Paleogene Development of Sundaland

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ABSTRACT

The Paleogene tectonostratigraphy of Sundaland can be subdivided into Pre-rift (Pre-Cenozoic and Paleocene) and Syn-rift (Eocene and Oligocene) megasequences. The Pre-rift Paleogene, represented mainly by Paleocene, was the time of non-deposition and denudation practically over the whole Sundaland, except at a few places along its peripheries, where arc volcanism took place. These volcanics are the Jatibarang and the Cikotok Volcanics in western Java, with its respective associated subduction zones at Loh Ulo and Ciletuh. In Sumatra, they are the Kikim Tuffs (South Sumatra) and the Brueh Volcanics (North Sumatra) and its associated back-arc and shelf basins (carbonate platform). At this time, the Sundaland was tectonically stable. The Syn-rift Paleogene consists of Eocene and Oligocene deposits, mainly of terrestrial facies (fluviatile and lacustrine), partly with marine incursions, such as in the North Sumatra and South Sumatra. Sedimentation was restricted to narrow rift-valleys grabens and half-grabens surrounding the core of the Sunda Shield in SW Kalimantan. The bounding faults show a definite pattern, anti-clock-wise from N Sumatra-NW Java, NW-SE and N-S; Eastern Java E-W and NNE-SSW; SE Kalimantan WNW-ESE; E. Kalimantan NNW-SSE, and Natuna basin: NE-SW and NW-SE. Tectonically, Sundaland was in an extensional regime during most of the Paleogene. In its western part, Sundaland is characterized by trans-tensional tectonics: the NW-SE trending right-lateral Mentawai Trans-current Fault (transform fault) formed a plate-boundary with corresponding Padang Island Fault forming a couple to form the N-S and NW-SE trending grabens. In the east, the West Sulawesi micro-continent rifted away to form the Makassar Strait basins, initiating NNE-SSW trending grabens and half-grabens with syn-rift deposition. To the south, the presence of a subduction is questionable, as no volcanic rocks of either Eocene and Oligocene age has been radiometrically identified. At the continental edge, however, at least in western Java, a prograding depositional sequence of deltaic to shallow marine deposits overlain by reefal limestones have been identified similar to a passive margin depositional sequence. To the north in west central Kalimantan arc volcanism indicates the presence of fore-arc basins.

Keywords: *Paleogene, tectonostratigraphy, Western Indonesia, Sundaland*

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INTRODUCTION

This paper presents a review and subsequent interpretation of the stratigraphic and tectonic development of Sundaland during the Paleogene Period. Therefore, in this paper, only the Paleogene tectonostratigraphy will be discussed in a detail.

The Neogene tectonostratigraphy will be mentioned briefly only. The Sundaland is located on Southeast Asia Sub-continent and includes the western part of Indonesia. From a geo-tectonic point of view (Fig. 1), Indonesia is subdivided by Koesoemadinata (2020) into:

1. Western Indonesia: Sundaland which is part of the Southeast Asian Subcontinent, located on the Asian continental plate
2. Central Indonesia: mixed micro-continents and micro-oceanic plates (Asia and Australia derived micro-continents, Pacific and Indian Oceanic Platelets
3. Eastern Indonesia: Arafuraland, which is part of the Australian Continental plate

DATA SOURCE AND METHODOLOGY

This paper is a compilation of available literatures on the geology of Indonesia. The main data source consists of Systematic Geologic Map sheets with its Explanatory Notes published by the Geological Research and Development Centre (presently known as Center for Geological Survey) of the Ministry/Department of Energy and Mineral Resources from 1969 until 1998.

For this study, it is mainly the Systematic Geologic Sheet of Java and Madura at a scale of 1:100,000, the Systematic Geologic Map sheet of Sumatra at a scale of 1: 250,000, the Systematic Geologic Map sheets of Kalimantan, at a scale of 250,000, and western sheets of the Systematic Geologic map sheet of Sulawesi at a scale of 1: 250,000.

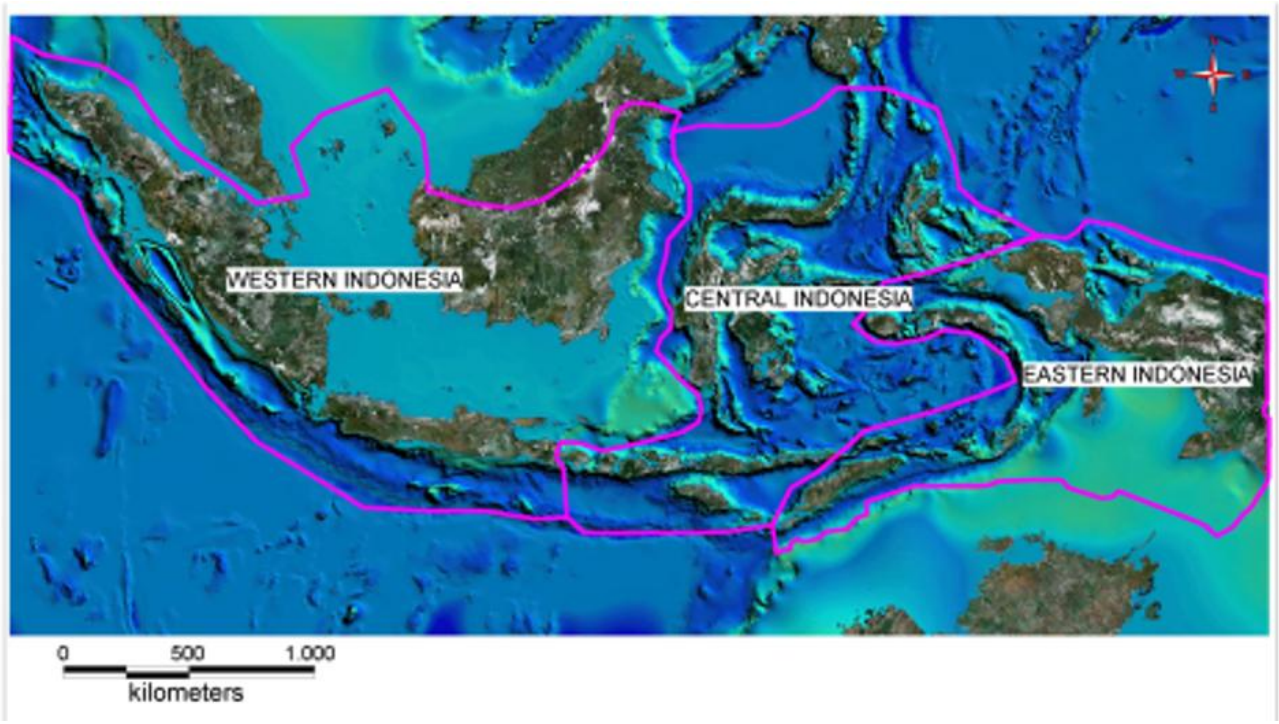


Fig. 1. *Indonesia Geotectonic Subdivision (after Koesoemadinata, 2020)*

The stratigraphic nomenclature used in these map sheets/quadrangles have also been compiled in the Stratigraphic Lexicon by Harahap et al. (2003), also published by GRDC.

Subsurface data, based on interpretation of seismic surveys and exploration wells of petroleum companies, have been compiled by numerous authors working in the petroleum industry and were published as numerous papers in various journals, mainly in the Proceedings of the Indonesia Petroleum Association Annual Convention and Special Publications; notably a standard stratigraphy was assigned for each oil producing basin. The stratigraphic nomenclature used by petroleum industry is not always the same with that used by the GRDC, and the author of this paper has to comply with this situation. In general, the author used the petroleum industry nomenclature when discussing sedimentary basins, because it is more widely used.

