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Abstract: The coals in the TOP mine area are of low rank and contain high content of huminite and low contents of inertinite and liptinite. From the TPI-GI Diagram that TOP Coal basin, which is on the eastern part of Kutai basin, the palaeo-environment was mostly wet forest swamp condition, and the plant remnants were better conserved in TOP Mine basin. The inertinite content in the samples is very small, resulting in high GI values. The latter suggest continuously wet conditions through deposition, although some seasonal dryings are not excluded, as indicated by the presence of macrinite. The low sulfur content of the studied coals clearly indicates that during deposition there was no significant marine influence; instead peat growth occurred in a fresh water environment. TOP mine present in rain forest zone, this is typical of wet forest swamp, which is generally characterised by relatively high water level and gelification of the organic material. The TOP Coal seam shows high GI and low TPI, low GWI and low WI indicate a fresh water peat swamp with plant materials accumulated with little transport, characteristic of fresh water swamp. TOP coal density is controlled by the presence of semifusinite macerals because of low ash and low mineral matter content. HGI is having a negative correlation with coal density. In TOP coal mine the HGI is low due to low vitrinite and high huminite content. The physical factor HGI is correlated with Densinite, Cutinite/Sporinite and Vitrinite. All these macerals have positive influence on HGI values.

Key Words: Coal facies, Maceral, gelification index (GI), tissue preservation index (TPI), groundwater index (GWI), wood index (WI), palaeoenvironment, factor analysis.

I. Kutai Coal Basin

The Muara Wahau area is contained within part of the Tertiary Age Sediment Basin of Kalimantan known as Kutai Basin (Figure 1). The Kutai Basin is the middlemost major sedimentary basin developed along the eastern coast of Kalimantan. The Kutai Basin began to develop during a Palaeogene to Neogene age transgression, and is intruded by igneous rock and covered unconformably by alluvial deposit products of older rock deformation. Tectonic activity in this area started in the Mesozoic period as shown by the occurrence of ultramafic rock. During the early Cretaceous, the deposition of the Telen formation took place. During the late Eocene, the Embaluh group was overlain unconformable by the Telen formation, followed by magmatic activity of Kelai granitic intrusion and the occurrence of Kelinjau mélange. During the late Miocene to Quaternary, volcanic activity took place and resulted in Metulang volcanic rock (Figure 2).
TOP mine Wahau Formation: This formation consists of alternating clay stone, quartz sandstone, clayey sandstone and sandy clay stone. The clay stone is dark grey, bedded of 10 to 25cm thickness. The quartz sandstone is yellowish grey, dense, fine to medium grained, well sorted, tuffaceous, micaceous, calcareous and contains fragments of coral shells. Clayey sandstone and sandy clay stone are yellowish grey, calcareous and locally carbonaceous, well bedded and contains coral shells. The lower part of this unit shows intercalation of algae and coral fossil rich limestone. The upper part of this unit has intercalations of white tuff, lignite and brown coal. This formation was deposited in the shallow marine to terrestrial environments with the thickness of up to 2,000m. The Wahau formation unconformable overlies the Marah formation. The Wahau formation was deposited in a deltaic/paralic environment during the Oligocene and early Miocene. The coal depositional area of Kutai Basin has undergone several structural deformations during this period. Mostly the synclinal and anticline folding are predominantly present followed by post depositional regional as well as localized faulting. No such igneous intrusions have been recorded in Kutai Basin

The project area is located in the northern part of Kutai Basin, the deepest Tertiary sediment basin in Indonesia. The thickness of the sediment is approximately 10,000 meter, measured from the center of the basin. Kutai Basin is tectonically separated by Tarakan Basin and Mangkalihat High at the north and eastern parts. The west side is bordered by Kuching High and the southern part is separated from Barito Basin by Patar-Noster High. In the east side, this basin opens toward Makassar Strait where sediments are transported and deposited. Rock formation in the project area is generally Wahau Formation from Upper Oligocene period. Coal is carried by this formation. This rock formation is covered in non-conformance by alluvial sediment.

