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# FACTORS CONTROLLING PETROGRAPHIC COMPOSITION OF NEOGENE TENGGARONG COALS-KUTAI BASIN-EAST KALIMANTAN

## *FAKTOR-FAKTOR PENGONTROL KOMPOSISI BATUBARA TENGGARONG NEOGEN-CEKUNGAN KUTAI-KALIMANTAN TIMUR*

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**ABSTRACT**

Petrographic composition of the Neogene Tenggarong coals in the Kutai Basin-East Kalimantan indicates its geological setting. The aim of this study is to obtain an understanding of the geologic aspects controlling the petrographic composition of the coals.Variation of type and rank in the coals was determined by petrographic examination of twenty-two samples. The coals are absolutely dominated by vitrinite, common liptinite and rare inertinite and mineral matter. Vitrinite macerals are dominated by detrovitrinite and telovitrinite. Cutinite and resinite are the dominant liptinite macerals in the coals. The inertinite macerals include semifusinite, inertodetrinite and sclerotinite. Clay and pyrite are the dominant mineral matters in the coals. The type differences largely reflect climatic influence and differences in peat conditions. Rank of the coals, in general, depends largely on the stratigraphic position. Reflectance measurements on the coals indicate that there is a slightly difference in rank. The coals are sub-bituminous rank ($R_v$max of 0.40-0.47%). The change in vitrinite reflectance of the coals is due to the thicker cover/overburden on the high rank coals. Nevertheless, the vitrinite reflectance is higher in some coals in the Loa Kulu area ($R_v$max of 0.48-0.57%) due to its stratigraphic position that is at the bottom of the sequence. The type and rank characteristics of the coals clearly influence the utilization. The coals are suited to utilize for direct combustion and therefore, the major utilization potential would be for power generation.

Keywords: Neogene coal, petrography, type, rank, geologic aspects

***ABSTRAK***

*Komposisi petrografis batubara Tenggarong berumur Neogen dalam Cekungan Kutai di Kalimantan Timur mengindikasikan tataan geologisnya. Tujuan studi ini adalah memberikan gambaran tentang aspek-aspek geologis yang berpengaruh terhadap komposisi petrografis batubara di daerah penelitian.Variasi jenis dan peringkat batubara tersebut ditentukan dengan cara melakukan pengujian petrografis terhadap 22 percontoh. Batubara ini didominasi oleh vitrinit, diikuti oleh liptinit dan sedikit inertinit dan mineral. Vitrinit tersebut didominasi oleh detrovitrinit dan telovitrinit. Kutinit dan resinit merupakan maseral dominan dalam kelompok liptinit. Maseral-maseral inertinit di dalam batubara ini meliputi semifusinit, inertodetrinit dan sklerotinit. Mineral lempung dan pirit terkandung di dalam batubara ini. Keberagaman jenis batubara ini dipengaruhi oleh kondisi cuaca pada saat pembentukan gambutnya. Peringkat batubara ini secara umum tergantung dari posisi stratigrafisnya. Pengukuran reflektan vitrinit menunjukkan sedikit perbedaan peringkat batubara. Batubara Tenggarong berperingkat subbituminus (Rvmax: 0,40-0,47%). Perbedaan peringkat ini disebabkan oleh oleh ketebalan lapisan penutup batubara. Sekalipun demikian, reflektan vitrinit di daerah Loa Kulu memperlihatkan nilai yang lebih tinggi ($R_v$max of 0,48% to 0,57%), karena posisi stratigrafis batubara ini terletak pada bagian bawah sekuen batuannya. Karakteristik jenis dan peringkat batubara ini berpengaruh besar terhadap pemakaiannya. Batubara ini sangat cocok dimanfaatkan untuk*

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*pembakaran langsung. Jadi, pemakaian utama yang potensial adalah untuk pembangkit listrik berbahan bakar batubara.*

*Kata kunci: batubara Neogen, petrografi, jenis, peringkat, aspek-aspek geologis*

## INTRODUCTION

Petrographic characteristics of coal can specifically be considered in terms of two essentially independent concepts, namely coal rank and coal type. Coal rank can be defined as the relative position of coal in the series of peat to anthracite (degree of coalification). The rank of coal is measured by vitrinite reflectance. The vitrinite reflectance increases as the rank of coal increases. Coal type is related to the type of plant material in the peat and the extent of its biochemical and chemical alteration. It is a response to the first (biochemical) stage of coalification (Belkin *et al.*, 2009; Thomas, 2012; Daulay, Santoso and Ningrum, 2015; Santoso, 2015; Susilawati *et al.*, 2015; Friederich, Moore and Flores, 2016).

Coal petrology contributes to an understanding of the nature and aids in determining its utilisation potential. The Kutai coals have been chosen for this study due to its potential reserve of 2.4 billion tons (Directorate General of Mineral and Coal, 2015) that can be used to supply the energy demand in the surrounding areas. The Indonesian Government is aware that the coals have an important role in the regional/national energy development, particularly in the utilisation for direct combustion of steam generation and industrial processes. To use the coals as effectively as possible, studies on coal petrography are desirable. Petrographic methods are generally the most suited for determining the genetic characteristics of coal, largely because they lead to expressions of the variations in coal properties. The coal characteristics are identified and related to rank and type that are important in combustion process.

