrite in the samples.

Table 4. Petrographic results (maceral and mineral composition) (% By Volume) (Mangs et al., 2022).

Location		L1		L2		L3		L4		L5		L6				L7		L8		L9		L10		L11		L12			
	Sample number	10		18		19		20		21		22		23		24		25		26		27		28		29		Average	
Maceral Group	Maceral	Inc. mm	mmf	Inc. mm	mmf	Inc. mm	mmf	Inc. mm	mmf	Inc. mm	mmf	Inc. mm	mmf	Inc. mm	mmf	Inc. mm	mmf	Inc. mm	mmf	Inc. mm	mmf	Inc. mm	mmf	Inc. mm	mmf	Inc. mm	mmf	Inc. mm	mmf
Vitrinite	telinite	0,8	0,9	0,0	0,0	1,5	1,7	0,2	0,2	0,0	0,0	0,0	0,0	0,8	0,9	1,0	1,2	0,0	0,0	0,4	0,4	0,2	0,2	0,0	0,0	0,2	0,2	0,4	0,4
	collotelinite	4,0	4,5	4,8	5,1	6,9	7,7	0,8	0,9	3,5	3,9	7,3	7,5	8,8	10,0	7,5	9,2	12,0	12,4	6,9	7,3	5,0	5,3	5,2	5,4	10,4	10,9	6,4	6,9
	vitrodetrinite	1,8	2,0	1,4	1,5	4,2	4,7	6,4	7,7	3,9	4,3	0,4	0,4	2,9	3,3	11,0	13,6	2,2	2,3	1,4	1,5	0,8	0,8	0,6	0,6	1,7	1,8	3,0	3,4
	collodetrinite	41,2	46,3	26,2	27,8	22,6	25,1	20,5	24,7	20,0	21,9	29,5	30,3	28,7	32,5	24,6	30,3	34,9	36,2	16,9	17,7	40,8	43,5	38,3	39,8	51,7	54,1	30,5	33,1
	corpogelinite	4,8	5,3	0,4	0,4	11,0	12,2	2,1	2,6	3,3	3,7	3,0	3,1	7,9	8,9	3,5	4,4	2,8	2,9	2,2	2,3	7,2	7,6	3,6	3,7	4,4	4,6	4,3	4,7
	gelinite	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,2	0,2	0,4	0,4	0,2	0,2	0,0	0,0	0,0	0,0	0,0	0,0	0,1	0,1
	pseudovitrinite	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Inertinite	fusinite	8,5	9,6	35,8	38,0	19,7	21,9	28,8	34,7	38,5	42,2	36,0	37,1	16,9	19,2	4,1	5,1	34,7	36,0	54,0	56,5	22,3	23,8	35,5	36,9	2,3	2,4	25,9	27,9
	semifusinite	1,6	1,8	15,1	16,0	1,4	1,5	2,7	3,3	2,4	2,6	8,9	9,2	1,6	1,8	0,8	1,0	3,0	3,1	3,2	3,3	2,8	3,0	2,0	2,1	0,6	0,6	3,5	3,8
	micrinite	3,2	3,6	0,6	0,6	1,7	1,9	5,2	6,3	3,3	3,7	0,0	0,0	4,1	4,7	1,6	1,9	0,6	0,6	0,8	0,8	1,2	1,3	0,8	0,8	2,9	3,0	2,0	2,3
	macrinite	0,8	0,9	1,2	1,3	1,2	1,3	0,0	0,0	0,0	0,0	1,8	1,8	0,6	0,7	0,8	1,0	0,0	0,0	0,0	0,0	1,0	1,1	0,0	0,0	0,8	0,8	0,6	0,7
	secretinite	0,4	0,4	0,0	0,0	1,2	1,3	0,6	0,7	0,6	0,6	0,4	0,4	1,6	1,8	0,2	0,2	2,8	2,9	0,4	0,4	1,8	1,9	1,2	1,2	0,8	0,8	0,9	1,0
	funginite	0,6	0,7	0,0	0,0	0,8	0,9	0,2	0,2	0,2	0,2	0,4	0,4	0,6	0,7	0,4	0,5	0,2	0,2	0,4	0,4	1,2	1,3	0,6	0,6	0,4	0,4	0,5	0,5
	inertodetrinite	1,0	1,1	2,4	2,5	2,7	3,0	3,7	4,4	8,8	9,7	0,8	0,8	5,5	6,2	4,3	5,3	0,2	0,2	1,4	1,5	2,4	2,5	1,4	1,4	0,0	0,0	2,7	3,0