This compilation of data and subsequent systematic arrangement of data actually took place during the author's life-time research for the writing of the author's book "INTRODUCTION INTO THE GEOLOGY OF INDONESIA". The source, data base and maps for this paper then is referred to this book

THE GEOTECTONIC SETTING OF SUNDALAND

As it has been discussed the geotectonic position of the Sundaland is practically Western Indonesia (Fig. 2). The Sundaland is supposed to be entirely underlain by continental crust, but in detail it is composed of micro-continents stitched together by sutures forming collage tectonics (see Fig. 3). In addition, some parts of the crust are intermediate to oceanic crust through accretion, or extension. The crustal composition plays a role in the tectonic development. The continental crust at the western periphery of Sundaland extended all the way to the

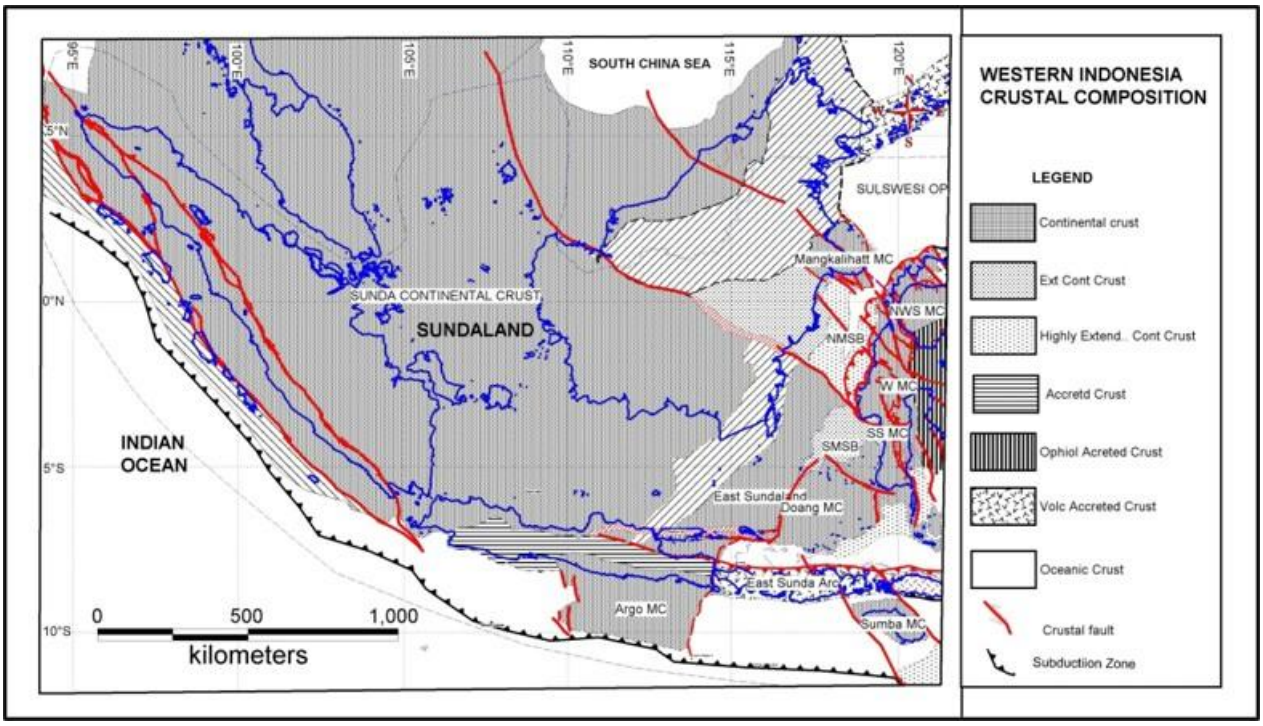


Fig. 2. *Western Indonesia "Sundaland" crustal composition (after Koesoemadinata, 2020).*

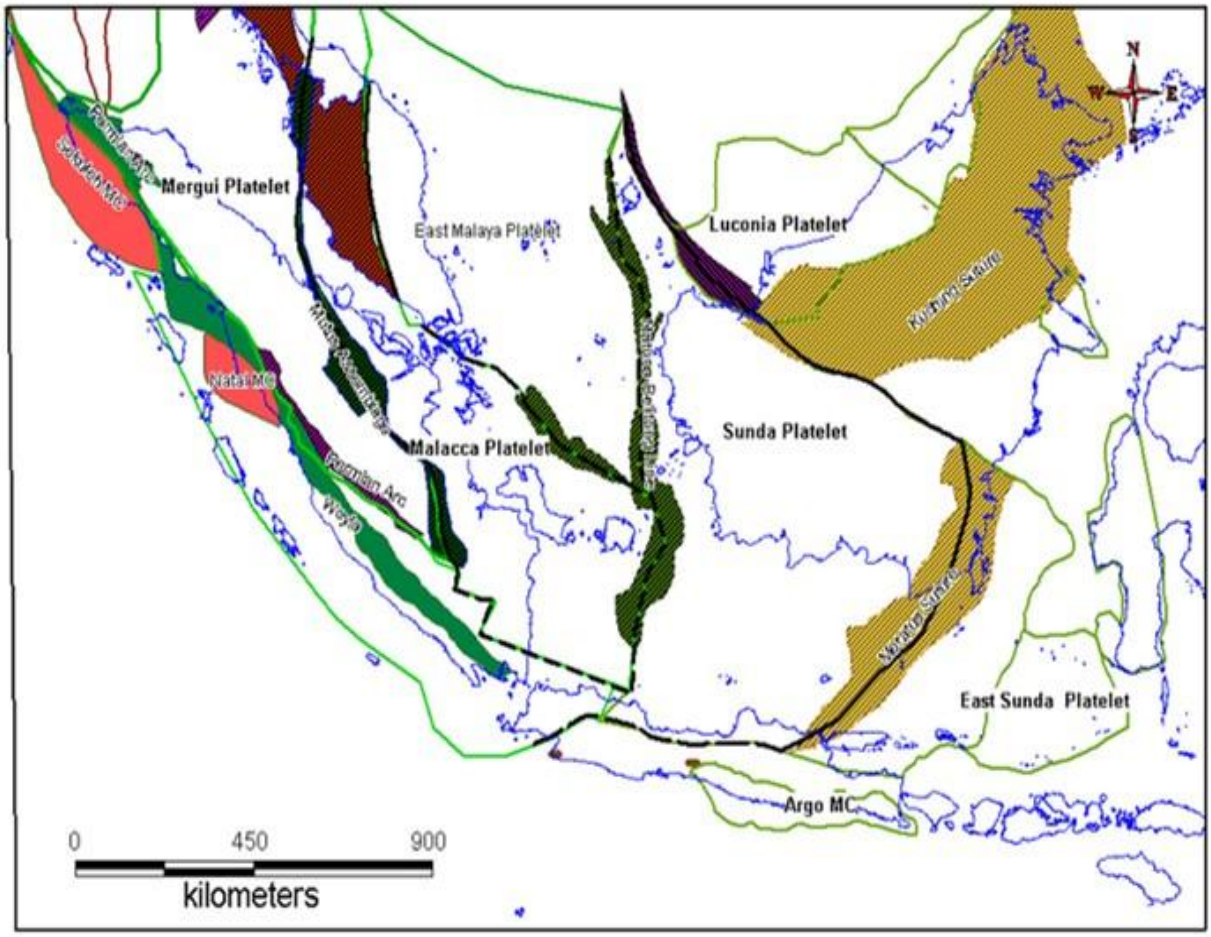


Fig. 3. *Western Indonesia at the end of Mesozoic: A collage of micro-continents separated by sutures. Compiled after Stauffer (1974, 1983), Metcalf (1988), Pulunggono & Cameron (1984), and others.*

outer arc island west of Sumatra, where the Indian Ocean plate is subducted beneath the Sunda continental crust, creating a narrow sliver of accreted crust.