Macerals are the microscopic organic components typically identified in coals. They derive from terrestrial, lacustrine and marine plant remains, and their appearance is a function of the parent material, of initial decomposition before and during the peat stages and also of the degree of evolution undergone. Macerals are distinguished from one to another on the basis of their physico-optical properties and universal acceptance is given to the ICCP classification of macerals [1-6]. In three groups: liptinite, inertinite and huminite/vitrinite. These groups are subdivided into a variety of maceral subgroups, macerals, and maceral varieties. In the evaluation of coal seam quality or for coal utilization it is always necessary to know the quantitative composition of a coal in terms of macerals (and minerals in some cases) or maceral groups. This is because differences in maceral composition indicate differences in chemical composition and therefore in the technological properties of the coal. Vitrinite comes from wood matter, while Exinite mainly consists of products of digested sludge. The third maceral group, inertinite, which requires further analysis before being confirmed as originating from the vegetable matter, is relatively unreactive [7]. With brown coal, the maceral groups distinguished are huminite, liptinite and inertinite, where huminite and liptinite, as far as their origin is concerned, correspond to the hard coal maceral groups of vitrinite and Exinite, but with a lower degree of decomposition [8]. The maceral analysis in coals is performed using optical microscopy with a point-counter coupled to the microscope stage.

The study on coal facies may provide genetic information of coal-forming conditions, coal-forming process and coal-forming plants. The coal facies and its evolution features may be determined by the study on the types of peat
accumulation, plant community, sedimentary environment (including pH values, bacterial activities and sulfur influences), reduction-oxidation potential, and geochemistry features. The aim of coal facies studies is mainly to determine the paleo-environmental conditions under which the precursor peats accumulated by classifying the coal facies through the various marks of genesis contained in the coal seam itself. This paper relies on various indices, including the gelification index (GI), tissue preservation index (TPI), groundwater index (GWI) and a wood index (WI) accompany with the lithotype, maceral and sedimentary analysis to reflect the peat accumulation information, such as coal-forming plants, mire medium conditions and sedimentary environments. GI is the ratio of gelified and fusinitized macerals whereas TPI emphasizes the degree of tissue preservation versus destruction. TPI can be used as a measure of the degree of humification and GI is related to the continuity in moisture availability. The gelification index is the ratio of gelation components to non-gelation components reflecting the wet degree and duration of peat mire. Higher values of GI usually indicate wet mire, whereas lower values indicate dry mire. The GI values are often low at the relatively dry basin margins, but increase in the direction of accelerated basin subsidence. The GI is used to determine the moisture conditions of the peatland and is defined as the ratio of the gelified macerals to the non-gelified macerals. The TPI indicates tissue degradation and the ratio of wood in coal-forming plants [9]. Given the similar source material, the TPI can also reflect pH value because in a low pH-value environment, microbial activity is weak and plants can be well preserved and consequently a high TPI. Reversely, in a middle-high pH-value environment, microbial activity is strong and bacterial breeding is fast and then a low TPI [10]. The maximum TPI value (and GI) can also indicate a balanced ratio of plant growth and peat accumulation versus rise in groundwater table [10, 11]. The GWI ratio based on the gelification and the mineral matter input indicates the level of water at the time of peat accumulation. Higher water levels are usually associated with higher degradation of macerals and higher mineral content [12]. GWI values of less than 1 are thought to identify ombrotrophic, raised mires to mesotrophic fens and GWI values between 1 and 5 have been related to rheotrophic mires. The inclusion of significant amounts of minerals, which should be restricted to waterborne detrital varieties, commonly yield GWI values above 5 which signifies flooding of the mire surface [10, 12]. Because the liptinite group is absent in the macerals, the wood index was adapted instead of vegetable index by Calder et al. (1991) [12]. WI was originally proposed by Zhang et al. (1997) [13] when he studied the coal facies of the western China coal basins. The WI characterizes the coal forming vegetation and the degree of preservation; values higher than 0.5 are generally linked to forest peat swamp [13]. TPI (Tissue Preservation Index) and VI (Vegetation Index) values were used to determine the paleo depositional environments [9]. Low TPI values developed either depending on the vegetation type (high angiosperm/gymnosperm ratio), or on low tissue preservation conditions [14]. The GI value indicates underground water level and/or pH level. For jellification, regular water flow, bacterial activity and low acidic conditions are essentials [15]. Coalification was developed in an underwater level with normal subsidence rate; taking places in autochthonous to hypautochthonous conditions. Here, high alkalinity conditions were the case in point. Low TPI value indicates high bacterial activity and high pH value [16]. The TPI vs. GI diagram proposed by Diesel [17], is used to assess the palaeoenvironment of peat formation. The tissue preservation index (TPI) is a measure of humification grade of the initial organic matter and is defined as the ratio of the structured to the structureless macerals. With this contextual understanding an attempt was made to establish the palaeo-environment of TOP Mine coal basin in Muarawahau area which is a part of Kutai Basin in East Kalimantan, Indonesia.