Liptinite	sporinite	0,0	0,0	2,8	3,0	0,6	0,6	0,2	0,2	0,0	0,0	0,4	0,4	0,0	0,0	0,2	0,2	0,8	0,8	0,2	0,2	0,0	0,0	0,4	0,4	0,2	0,2	0,4	0,5
	cutinite	6,5	7,3	2,6	2,7	9,7	10,7	3,7	4,4	4,7	5,2	7,1	7,3	4,9	5,6	2,6	3,2	0,8	0,8	1,8	1,9	3,0	3,2	1,2	1,2	16,6	17,4	5,0	5,5
	resinite	12,1	13,6	1,0	1,1	4,2	4,7	6,4	7,7	1,6	1,7	1,2	1,2	2,6	2,9	15,9	19,7	1,0	1,0	5,4	5,6	4,2	4,5	5,6	5,8	1,9	2,0	4,8	5,5
	alginite	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	liptodetrinite	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,2	0,2	0,0	0,0	0,6	0,7	0,2	0,2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,4	0,4	0,1	0,1
	suberinite	1,8	2,0	0,0	0,0	0,0	0,0	0,4	0,5	0,2	0,2	0,0	0,0	0,2	0,2	2,2	2,7	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,4	0,4
	exsudatinite	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,2	0,2	0,0	0,0
Mineral matter	silicates clay	7,7		1,4		5,4		12,2		3,5		0,2		8,4		15,7		1,2		2,2		2,0		1,6		3,7		5,0	0,0
	silicates quartz	0,8		1,2		1,4		1,2		1,2		1,8		1,8		2,2		0,6		1,2		1,0		1,4		0,0		1,2	0,0
	sulfide	2,4		3,2		1,7		3,3		3,3		0,8		1,2		0,8		2,0		1,2		1,8		0,8		0,6		1,8	0,0
	carbonate	0,0		0,0		0,0		0,2		0,0		0,0		0,0		0,0		0,0		0,0		0,0		0,0		0,0		0,0	0,0
	other	0,2		0,0		1,5		0,2		0,6		0,0		0,4		0,4		0,0		0		1,4		0,0		0,2		0,4	0,0
Summary Table																													
Maceral Group Totals (Vol %)	Vitrinite	52,5	59,0	32,8	34,8	46,3	51,5	29,9	36,0	30,8	33,8	40,2	41,3	49,1	55,7	47,7	59,0	52,2	54,2	28,0	29,3	54,0	57,5	47,6	49,5	68,5	71,7	44,6	48,7
	Inertinite	16,0	18,0	55,1	58,4	28,6	31,8	41,1	49,5	53,8	58,9	48,3	49,7	30,8	35,0	12,2	15,0	41,4	43,1	60,1	63,0	32,7	34,8	41,5	43,1	7,7	8,1	36,1	39,1
	Liptinite	20,4	22,9	6,4	6,8	14,5	16,1	10,6	12,8	6,7	7,3	8,7	9,0	8,3	9,4	21,0	26,0	2,6	2,7	7,3	7,7	7,2	7,6	7,1	7,4	19,3	20,2	10,8	12,0
	Min. Mater	11,1		5,8		10,0		17,0		8,6		2,8		11,8		19,1		3,8		4,6		6,2		3,8		4,4		8,4	0,0
	Tot .Inertinite	16,0	18,0	55,1	58,4	28,6	31,8	41,1	49,5	53,8	58,9	48,3	49,7	30,8	35,0	12,2	15,0	41,4	43,1	60,1	63,0	32,7	34,8	41,5	43,1	7,7	8,1	36,1	39,1
Total Reactive Macerals		72,9	82,0	39,2	41,6	60,8	67,6	40,5	48,8	37,5	41,1	48,9	50,3	57,4	65,0	68,8	85,0	54,8	56,9	35,3	37,0	61,2	65,2	54,8	56,9	87,8	91,9	55,4	60,7