On the southern periphery, however, the accreted crust underlies most of the island of Java, and is called intermediate crust by Hamilton (1979). Hamilton (1979) based this concept on the petrochemical composition of the Sumatra present-day arc volcanoes which tend to be acid and explosives; while those of the Java arc volcanoes tend to be more basic. The Java volcanoes appear to be underlain by an intermediate to oceanic crust in contrast with the Sumatra volcanoes, which are inferred to be underlain by continental crust. More recently, Smyth (2005) postulated that the Southern Mountains of East Java be is underlain by a micro-continent as indicated by the explosive volcanism and also the presence of zircon with isotopes typical of the Gondwanaland (Smyth et al., 2008).

This micro-continent is called Argoland and underlies the entire East Java Southern Mountains all the way to the subduction zone in the south, shown by presence of shallow sea of the subduction accretionary wedge. To the north this micro-continent does not continue to join the East Sunda Micro-continent, as it's separated by the Java intermediate crust of Hamilton (1979). The fore- runner of the Argoland is subducted beneath the (East) Sunda continental plate, as indicated by

the strong negative anomaly of the Kendeng Zone, where the deep marine turbidites sequences are thrusted northward towards the East Sunda continental crust.

Intermediate or accreted crusts are further interpreted to be present along the partly uplifted Meratus suture; it is seen to separate the East Sunda from the Main Sunda continent (Fig. 2); and the Kuching Zone, equally separating the Sunda continent from the Luconia micro-continent in the South China Sea.

An extended continental crust is indicated beneath the Kutei Basin, facilitating the deposition of extremely thick pro-grading Neogene deltaic sediments. Highly extended continental crust is also interpreted beneath the North and South Makassar Strait, as the West Sulawesi and South Sulawesi micro-continent are being rifted apart and separated. There are indications that in the North Makassar Basin the separation has been completed with the presence of submarine volcanic cones previously interpreted as carbonate reefs.

It is toward the end of the Mesozoic or at the beginning of the Cenozoic that Sundaland consolidated by accreting to the Southeast Asia subcontinent of Asia; entirely exposed as land area, subject to erosion and denudation, that created a regional unconformity representing the entire Paleocene.

CENOZOIC TECTONIC DEVELOPMENT: TECTONOSTRATIGRAPHY

Western Indonesia tectonic setting consists of a stable Sundaland with its core in SW Kalimantan and being an extension from the Malaya Peninsula. This Sundaland is surrounded by Cenozoic sedimentary basins of various origin. On the west, southwest and south periphery it is subjected to the subduction of the Indian Oceanic plate beneath the Sundaland continental plate, resulting into a volcanic island arc system with its fore arc and back-arc sedimentary basis. On its eastern periphery the Sundaland terrains have been rifted eastward to form a passive margin which develop deltaic basin and platform, notably the Kutei Basin, (see Fig. 4).

These basins on the margin of the Sundaland have been thoroughly explored by oil companies resulting a huge database of subsurface geology (seismic and well data). These subsurface data reveal that practically all the Cenozoic basins actually are composite multi-story basin, which consists of Paleogene rift-valley basins superimposed by Neogene basins of various origin as mentioned above (fore-arc and back-arc basins of Sumatra and Java islands, and passive margin basins in Eastern Kalimantan).

Given the Cenozoic basins are poly-history in nature, the Cenozoic development is then best approached using tectonostratigraphic analysis. The following tectonostratigraphic megasequences can be recognized through-out the basins of entire Sundaland (see Fig. 5, from base to top):

- Pre-rift mega-sequence
- Syn-rift mega-sequence: Middle Eocene-Late Oligocene
- Post-rift mega-sequence: Early Miocene
- Syn-orogenic mega-sequence: Middle Miocene-Pleistocene

However, the age of rifting varies across the basins. In the western Sundaland basins (Sumatra and Western Java, see

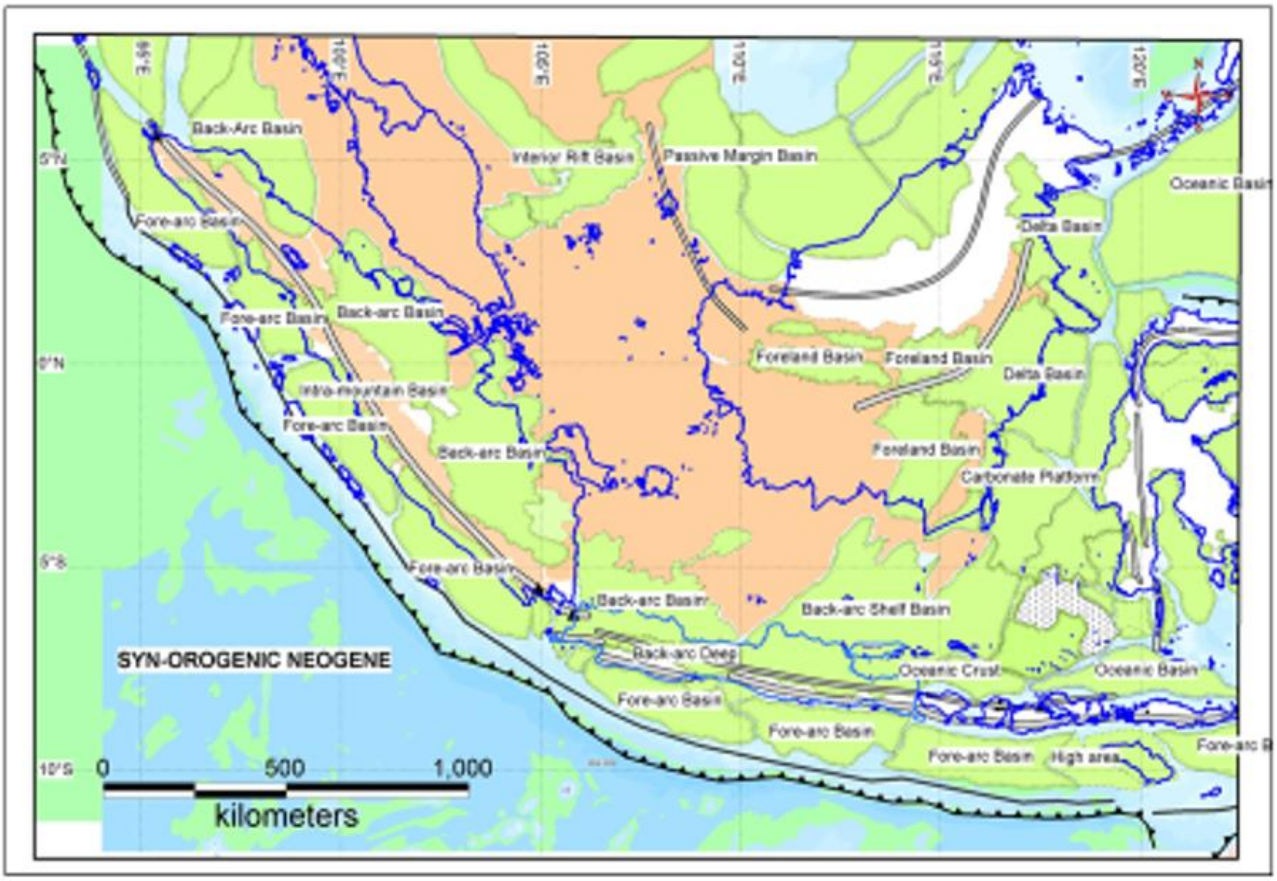


Fig. 4. *Present day sedimentary basin coverage of Western Indonesia: Cenozoic Composite poly-history basin. Neogene basins (in light green) are the results of subduction (back-arc and fore-arc basins) as well as rifting (passive margin platforms and deltaic basins) activities. These Neogene basins are overlying masking Paleogene basins, which are mainly rift-valley basin, mainly known from subsurface data.*

Fig. 2) the rifting ceased at the end of Oligocene, while in the Eastern Sundaland (Eastern Java and Eastern Kalimantan) the rifting ceased at the end of Eocene, or even much earlier. Rifting may also have started at different points in time from Paleocene to Early Eocene.