This study is aimed at obtaining an understanding of the aspects as follows:

- To determine type and rank characteristics of the coals by making maceral analyses and reflectance measurements.
- To establish the broad patterns of variation of rank and type.
- To examine the implications of the petrographic data with respect to the utilisation of the coals.

## METHODOLOGY

Twenty-two coal samples studied were obtained from Tertiary coalfields of the Kutai Basin in East Kalimantan based on the procedure of the Australian Standard (1998). All samples were examined in the laboratory of coal petrography, Research and Development Centre for Mineral and Coal Technology, Bandung. They were examined in reflected white light and reflected ultraviolet light excitation. Maceral analyses were determined in oil immersion in reflected plane polarised light at a magnification of x500. The liptinite group of macerals was studied using ultraviolet light excitation at a magnification of x500. An orthoplan microscope fitted with a Leitz Vario-Orthomat camera was used for all photography.

Reflectance measurements were carried out using a Leitz Ortholux microscope fitted with a Leitz MPV 1 microphotometer. The microphotometer was calibrated against synthetic garnet standards of 0.917% and 1.726% reflectance and a synthetic spinel of 0.413% reflectance.

Normal point count techniques were applied for maceral analysis. Approximately 500 points were counted for each maceral analysis (Australian Standard, 1998). After completion of the analysis, maceral group or mineral was expressed as a percentage of the total points recorded. Each point could be examined in reflected white light and fluorescence mode.

Reflectance measurements were made on vitrinite, because it undergoes changes consistently with rank (Australian Standard, 2000). Vitrinite shows some inherent variability in reflectance according to type. It is the most abundant maceral in most coals and occurs as relatively large particles, thereby enabling easy measurement. The Standards recommend taking 100 measurements to obtain a precise mean value. The result of the measurements is called the mean maximum vitrinite reflectance ($R_v$max%).

## GEOLOGIC SETTING

The Kutai Basin situated in East Kalimantan (Figure 1) is the largest (165,000 km$^2$) and the deepest (12,000-14,000 metres) Tertiary sedimentary basin in Indonesia as stated by many authors i.e. Addison, Haryoko and Land (1982), Darman (2000), Koesoemadinata (2000), Belkin *et al.* (2009), Geological Agency (2009) Singh *et al.* (2010) Widodo *et al.* (2010), Moore (2012), Moore and Nas (2013). The basin is defined to the north by the Mangkalihat High, to the south by the Adang Fault, to the west by the Kuching High and to the east by the Makassar Strait (Figure 1). The Tertiary stratigraphic succession within the basin began with the deposition of Palaeocene sediments in the inner basin. The basin was subdivided during the Late Palaeocene-Middle Eocene to Oligocene, because of basement rifting, and became the site of deposition of the Mangkupa Shale in a marginal to open marine environment. Some coarser siliciclastics, the Beriun Sands, are locally associated with the shale sequence, indicating an interruption of basin subsidence by uplift. The basin subsided rapidly after the deposition of the Beriun sands, mostly through the mechanism of basin sagging, resulting in the deposition of marine shales of the Atan Formation and carbonates of the Kedango Formation (Satyana and Biantoro, 1995). Subsequent tectonic events uplifted parts of the basin margin by the Late Oligocene. The uplift was associated with the deposition of the Sembulu Volcanics in the eastern basin.

The second stratigraphic phase was contemporaneous with basin uplift and inversion started in Early Miocene. During the time, a vast series of alluvial and deltaic deposits were deposited in the basin. They consist of deltaic sediments of the Pamaluan, Pulubalang, Balikpapan and Kampungbaru Formations, prograding eastwards, which range in age from the Early Miocene to Pleistocene times (Figure 2). Deltaic deposition continues to the present day as the basin continuously subsides and extends eastwards into offshore Kutai Basin. At present, the structural style of the basin is dominated by a series of north-northeast to south-southwest trending folds that are parallel to the coastal line, and are known as the Samarinda Anticlinorium-Mahakam Fold Belt (Figure 3). These fold belts are characterised by tight, asymmetric anticlines, separated by broad synclines, containing Miocene siliciclastics. These features dominate the eastern basin and are also identifiable offshore. The deformation is increasingly more complex in the onshore direction. The western basin has been uplifted and a minimum of 1,500 m to 3,500 m of sediments has been removed by a mechanism of inversion (Wain and Berod, 1989; Courteney and Wiman, 1991). Not much is known about the structure of the western basin, although large structures are evident, a similarity in structural trend and style is not apparent from the data (Ott, 1987). In this region, the tectonics may involve the basement. Tectonic reversal in terms of origin and its strain response is not as obvious as in the Barito Basin.

Prograding deltaic sediments have contributed to the mechanism of structural inversion, by a mechanism of diapirism or growth faulting. These mechanisms are very different from those, which affected the Barito Basin. The origin of folds and faults in the Kutai Basin remains unresolved (Rose and Hartono, 1978; Ott, 1987).

