Paleogene paleogeographic reconstructions of the Kutai Basin: Refinement based on outcrop and subsurface data

Herman Darman (INDOGEO Social Enterprise, Jakarta)

Corresponding author: herman_darman@yahoo.com

ABSTRACT

The Kutai Basin is a Cenozoic sedimentary basin located in the eastern part of Borneo Island. Many studies were done on the eastern part of the basin, which is dominated by Neogene sediments. The west margin of the basin is outcropped onshore and to the east, the basin opens up to the Makassar Strait. Paleogene and older rocks outcrop in the west margin of Kutai Basin. The terrain and the access to the area are difficult and no significant hydrocarbon discovery was made in Paleogene sediments up to now.

This study revisited the field works completed in the 1970s by a Shell team, which focused on the Paleogene section of the Kutai Basin. The result was integrated with later studies, and altogether were synthesized into a series of paleogeographic maps. A new set of paleogeographic maps is proposed in this paper, for Middle Eocene, Late Eocene, Early Oligocene, and Late Oligocene levels. The works included in this study comprised outcrop observations, biostratigraphy analysis of the samples and limited seismic in parts of the area. The results were integrated with other more recent work to build the new set of Paleogene paleogeographic maps.

Outcrops data and well information show the distribution of shallow marine sediment in the Middle Eocene time with some fluvial input from the north and southwest of the basin. In the Late Eocene, some carbonates developed in the north of the basin. During Early Oligocene, the carbonate complex developed both in the south and in the north of the basin. In the Late Oligocene, the carbonate in the south became more stable. Through Paleogene time the center of Kutai Basin was dominated by the bathyal section.

Keywords: Upper Kutai, Paleogene, Eocene, Oligocene, paleogeography

Manuscript received: 24 Nov 2022, revised manuscript received: 2 Dec 2022, final acceptance: 8 Jan 2023.

DOI: 10.51835/bsed.2023.49.1.397

INTRODUCTION

The Kutai Basin is located in the eastern part of Borneo Island (Figure 1). The basin is tilted to the east. The west margin is located in onshore Borneo, with exposed Paleogene age rocks and the east side opens into the Makassar Strait. The basin is sub-divided into Upper and Lower Kutai Basin. The Lower Kutai Basin is dominated by Neogene sediments with significant petroleum discoveries such as the Mutiara, Tunu, and Tambora Fields. The Upper Kutai Basin covers the western margin of the basin. It has more

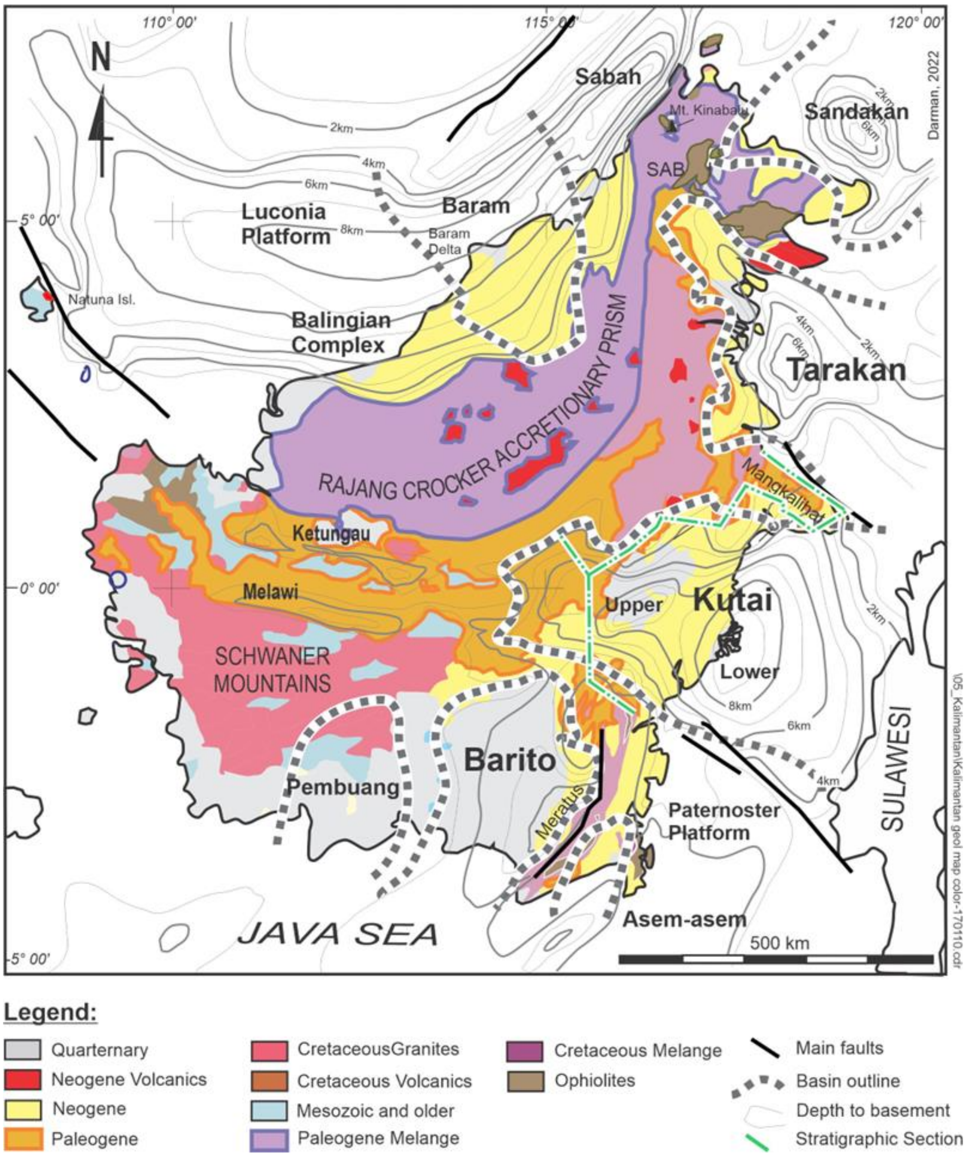

Figure 1: *Simplified geological map of Borneo. Kutai Basin is located in the east of the Island. This basin has two depocenters so-called the Upper and Lower Kutai, shown by the depth to basement contours. The Paleogene outcrops are observed in the basin margin. In Lower Kutai the Paleogene is too deep to observe.*

Paleogene outcrops, and except for the small Kerendan gas field (Unocal, 1982), there is no significant petroleum discovery in this region until now. The Paleogene outcrops are located in remote areas, at more than 200 m altitudes above sea level (Figure 2).

Most of the ‘modern’ work on the Upper Kutai basin is from the 1970s and later. However, there is a significant, but poorly-known body of work from the Dutch colonial era, including reports of geological expeditions, the Central Borneo Expedition by G. Molengraaff in 1894 (Molengraaff, 1900), the Midden-Oost Borneo Expeditie of 1925 by H. Witkamp (Witkamp, 1927; M.G. Rutten, 1948; Albrecht, 1946), work by the Geological Survey (Harting, 1925, 1930; Ubaghs, 1937), the Koetai Expedition of M. Hartmann in 1937 and unpublished BPM and NKPM oil company work (for references see www.vangorselslist.com). All these old geologists reported widespread intensely folded Jurassic-Cretaceous oceanic sediments with radiolarian cherts (“Danau Formation” of Molengraaff, 1902), intruded by granitoids, unconformably overlain by relatively little-deformed Middle and Late Eocene non-marine and shallow marine sediments (incl. limestones with Letter Stages Ta and Tb foraminifera).

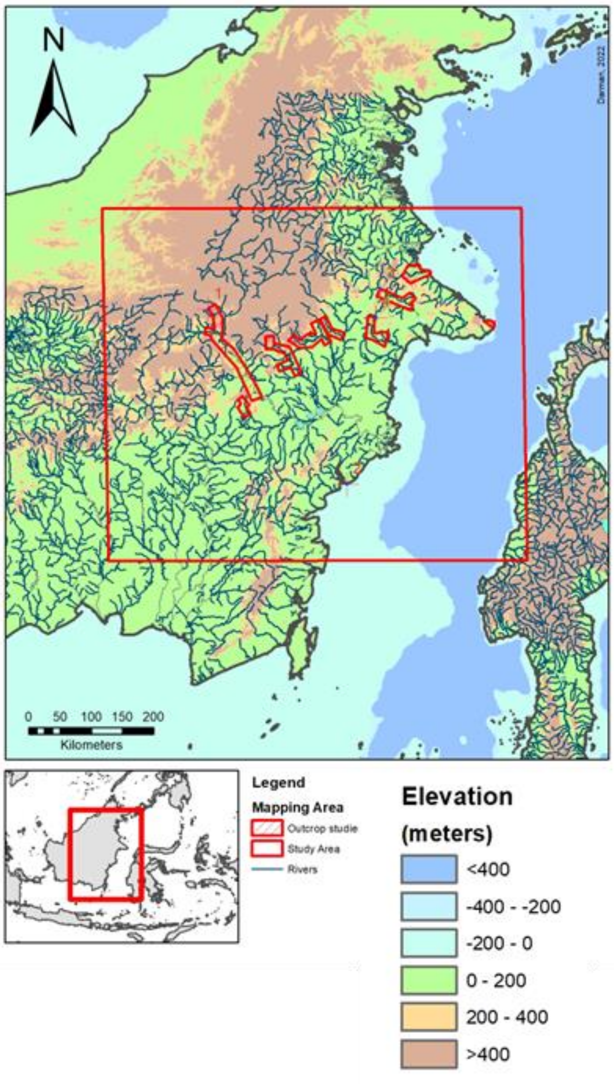

Figure 2: *Terrain of the study area which covers>200 m elevation above sea level. The field mapping area is located in the interior part of Borneo Island with difficult road access. The red box is the area of interest in this study and the red polygons are Cartier and Yeats (1973) working area which is revisited in this study.*

As the more prolific part of the basin, there are many seismic and well data in the Lower Kutai Basin. Hence there are many publications in this area. The Upper Kutai Basin, however, has much-limited subsurface data. There are several outcrop studies in different parts of the basin margin such as Van de Weerd and Armin (1992), Saller and Vijaya (2002), Bachtiar et al. (2013) in the southwest, Wilson et al. (1999, 2002), Guritno et al. (1999, 2012), and Moss et al. (1997, 1999) in the northwest of the basin (Figure 3). Generally, the outcrops in this area are relatively weathered and many parts are covered by vegetation and the logistic to reach this area is very challenging.

Several basin-wide regional paleogeographic maps were completed by previous authors e.g., van de Weerd and Armin (1992), Laya et al. (2013), Bachtiar et al. (2013a, b), Darmawan et al. (2013), and Darman (2017). Other authors published detailed paleogeographic maps for certain parts of the basin, e.g., Saller and Vijaya (2002) for the southern margin and Wilson and Evans (2002) for the Mangkalihat area in the north.