In the western Sundaland the end of rifting and active sediment fill was followed immediately by a marine clastic transgression and then by the development carbonate platforms (Peutu and Baturaja Fm.) forming the immediate post- rift mega-sequence. In Mid-Miocene this was followed by a subduction, the uplift of a volcanic arc and the development or subsidence of the associated basins resulting into the Syn-orogenic mega-sequence. In the western and eastern Java, the back-arc basins developed into deep marine troughs with turbiditic and volcanic debris flow deposits. It is noted that, Bogor Trough and Kendeng Trough lie in proximity of the volcanic arc and shallowing shelf basins to the north where carbonate shelf facies developed, e.g. NW Java Basin and NE Java basin, which are hardly affected by the subduction tectonics.

In Eastern Kalimantan rifting resulted into the thinning of the continental crust and separation from the West Sulawesi micro-continent and a passive margin type basins developed during post-rift time (Kutei Basin and Tarakan Basins).

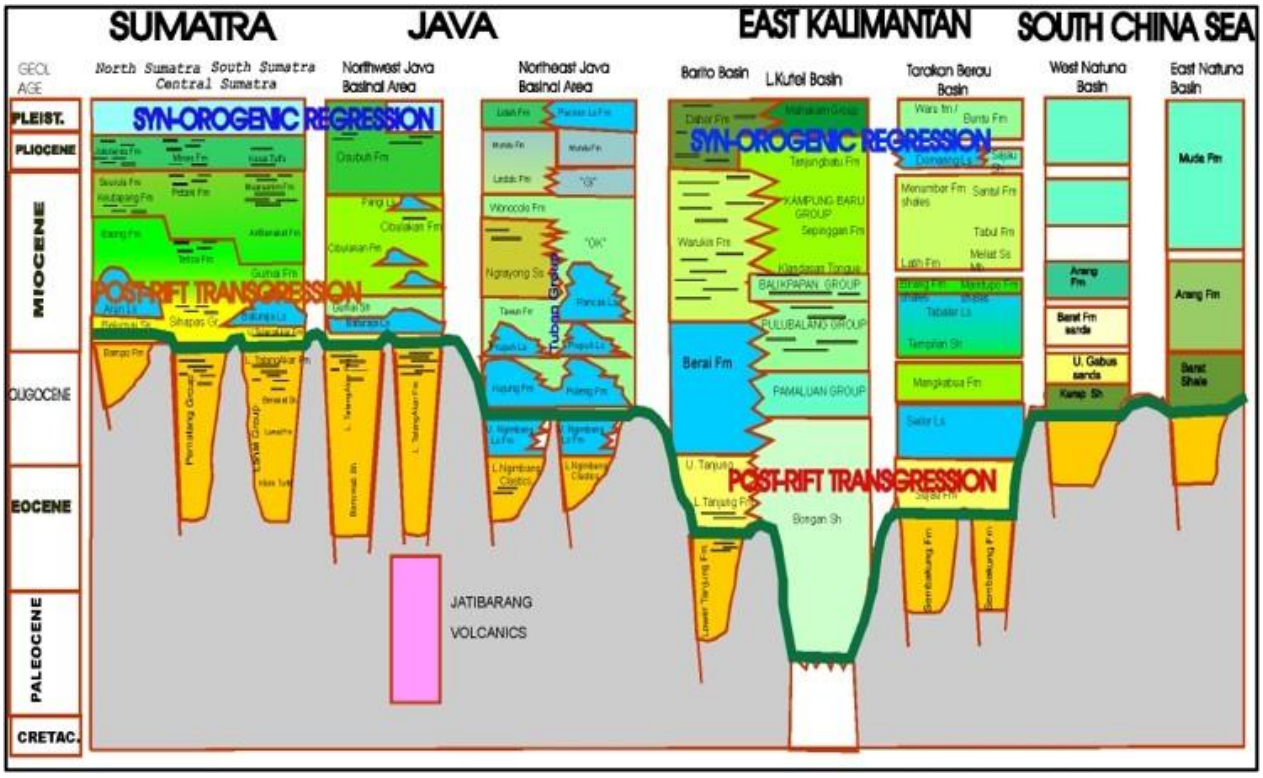


Fig. 5. *Western Indonesia tectonostratigraphic development.*

The coeval uplift of the Kuching Mt. Range to the northwest provided sediments that

accumulated as large pro-grading large delta basins of Eocene age, presumably preceded by a clastic transgression and carbonate platform development (see Fig. 8 and Fig. 9). In Southeast Kalimantan the Meratus Suture was uplifted into the present mountain range, shedding clastics into developing a foreland basin (Barito Basin) and two hinterland basins (Pasir and Asem-asem basin). These Late Miocene to Pliocene sediments therefore belong to the Syn-orogenic mega-sequence.

PALEOCENE PRE-RIFT OCCURENCES

Paleocene Pre-rift occurrences have been identified at several localities in Sundaland as follows (see Fig. 6).

North Sumatra (Cameron et al., 1980): Paleocene is indicated by the Tampur platform limestone which is underlying the syn-rift Bruksah Fm. The Tampur Fm. is correlated with the Meucampli clastics with slight volcanics, interpreted as a back-arc basin deposit; and the Brueh Volcanics representing the volcanic arc.

South Sumatra (Ryacudu, 2005): Pre-rift volcanics is indicated by the Kikim Tuffs; established as underlying the non-marine Lemat Fm of the Lahat Group syn-rift deposit.

Java (Hutabarat, 2011): Pre-rift is represented by 2 occurrences of Jatibarang volcanics, geochemically interpreted as arc volcanics. The first was dated 57,8 ± 1,4 Ma to 50,3 ± 2 Ma, while the second was dated 47 Ma to 39,19 Ma, with corresponding subduction at Loh Ulo Mélange. Pre-rift indicated in southern Banten (Western Java) by the pre-Cikotok Volcanics, with its corresponding subduction represented by Ciletuh Mélange.

