PROCEEDINGS, INDONESIAN PETROLEUM ASSOCIATION
Forty-First Annual Convention & Exhibition, May 2017

MIDDLE EOCENE PALAEOGEOGRAPHY OF THE GREATER MAKASSAR STRAIT REGION, INDONESIA: A REVIEW OF EOCENE SOURCE ROCK DISTRIBUTION

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ABSTRACT

The hydrocarbon exploration in the Greater Makassar Strait region now becomes challenging and attractive though some deep exploration wells drilled in the region have resulted in unsuccessful results. This is because of lack of subsurface data and poor understanding of the Paleogene petroleum system of the region though some geological and geophysical studies are available including geological fieldwork to review the stratigraphic sequences, structural development, and hydrocarbon seepage samples in the onshore southwestern Sulawesi and Kalimantan. However, many oil and gas fields have already been discovered and produced in the Neogene, shallower reservoirs.

Regional geology, drilling results, and seismic interpretation suggest that the Early-Middle Eocene syn-rift sequence in the basins of onshore East Kalimantan region, ie. Kutei and Barito; basins in the Makassar Strait region, ie. North Makassar and South Makassar; basins in the west Sulawesi, ie. Lariang and Karama; and basins in the southwest Sulawesi, ie Sengkang, were all deposited in a non-marine lacustrine, fluvio-deltaic to restricted shallow marine depositional environments as a basin margin of Sundaland Craton. Later, strong marine influence started to occur in Late Eocene as the earliest marine transgression cycle in the region.

Based on the palaeogeographic reconstruction and interpretation, and geochemical analyses, it is believed that mature shales and coals of the Eocene sequence become the major source rocks for hydrocarbon accumulation in the Paleogene reservoirs and may also include the Neogene sequence.

INTRODUCTION

The Early-Middle Eocene sediments in the Greater Makassar Strait are the oldest sequence deposited in the syn-rift in the southeastern end of Sunda Craton (Figure 1). The sediments were generally deposited in non-marine fluvio-deltaic-lacustrine geologic to marginal shallow marine settings and gradually tend to become deeper marine toward east and northeast. The lateral distribution of this sequence covers several basins including Barito and Kutei Basins in the west, North and South Makassar Basins in the center, Lariang and Karama Basins in the east, and Sengkang Basin and onshore southwest Sulawesi in the southeast (Figure 2).

There are many Eocene stratigraphic nomenclatures have been used in the published papers, but most of them are in lithostratigraphic approach. This has caused the beginning of confusion of the nomenclature utilization, extension, and correlation across a large (regional) area such as the Greater Makassar Strait. The syn-rift sequences were deposited laterally in relative narrow of many grabens and horsts with rapid facies changes laterally and vertically (Figure 3) in each basin. In this paper, the sequence has been assigned lithostratigraphically to be the Tanjung Formation and/or time equivalent sequence dated as Early-Middle Eocene.

Marine influence started to occur at the latest stage of the deposition in late Late Eocene as the earliest transgression cycle in the region as indicated by the presence of deposition of marls and carbonate stringers with large *Foraminifera* and shells (Siregar and Sunaryo, 1980) in Early Oligocene. Later, the formation is overlain by significant development of carbonates of the Berai Formation in the eastern Kalimantan region and Makassar Straits or Toraja Formation in the west and southwest of Sulawesi.

The Eocene shales and coals have been recognized as mature source rocks and have potential to produce oil and gas. Curiale and Decker (2010) confirmed that the occurrence of oil-prone, terrigenous Eocene source potential in extensive areas of eastern Kalimantan and western Sulawesi; and oil-prone, lacustrine Eocene potential in the southern portion of Makassar Strait.

The purpose of this paper is to review the overall Eocene source rocks over the Greater Makassar

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Strait region following the most recent published data and analysis, and many internal exploration studies and interpretation. The Middle Eocene palaeogeography has been reconstructed to show the development and lateral distribution of the source rocks across the region though there is still lack of data available in public to cover many parts of the region.

EOCENE SEQUENCE IN EAST KALIMANTAN REGION

Barito Basin

In Barito Basin, the Tanjung Formation consists of sandstones, conglomerates, shales, and seam of coals deposited in non-marine fluvio-deltaic lacustrine syn-rift and later, transgressively became dominantly shallow marine shales and marls of the Early Oligocene section. The formation is well-exposed in the northern part of the basin ("Barito-Kutei Cross-High") and western flank of Meratus High (Siregar and Sunaryo, 1980).

In the northern part of the basin, Panain-1 (Union Oil, 1974), Sorai-1 (Union Oil, 1975), and Mukut-1 (Unocal, 1989) penetrated the Middle Eocene fluvio-deltaic section of the Tanjung Formation, but dry. Ngurit-1 (Permin Tracer, 1995) encountered non-commercial wet gas (aggregate flow of 1,500 MSCFD) in several Lower Tanjung sandstones and reached a total depth of 3270 feet (Heriyanto et al, 1996) in the Senonian quartzite basement. Good shows of residual oil were detected in the sidewall cores from two gas-condensate productive sandstones. Good to excellent potential source rocks in the Lower Tanjung come from the shales and coals which have total organic carbon (TOC) of 1-20 wt% and hydrogen index (HI) of 200-400 mgHC/g TOC. The kerogen type is a mix of Type II/III terrestrial plant (coaly) debris and Type I/II lacustrine algal matter (Heriyanto et al, 1996). Towards southeast nearby Tanjung Oil Field, in Muya-1 (Permin Tracer, 1995) well, oil shows were also observed in the sidewall cores, but no liquid hydrocarbon was recovered.