The aim of this paper is to gather and revisit earlier Paleogene outcrop sections, mainly using the work by Cartier and Yeats (1973), with additional data analysis by Moss and Chambers (1999) and other subsurface data. These data were then utilized to refine Paleogene paleogeographic maps. The integration of published maps, controlled by outcrop and subsurface data, resulted in several updated paleogeographic maps for the Middle Eocene, Late Eocene, Early Oligocene, and Late Oligocene.

REGIONAL GEOLOGY

Topographically, Borneo Island is cored by a curving mountainous terrain called the Rajang-Crocker Range (Figure 1), which is a mid-Cenozoic paleo-accretionary prism, mainly consisting of hemipelagic and turbidite deposits (Stauffer, 1966). These deep-water deposits are now partly metamorphic and of Cretaceous to Late Eocene age. Some ophiolite fragments were found within this unit.

In the southwest of Borneo Island, there is another mountainous terrain, which is called the Schwaner Mountains (Figure 1). It consists of Cretaceous granites, which are the main provenance of quartz minerals of the clastic sediments in the surrounding basins, including the Melawi, Ketungau, Kutai and Barito Basins. The lithology and age of Schwaner Block indicate that it is part of the continental crust of Sundaland.

The Melawi and Ketungau basins are the sedimentary basins located between Rajang-Crocker Range and the Schwaner Block, containing very thick Eocene non-marine clastics and probably representing Eocene-Oligocene rift basins (Williams et al., 1989). These Paleogene sediments were also transported to the east and are exposed in the western margin of Kutai Basin. Investigation of these outcrops shows that most of the Eocene is composed of marine shale deposits, which are believed to be the distal parts of Melawi and Ketungau Basins. Shallow to deep water sandstone occurs in Late Eocene (Figure 4).

The oldest sediments in the Kutai Basin are of Middle Eocene age; they unconformably overlie more deformed Cretaceous and possibly older rocks. The Middle Eocene onset of the Paleogene depositional cycle of the greater Kutai Basin is supposed to be controlled by the Middle Eocene and younger rifting episode that affected much of Western Indonesia, and created the adjacent Barito and Tarakan Basins.

During the Oligocene, carbonates developed both in the northern and southern margins of Kutai Basin. The carbonate in the north of the Kutai Basin occurs on basin highs from Oligocene up to Pliocene (Figure 4). In the south, Oligocene carbonate developed on a relatively stable area called the Barito Platform, which extends offshore to the Paternoster Platform in the Makassar Strait.

DATA DISTRIBUTION

Cartier and Yeats (1973) conducted field surveys of the northwest and northeast margins of the Kutai Basin for the Kaltim Shell oil company. Data were collected from 14 locations in the Upper Kutai Basin (Figure 3), namely:

1) Muruh;
2) Konyatan;
3) Lower Mahakam / S. Nyawatan;
4) Upper Mahakam / S. Boh;
5) S. Belayan, S. Ritan, S. Len;
6) S. Atan / S Menyok;
7) S. Klinjau;
8) S. Marah;
9) S. Bungalun / S Mangkupa;
10) Saka-1 well, NW Kariorang, Sambang-1 well cluster;
11) Birah-1 well;
12) Tg. Mangkalihat / Gn. Antu;
13) Tabalar A&B; and
14) Karangan

(See Figure 3 caption for abbreviation information).

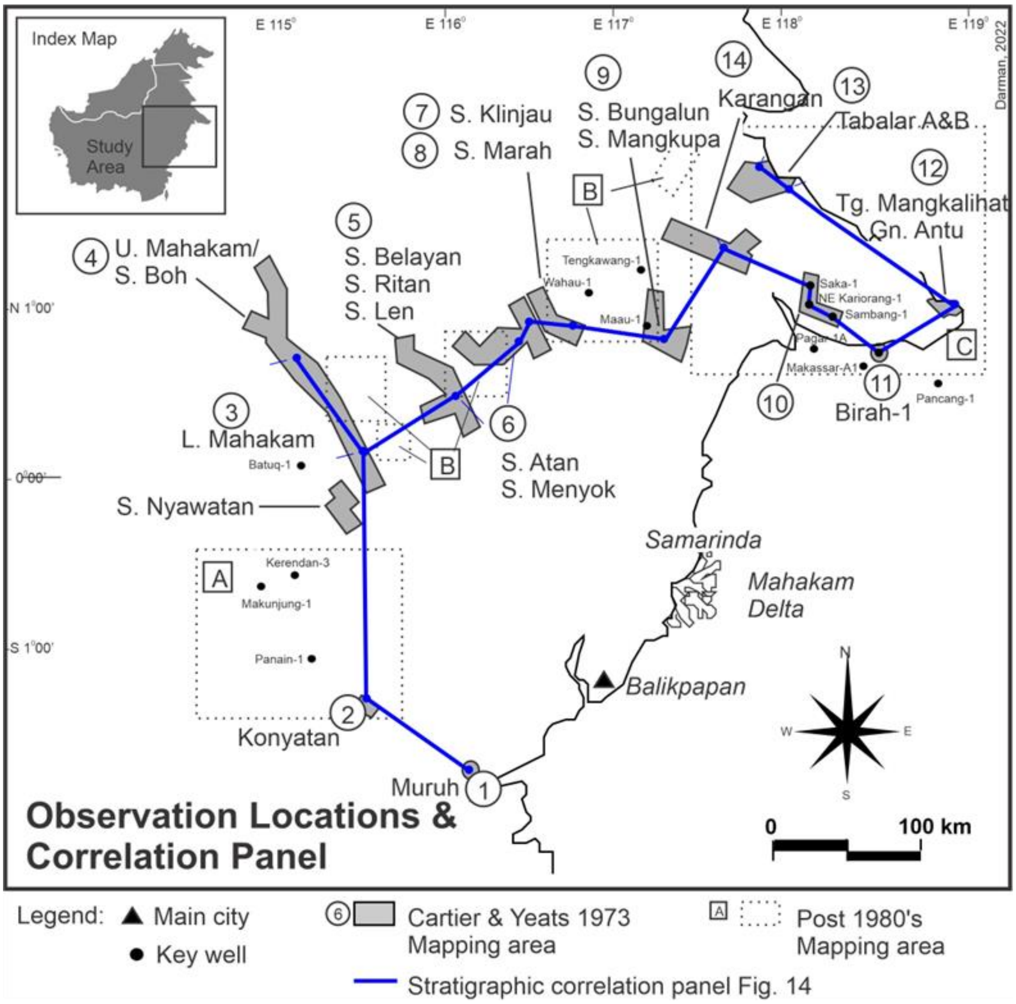

Figure 3: *Location map of outcrop mapping with circled numbers 1 to 14. A, B, and C are areas of other papers referred to in this paper. A = Kerendan Area, B = areas studies by Moss & Finch (1997); B = Mangkalihat Peninsula Area. "S" is an abbreviation of Sungai, which means river; "Tg" is for Tanjung which means peninsula and "Gn" is Gunung which means mount.*

Their report includes stratigraphic sections of each area with foraminiferal studies for age dating and depositional environment identification. Additional biostratigraphic data were provided by Moss and Finch (1997), including nannofossils, which provided additional age control of the outcrops (Figure 3).

The southwest margin of the basin was studied by Unocal geoscientists, who were focused on the Kerendan area (Figure 3), e.g., van de Weerd et al. (1987), van de Weerd and Armin (1992), and Saller and Vijaya (2002).

Their studies include some sections based on 2D seismic interpretation, which clearly defined the Kutai basin margin. Bachtiar et al. (2013) also did intensive fieldwork in this area and their

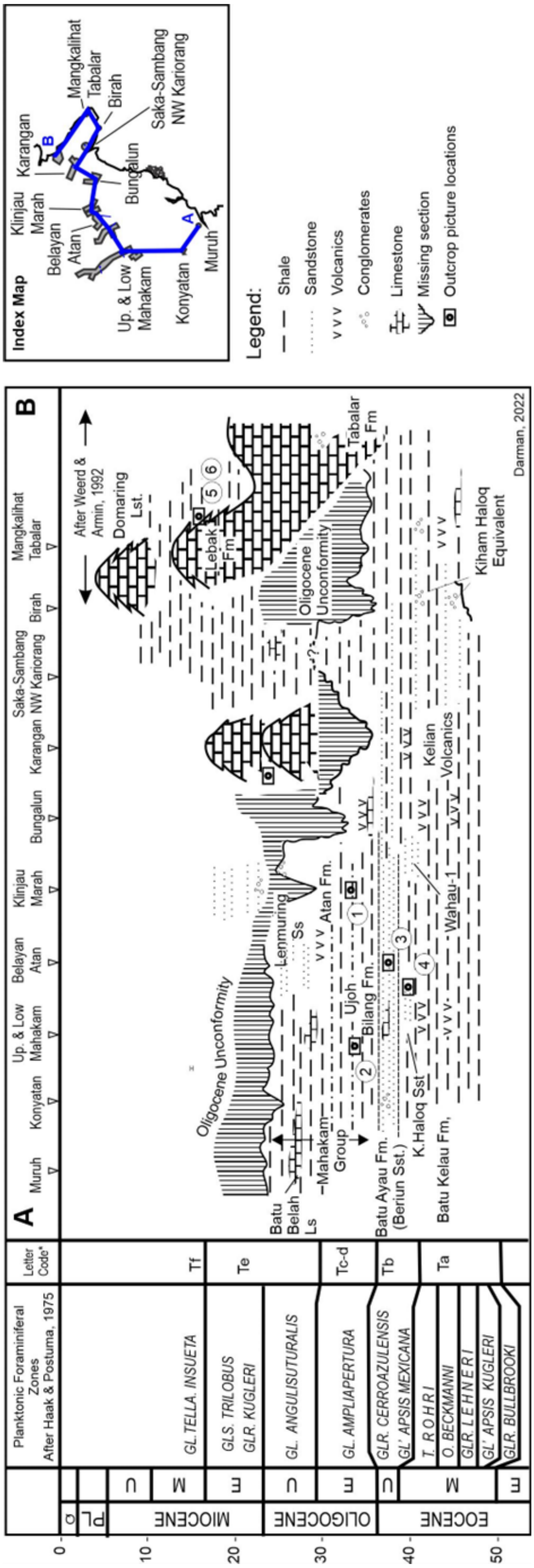

Figure 4: *Stratigraphy of the study areas. Beriun sandstone gets shalier to the east. Oligocene unconformity erodes deeper sections in the east. The unconformity didn't develop in the Saka-Sambang-NW Kariorang area. The camera symbols indicated the location of the outcrop photos. 1) Fig. 5; 2) Fig. 6; 3) Fig. 8a; 4) Fig. 8b; 5) Fig. 12-8a; 5) Fig. 12-8b. *Letter code after van der Vlerk & Umbgrove (1927).*

data points were integrated into this study.