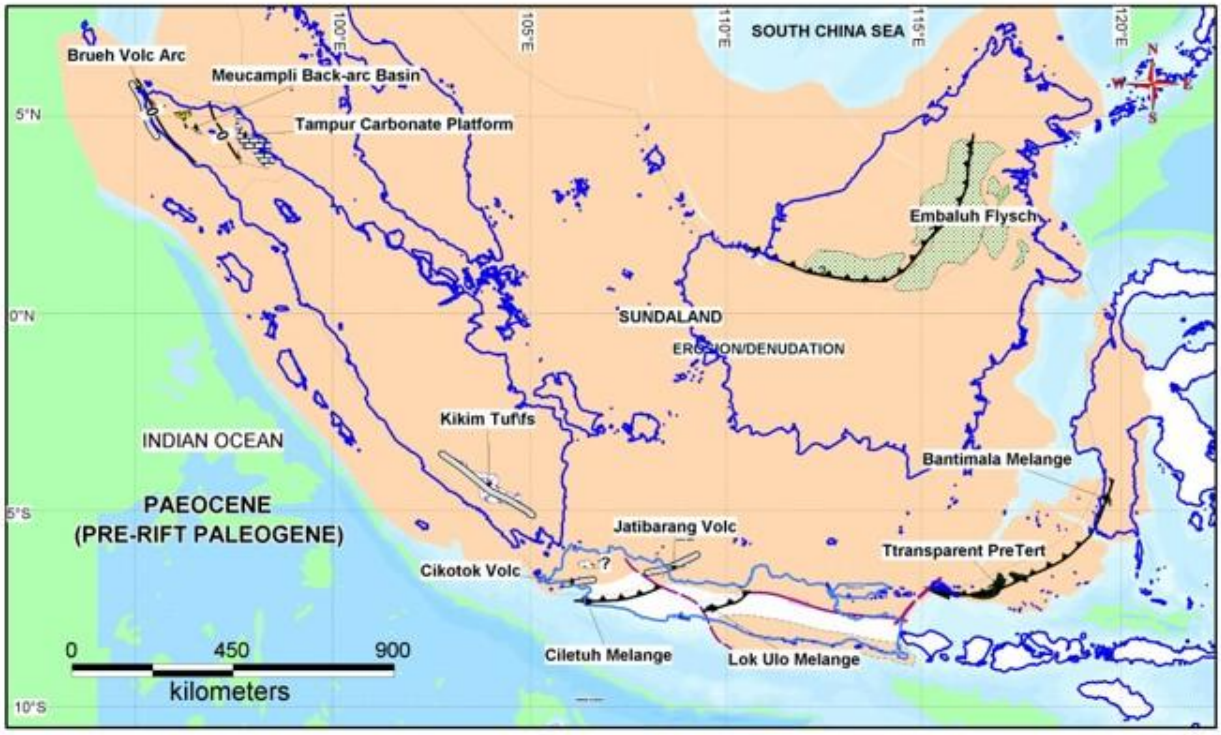


Fig. 6. *Western Indonesia Paleocene Pre-rift Development.*

North-central Kalimantan (Soeria-Atmadja et al., 1999) represented by radiometrically dated volcanics interpreted as volcanic arcs with the associated subduction zone and the occurrences of deep marine flysch sediments.

During the Paleocene time the Sundaland was generally a land area with arc volcanism at its periphery, subject to erosion and denudation, resulting a great unconformity and no Paleocene deposits with fossils have been found, except probably in North Sumatra and Northern Kalimantan.

PALEOGENE SYN-RIFT DEVELOPMENT (MIDDLE MIOCENE–LATE OLIGOCENE)

The main Paleogene Period as represented by Eocene and Oligocene developed as isolated rift-valley grabens and half-grabens (Fig. 7), which tend to be elongated, often interconnected by rivers. Syn-rift deposits have limited lateral continuity being restricted within grabens/half-grabens only, while on the intervening horst pre-rift sediments are directly overlain by the Early Miocene post-rift deposit.

Distribution

The presence of rift valley/graben type basins was first recognized in the West Natuna basinal area (White, Jr. & Wing, 1978) and at the base of the Central Sumatra Basin (Mertosono & Nayoan, 1974).

Later, it was also recognized and described in North Sumatra Basin (Caughey & Wachyudi, 1993), South Sumatra Basin (Ryacudu, 2005), Sunda and Asri basins (Wicaksono et al., 1995; Aldrich et al., 1995); Northwest Java basin (Gresko et al., 1995, Noble et al., 1997) and Northeast Java Basin (Bransden & Matthews, 1992; Manur & Barraclough, 1994). These grabens are also known at

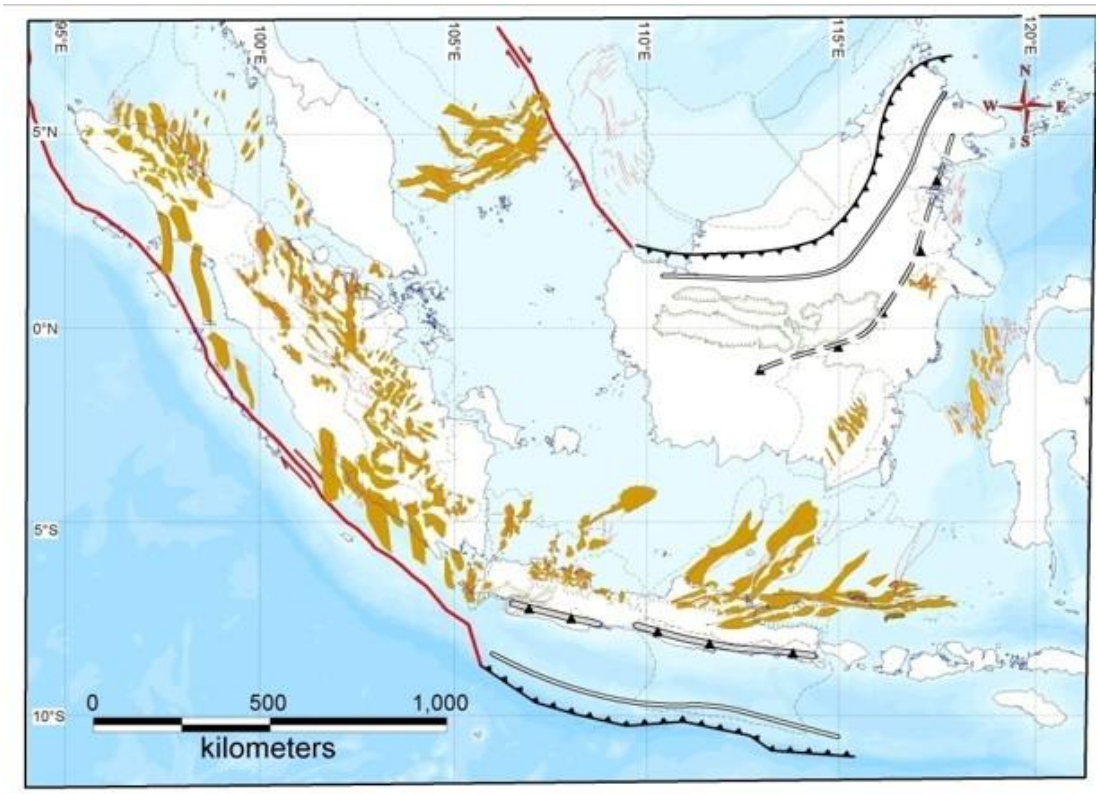


Fig. 7. *Western Indonesia Paleogene Syn-Rift Development.*

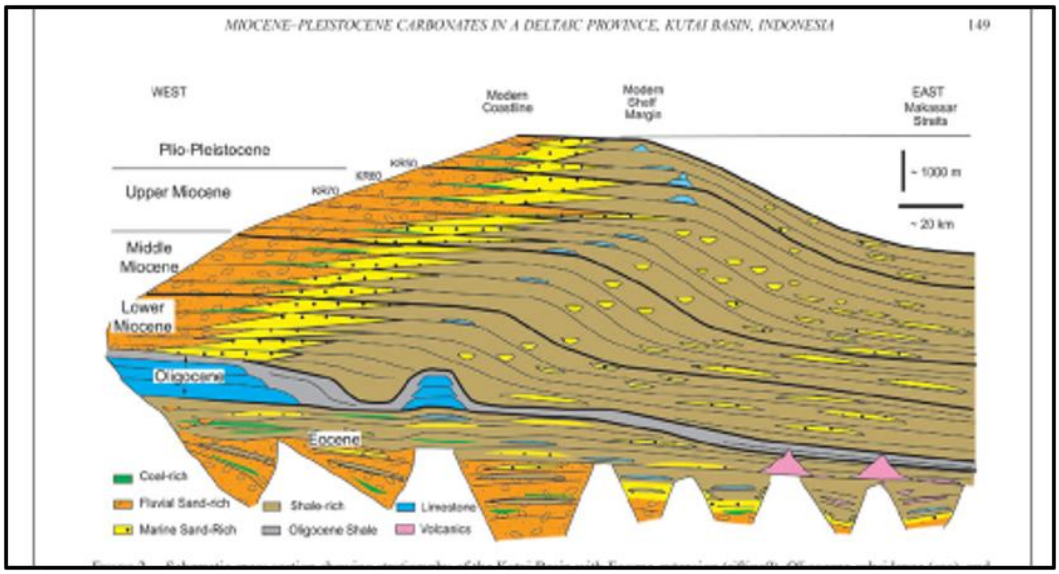


Fig. 8. *Central Kutei Basin E-W Section, showing the presence of half-graben fill (after Saller et al., 2010).*

the base of fore-arc basin of NW Sumatra. Syn-rifts deposits are generally recognized at the base of Neogene basins, but it is also recognized as inter-montane basins along the Bukit Barisan (e.g. Ombilin Basin, Koning, 1985).