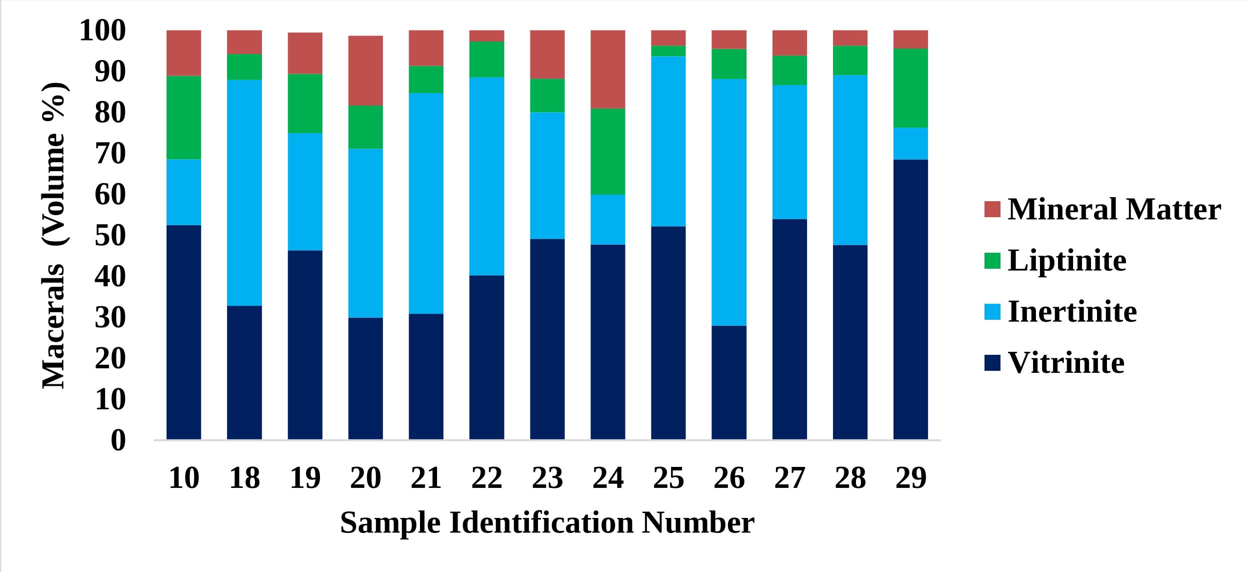


Figure9. Overview of maceral groups and mineral content (vol%)

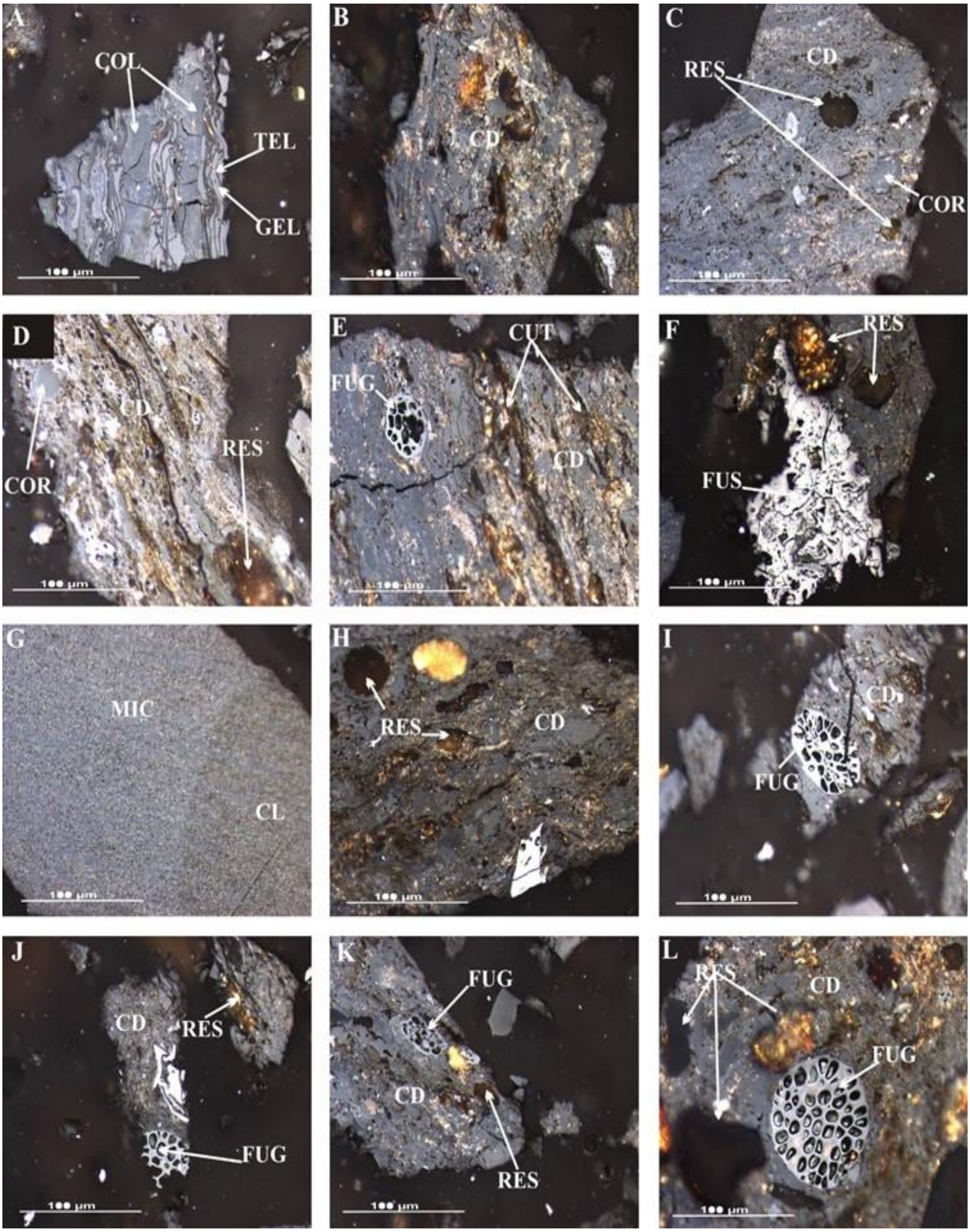


Figure 10. Sample 10 (A-L) Choice macerals detected in reflected white light (X 500, scale bar = 100μm, oil immersion) (Mangs 2023)

Note:

(CD: Collodetrinite; CL: Clay; COL: Collotelinite; COR: Corpogelinite; CUT: Cutinite; GEL: Gelinite; FUG: Funginite; FUS: Fusinite; MIC: Micrinite; TEL: Telinite; RES: Resinite)