Palaeogene coal measures are present at the southeastern part of the Kutai Basin that is recognised as the Pasir Sub-basin. Resting on pre-Tertiary ultramafic rocks and mudstone or conglomerate, three coal seams are recognised in this sub-basin (Samuel and Muchsin, 1975). Neogene coal measures are also present in the Kutai Basin. The principal coal-bearing strata in this basin are the Early Miocene Pamaluan and Pulubalang Formations and the Miocene to Pliocene Balikpapan and Kampungbaru Formations. In the west and south of Samarinda, the Pulubalang Formation consists of a series of limestone lenses, calcareous mudstones and thin sandstones, which are essentially marine. The overlying Lower Balikpapan Formation comprises a series of coal measures, which are indicative of a deltaic environment (Samuel and Muchsin, 1975; Siregar and

Sunaryo, 1980). The Upper Balikpapan Formation contains a greater proportion of sandstone, the deltaic sequence becoming more strongly influenced by fluvial processes.

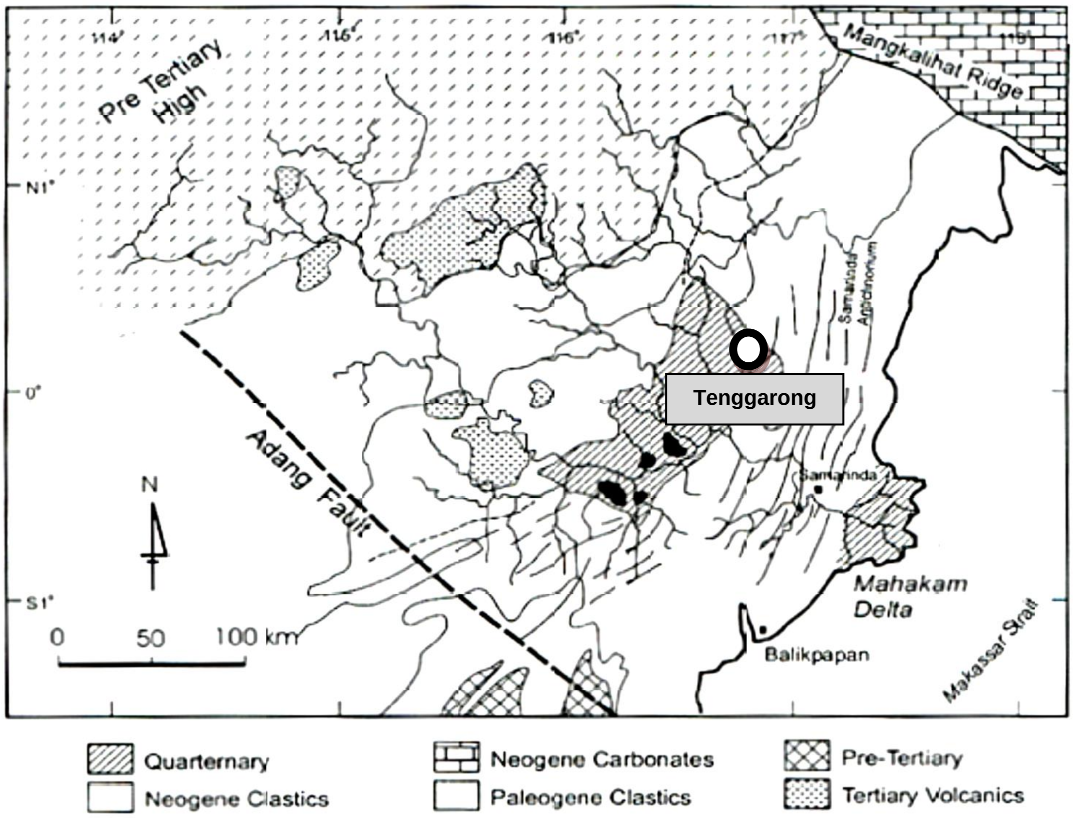


Figure 1. Simplified geological map of Kutai Basin, East Kalimantan (Darman, 2000)

| EPOCH | | FORMATION | LITHOLOGY | THICKNESS (m) |
|---|---|---|---|---|
| QUTERNARY | Pleistocene | Alluvium | Sandstones Siltstones Claystones | - |
| TERTIARY | Pliocene | Kampungbaru | Sandstones Siltstones Mudstones Coals | 900 |
| | Middle-Late Miocene | Balikpapan | Sandstones Coals Limestones | 3.000 |
| | Early Miocene | Pulubalang | Mudstones Limestones Sandstones | 2.750 |
| | Oligocene | Pamaluan | Sandstones | - |

Figure 2. Tertiary stratigraphy of Kutai Basin (Addison, Haryoko and Land, 1982)