II. Experimental

In the first step, about 50 gms of crushed drill core coal samples are taken from the bulk screened through sieve to generate – 30 & + 20 size range. A mixture of Epoxy Resin and hardener in the ratio of 10:1 is prepared by thorough mixing of the two liquids. The mixture is put in a vacuum chamber to drive away the trapped air bubbles. A part of the coal sample is mixed thoroughly and put in a dies. A hydraulic press is used to compress the sample at the bottom of the dies and also to drive away the trapped air so that the entire part is homogenous. It is then kept for 48 hours in a desiccators (lower space filled with crystals of Calcium Fluorides) to avoid influence of external humidity and also for hardening of the sample. When hardened, the sample is taken out by applying hydraulic press. It is then polished using carborandum powder paste of 300µm & 600 µm and alandum powder paste of 1000µm grade. The planner and smooth surface is the rubbed on a piece of Chamois leather as a final polish to generate brightness of the surface to be studied. The sample is then ready to study under microscope.

Brown coal represents a very low rank in the process of coalification. As a result, the aromatic structures are not well developed and a combination of aliphatic and aromatic compounds along with dispersedly oriented inorganic mineral matter exists. The maceral contain well defined signatures of plant remnants and amorphous character dominates over the crystalline phase. Due to this reason, differentiation of the inorganic content becomes difficult as many of the maceral do not allow reflection of light from the polished surface as being non-crystalline and are dark under normal light. Fluorescence microscopy has made the identification of maceral in
low rank coal which enable the estimation of the inorganic content which is quite important in determination of energy value of low rank coal. For this purpose, all the samples are studied under Microscope with fluorescence attachment where maceral and mineral matters are clearly identifiable. For the present investigation, 20 drill core samples were used and maceral study of one thick seam named S2B of TOP MINE in Muarawahau area in East Kalimantan, Indonesia was conducted. The microscope stage is moved through the point-counter in a series of fixed intervals according to the total points to be recorded on the whole sample, and the identity of the maceral falling beneath the cross-hairs or micrometer after each advance is recorded. For that the microscope should be equipped with incident white light, oil immersion objectives (25x-50x magnification) and 8x to 10x oculars, one of which must contain an adjustable eyepiece with a micrometer or crosshair. The analytical procedure for maceral analysis is standardized by the ASTM normative protocols. Automated methods using computerized image analysis were also developed in the last decades for maceral analysis although the manual point-counting method is the most extensively used. Although maceral analysis is carried out in white light, supplementary observations in fluorescence mode are recommended. Results of maceral analysis are reported on a volume percent basis. Finally the maceral constituents have been correlated with physico-chemical properties with the aid of multivariate analysis.

III. Results and Discussion

All the prepared samples are investigated under both reflected light and fluorescence light. In general the maceral constituents are shown in Table 1 and detailed below.