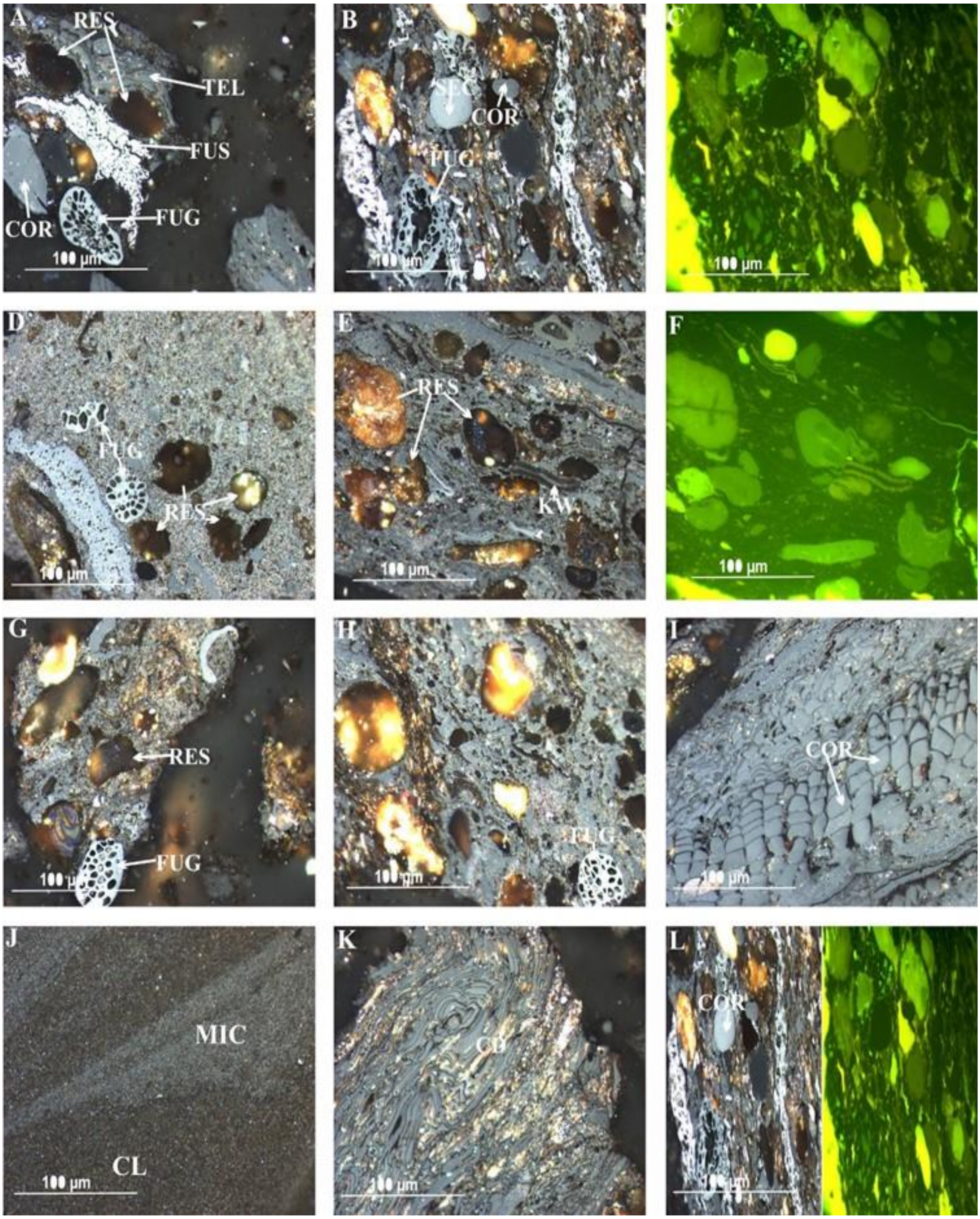


Figure 11. Sample 24 (A-L) Choice macerals detected in reflected white light (X 500, scale bar = 100µm, oil immersion) (Mangs 2023)

Note:

(CD: Collodetrinite; CL: Clays;COL: Collotelinite; COR: Corpogelinite; CUT: Cutinite; FUG: Funginite; FUS: Fusinite; GEL: Gelinite; KW: kaolinite worm; MIC: Micrinite; RES:Resinite; SEC: Secretinite; SP: Sporinite; TEL: Telinite)

