Marine influence during deposition of the Kiliranjao Brown Shale, Central Sumatra, from palynology point of view

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Abstract. The Eocene to Oligocene succession of the Kiliranjao Brown Shale was deposited in a lacustrine environment. This study combines palynological analysis and XRD analysis technique to investigate the possibility of marine influence during deposition of Kiliranjao lacustrine shale. Two biostratigraphic zonations of Karbindo section are Middle to Late Eocene Proxapertites operculatus Zone and Oligocene Meyeripollis naharkotensis Zone. The marine flooding surface, as shown by the peak of the abundance of mangrove pollen, is used to delineate the section into five parasequences. The tripartite stratigraphic architecture of Karbindo section is consists of early rift deposit (TS1), syn-rift deposit (TS2), and syn-rift deposit (TS3). Middle to Late Eocene coal and limestone facies (parasequence I) represents the TS1. Late Eocene to Oligocene parasequence II to IV (below MFS) shows the TS2 (deepening-upward lacustrine succession), and the shallowing-upward lacustrine succession of Oligocene parasequence V (above MFS) indicate the TS3. The abundance of mangrove and back mangrove palynomorph assemblages and the high amount of carbonate mineral from XRD analysis are the evidence of marine influence to the deposition of Karbindo section Brown Shale. The marine incursion to the lacustrine environment occurred from the adjacent nearby open sea, that separated by shoal area, which can submerge below sea level during a marine transgressive event. Marine incursion events did contribute to the deposition of Kiliranjao Brown Shale though further work is still needed.

Keywords: Kiliranjao, brown shale, Eocene to Oligocene, palynology, marine incursion

1. Introduction
The study area is located at the coal mine of PT. Karbindo Abesyapradhi, Kiliranjao area, West Sumatra Province. The geology of this coal mine has been studied by [1-9]. Kiliranjao shale unit is well known as the Brown Shale unit of Pematang Group [1, 10]. The unit is well exposed in Kiliranjao Sub-basin, which was deposited in the flexural margin of a small rift basin [1], situated in the southwest part of Central Sumatra Basin (figure 1) [11-14].

The outcrop succession at this coal mine is started by 25 m paleosol that deposited at continuous subsidence condition in a low relief fluvial setting [1]. It is overlain by ~20 m succession of coal interbedded with limestone, which deposited at a slowly subsiding reed swamp [1] or freshwater to brackish swampy mire [9]. Above coal is ~200 m Brown Shale unit [8, 9]. In addition, Sunardi [9] divided coal and Brown Shale of the Karbindo outcrop into seven lithofacies associations (figure 2).
According to de Smet et al. [10], the horst and graben stages through the Sundaland were commenced in the Late Eocene or earliest Oligocene, which resulted in the deposition of scree, alluvial fans, fluviatile sediments, and lake deposits. At this time interval, the only area that attached to the marine influence was northern Sumatra [10]. Some of the previous researchers, i.e., [1, 5, 8, 9, 15] agreed that the Brown Shale unit in the upper part of the coal mine was deposited in freshwater lacustrine environments. The simple objective of this paper is to provide new evidence that Kiliranjao shale in small rift Kiliran Sub-basin was influenced by marine incursion during its deposition, based on palynological data and support by XRD analysis.

2. Methodology
The fieldwork was conducted at the Karbindo coal mine to measure stratigraphic section and to collect rock samples. The palynological analysis was applied in this study to establish the biostratigraphy and depositional environmental interpretation. It is a micropaleontological technique for dating and correlation of non-marine sediments [16]. The pollen and spore contained in the sample can reflect the surrounding vegetation during the time of deposition of the sediments [17]. The presence of mangrove species (tolerant to saltwater) and back mangrove species (limited tolerance to salt or brackish water) in the studied sample is an indication of a nearby coast from the site of deposition. Furthermore, XRD analysis was performed for mineralogical composition characterization for each sample, particularly for the carbonate and pyrite content which can indicate the marine incursion to the depositional environment.

The palynological analysis was undertaken in GeolLabs, Pusat Survei Geologi, involved extraction from 100-gram samples was carried out using HF and HCl. Palynomorphs were separated from the substrate using a zinc chloride solution. The residue was then sieved with a five μm mesh and mounted on slides with glycerin jelly. Palynomorphs observation was done using 1000X magnification light microscope. XRD analysis also performed in GeolLabs. The position of the rock samples in the section are present in figure 2.

Figure 1. The study area is illustrated by the red dot, show the position of Kiliran Graben/Sub-basin at the westernmost part of the Pematang Graben Group. Map of Pematang Graben Group modified from [11-14].
3. Results and discussion

3.1. Biostratigraphy
The overall palynomorphs recovered from 19 samples are ranging from poor (< 50 total palynomorph count on coverslip) to good recovery (> 100), with the preservation of poor/moderate to moderate/good.