In the northwest margin of the basin is the Mangkalihat Peninsula area (Figure 3), where Wilson et al. (1999) and Wilson and Evans (2002) studied the carbonate outcrops in great detail. Satyana and Biantoro (1995), Guritno and Chambers (1999) and Guritno et al. (2012) included subsurface data in this area and provide additional perspectives on the Paleogene section of the northern area of Kutai Basin.

OUTCROP ANALYSIS

Outcrop observations reported by Yeats and Cartier (1973) are revisited here by integrating them with newer data and analysis.

Their outcrop sections have been correlated with each other and displayed in five correlation panels to provide a better stratigraphic understanding (Figures 4, 7, 9, 10, 11).

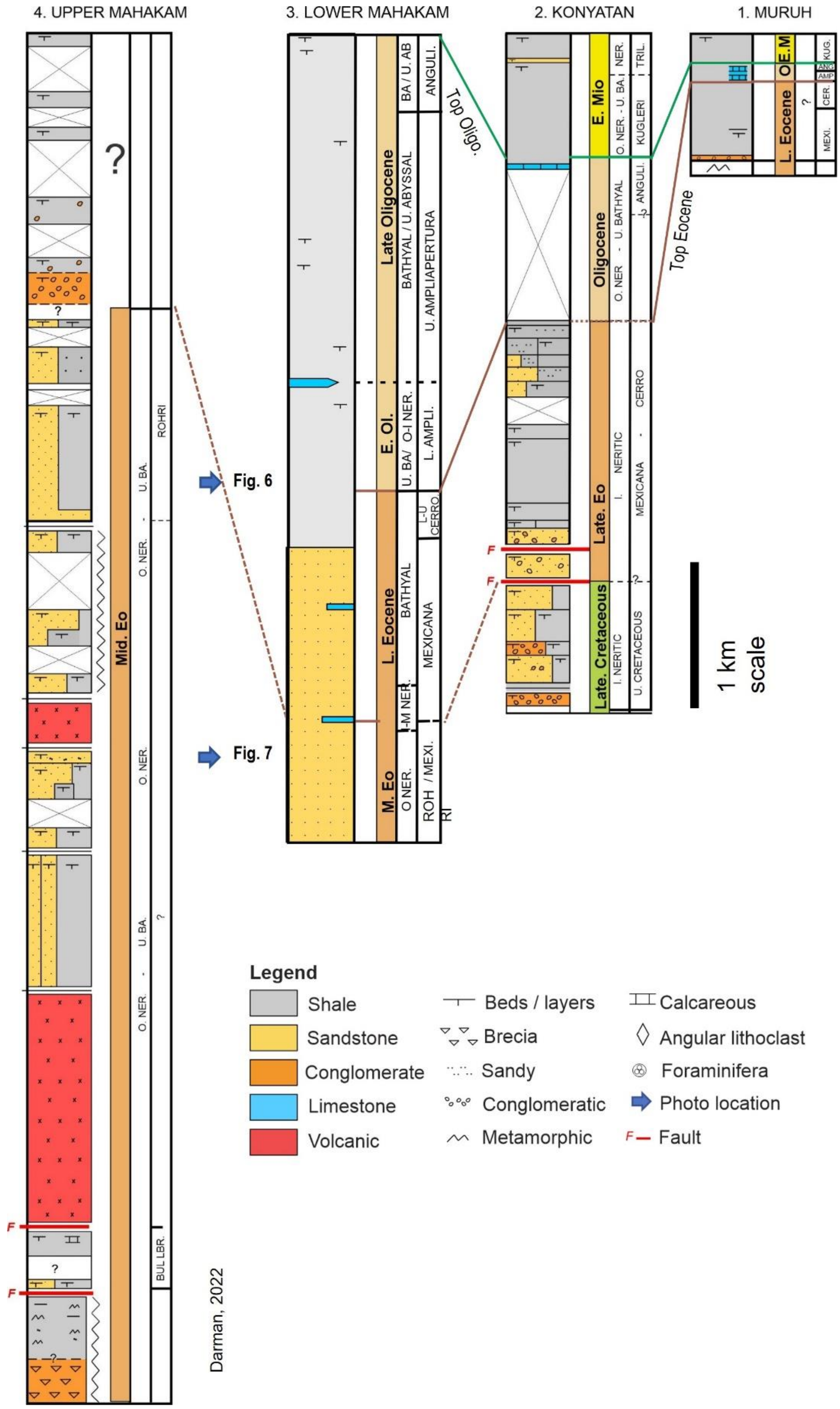

Figure 5: *Panel-1. Stratigraphic sections of 1) Muruh, 2) Konyatan, 3) Lower Mahakam and 4) Upper Mahakam after Cartier and Yeats (1973), roughly Northwest to Southeast orientation (see Fig. 3 for location). Both the Oligocene and Eocene units are thinning to the east. The blue arrow is the position of the outcrop photos.*

Figure 6: *Oligocene Atan Fm. which is dominated by bathyal shale deposit. Photo courtesy Rusniati S. Mehang. The clift on the left is about 5 meters high.*

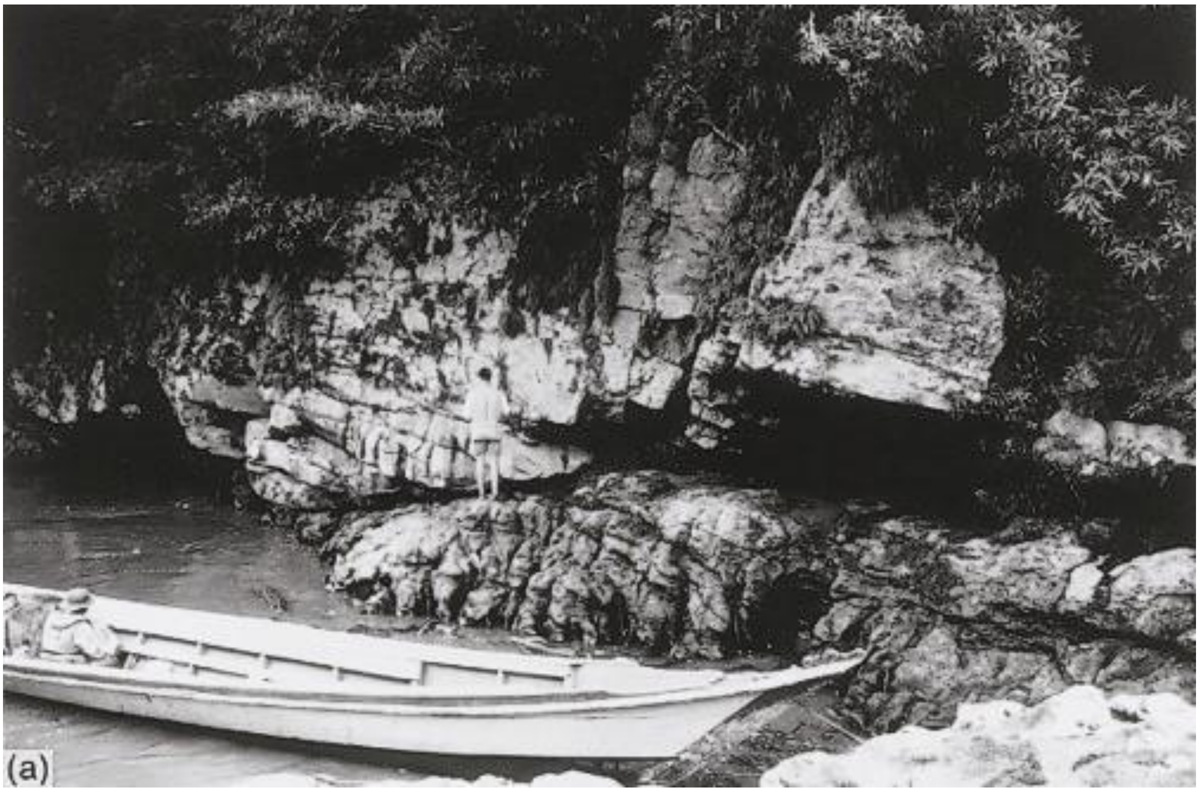

Figure 7: *A field photo of a sandstone channel incised into an earlier channel within the early syn-rift facies of the Middle Eocene Kiham Haloq Sandstone Formation. Upstream from Long Bangun. After Moss & Chambers (1999).*

Panel 1 (Figure 5): This panel went through the eastern part of the Kerendan Area (Figure 3), from Muruh to Upper Mahakam, which is the distal part of the SW margin of the Kutai Basin. Pre-Tertiary rocks were observed at the bottom of the Konyatan section (Cretaceous) and the meta-sediment section at the bottom of Muruh section with an inconclusive age. Middle Eocene section was observed in the Lower and Upper Mahakam sections, and they are identified based on the occurrence of *Acarinina bullbrooki* in Upper Mahakam and *Acarinina rohri* in both Upper and Lower Mahakam (Figure 4). Both forams identified Middle Eocene age (equivalent of Letter Stage Ta of van der Vlerk and Umbgrove, 1927), deposited in upper bathyal to outer neritic environment. Volcanic deposits were observed in the Middle Eocene of the Upper Mahakam section.

Late Eocene sections were encountered in Lower Mahakam, Konyatan, and Muruh. They were deposited in bathyal to inner neritic environments. Middle Eocene sandstone was observed by Moss and Chambers (1999) at Kiham Haloq (Figure 7). Although they reported the outcrop as a fluvial channel deposit, Cartier and Yeats (1973) and Moss and Finch (1997) reported foraminifera and identified the sandstone as a shallow marine / neritic deposit. In Lower Mahakam, the section is dominated by sandstone, whilst in Konyatan it becomes much shalier. In Upper Mahakam, the outcrops are not well exposed and the biostratigraphic analysis was inconclusive.

From Lower Mahakam to Muruh, the Oligocene section becomes thinner, and it is a shale-dominated section with some limestone lenses, called the Atan Formation (Figure 6). Benthonic foraminifera analysis indicated an abyssal to an outer neritic environment of deposition. The analysis of the Konyatan Oligocene section is only from the top part of the section as the majority is unobservable in the field. This stratigraphic unit is overlain by Early Miocene sections which are observed in the eastern part of the area, in Konyatan and Muruh.