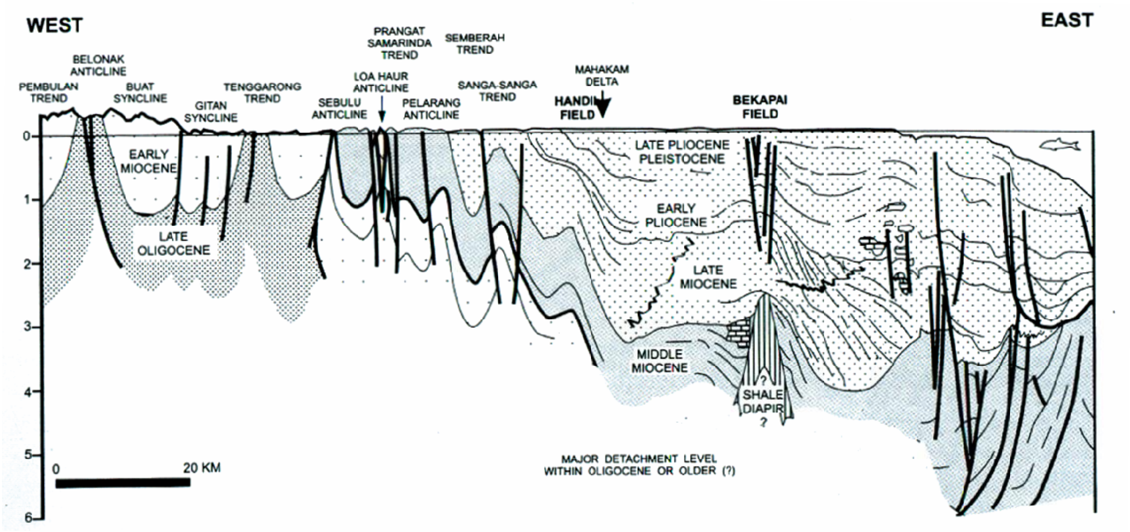


Figure 3. Kutai Basin cross section (Darman, 2000)

## RESULTS AND DISCUSSION

In order to determine type and rank, maceral analyses and vitrinite reflectance measurement were respectively carried out for the Tertiary Kutai coals.

### A. Type

The Kutai coals comprise mostly vitrinite and liptinite with minor inertinite (Table 1 and Figure 4). The vitrinite and inertinite contents slightly decrease from Neogene to Palaeogene coals. Otherwise, the liptinite and mineral matter contents increase slightly from Neogene to Palaeogene coals. The liptinites of the Palaeogene coals show yellow to orange fluorescence, whereas the Neogene coals having yellow to orange fluorescence. Cutinite is dominant in both Palaeogene and Neogene coals.

**Palaeogene**

Vitrinite is the dominant maceral of Palaeogene coals in East Kalimantan (Santoso and Daulay, 2005a, 2005b; Belkin *et al.*, 2009; Daulay, Santoso and Ningrum, 2015; Santoso, 2015). Its content ranges from 80% to 88% with an average of 84%. Liptinite constitutes from 5% to 13% with an average of 10%. The liptinite shows yellow to orange fluorescence. Inertinite is rare, containing less than 5%. Mineral matter comprising clay and pyrite is common with some samples containing more than 5%.

Telovitrinite is formed as thin isolated bands in thicker layers with a detrovitrinite matrix. Gelovitrinite that mainly consists of corpovitrinite and porigelinite is scattered throughout the coals. It is mostly associated with cutinite.

Liptinite of the Palaeogene coals is dominated by cutinite, resinite and sporinite. Cutinite having weak yellow to orange fluorescence constitutes up to 6% and is present as thin cuticle. Resinite constitutes up to 3% and commonly occurs as rodlets and infilling cell lumens in the coals. It has yellow to orange fluorescence. Like cutinite, sporinite also constitutes up to 3% in the coals. The sporinite typically occurs evenly disseminated throughout the coals. It fluoresces yellow to orange.

Sclerotinite and inertodetrinite are the dominant inertinite maceral, whilst semifusinite is only present in a minute amount in the coals. Sclerotinite including single and twin-celled teleutospores constitutes a trace to 2%. It is mostly disseminated throughout the coals. However, some local concentrations take place. Inertodetrinite content ranges from a trace to 2% and is evenly disseminated throughout the coals. Semifusinite usually forms thin layers or lenses isolated in a detrovitrinite matrix. It constitutes mostly traces except for one sample containing 1%.

Table 1. Petrographic composition of Tenggarong coals

| Sample Number | Neogene | Maceral | | | | | | | | | | | | MM (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Vitrinite (%) | | | Inertinite (%) | | | | Liptinite (%) | | | | | |
| | | TV | DV | GV | Sf | Fus | Scl | Inert | Res | Cut | Sub | Spo | Lipt | |
| 1 | Loa Duri | 25 | 47 | 15 | 1 | - | tr | 1 | 3 | 3 | 3 | 1 | - | 1 |
| 2 | | 25 | 50 | 12 | 2 | - | 1 | 2 | 3 | 3 | 1 | - | tr | tr |
| 3 | | 39 | 36 | 7 | 3 | - | 1 | 2 | 3 | 5 | 1 | tr | tr | 1 |
| 4 | | 46 | 29 | 8 | 1 | tr | 1 | - | 3 | 7 | 1 | - | - | 1 |
| 5 | | 41 | 37 | 12 | 2 | tr | - | - | 2 | 2 | tr | - | - | 1 |
| 6 | | 63 | 23 | 5 | tr | - | tr | tr | 2 | 1 | tr | - | tr | 1 |
| 7 | | 73 | 12 | 6 | 1 | - | tr | - | 3 | 1 | - | - | - | 1 |
| 8 | | 46 | 29 | 8 | 1 | tr | tr | 1 | 2 | 7 | 1 | - | 1 | 2 |
| 9 | | 40 | 38 | 6 | tr | - | 1 | 1 | 3 | 3 | 1 | tr | tr | 1 |
| 10 | | 31 | 44 | 15 | 1 | - | tr | 1 | 2 | 3 | 1 | - | - | 1 |
| 11 | | 43 | 41 | 11 | 1 | - | tr | 1 | tr | 1 | tr | tr | - | 1 |
| 12 | | 26 | 40 | 9 | 8 | 1 | 2 | 5 | 1 | 4 | 1 | - | tr | 1 |
| 13 | | 48 | 36 | 10 | 3 | - | - | 1 | tr | 1 | tr | - | - | tr |
| 14 | | 26 | 58 | 8 | tr | - | tr | 1 | 1 | 3 | 1 | tr | - | 1 |
| 15 | Loa Janan | 49 | 29 | 10 | 1 | - | tr | 2 | 3 | 3 | 1 | tr | - | 1 |
| 16 | | 53 | 30 | 6 | 1 | - | tr | 1 | 1 | 1 | - | 1 | 1 | 1 |
| 17 | Loa Kulu | 36 | 45 | 7 | 2 | 1 | - | 2 | 2 | 1 | 1 | tr | tr | 2 |
| 18 | | 45 | 37 | 9 | 2 | tr | 1 | 2 | 1 | 1 | tr | - | tr | 1 |
| 19 | | 16 | 53 | 9 | 4 | 1 | 1 | 3 | 2 | 3 | 1 | tr | 1 | 1 |
| 20 | | 29 | 47 | 7 | 1 | - | tr | 1 | 3 | 8 | 1 | tr | tr | 2 |
| 21 | | 30 | 43 | 9 | - | - | - | - | 6 | 4 | 1 | - | 1 | 2 |
| 22 | | 31 | 47 | 8 | 2 | - | 1 | 2 | 3 | 3 | tr | 1 | - | 1 |