Some of the Brown Coal samples exhibit features of geochemical alteration as is evidenced from vitrination and Fusinitisation of the maceral. This is not considered as a thermochemical alteration as the structure of the material is almost unchanged but considerable increase in the reflectance character is readily recognizable. Vitrination is the process of compaction and homogenization of the gelified Huminites to form members of the vitrinite group of maceral. Maceral Semifusinite, Micrinites and Sclerotinite are the representatives of the Inertinite Group. In parts of the samples, these maceral are founded interbanded with the Vitrinite Group maceral. This feature is very common in thermochemically altered and matured rank bituminous coals. Besides this banded part, these coals also contain small amount of Textinite, Resinite, Cutinite, Sporinite and some fungal spores. Detail of the petrographic investigation and various maceral content (in percentage) of each of the samples studied is given in the following Table 2.

Coal Facies Study: The GI and TPI are used in the present study as they are proposed by Kalaitzidis et al. [10].

\[
GI = \frac{(\text{Textinite} + \text{Attrinite} + \text{Inertinite})}{(\text{Ulminate} + \text{Gelohuminite} + \text{Densinite})}
\]

\[
TPI = \frac{\text{(Attrinite +Densinite + Gelinite + Inertodetrinite)}}{(\text{Telohuminite + Corpogelinite +Fusinite})}
\]

Both the GI and TPI are plotted for the TOP coal and shown below (Figure 4). It can be seen from the TPI-GI Diagram that TOP Coal basin palaeo-environment was mostly wet forest swamp condition, and the plant remnants were better conserved in TOP Mine basin. Few samples

<table>
<thead>
<tr>
<th>Table 1 Average Maceral Constituent TOP Coal</th>
<th>Macerals Type</th>
<th>Avg. Wt.%</th>
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</thead>
<tbody>
<tr>
<td>Huminite</td>
<td>45</td>
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</tr>
<tr>
<td>Exinite</td>
<td>17</td>
<td></td>
</tr>
<tr>
<td>Inertinite</td>
<td>3</td>
<td></td>
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<tr>
<td>Vitrite</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Amorphous Carbon</td>
<td>11</td>
<td></td>
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<tr>
<td>Mineral Matter</td>
<td>18</td>
<td></td>
</tr>
</tbody>
</table>

![Figure 4 GI vs TPI plot for TOP MINE drill core coal samples](image-url)

![Figure 5 VI vs GWI plot for TOP MINE drill core coal samples](image-url)
show Limnic - Quiet depositional environment, so that less silt is carried in, so the ash content is less in TOP Coal. This observation is totally different from the Miocene coals of Sumatra, which are high GI and low TPI, that originate from decomposed wood in forested peatlands or herbaceous plants in tree-less marshes. Also, undisturbed post-depositional environment, possibly anaerobic would enable lithification (or coalification, particularly in the early peat stages) to progress undisturbed. Fen is a rheotrophic ecosystem in which the dry season water table may be below the peat surface. Less wooded fen environments are also indicated, particularly by TPI/GI plots and a sparse assemblage suggesting incursion of flood waters and dominance of herbaceous vegetation [19]. Tissue Preservation Index ranges more widely than Gelification Index. This reflects the changes in abundance or preservation of woody plants, in turn probably controlled by rising and falling of water table [20].

The VI vs. GWI diagram (Figure 5) is used to classify peat-forming environments according to their hydrological regime and especially the inflow of nutrients into the peatland [21]. In this study both the VI and GWI indices are used as proposed by Kalaitzidis et al. (2004) [18]. The groundwater influence index (GWI) is a measure of the moisture conditions. The vegetation index (VI) depends on the peat-forming plant species. It is defined as the ratio of macerals derived from arboreal vegetation to those derived from herbaceous vegetation.

\[ \text{GWI} = \frac{(\text{Telohuminite} + \text{Attrinite})}{(\text{Gelohuminite} + \text{Densinite} + \text{Mineral Matter})} \]

\[ \text{VI} = \frac{(\text{Detrohuminite} + \text{Inertodetrinite} + \text{Other Liptinites})}{(\text{Telohuminite} + \text{Fusinite} + \text{Semifusinite} + \text{Cutinite} + \text{Sporinite})} \]