Panel 2: (Figure 8) is a correlation panel with several outcrop sections described by Yeats and Cartier (1973) in the north-western margin of Upper Kutai Basin. It starts with the Belayan section in the west and ends with the Bungalun section in the east. The oldest section encountered is a metasediment in the Klinjau area. Middle Eocene sections were only found in Atan and Bungalun, indicating a bathyal environment in the

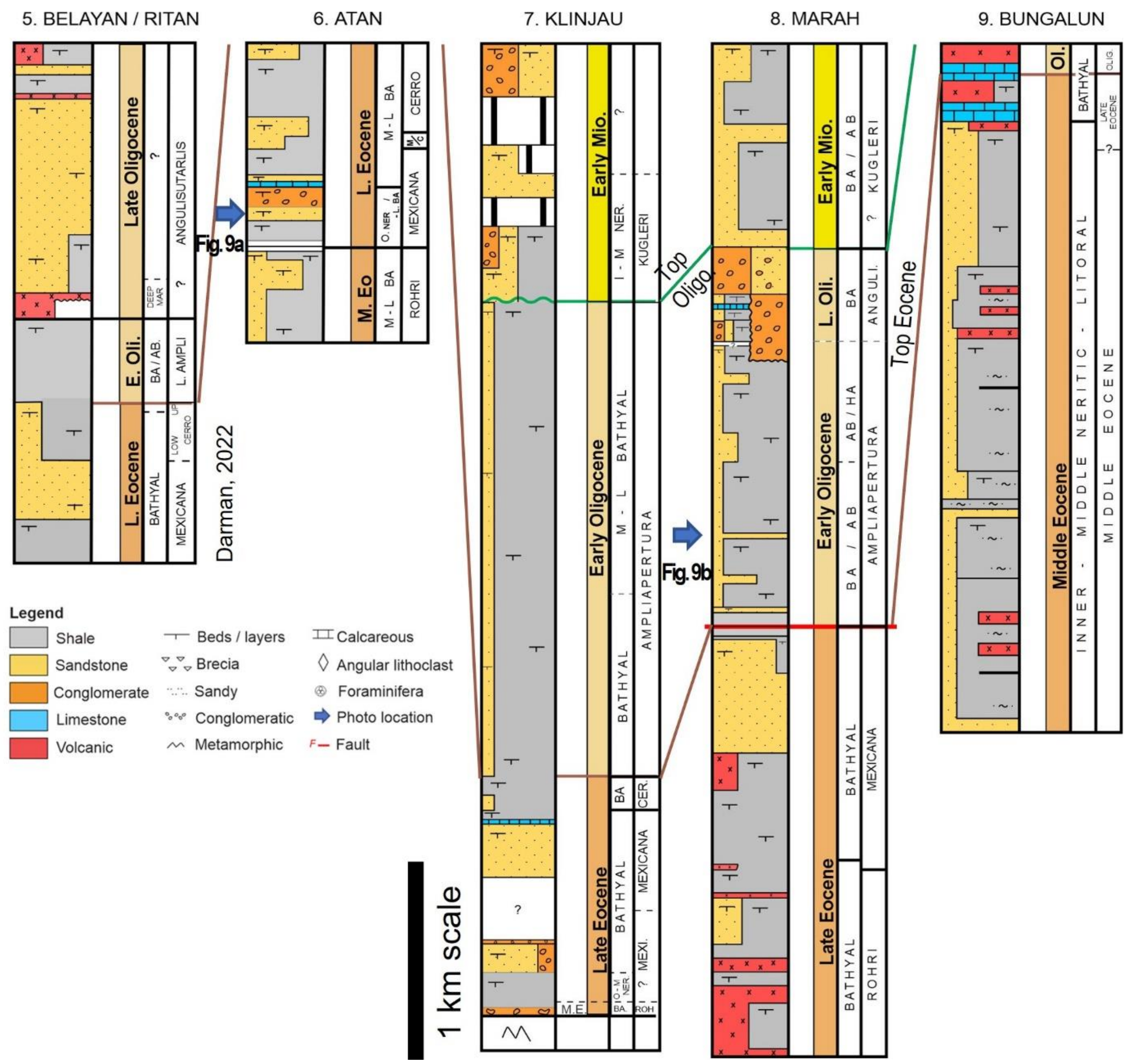

Figure 8: *Panel 2. Stratigraphic sections of 1) Muruh, 2) Konyatan, 3) Lower Mahakam and 4) Upper Mahakam, approximately West to East orientation (see Fig. 3 for location). The Oligocene unit is thinning to the east. Blue arrow indicates the outcrop photo location.*

west to a littoral environment in the east. The Bungalun section in the east contains Middle Eocene clastics with higher shale composition. Some thin layers of volcanic rocks were observed in the area.

Late Eocene sections were found in all 5 locations, and they are dominated by clastic sediments deposited in bathyal environment. *Globorotalia mexicana* and *Turborotalia cerroazulensis* are common index planktonic foraminifera in these sections (Figures 4 and 8). The bottom of the Late Eocene section in Bungalun is not well-identified biostratigraphically. In Atan, the section contains cross-bedded sandstone with minor conglomerates (Figure 9a) and thin limestone beds. In Bungalun, some

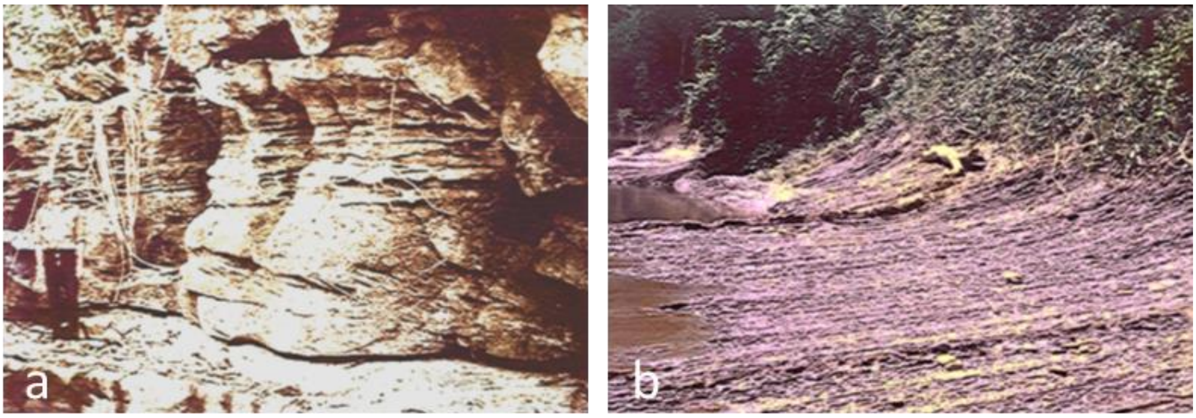

Figure 9: *a) Crossbedded sands and conglomerates from the Kiham Haloq clastics, Late Eocene (Mexicana Zone) of Sei Atan. Crossbedded units such as this are not found further north; b) Typical Atan Clastics, Early Oligocene ("Ampliapertura Zone") in Sei Marah. 10 cm turbidite sands from up to 20% of the section in a dominantly bathyal clay lithology. The river is at a low stage and so outcrop conditions are very good.*

volcanic and limestone beds occur in the outcrops.

A shale-dominated unit of Early Oligocene overlies the Late Eocene unit. This stratigraphic unit is indicated by the presence of *Turborotalia ampliapertura*. The benthonic forams of this section indicated a dominantly bathyal setting. In parts, there are indications of abyssal setting. This section is missing in Atan and only a short section remains in Bungalun.

Late Oligocene sections, which overlie the Early Oligocene unit, are found in Belayan/Ritan and Marah (Figure 9b). In Klinjau there is an unconformity above the Early Oligocene section, below the Miocene succession, which indicates that the Late Oligocene has been eroded. The Belayan/Ritan section is dominated by sandstones which are calcareous in parts and contain some volcanic layers. The Marah section has some conglomerate units and minor limestone. Potentially it is a slope deposit in deeper water.

The Late Oligocene section is overlain by Early Miocene deposits indicated by the presence of *Paragloborotalia kugleri*. Early Miocene sections were observed in the Klinjau and Marah areas. The section in Klinjau is conglomeratic, deposited in the inner to the middle neritic environment with relatively high energy. In Marah, the section contains more shale units with thin turbidite sands (Yeats and Cartier, 1973), deposited in a more distal environment.