Note: TV: telovitrinite, DV: detrovitrinite, GV: gelovitrinite
Sf : semifusinite, Fus : fusinite, Scl : sclerotinite, Inert : inertinite
Res : resinite, Cut : cutinite, Sub : suberinite, Spo : sporinite, Lipt : liptodetrinite
MM : mineral matter, tr : trace

Mineral matter consisting of clay and pyrite is significantly common in Palaeogene coals (Singh *et al.*, 2010; Widodo *et al.*, 2010). Its content varies from 1% to 11%. It mostly forms as pods disseminated throughout the coals and in some cases infilling cell lumens.

The liptinite and inertinite contents of the Palaeogene coals are systematically related to the vitrinite content. The liptinite and inertinite contents decrease with increases in the vitrinite content. The liptinite content is not related to the inertinite content (Santoso and Daulay, 2005a, 2005b; Belkin *et al.*, 2009; Daulay, Santoso and Ningrum, 2015; Santoso, 2015).

**Neogene**

According to the petrographic studies on the coal samples, it reveals that all the samples have a high vitrinite content, common liptinite and trace inertinite content (Santoso and Daulay, 2005a, 2005b; Belkin *et al.*, 2009; Daulay, Santoso and Ningrum, 2015; Santoso, 2015). Mineral matter that is mainly clay and pyrite are present (Singh *et al.*, 2010; Widodo *et al.*, 2010).

Vitrinite of the Neogene coals ranges from 75% to 95% with an average of 86%. Vitrinite mostly takes place as thick layers with a detrovitrinite matrix interbedded with thin bands of telovitrinite. Thick massive telovitrinite, in some cases, is present with the detrovitrinite-dominated coal. Gelovitrinite comprising corpovitrinite and porigelinite occurs as small discrete masses throughout the coals. Liptinite of the Neogene coals varies between 1% and 12% with an average of 8%. The liptinite maceral is dominated by cutinite, resinite and suberinite. Sporinite and liptodetrinite are rare. Cutinite consisting of thick and thin wall cuticles constitutes up to 8%. It has strong yellow to orange fluorescence. Resinite content varies between a trace and 6% with an average of 2%. It mostly occurs as discrete small bodies throughout the coals. Some resinite infilling cell lumens occurs as distinct layers. It fluoresces greenish yellow to yellow.

Suberinite that has weak yellow fluorescence constitutes a trace to 3% and is mostly associated with corpovitrinite.

Inertinite is rare in the Neogene coals, with a sample containing 8% inertinite (Santoso and Daulay, 2005a, 2005b; Belkin *et al.*, 2009; Daulay, Santoso and Ningrum, 2015; Santoso, 2015). Semifusinite is the dominant inertinite maceral. It mostly takes place as thin layers or lenses isolated in detrovitrinite matrix. In some cases, the semifusinite occurs as thin to thick layers interbedded with thin bands of telovitrinite. Inertodetrinite containing up to 5% is disseminated throughout the coals. Sclerotinite including single, twin-celled teleutospores and sclerotia constitutes a trace to 2%. It is usually scattered throughout the coals. Fusinite is trace in some samples.