The low GWI indicate that the precursor mires were maintained by rainfall and with no influence from the groundwater level [21], which is representative of TOP mine present in rain forest zone. This is typical of wet forest swamp, which is generally characterised by relatively high water level and gelification of the organic material. The TOP Coal seam shows high GI and low TPI, low GWI and low WI indicate a fresh water peat swamp with plant materials accumulated with little transport, characteristic of fresh water swamp. All the samples are plotted within the area that indicates wet and reducing conditions during peat accumulation. This prevented the oxidation of the organic matter and the formation of inertinite. So the inertinite content in TOP Coal was found to be considerably low. Semifusinite like macerals indicate increase of oxidation and decrease of water levels within swamps in few areas occasionally. Mineral matter ratio average of 18% and mostly formed with clays and silicate minerals which probably formed as a result of biologic activities in the region. These levels indicate occasional inorganic material inputs instead of organic material, during peat development. High mineral matter content, detritic maceral inclusion and rare presence of the textures refer exposition of the materials to insitu transportations as well as tectonic activities in the surrounding during peat formation.

Low sulphur contents in coals result from the decreased availability of sulphate ions in fresh water (as opposed to sea water) coupled with the lesser activity of anaerobic bacteria. The pH value and the quantity of bacteria are lower in a freshwater swamp than in a salt marsh. Coals that formed under less reductive conditions are distinguished by a lower content of general and pyrite sulphur compared to coals that formed under reduced conditions of any rank. The TOP Coal total sulphur content of < 0.20 % supports the origin of fresh water swamp environment [22]. The above criteria’s applied for interpretation suggest that the fresh water swamp forest environment was developed in the early stages of peat deposition in Top Mine area, which change to cyclic dry forest swamp environment and wet forest environment with transition to wet forest environment in marsh areas. The dominant source of peat was woody vegetation and vegetation with high preservation potential.

In the present study an attempt was made to understand the correlation among the physico-chemical constituents with maceral constituents of the TOP coal analyzed from the drill core samples. As the variables are many, a multivariate (Varimax Factor Analysis) approach was made. The results of the factor analysis for the chemical and maceral constituents are shown in Table 3. The factor loading values below ±0.40 has been omitted from the cells because of their less significance and Eigen values are not shown as it were very low values.

Factor 1: Constitutes the primary chemical fractions like CV, FC, VM, TS and ADL. It is clearly seen that ADL has a negative correlation with all other fractions. Calorific value is the most important parameter that determines the Heating Value it is the heat energy available after reducing the loss of moisture known as 'Air Dried' coal is what is used in the laboratory for analysis. So ADL and other components will always have negative correlation. This factor is understood as basic chemical constituent of coal factor, carry no relation with macerals. The total sulphur belonging in this group indicates the sulphur source is primarily organic in TOP coal.

Factor 2: Surprisingly the relative density found to have relation with Semifusinite and Corpocolinite macerals in coal. Coal with higher contents of fusinite and semifusinite has higher densities has been known. Possibly the TOP coal density is controlled by the presence of semifusinite macerals because of low ash and low mineral matter content. This factor can be considered ad Density factor.
<table>
<thead>
<tr>
<th>Sample No.</th>
<th>HUMITE (Woody material)</th>
<th>ENHANCE / LIPIDITE (Space, Resin, Calidite)</th>
<th>INERTITE (Oxidized plant material)</th>
<th>Vitrinite</th>
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<tbody>
<tr>
<td></td>
<td>Textinite</td>
<td>Phlobaphorite</td>
<td>Macete</td>
<td>Corpore</td>
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<td></td>
<td>Woody tissue, with full cell structure</td>
<td>Woody tissue, with no cell structure</td>
<td>Woody tissue, with no cell structure</td>
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<td>Source</td>
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<td>Total Huminite</td>
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<td></td>
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<td>Total Liptinite</td>
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Table 2: Results of Maceral Study of Drill core samples of TOP Coal Mine
Factor 3 & 5: The physical factor HGI is correlated with Densinite, Cutinite/Sporinite and Vitrinite. All these macerals have positive influence on HGI values. The analysis of grindability of British coal confirmed wide relation of HGI values between the quality group of coal, volatile combustible matter contents, carbon and hydrogen [23]. It is generally valid that the occurrence of vitrinite in coal increases the HGI value, whereas the Micronite and Liptinite macerals decrease the grindability [24]. On the basis of research of black coal from Kentucky, Hober and Wild [25] have derived that part of the HGI change can be explained by maceral composition, mainly by liptinite contents, which is the most important maceral group affecting grindability and coal class expressed in this study by the value of maximum reflectance of vitrinite. The grindability is significantly influenced also by the contents of ash in coal [26] although it’s not in case for TOP Coal. Why densinite is having negative correlation with HGI is not clear. This factor is controlled by HGI.