<u>Panel 3 (Figure 10):</u> Four wells were drilled in the southern part of

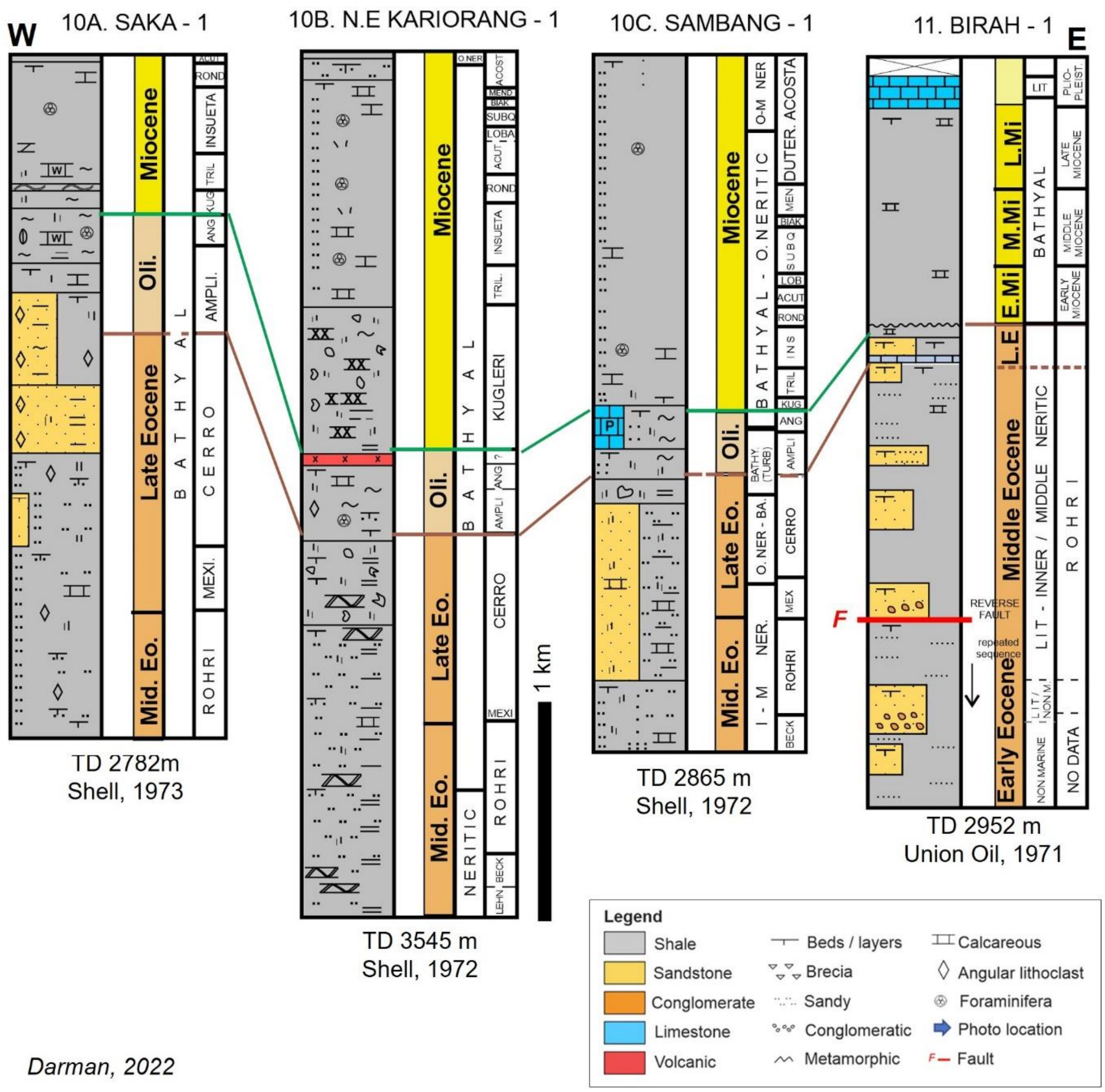

Figure 10: *Panel 3. Correlation panels of 4 wells in the south of Mangkalihat peninsula showing a complete Mid-Eocene to Miocene section. The Oligocene section was missed only in Birah-1. Modified after Cartier and Yeats (1973).*

Mangkalihat Peninsula, namely Saka-1 (Shell, 1973), NE Kariorang-1 (Shell, 1972), Sambang-1 (Shell, 1972), and Birah-1 (Union Oil, 1971), which is displayed in Panel 3 (Figure 10). The correlation panel's orientation is west-east and the first 3 wells in the west are located onshore. Yeats and Cartier (1973) identified an Early Eocene non-marine deposit at the bottom part of Birah-1 well.

Overall, Panel 3 shows that these wells penetrated shale dominated Middle Eocene sections. Saka-1 section indicated a bathyal deposit and NE-Kariorang have neritic deposits in the lower section and a bathyal deposit in the upper section. Both Sambang-1 and Birah-1 are dominated by neritic deposits. The lower section of Birah-1 is interpreted as non-marine to littoral as the interval is barren. The conglomeratic sandstone in the unit indicates a high-energy environment.

A Late Eocene section is encountered in all four wells in this panel. They are bathyal deposits in Saka-1 and NE-Kariorang-1 in the west and change to a neritic-bathyal setting in Sambang-1. To the east, Birah-1 shows most of the Late Eocene section has been eroded. The Pagar-1A and Makassar-1A wells in the area also penetrated this stratigraphic unit (Guritno et al., 2015; See Figure 3 for well location map) and they are useful as additional control points to understand Late Eocene paleogeographic setting.

The Oligocene section in the southern part of Mangkalihat thins to the east as shown in Panel 3. This stratigraphic unit overlies the Late Eocene section, but in Birah-1, the easternmost well in Panel 3, the Oligocene section has been eroded. An Oligocene volcanic bed was encountered in NE-Kariorang-1 and an Oligocene limestone bed was penetrated in Sambang-1. The Oligocene section is overlain by Miocene bathyal shale.

<u>Panel 4 (Figure 11):</u> A metamorphic unit at the bottom of Gunung (Mount) Antu is the oldest unit in Panel 4 (Figure 11), but the age is undetermined, and it has a fault contact with the Eocene unit.

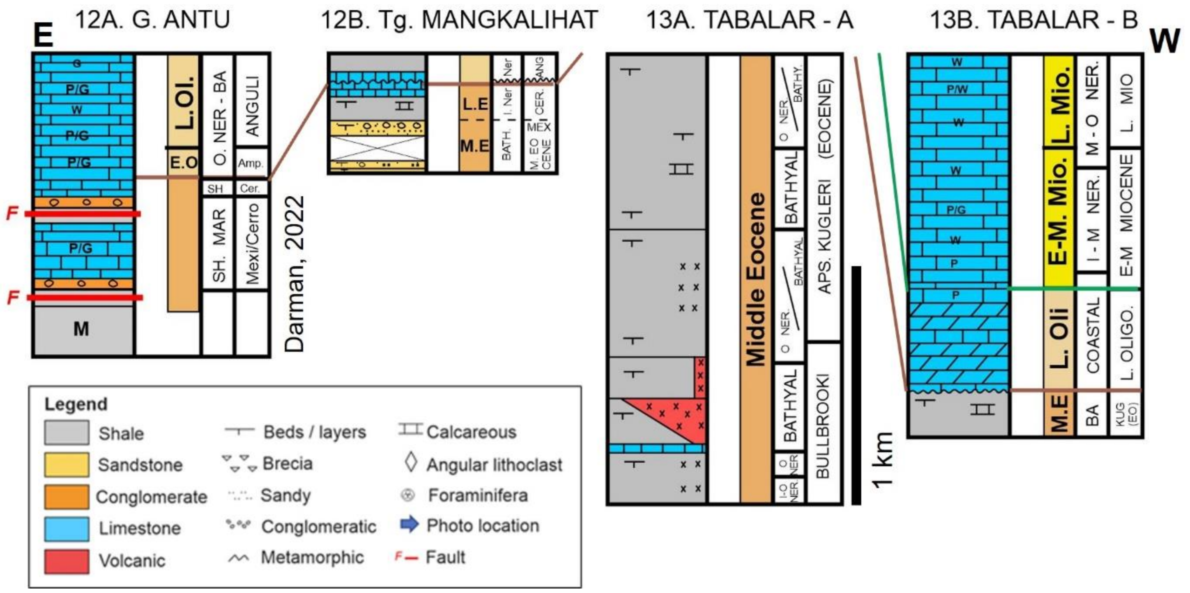

Figure 11: *Panel 4. Stratigraphic sections of outcrops in the north of Mangkalihat Peninsula, modified after Cartier and Yeats (1973). P=packstone, G=grainstone, W=wackestone, M=mudstone.*

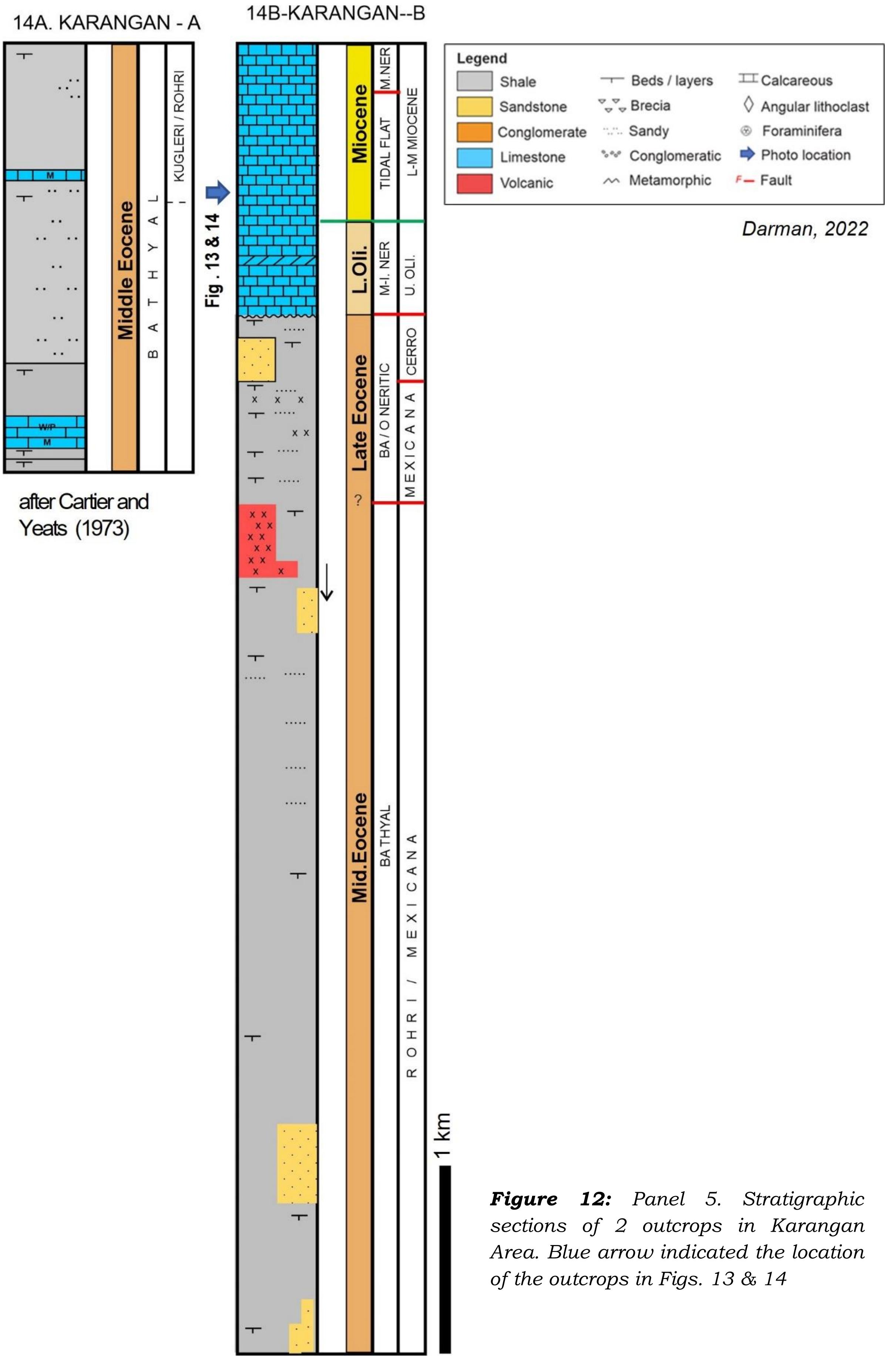

Figure 12: *Panel 5. Stratigraphic sections of 2 outcrops in Karangan Area. Blue arrow indicated the location of the outcrops in Figs. 13 & 14*

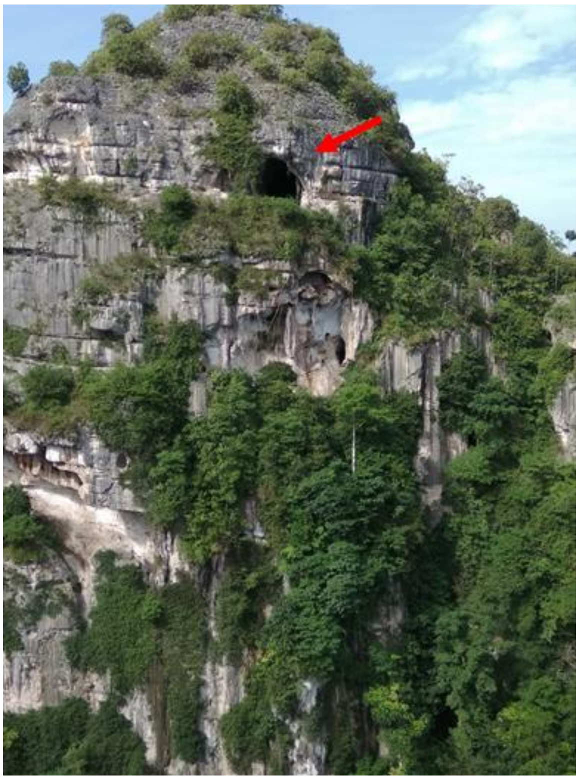

Figure 13: *Gua Mengkuris in Karangan Area. The geology consists of Upper Oligocene to Miocene carbonate outcrop, part of Lebak Fm. Photo courtesy: Thyo Theviking. The cave (red arrow) is about 4 m high.*

Middle Eocene unit is encountered in Tg Mangkalihat, Tabalar-A and Tabalar-B section and they are dominated by bathyal deposits (Cartier and Yeats, 1973). Only the section in Tabalar-A has some outer neritic deposits. *Globigerinatheka kugleri* is the index fossil for this Middle Eocene section.