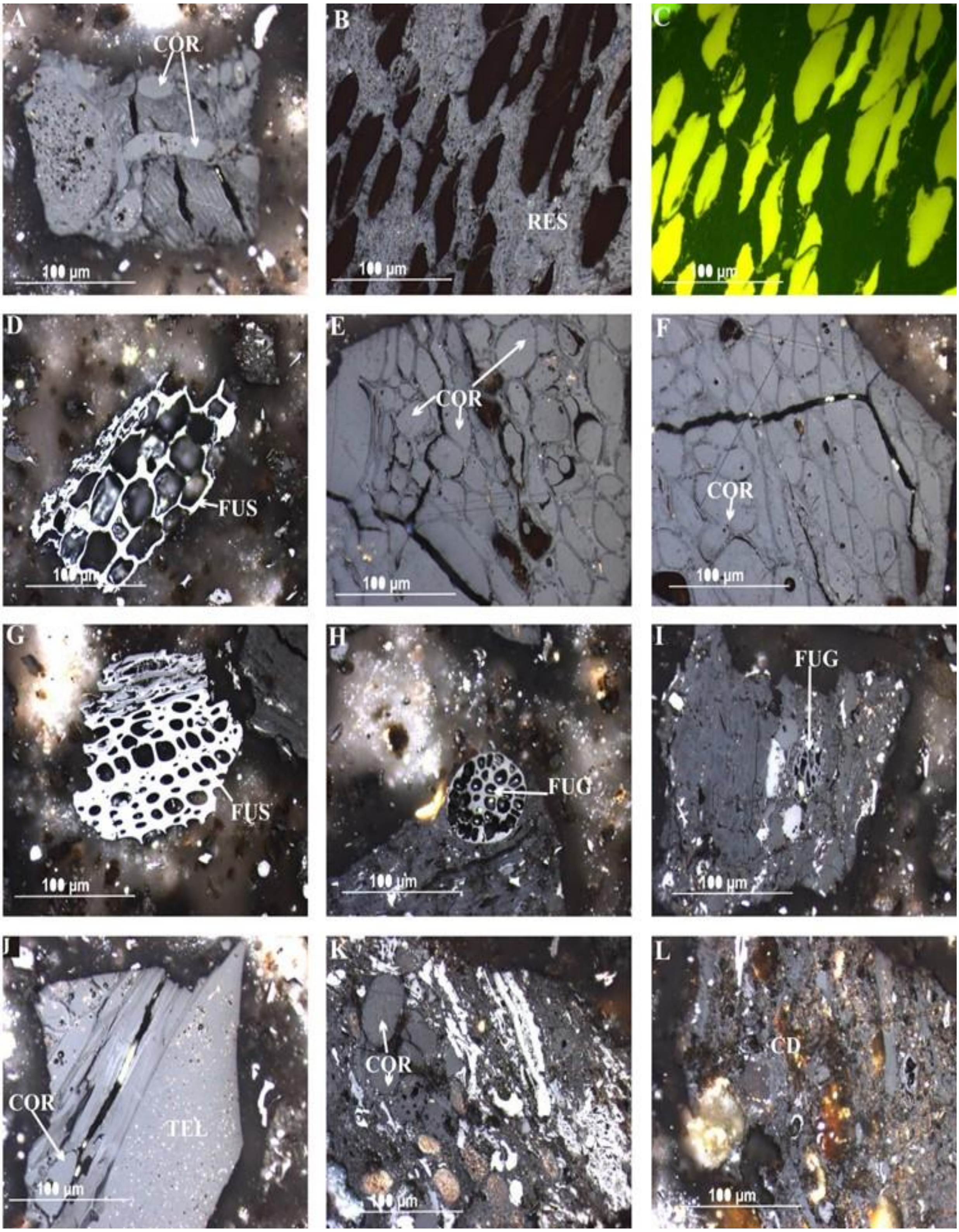


Figure 12. Sample 25 (A-L) Choice macerals detected in reflected white light (X 500, scale bar = 100µm, oil immersion) (Mangs 2023)

Note:

(CD: Collodetrinite; COR: Corpogelinite; FUG: funginite; FUS: Fusinite; GEL: Gelinite; RES:Resinite; TEL: Telinite)