Biostratigraphic zonation of the Karbindo section is divided into two zones (figure 3). The first is Proxapertites operculatus Zone, which is shown by the presence of Florschuetzia trilobata (sample B) and Proxapertites operculatus (sample D). This zone is considered as Middle–Late Eocene [18]. The second zone is Meyeripollis naharkotensis Zone. The first occurrence of Meyeripollis naharkotensis defines this zone at its base (sample E) and the last occurrence of Meyeripollis naharkotensis at the top (sample R). The co-occurrence of Florschuetzia trilobata without the occurrence of Proxapertites operculatus suggests Oligocene age for this zone [18].

3.2. Parasequences
There are five parasequences recognized in this section based on the depositional environment interpretation (figure 3). Parasequences are bounded by flooding surfaces and their correlative surfaces and consists of genetically related beds or bedsets in a relatively conformable succession [19]. Sample D, H, L and P shows the highest abundance of mangrove palynomorphs. The base of these samples interpreted as the marine flooding surface separating the parasequences. Marine flooding surfaces is a surface separating younger strata from the older one, which there is evidence of an abrupt increase in water depth [19]. High mangrove palynomorphs abundance are representing the marine flooding surface [20].

Parasequence I was deposited in a freshwater swamp with predominantly strong terrestrial palynomorphs influence. Parasequence II and III show succession from mangrove, back mangrove to strong terrestrial palynomorphs influence cycles, while parasequence IV reflect mangrove to back mangrove palynomorphs influence. The changes from a deposition in a relatively shallower environment (parasequence I) to a deeper environment (parasequence IV) is interpreted as a deepening-upward succession. Parasequence V is interpreted as a shallowing-upward succession.
suggested by the presence of strong terrestrial palynomorphs influence environment in sample S. The boundary between deepening-upward with shallowing-upward succession at sample P is selected as the maximum flooding surfaces (MFS) for the entire section. This interpretation also supports by the peak abundance of mangrove–back mangrove palynomorphs in sample P.

3.3. Tectonostratigraphic

Samples A to D represents the Middle to Late Eocene interval (figure 3). Sample A to C (the coal and limestone facies) [9] are considered equal in age with the Lower Red Beds [21], which was deposited in alluvial and fluvial environments. The early rift systems are displaying north-south and northeast-southwest formed at the same time with the collision between the Indian Sub-continent and the Asian Plate [21]. This collision resulted in the extension, rifting, and opening of the Sumatran back-arc basins [21]. The early rifting deposit in the Central Sumatra Basin occurred from Early Eocene [10]. Therefore, the coal and limestone facies (parasequence I) is interpreted as the product of the early rift phase.

The early rifting deposit of several non-marine rift basins in varied geographical setting and geological age shows a remarkably similar stratigraphic architecture, which is initiated by fluvial deposits [22]. The early rifting deposit in Kiliranjao Sub-basin (the coal and limestone facies/parasequence I) were deposited in a freshwater swamp environment. By contrast, the other early rift deposits in Central Sumatra, i.e., sandstones, shales, and conglomerate of Lower Red Beds in the Central Sumatra Basin [21] and red breccias, conglomerates, and sandstones of Berani Formation in the Ombilin Basin [23] were deposited in alluvial fan and fluvial environments. The different of the paleoenvironmental condition during early rift stage is probably due to the smaller geometry of the Kiliranjao Sub-basin and the lower topographic relief of its adjacent horsts compared to the Central Sumatra and Ombilin Basins. The absence of coarse-grained sediments such as coarse sandstone, conglomerates, and breccias in the Karbindo sections supports this interpretation. During the early stage of rifting of the Kiliranjao Graben, the basin capacity may have exceeded the sediment supply allowing accumulation and deposition of coal and limestone in a freshwater swamp environment.

The similar stratigraphic architecture of non-marine rift basins is known as the tripartite stratigraphy [22]. It is consisting of basin-wide fluvial deposits (the early rift deposit, TS1) overlain by a relatively abrupt deepening-upward lacustrine succession (the syn-rift deposit, TS2), and then continued by a gradual shallowing-upward lacustrine and fluvial succession (the syn-rift deposit, TS3).

**Figure 3.** Palynomorphs distribution chart of Karbindo mine section, showing biostratigraphic age, depositional environment classification of each sample, tectonostratigraphic, and parasequences classifications.
In the studied section, TS1 represented by Middle to Late Eocene deposit (parasequence I). Parasequence II to V represents the Middle–Late Eocene to Oligocene syn-rift deposits (TS2 and TS3). TS2 is characterized by deepening-upward lacustrine succession from parasequence II to IV (below MFS), while TS3 is characterized by a shallowing-upward lacustrine succession of parasequence V (above MFS).