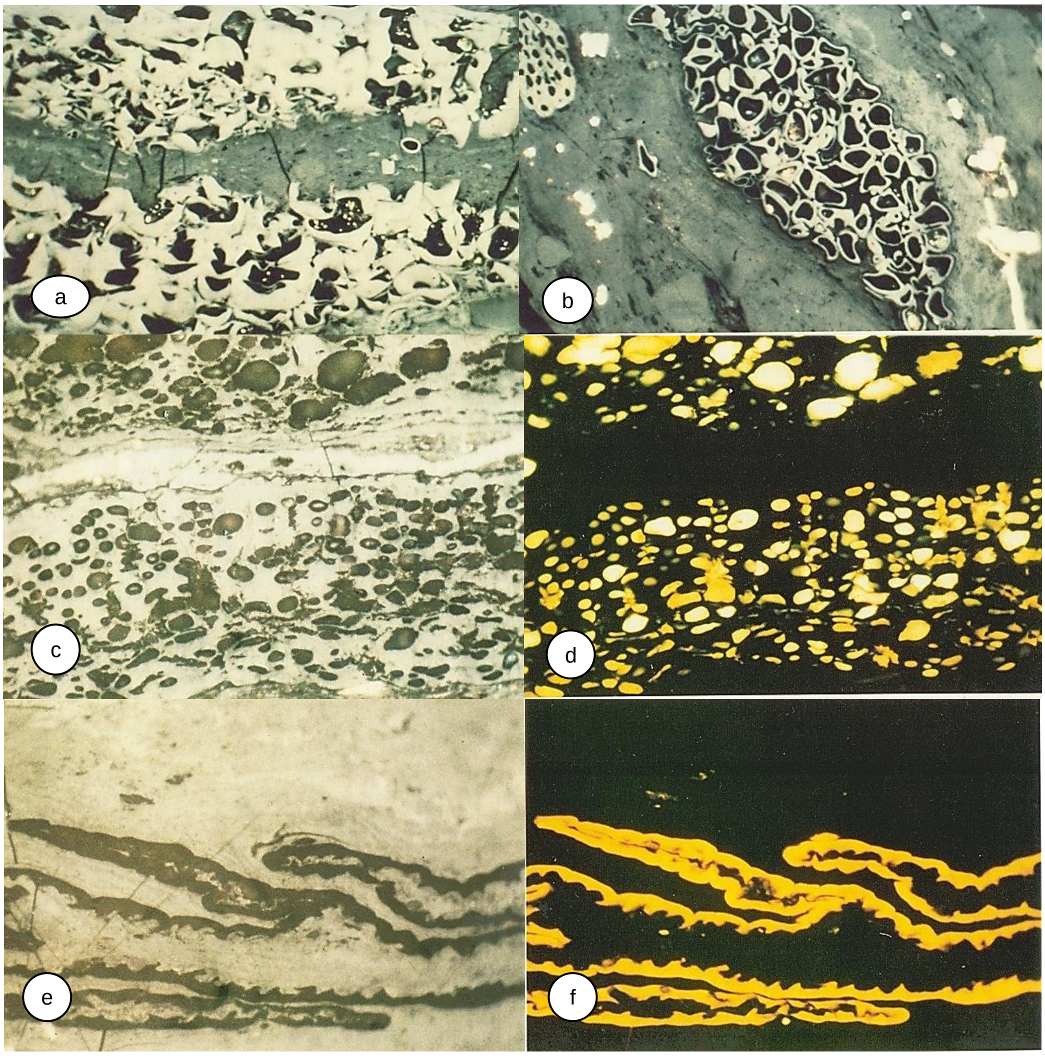


Figure 4. Macerals of the Tenggarong coals

a. Inertinite (particularly semifusinite) rich coal. Detrovitrinite and sclerotinite are present in the central layer. Loa Duri coal, $R_v max=0.46\%$, field width=0.44 mm, reflected white light.
b. Sclerotinite, vitrinite and pyrite. Loa Janan coal, $R_v max=0.47\%$, field width=0.34 mm, reflected white light.
c. Resinite infilling cell lumens in distinct layers with telovitrinite. Loa Duri coal, $R_v max=0.46\%$, field width=0.28 mm, reflected white light.
d. As for Figure 3c, but in fluorescence mode.
e. Thick wall cutinite in vitrinite. Loa Duri coal, $R_v max=0.45\%$, field width=0.28 mm, reflected white light.
f. As for Figure 3e, but in fluorescence mode.

Mineral matter that consists mainly of clay and pyrite constitutes a trace to 2% in the coals. It is commonly associated with detrovitrinite.

The liptinite and inertinite contents of the Neogene coals are systematically related to vitrinite content. Liptinite and inertinite contents decrease with increases in vitrinite content. The liptinite content is not related to inertinite content (Santoso and Daulay, 2005a, 2005b; Belkin *et al.*, 2009; Daulay, Santoso and Ningrum, 2015; Santoso, 2015).

**B. Rank**

Vitrinite reflectance was carried out on the Kutai Palaeogene and Neogene coals. Rank of the coals, in general, depends largely on the geological age (Belkin *et al.*, 2009; Thomas, 2012; Daulay, Santoso and Ningrum, 2015; Santoso, 2015; Friederich, Moore and Flores, 2016). Reflectance measurements on the coals indicate that there is a substantial difference in rank between Palaeogene and Neogene coals (Table 2). The Palaeogene coals are sub-bituminous to high volatile bituminous rank ($R_v$max of 0.57% to 0.67%), whereas the Neogene coals are sub-bituminous rank (Rvmax of 0.40% to 0.57%). The change in vitrinite reflectance from Palaeogene to Neogene coals is due to the thicker cover/overburden on the high rank coals (Santoso and Daulay, 2005a, 2005b; Santoso, 2015).

Proximate analysis of the Kutai coals reported by Santoso and Daulay (2005a, 2005b), Daulay, Santoso and Ningrum (2015) and Santoso (2015) illustrates that with increasing age, the specific energy becomes higher and the total moisture decreases (Table 3).