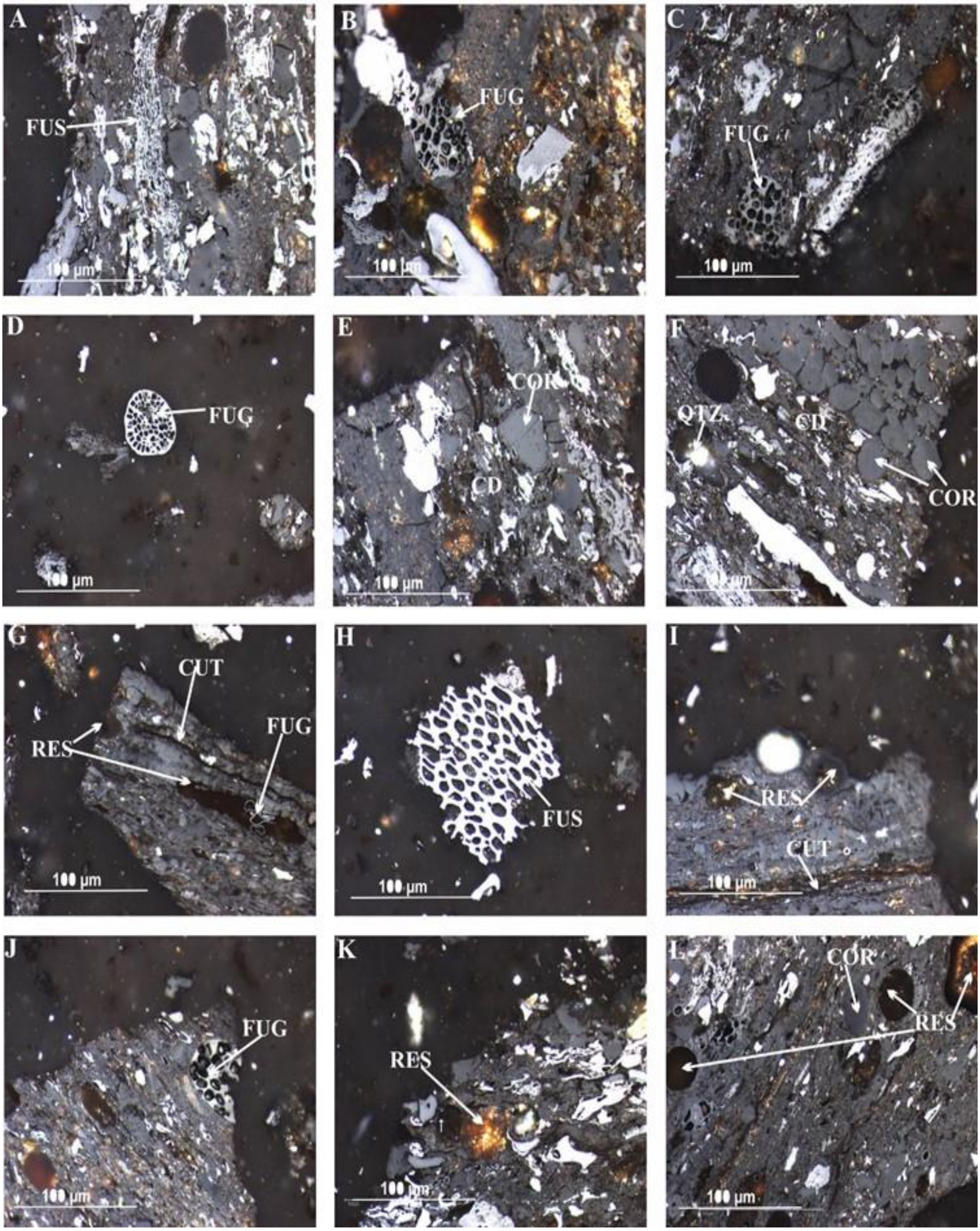


Figure 13.Sample 28 (A-L) Choice macerals detected in reflected white light (X 500, scale bar = 100µm, oil immersion) (Mangs 2023)

Note:

(CD: Collodetrinite; COR: Corpogelinite; CUT: Cutinite;FUG: Funginite; FUS: Fusinite; GEL: Gelinite;QTZ: Quartz;RES:Resinite; TEL: Telinite)

4. 4 Combustion reactivity of the coals in the Anambra Basin: Coal burning performance is often assessed through parameters extracted from the burning reactivity curve of the coal as it burns out as shown in the curves Figure 14.The thermogravimetric analysis is a signature used as a 'fingerprint' of the combustion profiles of coal, giving an assessment of its relative combustion characteristics, including ignition, flame stability, burnout and reactivity as shown in the burning profile curve in Figure 14. The coal is subjected to a deflagration process, starting with a negative deflection as observed in Figure 14 with the moisture loss. Immediately was a corresponding increase in mass due to solid-state oxidation of the organic matter (oxygen chemisorption). As the volatile loss commences, the point where the curve crosses the baseline is termed the initiation temperature (IT_{VM}). The burning profile represents the devolatilization and oxidation of the coal. With a small effect due to the decomposition of the minerals constituent in the coal samples. There is no clear distinctive boundary margin during the devolatilization and char burning (oxidation) which leads to the majority of the volatile matter being released a term called IT_{FC}. The reactivity order of the coal is assessed primarily based on the peak temperature (PT, called the temperature of the maximum rate of mass loss). The burnout temperature (BT) is the temperature at which combustion ceases (Jamaluddin et al., 1988)

The reactivity order curves for the LBT coal samples are characterized by variable peaks and moisture content (Figure14A and Table 5). On combusting the coal samples, the moisture content first devolatilized into a gaseous phase followed by volatile matters then the complete burning of the materials (Mendez et al., 2003). The first peak temperature ranged from 344.7 to 359.6℃ for samples: 25, 26, 27, and 28 (Figure14A, Table 5), due to high VM and fixed carbon with low ash yield which results in early combustion. The second peak temperature ranged from 392.5 to 439.2℃ for samples: 10, 18, 19, 20, 21, 22, 23, and 29 while sample 24 had a peak temperature that fell in between the first and second peaks due to heterogeneous combustion.