Factor 4: Total moisture has got negative correlation with Vitrinite and Ulminite content. Generally vitrinite contains the most moisture and inert macerals the least [27]. Roberts (1991) [28] found a weak positive correlation of inertinite content with “inherent moisture”, which based upon the way he sampled, is an estimate of bed moisture. During the coalification process, with the increase in rank of the coal the vitrinite content increases with a depletion of total moisture, so the factor is understood. Inertinite contains more macroporosity (30 nm to 10 μm pore diameter) than vitrinite [29], and this demonstrates some agreement with higher inherent moisture. Also, inertinite tends to contain more oxygen functional groups, and thus more hydrophilic sites.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Factor 1</th>
<th>Factor 2</th>
<th>Factor 3</th>
<th>Factor 4</th>
<th>Factor 5</th>
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<td></td>
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<td>Resinite</td>
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<td>HGI</td>
<td></td>
<td></td>
<td>-0.63</td>
<td>0.50</td>
<td></td>
</tr>
<tr>
<td>RD ISO, gm/cc</td>
<td>-0.87</td>
<td></td>
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</tbody>
</table>

IV. Conclusion

Peat and coal facies are controlled by the evolution of depositional environments. Factors such as temperature, rainfall, subsidence and morphology of the basin, lithology of rocks in the hinterland, volcanic activity, and the accumulation of peat itself control deposition and preservation of plants and minerals [30]. The coals in the TOP mine area are of low rank and contain high content of huminite and low contents of inertinite and liptinite. From the TPI-GI Diagram that TOP Coal basin, which is on the eastern part of Kutai basin, the palaeo-environment was mostly wet forest swamp condition, and the plant remnants were better conserved in TOP Mine basin. The inertinite content in the samples is very small, resulting in high GI values. The latter suggest continuously wet conditions through deposition, although some seasonal dryings are not excluded, as indicated by the presence of macrinite. The low sulfur content of the studied coals clearly indicates that during deposition there was no significant marine influence; instead peat growth occurred in a fresh water environment. TOP mine present in
rain forest zone, this is typical of wet forest swamp, which is generally characterised by relatively high water level and gelification of the organic material. The TOP Coal seam shows high GI and low TPI, low GWI and low WI indicate a fresh water peat swamp with plant materials accumulated with little transport, characteristic of fresh water swamp. All the samples are plotted within the area that indicates wet and reducing conditions during peat accumulation. This prevented the oxidation of the organic matter and the formation of inertinite. So the inertinite content in TOP Coal was found to be considerably low. Semifusinite like macerals indicate increase of oxidation and decrease of water levels within swamps in few areas occasionally. Mineral matter ratio average of 18% and mostly formed with clays and silicate minerals which probably formed as a result of biologic activities in the region. These levels indicate occasional inorganic inputs during peat development. High mineral matter content, detritic maceral inclusion and rare presence of the textures refer exposition of the materials to insitu transportations as well as tectonic activities in the surrounding during peat formation. The lithotypes represent a broad spectrum of depositional environments from forest swamps to dry, herbaceous and/or shrubby marshes. Compositional differences between lithotypes are due to vegetational characteristics as well as differences in the rate of accumulation and decomposition of plant communities. Lateral and vertical variation in lithotype composition was controlled by groundwater levels and proximity to active fluvial systems. Forest swamps were dominated by coniferous trees with a significant component of ferns as herbs or low trees.