Table 2. Rank ($R_v$max%) of Tenggarong coals

| Sample Number | Vitrinite Reflectance ($R_v$max %) | | Rank (Australian Standard) |
|---|---|---|---|
| 1 | | 0.40 | Sub-bituminous |
| 2 | | 0.41 | Sub-bituminous |
| 3 | | 0.41 | Sub-bituminous |
| 4 | | 0.43 | Sub-bituminous |
| 5 | | 0.45 | Sub-bituminous |
| 6 | | 0.42 | Sub-bituminous |
| 7 | Loa Duri | 0.46 | Sub-bituminous |
| 8 | | 0.46 | Sub-bituminous |
| 9 | | 0.45 | Sub-bituminous |
| 10 | | 0.45 | Sub-bituminous |
| 11 | | 0.46 | Sub-bituminous |
| 12 | | 0.46 | Sub-bituminous |
| 13 | | 0.46 | Sub-bituminous |
| 14 | | 0.47 | Sub-bituminous |
| 15 | Loa Janan | 0.45 | Sub-bituminous |
| 16 | | 0.47 | Sub-bituminous |
| 17 | | 0.47 | Sub-bituminous |
| 18 | | 0.47 | Sub-bituminous |
| 19 | Loa Kulu | 0.43 | Sub-bituminous |
| 20 | | 0.41 | Sub-bituminous |
| 21 | | 0.48 | Sub-bituminous |
| 22 | | 0.57 | Sub-bituminous |

Table 3. Relationship between vitrinite reflectance and proximate analysis of Kutai coals

| Age | Specific Energy (kcal/kg) | Total Moisture (%) | $R_v$max (%) |
|---|---|---|---|
| Neogene | 5,000-6,000 | 8-20 | 0.40-0.57 |
| Palaeogene | 6,400-7,000 | 3-7 | 0.57-0.67 |

## CHARACTERISTICS OF UTILISATION

Utilisation of the Kutai coals for the domestic purposes can be divided into two broad categories:

- as a fuel, for steam raising, lime brick and cement processing.
- as a feedstock for chemical industry or as a raw material for coking.

In order to use the coals as effectively as possible, studies on coal petrography are desirable. Petrographic methods are generally the most suited for determining the genetic characteristics of coal, largely because they lead to expressions of the variations in coal properties.

With regard to utilisation of the coals as a raw material for combustion, liptinite macerals are important. In combustion and coking processes, liptinites are the main precursors of tar (Hower *et al.*, 2005; Hower, Suárez-Ruiz and Mastalerz, 2005; Senior, 2006; Suárez-Ruiz and Crelling, 2008; Osborne, 2013). Spores were designated as tar and gas producers and bands of coal rich in liptinite produce significant amounts of tar. The yield of tar from spores and cuticles in general varies between 20% and 40% by weight, but resins, waxes and carbohydrates form as much as 80% to 90%. The yield of tar increases with the proportion of hydrogen. In contrast to liptinite, the inertinite maceral group is subhydrous and richer in carbon. Inertinites show little or no fluidity during coking processes (Suárez-Ruiz and Crelling, 2008).

Direct combustion of coal currently accounts for the largest consumption in Indonesia and will probably continue to do so for many years in the future. This is caused by subsidy of fuel price that is gradually reduced by the government to follow the international price. The primary use of this energy source is for steam generation. This energy is used directly and indirectly in industrial processes and by utilities for electric power generation.

Mackowsky (1982) and Suárez-Ruiz and Crelling (2008) identified four coal characteristics (most of which are related to rank and type) that are important in combustion: specific energy, grindability, swelling behaviour and ash properties. Quality-related variables for the Kutai coals are summarised in Table 4. Specific energy increases with increases in vitrinite reflectance, up to approximately 0.37%.

Coal used for pulverised fuel combustion is ground to a particle size mainly below 65 microns (Ceely and Daman, 1981). Due to the energy required for this grinding, grindability of a coal is a significant characteristic. Hardgrove Grindability Index (HGI) is related to rank and type (Neavel, 1981). The HGI of the Kutai coals increases with increases in rank to about 0.37% vitrinite reflectance. Higher HGI values indicate that less energy is required for grinding than for lower HGI values. HGI values of the coals increase with increases in mineral matter content. Higher inertinite and liptinite concentrations of the coals cause high volatile coals to be tougher (lower HGI value, Neavel, 1981; Suárez-Ruiz and Crelling, 2008). The coals that mostly consist of brighter lithotypes are easy to grind and commonly accumulate in the finer fractions. The Palaeogene liptinite-rich coals (generally tougher than the Neogene liptinite-poor coals) are difficult to grind and are commonly concentrated in coarser sizes.

For the Kutai coals, an increase in explosive tendencies of dust was correlated with increases in the sum of liptinite, vitrinite and pyrite (Neavel, 1981; Suárez-Ruiz and Crelling, 2008). He also noted that the tendency for spontaneous combustion in storage piles could occur with coals rich in fusinite and pyrite. Some of the coals containing less than 1% fusinite but have pyrite contents (up to 11%) tend to be prone to spontaneous combustion.