A short section of Late Eocene was observed in G. Antu and Tg. Mangkalihat, both containing limestone beds. The Late Eocene section in Gunung Antu has a fault contact with the metamorphic unit below it. The Middle Eocene interval that overlays this section contains mudstone, packstone and wackestone carbonate layers, but overall, this section is very shaly. A couple of sandstone interbeds were observed in places. Volcanic units occur in the latest part of the Middle Eocene.

A thin Early Oligocene deposit overlays the Late Eocene unit in G. Antu and Tg Mangkalihat, but it is missing in Tabalar-A and Tabalar-B. Late Oligocene carbonate beds occur in G. Antu and Tabalar-B. The biostratigraphic analysis indicated a distal environment in the east and a proximal environment in the west. The section in Tabalar-B also has dolomitic units. Thick Miocene carbonates were deposited above the Late Oligocene section as observed in Tabalar-B.

Panel 5: In the west of Mangkalihat Peninsula, there are 2 outcrop observations in Karangan (Figure 12). The sections are called Karangan-A and Karangan-B. In the Karangan area, the Middle Eocene is an extremely thick bathyal deposit. There are carbonate interbeds with reworked material and there are also minor volcanic interbeds. The Upper Eocene is observed in Karangan-B, and it is a transition from

Figure 14: *Mt. Kulat carbonate outcrop, Upper Oligocene to Miocene carbonate outcrop, Lebak Formation (GRDC) Photo courtesy: Dasep Gunawan.*

bathyal to an outer neritic environment, dominated by shale.

The Lower Oligocene is missing in Karangan-B, but the Upper Oligocene carbonate occurs above the Upper Eocene unit with an unconformity contact. The carbonate is deposited in the middle to inner neritic, followed by Miocene carbonate (Figures 13 and 14) which is deposited in a tidal flat to the middle neritic environment. The age of the carbonate is not fully determined by biostratigraphic analysis.

PALEOGEOGRAPHIC SETTING

Observation and data for Early Eocene interval are limited, therefore paleogeographic reconstruction for this level is too difficult to construct. Middle Eocene to Late Oligocene paleogeographic maps for the studied area were prepared, based on outcrop analyses, wells and seismic interpretation, which were completed previously.

1. Middle Eocene

Middle Eocene fluvial deposits were identified in the west of Kutai Basin e.g., in the Ketungau and Melawi Basins (Figure 1) and in the south in the Barito Basin (Figures 1 and 15). Guritno and Chambers (1999) reported a Middle Eocene fluvial deposit in Wahau-1 well (Figures 3 and 15). Bachtiar et al. (2013) identified some non-marine deposits in the southwest margin of the Kutai Basin.

Littoral to sublittoral deposits occur in the southwest of the Kutai Basin. Cartier and Yeats (1973) found Middle Eocene shallow marine deposits in most of their sampling locations. In places like Atan, Klinjau, Karanga and Tabalar-B, there are bathyal shale-dominated deposits with some sandstone units. There are limited data available around the border of the facies belt, therefore the extent of the depositional units is approximate.

2. Late Eocene

Late Eocene shallow marine outcrops were identified in the southwest margin of Kutai Basin (e.g., Bachtiar et al., 2013) and in the northeast margin around Klinjau and Marah area (Figure 16). There are changes from neritic to bathyal at a later stage of Late Eocene as observed in Bungalun, Atan, Lower Mahakam, and also in Sambang-1 well.

Late Eocene biostratigraphic analysis of samples from Belayan, Klinjau, and Marah outcrops identified the bathyal environment of deposition. Saka-1 and NE Kariorang-1 well in the north of the basin encountered deep marine shale sections. Many believed that towards the center part of the basin there are more deep marine deposits, but these are now buried at great depths, beyond the reach of conventional oil wells.

3. Early Oligocene

In the Early Oligocene, there were fewer littoral deposits in the west of the studied area (Figure 17). Shallow water carbonates developed in the SW and NE margins of the Kutai Basin. The Barito and Paternoster Platform are large carbonate complexes developed in the south. The northern edge of both platforms followed a trend which was probably caused by WNW-ESE trend Adang Fault. The Maratua Carbonate Complex developed in the north of the Mangkalihat Peninsula. The facies distribution and facies changes in the SW are relatively well-constrained as there are more data points. The Upper Mahakam section NW of the area indicates a transition from a deep-water to a shallow-water environment (Figures 4 and 17).

Panel 2 which shows a correlation panel from Belayan to Bungalun (Figure 7) goes along strike at the northern margin of Kutai Basin. All Early Oligocene sections in this area show a bathyal environment of deposition. There are limited observation points in this area and the transition from neritic to bathyal is poorly constrained.