Few interesting observations are made from the inter-correlation of physical properties with maceral contents of TOP Coal. TOP coal density is controlled by the presence of semifusinite macerals because of low ash and low mineral matter content. In comparison, for Miocene lignite from Indonesia, Stankiewicz et al. (1996) [31] obtained densities of 1.43g/cm3 and above for almost pure huminite, whereas the fraction of 1.10g/cm3 was liptinite-rich. In that study, density fractions of 1.26 and 1.35g/cm3 were mixed fractions rich in both huminite and liptinite. This comparison suggests that for coal of low rank, densities of 1.38g/cm3 and above are characteristic of huminite. However, Rimmer et al., 2006 [32] suggest that densities of maceral groups can shift slightly in response to rank.

The physical factor hard groove index (HGI) is correlated with Densinite, Cutinite/Sporinite and Vitrinite content. There is a fixed relationship between Grind ability and rank of coal in the natural series from brown coal to lignite & anthracite. Coals easier to grind have 14 to 30 percent volatile matter. Coals with higher volatile matter are more difficult to grind. However Petrography & mineral constituents influence grindability. The Hardgrove grindability index value is influenced by petrographic composition of coal. The lithotypes of black coal with similar contents of volatile combustible matter include differences in the HGI values. Durite (dull coal) is a lithotype characteristic by low HGI and is generally the toughest (Temeeva, 1979) [33]. Labelling fusite as lithotype with the highest HGI value is disputable, because its extreme fragility is caused by origination of significant amount of fine fractions rather during screening that in the course of grinding in the testing device [34]. Glittering vitrinite lithotypes in black coal have significantly higher HGI values than durites in the same coal group. The difference in grindability of individual lithotypes allows for selective grinding [35-37]. It is generally valid that the occurrence of vitrinite in coal increases the HGI value, whereas the micrinite and liptinite macerals decrease the grindability [34]. The influence of liptinite, vitrinite, ash, and sulfur content on HGI was studied by a parametric study [38, 39]. The correlation between the proximate analysis of Chinese coal and HGI was studied. It was found in Shanxi Lingshui coal preparation plant from statistical analysis that, the higher the moisture and the volatile matter content in coal, the less the HGI will be. On the contrary, the higher the ash and the fixed carbon content in coal, the higher the HGI will be [40]. However, HGI and coal characteristics is obviously nonlinear [41].

HGI is having a negative correlation with coal density. HGI reflects the characteristics of coal in terms of fracture, hardness, and tenacity and is related to coal rank, petrography, moisture and mineral composition [42]. The density of fusain is the highest, but that of vitratin is the lowest. HGI value of vitratin is the lowest but that of fusain is the highest among the lithotypes. Friability of inertinite is the highest among the macerals, but Exinite is the lowest. The lower value of HGI of vitrain and friability of vitrinite indicates that they are not able to be ground. Each maceral group or maceral type clearly exhibits a range of densities (a density band) and corresponding range of atomic ratios [43]. Generally the density decreases as the coal rank is decreased, mainly due to the increased moisture fraction. In TOP coal mine the HGI is low due to low vitrinite and high huminite content. Two sets of input of Kentucky coal samples: (a) macerals, ash and moisture (b) macerals, elemental analysis and moisture, were used for the estimation of HGI. With the increase of micrinite and Exinite contents in coal, the HGI has been decreased and higher vitrinite content in coal results in higher HGI.

V References


[3]. Temeeva, H. 1979. Petrography and maceral analysis and moisture, were used for th


[22]. Laidmla Butuzova et. al.; Organic sulphur as a main index for determining the genetic type of low-rank coals; Bulletin of Geosciences, Vol. 80, No. 1, 3-8, 2005.


[27]. Barry Ryan; A Discussion On Moisture In Coal Implications For Coal bed Gas And Coal Utilization, British Columbia Resource Development and Geoscience Branch, Summary of Activities, 2006, F 139-149.


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