In Kalimantan Paleogene syn-rift deposits have been described by Kusuma & Darin (1989) in the Barito Basin, while in the Central Kutei Basin its presence is indicated from seismic section as shown by Saller et al. (2010) (see Fig. 8).

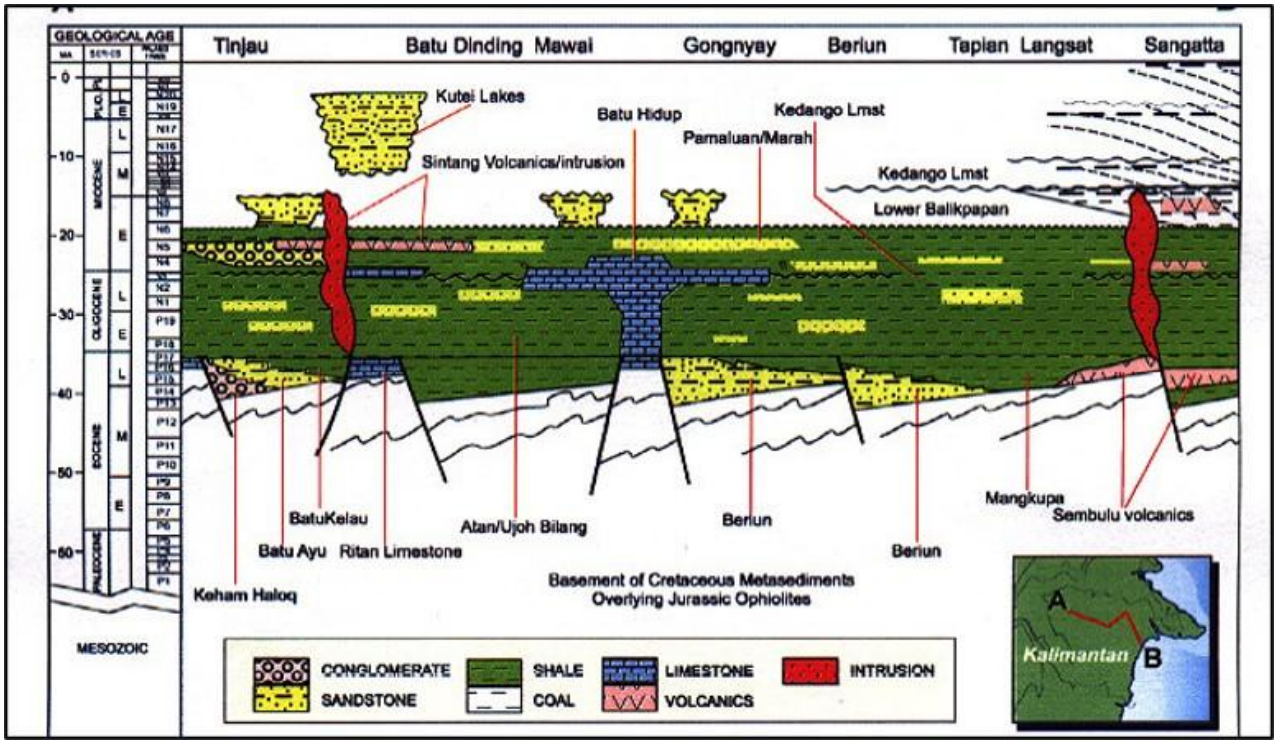


Fig. 9. *Northern Kutei Basin E-W section showing the presence of Horst and Graben structure with Eocene graben fills at the base of the Tertiary (after Feriansyah et al., 1999).*

In the Northern Kutei Basin, Eastern Kalimantan the Paleogene is outcropping and interpreted as a patch-work of graben/half-grabens and horsts, with environment of deposition ranging from non-marine lacustrine, fluviatile to deep a marine environment, called facies tracts (Feriansyah et al., 1999, see Fig. 9). In the Sangatta Block toward the east, the Paleogene is represented by at least 2 half-grabens: The Beriun Graben and the East Bungalun (Sembulu) Graben.

In South China Sea rift-valley grabens have been recognized as the West Natuna basinal area (Gage & Wings, 1980; Daines, 1985) at the intersection of the NW-SE trending Malay Basin and the NE-S opening trend of the South China oceanic spreading center.

Facies Development

The grabens are filled by alluvial fans and braided rivers as well as deltaic in a lacustrine environment, as these grabens often forming lakes or marshes with algal coal such as in the Central Sumatra Basin (Brown Shale, Pematang Group, Heidrick & Aulia, 1993), South Sumatra Basin (Lemat Fm of the Lahat Group, Ryacudu, 2005), Sunda and Asri Basin (Banuwati Shale, Aldrich et al., 1995), in the NW Java Basin (Jatibarang Fm, Gresko et al., 1985), and also in the West Natuna basinal area. Marine incursions often took place such as in the North Sumatra basin (Bampo Fm., Caughley & Wachyudi, 1993).

In the South Sumatra basin, marine syn-rift facies cannot be distinguished from the overlying post-rift facies, deep marine Gumai Fm. Basic volcanism sometime accompanied rifting in the South Sumatra Basin (Lahat Group, Ryacudu, 2005). In general, however, the syn-rift facies developed in fluviatile and lacustrine facies throughout Sundaland.

The lacustrine deposits that were deposited in a restricted anoxic environment host the main source rock for the overlying Miocene post rift sequences (Williams & Eubank, 1995; Lambiase, 1990; Lambiase and Morley, 1999). The role of Paleogene development in Sundaland and its role to the petroleum systems in Western Indonesia is discussed by Sudarmono et al. (1970).

The syn-rift deposits are generally well compacted. The sands are generally tight (Ombilin Basin, Koning, 1985), Barumun Basin/Kisaran Block, Aimar et al., 2016), but they are known to contain gas (Pagerungan Field, NE Java Basin (Yaseen et al., 1993, Kaldi et al., 1997), and Runtu Field in northern Kutei Basin, (Guritno & Chambers, 1999).

The shales are suitable for fracking shale oil (In the North Sumatra known as 'Black Clays' renamed as Bampo Fm, known since pre-World War II as *combustible shale* (Van Bemmelen, 1949).

Rift Bounding Fault Pattern and Origin of Rift Valley Basin

Rifting bounding faults in Sumatra and western Java show a definite a pair of trends: N-S and WNW-ESE (Heidrick & Aulia 1993; Longley et al., 1990; Moulds, 1989), see Fig. 10. As it will be discussed below the western periphery of the Sundaland during the Paleogene was an active plate margin represented by the Mentawai transcurrent fault, forming the active margin of the southwestern Sundaland continent and parallel trending Padang (Isle) Fault on the eastern side of the Central Sumatra Basin. (Heidrick & Aulia, 1993).