Combustion properties of coal in furnaces are also related to volatile matter yield and swelling characteristics. Volatile matter yield is principally rank related, for instance, it decreases with increases in vitrinite reflectance in the coals. Liptinite due to its high yield of volatile matter expands explosively and then quickly burns. Swelling characteristics, which can affect combustion properties in furnace, have been reported to be independent of rank (Neavel, 1981; Suárez-Ruiz and Crelling, 2008).

Suárez-Ruiz and Crelling (2008) in a series of experiments using a microscope with an attached heating stage showed that the order of ignition for the maceral groups was liptinite-vitrinite-inertinite. Among individual macerals, resinite was found to be especially reactive. At the other extreme, fusinite in the early stages of heating changed very little, except to become more fractured. Eventually as heating progressed, the fusinite was consumed, but at a slower rate than the other macerals. The studies show the concept of reactive and inert applies to the performance of macerals during combustion as well as in carbonisation or gasification. The Kutai coals generally contain less than 6% inert macerals. Combustion system for the coals can therefore operate with normal combustion temperatures that is 1,400ºC.

Ash content of the Kutai coals ranges between 1.1% and 11.0%. The ash properties are related to mineral matter composition (Reid, 1981; Ward *et al.*, 2006). Mineral matter affects heating values of the coals; variations in type of mineral matter affect ash fusion properties. Ash disposal is important with regard to the development of ash deposits and corrosion.

Sulphur is a major contributor to external corrosion. Sulphur content of the Kutai coals contains up to 2.8%.

Ward *et al.* (2006) found that fly ash in their experiments consisted of unreacted particles of fusinite, semifusinite, mineral matter and oxidised vitrinite. Fly ash can commercially be used in the manufacture of concrete products, cement, lightweight aggregates, soil stabilisation products, asphalt paving mixes and ceramic products (Reid, 1981; Ward *et al.*, 2006). The Kutai coals can be used for cement manufacture and also for lightweight aggregates, asphalt paving mixes, concrete, soil stabilisation and ceramic products.

Moisture level of coal should also be considered when they are used for combustion. High moisture level promotes low heating values. The Kutai coals contain less than 30% total moisture. The total moisture content of the coals decreases with increases of vitrinite reflectance.

In summary, the Kutai coals are in general suited for direct combustion, although high moisture contents and spontaneous combustion will present problems with some of the lower rank coals. The major utilisation will be for electricity generation. Use of the coals in other industries will be mostly related to the expansion of domestic cement production. The combustion process in influenced by coal rank and type. Vitrinite reflectance is the best method for measuring lateral and vertical variations of rank. Vitrinite-rich coals are suited for preparation in combustion, because the coals are easy to grind through to the finer fractions. The vitrinite-rich coals are generally tougher than the inertinite-rich coals.

## CONCLUSION

Type differences between the Neogene and Palaeogene coals in the Kutai Basin reflect the influence of peat environment and climate. Vertical and lateral rank variation characteristics result from contrasting burial and palaeotemperature histories. Both type and rank characteristics of the coals influence the utilisation.

Table 4. Quality of Kutai coals

| AGE | MACERAL+MINERAL (%) | | | | $R_v$max (%) | PROXIMATE ANALYSIS | | | ASH (%) | S (%) | HGI | FSI |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | V | I | L | MM | | SP.EN Kcal/kg | VM (%) | MOIS (%) | | | | |
| Neogene | 75-95 | 1-9 | 2-15 | 1-2 | 0.40-0.57 | 5,000-6,000 | 31.0-48.1 | 8.0-26.7 | 1.1-11.0 | 2.8 | 48.3 | 1 |
| Palaeogene | 76-94 | 1-6 | 3-19 | 1-6 | 0.57-0.67 | 6,400-7,000 | 33.7-38.1 | 8.0-20.0 | 1.2-5.2 | 0.1-1.9 | 57.8 | 2 |

Note: V: vitrinite, I: inertinite, L: liptinite, MM: mineral matter
SP.EN: specific energy, VM: volatile matter, MOIS: moisture, S: sulphur
HGI: hardgrove grindability index, FSI: free swelling index

Vitrinite is the dominant maceral in the coals consisting mostly of detrovitrinite and telovitrinite and minor gelovitrinite. Liptinite is common in the coals and its content is typically in the range of 2% to 13%. Cutinite is the dominant liptinite maceral in the coals, although resinite is dominant in some occurrences. Sporinite and suberinite are common and liptodetrinite is rare in the coals. Some of the coals, typically the Palaeogene coals, contain more than 4% inertinite (mostly semifusinite and sclerotinite). Mineral matter consisting mainly of clay and pyrite is common in the coals ranging from a trace to 11%. High proportions of vitrinite in the coals indicate that the original plant material consisted essentially of woody plant tissue and the peatification occurred under relatively wet reducing conditions.

The Kutai Neogene coals are typically much lower in rank than the Palaeogene coals. The Neogene coals have vitrinite reflectances in the range of 0.40% to 0.57%, whereas the Palaeogene coals varying from 0.57% to 0.67%. The vitrinite reflectance of the coals shows significant increases with depth.

The Kutai coals are generally suited to use for direct combustion. The major utilisation potential is for power generation. The absence of fibrous telovitrinite in the coals suggests that grindability characteristics should generally be favourable. The rank of the coals that is sufficiently low for spontaneous combustion could be a significant problem. Moisture contents of the coals are moderate to high, giving moderate to low specific energy.

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