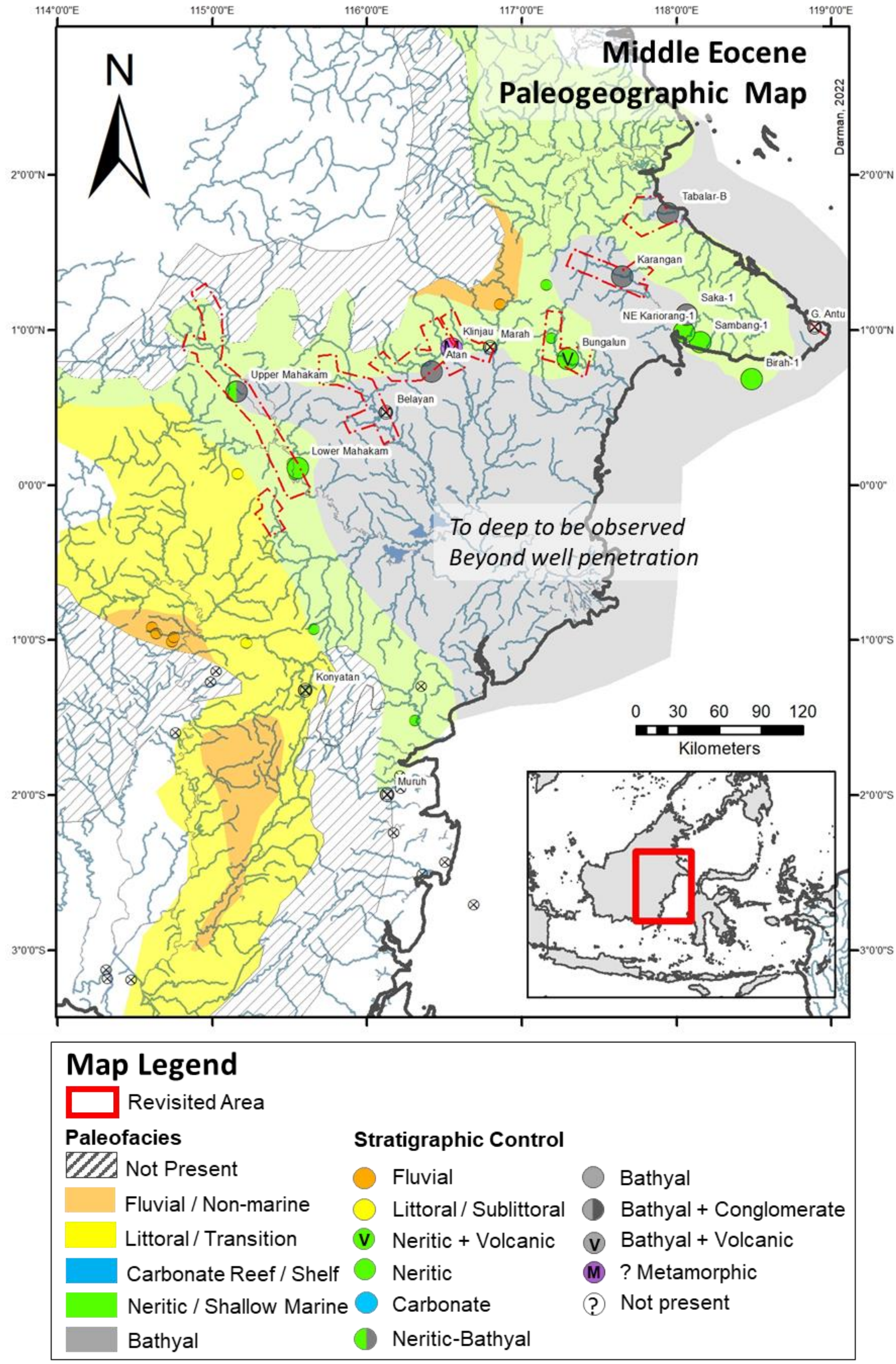

Figure 15: *Middle Eocene paleogeographic map.*

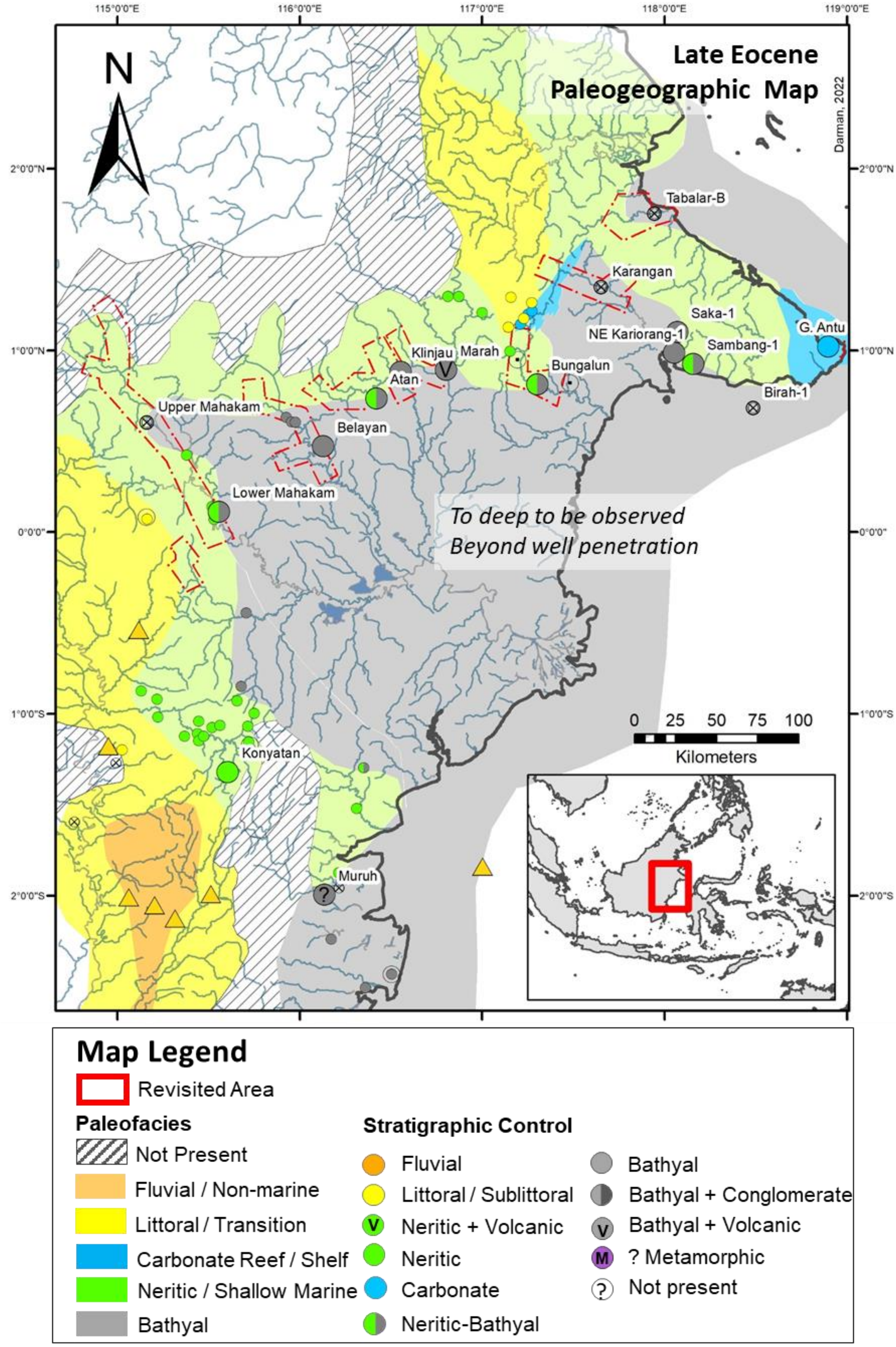

Figure 16: *Late Eocene paleogeographic map.*

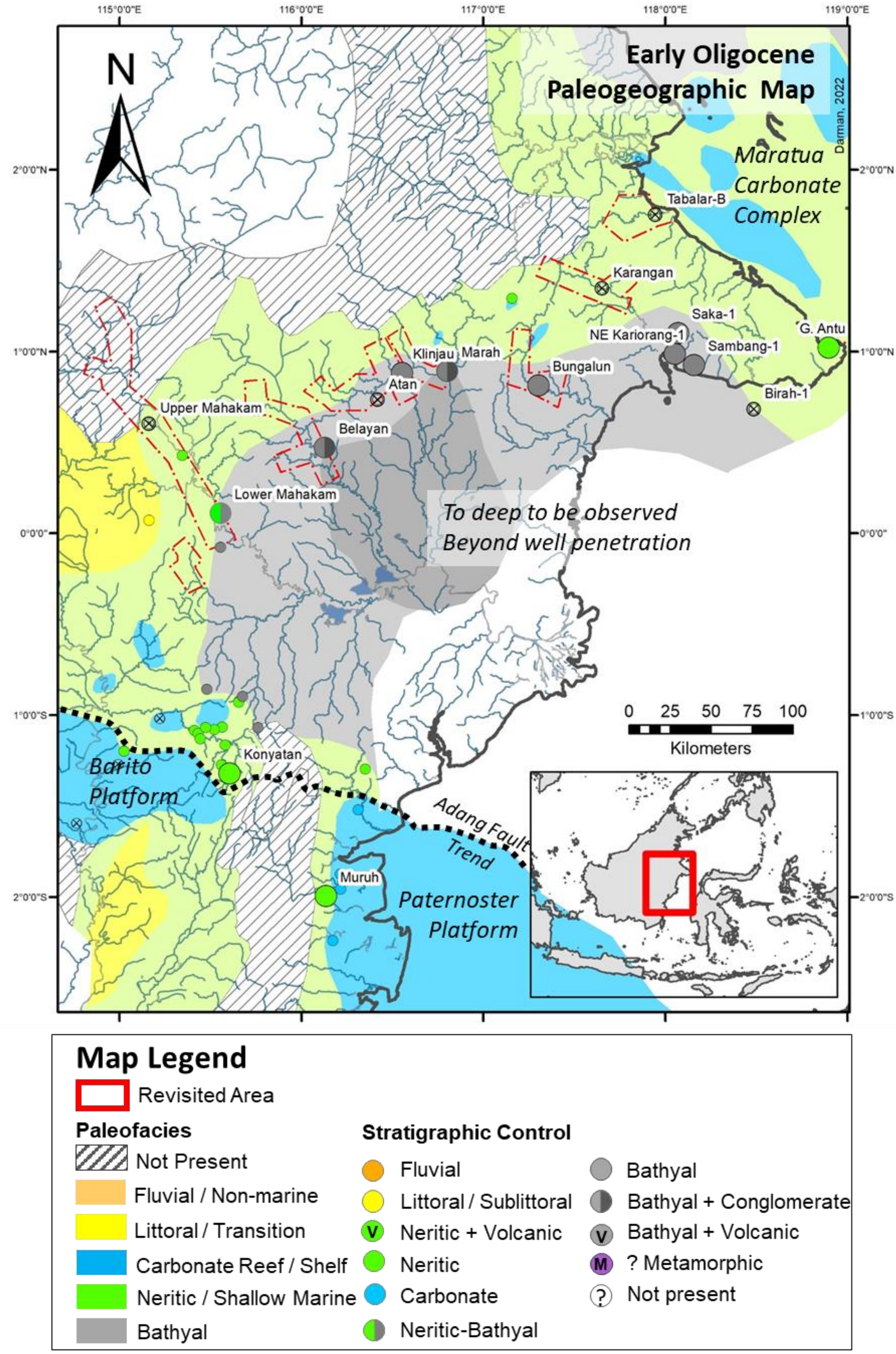

Figure 17: *Early Oligocene paleogeographic map.*

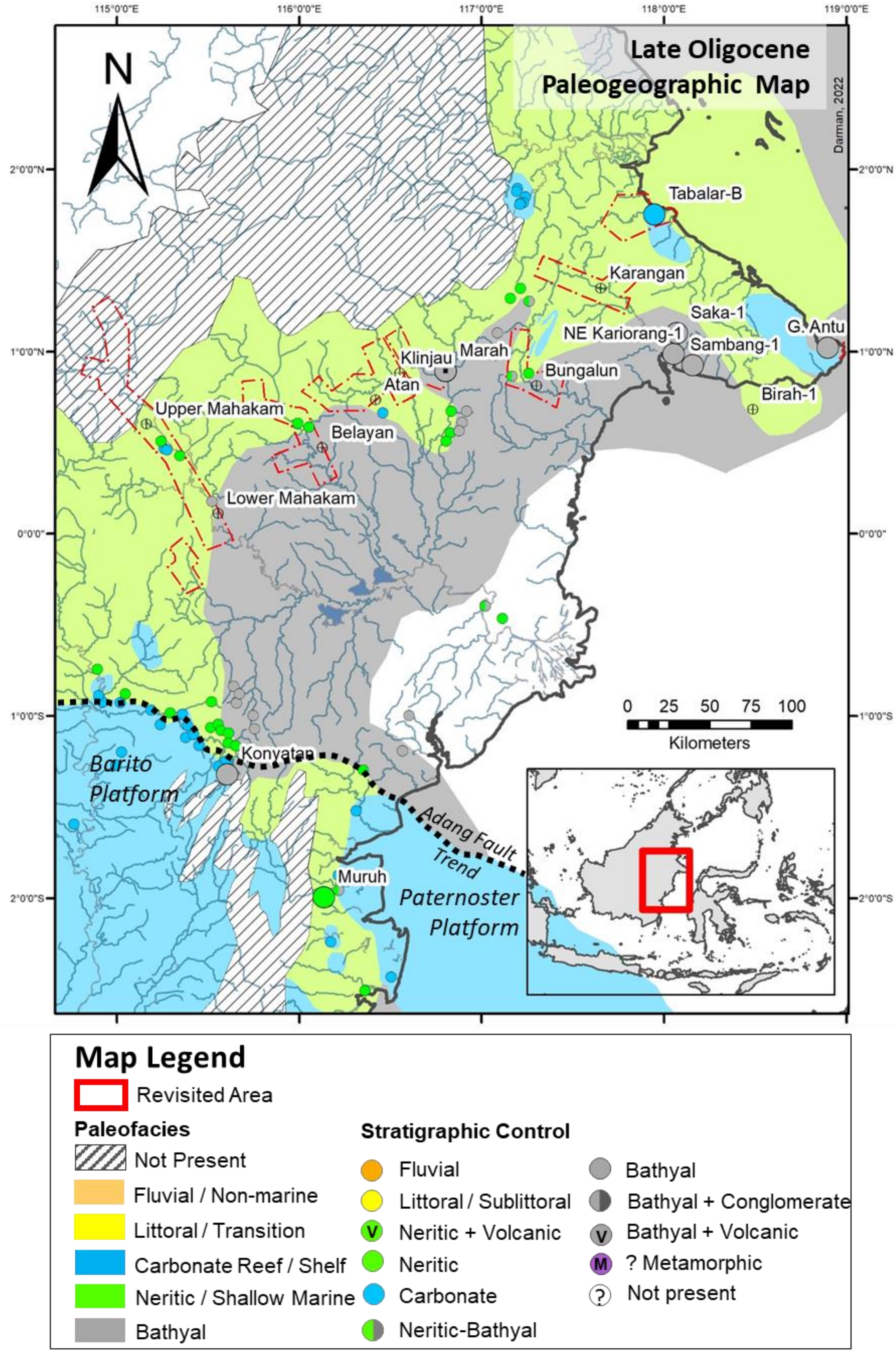

Figure 18: *Late Oligocene paleogeographic map.*

The Early Oligocene section is missing in a large part of the Mangkalihat Peninsula. Probably many of them have been eroded as indicated in Birah-1 well, Karangan, and Tabalar-B section (Figures 14 and 17). This area is part of the Mangkalihat High which separates the Kutai Basin from the Muara Sub-Basin in the north. Oligocene carbonates developed and are well preserved in the north of this high.