Rift bounding faults in Eastern Java also a show a coupled NE-SW and E-W trends (Fig. 10), which is tectonically difficult to

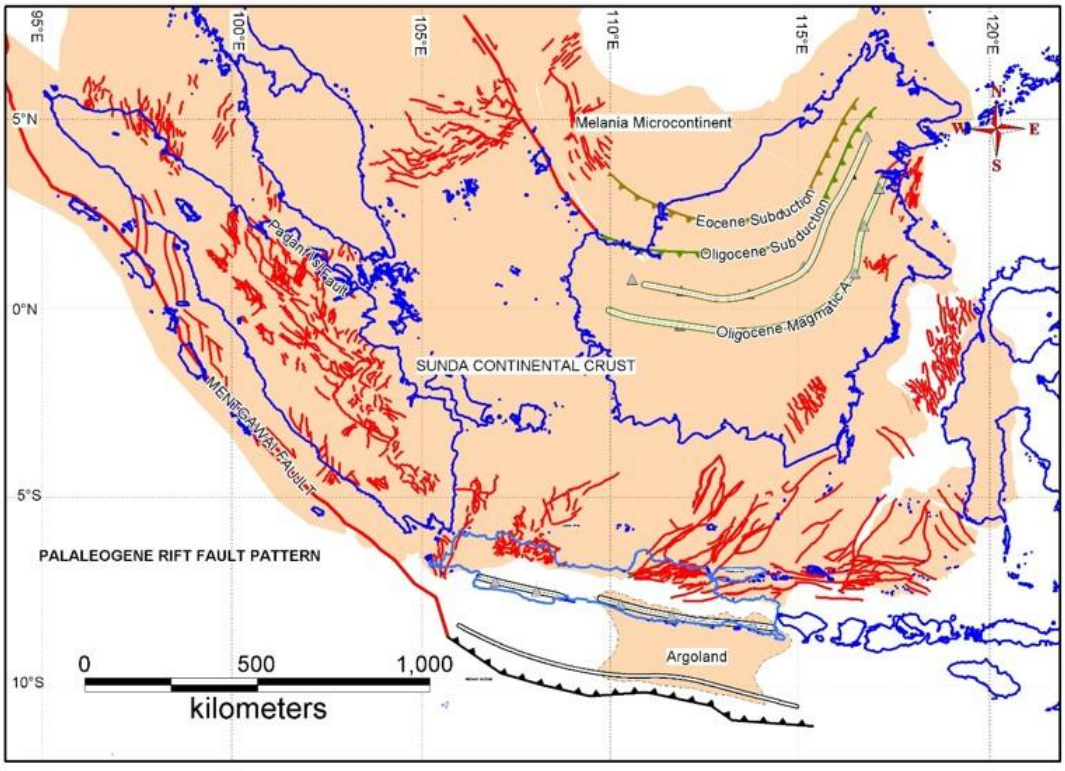


Fig. 10. *Rift bounding fault pattern (compiled by the author from various sources).*

explain. It is probably related to the E-W trending RMK Fault zone.

The rift pattern in Kalimantan is also not easy to explain, beneath the Barito Basin it is trending NNE-SSW (Kusuma & Darin, 1989). On the eastern side of the North Makassar Basin, occupied by the West Sulawesi Basin and on the West Sulawesi micro-continent it rifting is more northerly (Nur'aini et al., 2005). It is generally believed that the Kutei Basin is superimposed on a series of rift valleys (see Figs. 8 & 9), related to NNW rifting and the separation with West Sulawesi micro-continent from the Kalimantan (Fraser & Ichram, 1999). In the northern Kutei basin the bounding fault orientation is unclear but determined as trending N-S (Feriansyah et al., 1999).

Rift pattern in the West Natuna Basin: several rift-valley basins were formed in the Paleogene trending mainly in NE-SW direction. To the northwest, the West Natuna Basin adjoins the NW-SE trending Malay Basin. The boundary between the two basins is unclear. Structural features trending NE-W are considered typical of the West Natuna Basin, while NW-SE trending features are considered as the predominant style of the Malay Basin. (White Jr. & Wing, 1978; Wongsosantiko & Wirojudo, 1984; and Ginger et al., 1993).

Paleogene Sundaland Periphery and Non-Rift Basins

The Mentawai Dextral Transcurrent Fault in western Sumatra separated the Sundaland from the Indian Ocean (Fig. 11). The Mentawai Fault is represented on Outer Arc Islands as mélange; but most likely a fault mélange, rather than related to subduction processes.

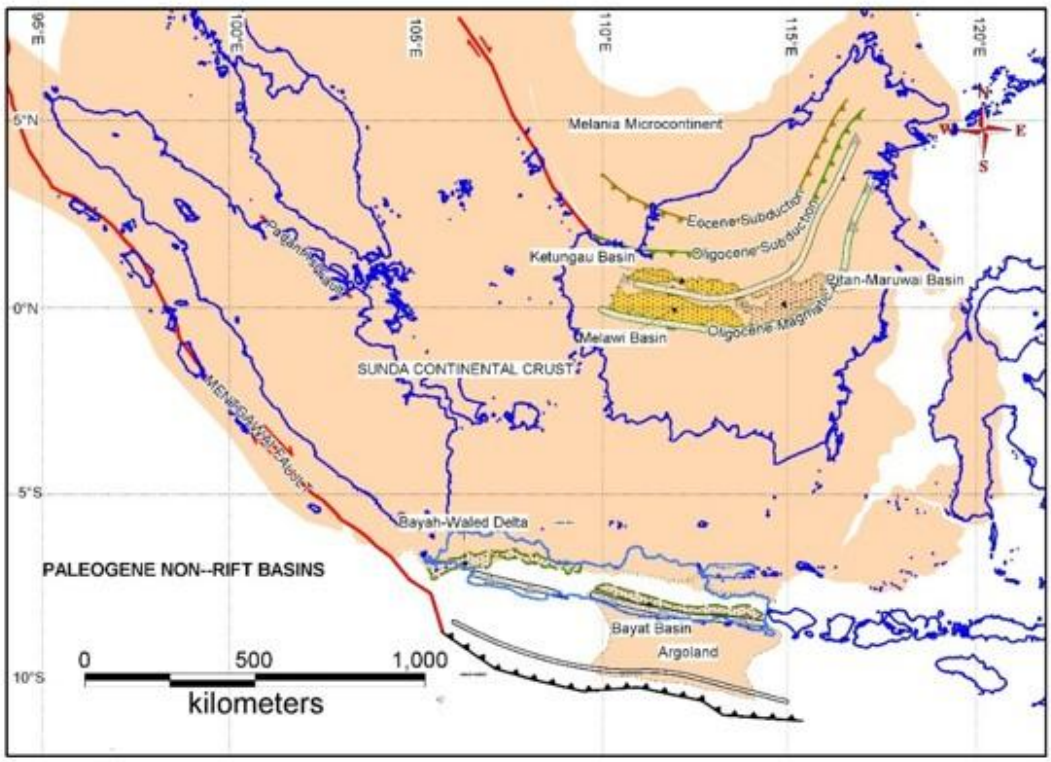


Fig. 11. *Sundaland Periphery and Non-Rift Basins (compiled by the author from various sources).*