3.4. Marine influence at depositional environment

The possibility of marine influence in the deposition of lacustrine sediments of Brown Shale unit in the Karbindo section is mostly indicated by the presence of mangrove and back mangrove palynomorphs. Mangrove palynomorphs preserved in this section is *Zonocostites ramonae*. The modern affinity of *Zonocostites ramonae* is *Rhizophora* from Rhizophoraceae Family [24]. Meanwhile, the assemblages of back mangrove palynomorphs in the studied section consist of *Proxaporites operculatus* (Palmae), *Oncosperma* (Arecaceae), *Acorstichum aureum* (Pteridaceae), *Chenopodipollis* sp. (Chenopodiceae), *Discoildites borneensis* (*Brownlowia/Tiliaceae*), and *Spinizonocolpites echinatus* (*Nypa fruticans/Palmae*) [24].

The marine influence to the lacustrine deposit is interpreted as a result of the adjacent nearby open sea which separated from the lake by shoal area, that able to submerge below sea level at the marine transgressive event (figure 4). During the transgressive phase, sea level was above the shoal barrier, which results at the incursion of seawater into the lake through the tidal inlet channel. This condition allows the transfer process of mangrove/back mangrove palynomorphs from the coastline into the lake environment. The beginning of the transgressive phase coincides with the event of marine flooding surface at the bottom of every parasequence (figure 3). After reaching its maximum transgression, sea level began to fall, then the phase of regression occurred [25]. During the regressive phase, the formerly tidal inlet channel was above the sea level and formed a land. Therefore, the connection between seawater and lake was terminated, as indicated by the abundance of freshwater palynomorphs deposited in the lake, at every top of parasequences.

The mineral composition from XRD analysis confirms the evidence of marine incursion during Brown Shale unit deposition in the Karbindo section. The high amount of carbonate mineral (23–97%) suggested a seawater incursion into the lake (figure 5). Widayat [6] also found that carbonate mineral (CaCO₃) is the major component in the Kiliranjao shale and formed from a non-evaporative precipitation origin. The presence of pyrite mineral (figure 5) in the Kiliranjao shale is also an indication of marine influence during depositional processes. Iqbal et al. [7] found framboidal pyrite in the coal mine site, which suggested a minor marine incursion into the freshwater environment.

**Figure 4.** Illustration of Kiliran Graben depositional environment at Oligocene time.
Gamma-ray log profile of Karbindo section is useful to recognize sequences/cyclic deposition (figure 5) [26]. Brito and Slatt [8, 15] reported four depositional stratigraphic cycles (or sequences) in Karbindo section. Rezaee [26] argued that there are at least two cycles. This depositional stratigraphic cycle indicates that if the Brown Shale is entirely lacustrine in origin, the effects of sea-level cyclicity are able to extend well into the paleo landward direction, either by the lowering of the fluvial base level or through connection to the ocean [26].

The Ombilin Graben in the north of Kiliran Graben is also situated in the western part of Pematang Graben Group (figure 1). The study by Zonneveld et al. [27] presented ichnological evidence which indicates local marine influences and intertidal flats environment in the Oligocene time of Ombilin basin. O’shea et al. [28] found sedimentary structures such as ripples with mud drapes, reactivation surfaces, bidirectional current ripples, and inclined heterolithic stratification at Oligocene sediments of Ombilin Basin, which indicate marginal marine deposition with tidal influences. The Kiliran and Ombilin Graben are located in the western part of Pematang Graben Group (figure 1), which suggest that during Oligocene time, there was a nearby coastline at the west.

4. Conclusion
Biostratigraphic zonation is divided into two zones: Proxapertites operculatus Zone, Middle to Late Eocene and Meyeripollis naharkotensis Zone, Oligocene. There are five parasequences in the studied section, divide by marine flooding surface which characterized by the peak of the abundance of mangrove palynomorphs. Middle to Late Eocene coal and limestone facies (parasequence I) represents the early rift deposit (TS1). The deepening-upward lacustrine succession of parasequence II-IV (below MFS) aged as the latest Eocene to Oligocene, exhibits the syn-rift deposit (TS2). Whereas, the Oligocene shallowing-upward lacustrine succession of parasequence V (above MFS) indicates the syn-rift deposit (TS3).

Furthermore, the abundance of mangrove and back mangrove palynomorphs assemblages and the high amount of carbonate mineral from XRD analysis are the evidence of the marine influence to the deposition of Karbindo section Brown Shale. Marine influence at lacustrine environment resulted from the adjacent nearby open sea which was separated from the lake by shoal area that able to submerge below sea level at the marine transgressive event. Marine incursion events did contribute to the deposition of Kiliranjao Brown Shale though further work is still needed.
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