4. Late Oligocene

The carbonate platforms in the southwest of Kutai Basin developed intensively in the Late Oligocene (Figure 18). The facies transition from the carbonate system to the littoral, and to the bathyal clastic environment are well constrained as there are many field-observation points in the area. The facies changes are also observed in seismic sections as reported by Saller and Vijaya (2002). Similar to Early Oligocene, the northern edge of Barito and Paternoster Platform follows the WNW-ESE Adang Fault trend.

The facies distribution in the northwest of the studied area has fewer control points. In the south of Marah, Moss et al (1997) collected some outcrop data. These observations are useful to observe the changes of the depositional environment of the sediments from the neritic to the bathyal setting.

In the Bungalun area there are also several locations to observe the changes. The limestone outcrop provides some detail of the basin margin. To the north, around the Mangkalihat Peninsula, there was a significant uplift and erosion, and parts of the Late Oligocene section are missing, e.g. in Bungalun, Karangan, and Birah-1. The carbonates here only develop locally.

DISCUSSION

The SW margin of Kutai Basin is best observed as there are seismic, well and outcrop data. Similarly, the NE margin part the basin is covered by some data points. Their data quantity and quality, however, are not as good as the SW. The NW margin of the basin is an area with much fewer data. There are not enough wells to observe the Paleogene section and no seismic data to cover this area. The paleogeographic reconstruction in this area is based on limited outcrop observation. More data is required to refine the facies boundary.

Eocene sandstone is the primary petroleum exploration target in the margin of the Kutai Basin. The southern area has better sandstone development compared to the north (Figure 14). They are located in a more proximal area as they are closer to the provenance.

Several authors observed that many of the Paleogene sandstones in outcrops around the Kutai Basin tend to be tight (e.g., Bachtiar et al., 2013a) and thermally overmature (e.g. Guritno and Chambers, 1999). The reason for this may be deep burial of Paleogene before the extensive ~mid-Miocene regional uplift of much of Borneo Island, including the Upper Kutai Basin, where 1000s of meters of sediments may have been eroded since the Middle Miocene, as well as uplifts in local inversion structures. In addition, reservoir quality of Middle and Late Eocene sandstones in the northern part of the Kutai Basin may be adversely affected by unstable volcanoclastic and chert grains, derived from the Late Mesozoic oceanic accretionary complex ('Danau Formation') in the likely source area (e.g., Guritno and Chambers, 1999).

Potential carbonate reservoirs developed in the Oligocene time and were covered by a younger seal in the south. The Kerendan gas field proved this play potential in the area. In the north, many carbonates were exposed to the surface with minimum seal.

CONCLUSION

The Eocene sediments along the present-day margin of the Kutai Basin, including the sand packages known as the Eocene Beriun Sandstone or the Kiham Haloq clastics, were for the most part deposited in neritic to deep marine environments. The source of these sediments mainly came from the west and southwest. The northwestern high source areas, formed as the NE-SW axis of Central and North -Borneo, only appeared after Late Oligocene.

There was less tectonic activity during Early Oligocene. The basin was generally subsided and filled with shale. There was more carbonates development in the NE and SW margins. In mid-Oligocene an uplift occurred in the north which generated an unconformity. The unconformity developed in the southwest in Late Oligocene. In Late Oligocene the southern part of Kutai Basin was very stable and a large carbonate system developed well. The carbonate in the north only developed around local tectonic high in the Mangkalihat area.

Paleogene potential traps for petroleum exploration developed well in the southern margin of the basin. Eocene clastics and Oligocene carbonates in this area are better preserved here compared to other parts of the Kutai Basin. The center part of the basin is very distal with a smaller chance for both clastic and carbonate reservoirs to develop. At present, it is also too deep to be explored.

ACKNOWLEDGEMENT

The author would like to acknowledge Nadiyah Tan who has done much graphical works to support this paper. Thanks to J. T. van Gorsel who has reviewed the manuscript of this paper and provided constructive feedback with additional information.

REFERENCES

Bachtiar, A., Heru N., D.H., Azzaino, Z., Utomo, W., Krisyunianto, A. and Sani, M., 2013a. Surface data re-evaluation, Eocene source rock potential and hydrocarbon seepage, and Eocene sand reservoir prospectivity in West Sangatta, Northern Kutai Basin. Proceedings of 37th Annual Convention, Indonesian Petroleum Association, IPA13-G-087, p. 1-29.

Bachtiar, A., Purnama, Y. S., Suandhi, P. A., Krisyunianto, A., Rozali, M., Nugroho, D.H.H. and Suleiman A., 2013b. The Tertiary paleogeography of the Kutai Basin and its unexplored hydrocarbon plays. Proceedings of 37th Annual Convention, Indonesian Petroleum Association, IPA13-G-126.

Cartier, E.G. and Yeats, A.K., 1973. The Lower Tertiary sequences in Kaltim Shell contract area, East Kalimantan. Results of 1972–1973 Field Surveys, Kaltim Shell, Balikpapan. (Unpublished report)

Darman, H., 2017. The Paleogene of East Borneo and its facies distribution. Berita Sedimentologi, 37, 5-13.

Darmawan, W., Subekti, A., Guritno, E., Smart, J., Mustapha, H., Nugroho, B. and Bachtiar, A., 2015. Structural and stratigraphic evolution and implications for Paleogene syn-rift exploration in northeast Bangkanai, upper Kutai Basin, Indonesia. Proceedings of 39th Annual Convention & Exhibition, Indonesian Petroleum Association, IPA15-G-112.

Guritno, E.E., and Chambers, J., 1999. North Runtu PSC: The First Proven Eocene Petroleum Play in the Kutai Basin. Proceedings of 27th Annual Convention & Exhibition, Indonesian Petroleum, IPA99-G-092.

Guritno, E., Muller, W., Drajat, D. and Purnama, M., 2012. The nature of the Mangkalihat Terrane, NE Borneo, Indonesia. Proceedings of 36th Annual

Convention & Exhibition, Indonesian Petroleum Association, IPA12-G-197.

Haak, R. and Postuma, J.A., 1975. The relation between the tropical planktonic foraminiferal zonation and the Tertiary Far East Letter Classification. Geol. en Mijnbouw, 54 (3-4), p.-195-198.

Laya, K.P., Nugroho, B., Hadiyanto, N., Tolioe, W., 2013. Paleogeographic reconstruction of Upper Kutei Basin: Implications for petroleum systems and exploration play concept. Proceedings of 27th Annual Convention & Exhibition, Indonesian Petroleum, IPA13-G-106.

Moss, S.J., Chambers, J., Cloke, I., Satria, D., Ali, J.R., Baker, S., Milsom, J. and Carter, A., 1997. New observation on the sedimentary and tectonic evolution of the Tertiary Kutai Basin, East Kalimantan. *In*: Fraser, A.J., Matthews, S.J. and Murphy, R.W. (eds), Petroleum Geology of Southeast Asia, Geological Society of London, Special Publication, No. 126, p. 395-416.

Moss, S. and Chambers, J.L.C., 1999. Tertiary facies architecture in the Kutai Basin, Kalimantan, Indonesia. Journal of Asian Earth Sciences 17(1-2), 157-181.

Moss, S. and Finch, E.M., 1997. Geological implications of new biostratigraphic data from East and West Kalimantan, Indonesia. Journal of Asian Earth Sciences, 15(6), 489-506.

Pieters, P.E., Trail, D.S. and Supriatna, S., 1987. Correlation of Early Tertiary rock across Kalimantan. Proceedings of 26th Annual Convention & Exhibition, Indonesian Petroleum Association.

Pertamina-Litbang EP, 1987. Study of the Kalimantan Paleogene, PT Pisca Engineering (unpublished report).

Satyana, A. H. and Biantoro, E., 1995. Seismic stratigraphy of Eocene Beriun Sands of West Bungalun, East Kalimantan, Indonesia: A contribution to the Paleogene stratigraphic knowledge of the Kutai Basin. Proceedings of International Symposium on Sequence Stratigraphy in SE Asia, Indonesian Petroleum Association, p. 383-393.

Saller, A. H. and Vijaya, S., 2002. Depositional and diagenetic history of the Kerendan carbonate platform, Oligocene, Central Kalimantan, Indonesia. Journal of Petroleum Geology, 25(2), 123-150.

Stauffer, P. H., 1966. Studies in the Crocker Formation, Sabah. Geological Survey Borneo Region Bulletin, 8, 1-13.

Van de Weerd, A. A., Armin, R. A., Mahadi, S. and Ware, P. L. B., 1987. Geologic setting of the Kerendan gas and condensate discovery, Tertiary sedimentation and paleogeography of the northwestern part of the Kutai Basin, Kalimantan, Indonesia. Proceedings of 16th Annual Convention & Exhibition, Indonesian Petroleum Association.

Van der Vlerk, I.M. and Umbgrove, J.H.F. 1927. Tertiaire gidsforaminiferen van Nederlandsch Oost-Indie. Wetensch. Meded. Dienst Mijnbouw Ned. Oost-Indie 3, 5-165. 6, p. 3-31.

Van de Weerd, A.A. and Armin, R.A., 1992. The origin and evolution of the Tertiary hydrocarbon bearing basins in Kalimantan (Borneo), Indonesia. AAPG Bulletin, 76 (11), 1778-1803.

Wain, T. and Berod, B., 1989. The tectonic framework and paleogeographic evolution of the Upper Kutai Basin. Proceedings of 18th Annual Convention & Exhibition, Indonesian Petroleum Association.

Wilson, M. and Evans, M. J., 2002. Sedimentology and diagenesis of Tertiary carbonates on the Mangkalihat Peninsula, Borneo: Implications for subsurface reservoir quality. Marine and Petroleum Geology, 19, 873–900.

Wilson, M., Chambers, J.L.C., Evans, M.J., Moss, S.J. and Nas, D.S., 1999. Cenozoic carbonates in Borneo: Case studies from northeast Kalimantan. Journal of Asian Earth Sciences, 17, 183-201.