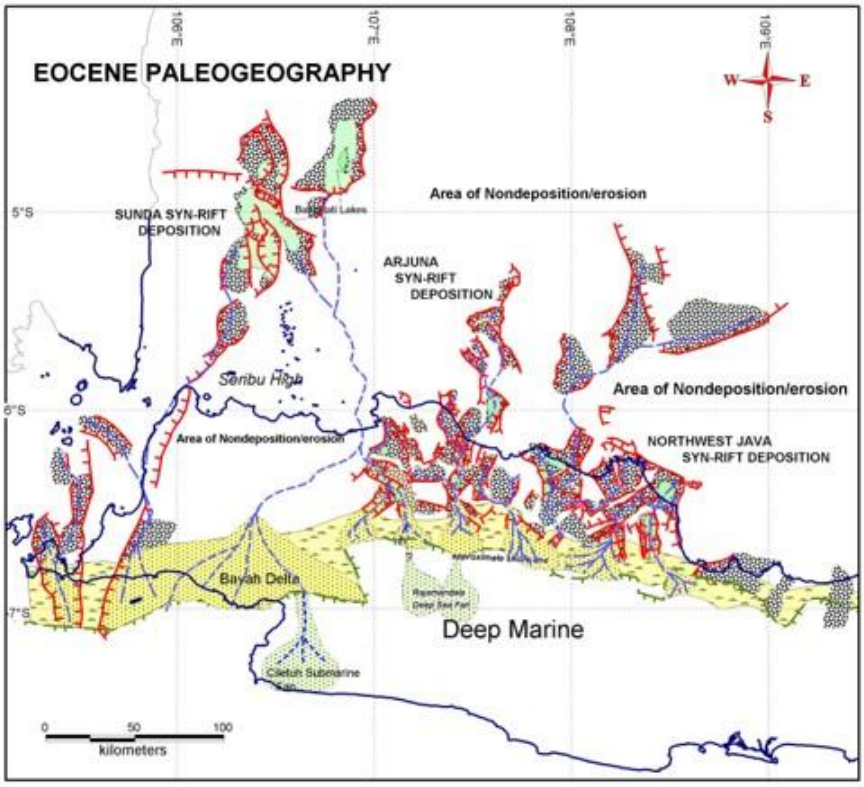


Fig. 12. *SW Java Eocene Development (Koesoemadinata, 2020).*

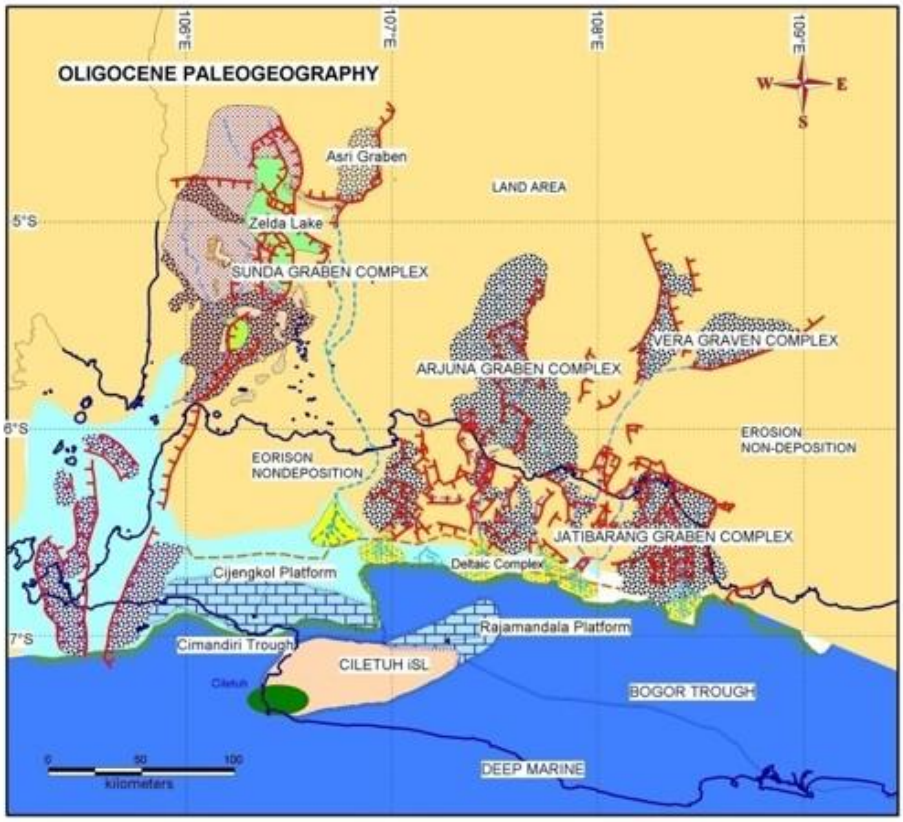


Fig. 13. *SW Java Oligocene Development (Koesoemadinata, 2020).*

In the north central Kalimantan, the Embaluh Zone is probably a subduction zone mélange and related to the volcanic arc to the south (Kelian Volcanic arc) and associated foreland /fore-arc basins in the Northern Central Kalimantan (Melawi, Ketungau and Ritan-Maruwai/Upper Kutei) basin. Note that the Ritan-Maruwai Basin is also known as Upper Kutei Basin. However, since this basin is separated by Kelian Volcanic arc from the Lower Kutei basin. This volcanic arc appears to be related to the subduction mélange of the Embaluh Zone. Accordingly, this basin is a fore-arc basin and therefore related to the Melawi-Ketungau basins.

The West Sulawesi micro-continent was still attached to East Kalimantan block, and the eastern periphery of the Sundaland was probably a subduction zone in which Banda oceanic plate was subducted below the West Sulawesi and South Sulawesi micro-continents.

The southern periphery of the Sundaland during Paleogene is rather complicated. The presence of subduction zone in southern Java is fairly well established by the presence of associated volcanic arc shown by their radiometrically dated volcanics (dykes and lava flows) in the Southern Mountains of Java [Pacitan (3), Bayat (2), Parangtritis (2), Kulon Progo (5), Karang Sambung (3), Pangandaran 2, (Soeria-Atmadja, et al, 1994)]; further indicating that during the Paleogene the Sundaland continental margin developed as a fore-arc basin in a passive margin setting. On this passive margin setting a delta basin developed in in SW Java; Bayah Delta, Waled Delta during the Eocene, developing into a carbonate shelf with reef growth (see Figs. 12 & 13). The relationship between the rift-valley basins and passive margin delta basin in Southwestern Java is shown in Figs. 12 and 13.

In Eastern Java the presence of the Argoland Microcontinent complicated the matter. This micro-continent does not appear to be fully enshrined into East Sundaland as most authors assume, because it is still separated by a deep oceanic trough with a negative Bouger gravity anomaly. The author interprets only the oceanic plate plate fore-runner of micro-continent that was subducted below the Sunda continental plate. Coevally, a passive margin basin setting developed on the northern slope of East Java Southern Mountain, leading to the deposition of Bayat coastal sand deposit and the overlying Gunung Wungkal platform carbonate.

SUMMARY & CONCLUSIONS

- Western Indonesia/Sundaland Cenozoic Development is viewed from tectonostratigraphic mega-sequences and can be subdivided into:
  - Pre-rift (Paleocene to Early Eocene)
  - Syn-rift (Middle Eocene to Late Oligocene)
  - Post-rift (Early Oligocene /Early Miocene)
  - Syn-orogenic (Middle Miocene to Pliocene)
- Pre-rift occur mainly in Paleocene time until Early Eocene and is characterized by erosion or denudation and non-deposition, except at its periphery with terrestrial arc volcanism related to a subduction.
- Paleogene is mainly developed as rift-valley basin with normal bounding faults; filled with terrestrial clastics, often containing

lacustrine facies in a restricted anoxic environment to form prolific source rock with potential shale oil.
- Post-rift is characterized by clastic transgression followed by a carbonate platform development, which in Eastern Sundaland took place as early as Oligocene time.

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