Table 5. Temperature characteristics (as indicative), proximate, ultimate, CV, and petrographic data of the coal deposits within the Benue Trough(Mangs et al., 2022)

TGA (TEMPERATURES ℃)				CV MJ/kg	PROXIMATE /ULTIMATE (Wt. %)				PETROGRAPHY (Vol%)				
S/ID	T_I	T_P	T_B	CV	Moist	Ash	VM	Carbon (daf)	RoV	Rank (ISO 11790)	Vit. mmf	Inert mmf	Lip mmf
10	225	401.3	539.7	27.07	0 9.8	03.2	42.9	73.86	0.45	Low R. A	59.1	18.0	22.9
18	226	435.5	569.5	28.34	03.5	11.0	33.7	80.00	0.43	Low R. A	34.8	58.4	06.8
19	225	420.4	570.4	27.36	03.6	12.6	31.7	78.20	0.46	Low R. A	51.9	31.9	16.2
20	224	421.2	571.5	27.84	03.7	11.5	37.0	78.33	0.42	Low R. A	36.9	49.5	13.6
21	220	422.5	572.6	24.58	05.8	12.8	30.6	72.26	0.52	Med..R.D	33.8	58.9	07.3
22	220	439.2	573.6	26.38	07.9	10.5	33.4	78.64	0.45	Low R. A	41.3	49.7	09.0
23	219	423.9	574.3	27.31	04.3	15.2	30.0	80.09	0.53	Med..R.D	55.6	35.0	09.4
24	227	392.5	575.2	24.95	04.4	16.6	39.4	72.19	0.49	Low R. A	59.0	15.0	26.0
25	220	359.6	526.3	24.72	07.9	13.4	32.8	74.33	0.43	Low R. A	54.2	43.1	02.7
26	221	344.7	527.6	26.10	08.7	05.8	36.6	73.79	0.42	Low R. A	29.3	63.0	07.7
27	220	345.4	528.7	25.61	13.0	06.5	36.5	74.23	0.45	Low R. A	57.5	34.9	07.6
28	200	346.8	529.9	24.85	10.6	07.3	35.3	71.59	0.39	Low R. B	49.5	43.1	07.4
29	200	397.3	497.1	25.53	15.8	05.9	30.9	74.97	0.37	Low R. B	71.7	08.1	20.2

Foot Note:IT: Ignition temperature; PT: Peak temperature; BOT: Burn out temperature; RoV: Random reflectance; Vit: Vitrinite; Vol % mmf: Volume mineral matter free; Inert: Inertinite; Lip: Liptinite; daf: Dry ash free; VM: Volatile matter; CV: Calorific value; Wt. %: Weight percent; Med. R. C: Medium rank C; Med. R. D: Medium rank D; Low R. A: Low rank A; Med. R. B: Medium rank B

Sample 29 reported low ash content (5.9%), with the highest moisture content (15.8 Wt.%) and the highest weight loss (94.1%) as shown in Figure14B. The combustion efficacy of the coal sample is mostly negated by the ash and moisture content (Şentorun, et al., 1996). The combustion behaviour by the samples confirmed the studied coal is categorized with low mineral matter as revealed in the proximate analysis.

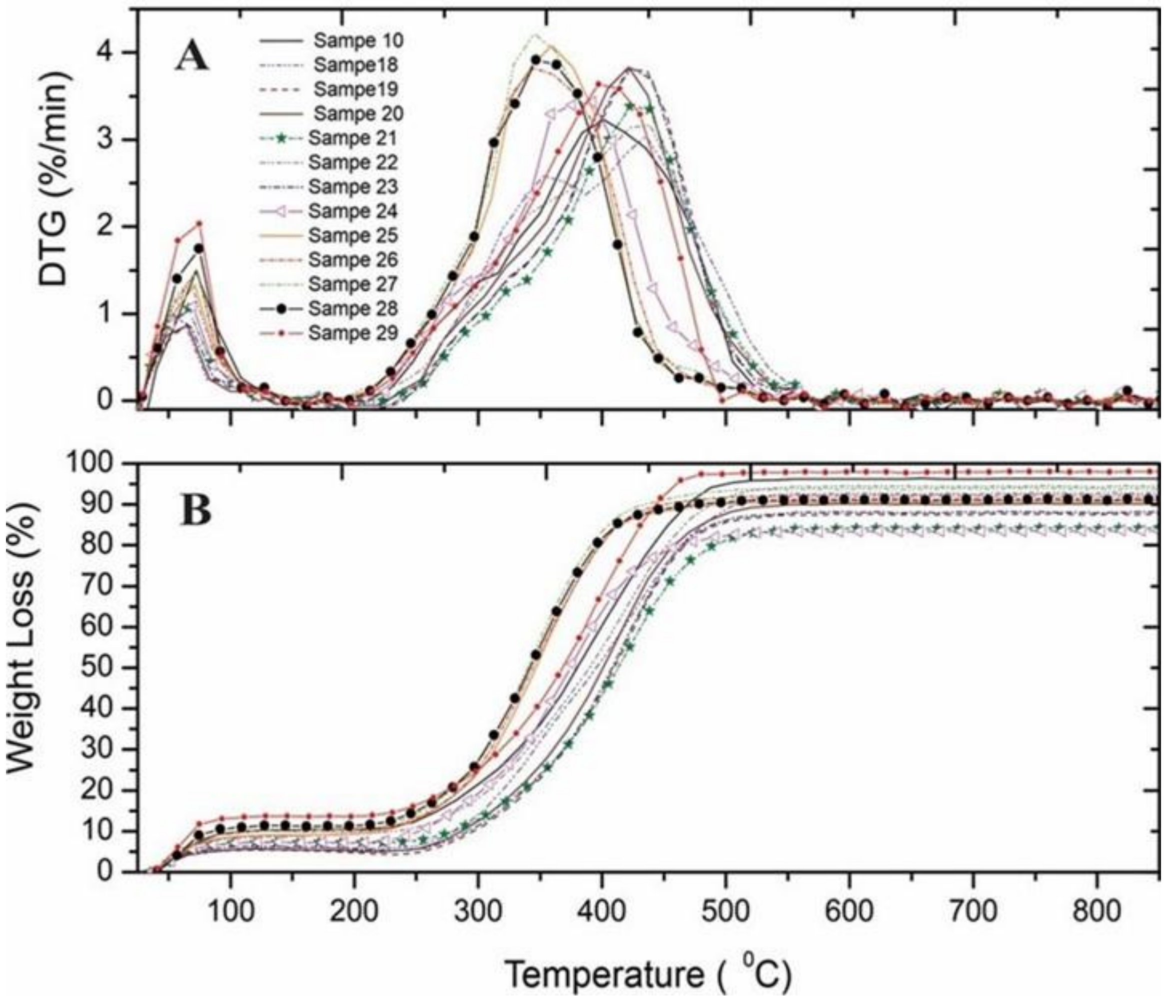


Figure14. Combustion reactivity profiles (Mangs et al., 2022)

4. 5 Discussion on the Results: Gross calorific value, proximate and ultimate data were summarised in Table 2and used to characterize the studied coal samples. Maceral constituents influence the combustion profile of each coal sample. Chemical parameters show a decrease in the volatile matter, hydrogen and oxygen contents, with the upsurge in carbon content playing very paramount factors in the thermal properties of coal application. The ash yield of the studied samples ranges from 3.2 - 79.0 wt.% (Table 5) and the main minerals identified were kaolinite and quartz (Akinyemi et al., 2012; Ogala et al., 2012; Odoma et al., 2015). From the combustion profiles presented in Figure 14, each performance is estimated through the burning profiles with the corresponding weight loss (%) Figure 14B.

Coal samples in the Anambra Basin shows a very good combustion profiles with prolong temperatures as shown in Figure14A and B, Table 5. Coal samples from the LBT sub-region are characterized as the best combusted coal samples that contained low mineral matter, low moisture content as revealed by the proximate, GCV and petrographic results. The variation in the coal seams was noted in the ash yield, GCV and the moisture affected the coal combustion performance as well as the coal quality as represented by each combustion profile.

Mass loss through the thermal decomposition processes might be credited to the degradation of maceral constituents (Akinyemi et al., 2021a). Characteristically, macerals, regardless of its rank, displayed varied levels of thermal activities through coal decomposition (Speight, 2012). Thermal activities also depend on lignocellulosic, resinous, and polymeric components derived from forestry materials exposed to coal formation (Landais et al., 1989; Dorrestijin et al., 2000; Speight, 2012).

5. CONCLUSION: Maceral Composition of the Coal in the Anambra BasinCoal were investigatedwith a view to exploring its potential for electricitygeneration.in this paper, and the following conclusions were drawn:

- Coal in the Anambra Basinis complex and heterogeneous in composition; hence it is only through a thorough and holistic analysis that the coal quality can be unpacked for an appropriate characterization and utilization.
- For steady and cheap sources of electricity supply, coal will continue to be a critical energy feedstock in the nearby future for third-world countries. The petrography, proximate, and CV data revealed the various properties and characteristics of the coal quality which is an integral component of the coal combustion profile.
- The proximate data show that the coal is rich in Volatile matter and fixed carbon which are heat-enhancing attributes of coal with low ash content. From the calorific values of the samples, majority areclassifiedmedium to high CV.
- The petrography data reveals the different maceral constituents of the coal, which are vitrinite-rich (collodetrinite, collotelinite, corpogelinite and telinite). The inertinite are the second dominant macerals rich in (Fusinite, semi-fusinite, micrinite, Secretinite, funginite and inertodetrinite). The liptinite maceral group is very scanty in the Anambra Basin with these macerals: cutinite resinite, suberinite liptodetrinite, alginate, exsudatinite, and sporinite. The mineral matter dominant in the coal sample is kaolinite and quartz with some few sulphides.
- The combustion profile curve in the Anambra Basin show that the peak temperatures range from 344.73 to 439.201°C, these temperatures are parameters for the boiler design for a power station. The reactivity order of the macerals: huminite (exinite) > vitrinite > inertinite; this was demonstrated from a complementary study on chars derived from maceral concentrates that inertinite chars burn more slowly than vitrinite chars or exinite-rich chars. The coals can be used for electricitygeneration.

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