The coarse clastic section of the conglomerates and sandstones are well-developed in the lower and middle parts as the Lower Tanjung sequence with widespread, shallow marine shales and marls in the uppermost part as the Upper Tanjung representing basal marine transgression deposition (Kusuma and Darin, 1989). These Early Oligocene marine transgression shales provide an effective top seal for the Tanjung plays. The thickest formation observed in the outcrops could be around 1900 m and thinning towards south and west. Age of the structuring rift is interpreted to be in Paleocene to Early Eocene resulted in structural basement lineaments of horst and graben structure in northwest-southeast direction (Kusuma and Darin, 1989; and Rotinsulu et al, 1993).

Deposition of the sequence began in Middle Eocene (Satyana and Silitonga, 1994; Witts et al, 2011; and Witts et al, 2014) in the northern and eastern part of the basin. The major sedimentary provenance of the formation is Schwaner Mountains immediately to the west besides paleocurrent data suggesting the presence of sediment source in Karimunjawa Arch in the south (Witts et al., 2011 and 2014). The Schwaner Mountains could be as a sedimentary provenance not only to Barito Basin but also to West Java in Late Eocene (Clements and Hall, 2008; Clements and Hall, 2011; and Setiawan et al, 2013). The Schwaner and Karimunjawa are the southeastern most part of the Sundaland Craton core.

The Tanjung sequences extended toward east across the present-day location of Meratus, Asem-Asem Basin, and Paternoster Platform. At the time of the Tanjung deposition, these features were connected forming a single, wide depocentre throughout much of the Paleogene as a stable, shallow shelf platform prior to the uplift of Meratus Complex between Early-Middle to Late Miocene (Bon et al, 1996; Rotinsulu et al, 1993; and Witts et al, 2014). The shelf was dipping towards northeast and east.

Rotinsulu et al (1993) reported that the deltaic shales in the Tanjung section are organically rich and have TOC of 0.6-5.4 wt% while thin coal layers have TOC of 43.6-65.9 wt%. Kerogen types are vitrinite Type III and amorphous Type I/II organic matter. The maturity varies from immature to early mature in the north to over mature near the present-day basin center. Initial hydrocarbon generation in the Paringin-Bangkau depocenter began in Middle Miocene. North-northwest orientation of vertical and lateral migrations takes place towards Tanjung Raya area where all of the hydrocarbon production is present.

Oil isotope and biomarker ratio indicate that the Tanjung oil type is lacustrine origin (Rotinsulu et al, 1993), but Kusuma and Darin (1989) suggested that the oil came from the Lower Tanjung coals. The oil has API gravity of 36.7°-41.9° with pour point of 105°F, paraffiniferous with low wax content and low sulphur of 0.01-0.05 wt%. The Warukin oil (fluvio-deltaic oil type) has been biodegradated due to water flushing at shallow depth and temperature less than 70° C.

Tanjung-1 well drilled in 1937 by Bataafsche Petroleum Maatschappij or BPM (the forerunner of Royal Dutch Shell) in Tanjung Raya area was completed with a total depth of 4661 feet at Maastrichtian basement granite as an oil and gas discovery in the Lower Tanjung sandstones. The well flowed 655 BOPD (40º API) with some gas over the interval 3484-3793 feet. Tanjung Field is the largest oil and gas field in the Barito Basin to date. Around 170 development wells have been drilled. Many wells were drilled to test the Lower Tanjung but have limited success. This is possibly caused by the Plio-Pleistocene tectonics destroying the existing traps and re-migrating the hydrocarbon into newly-formed traps (Rotinsulu et al, 1993). The Lower Tanjung section is generally, relatively thin. The Upper Tanjung thins could indicate the presence of the Lower Tanjung highs or possible paleo-anticlines (Satyana, 1995). The thin of the top seal and limited source quantity could increase the exploration risks in the basin. Investigation to search for less risk of petroleum system components is obviously required.

Kutei Basin

The Kutei Basin is geologically divided into two parts: Upper Kutai Basin in the upper drainage basin (upper Mahakam) area immediately to the northwest of the present-day Mahakam Delta, and Lower Kutai Basin over the delta and to the east-southeast toward present-day deepwater area. Cloke et al (1999) and Moss and Chambers (1999a and 1999b) suggested that the basin was opened in Middle Eocene. The origin of the basin is likely to be a peripheral foreland basin, but Moss et al (1997), and Moss and Chambers (1999a) suggested an extensional basin. In the Kutai Basin, the Tanjung Formation is equal to the Kuaro (Samuel and Muchsin, 1975); Kiham Haloq, Batu Kelau, and Batu Ayu Formations (Wain and Berod, 1989; and Laya et al, 2013); and Keham Haloq, Beriun and Mangkupa Formations (Guritno and Chambers, 1999).

The Eocene sedimentary section was exposed at the surface in the Upper Kutai region as a result of the Early Miocene and younger tectonics processes. The Paleogene to Early Eocene sequence in this basin is continental alluvial coarse clastic facies with minor thin coals (Samuel and Muchsin, 1975; van de Weerd et al, 1987; and Wain and Berod, 1989). The sedimentary fills vary depending on the position with respect to sediment source, paleo-water depths, and geometries of the half-graben (Moss and Chambers, 1999b). The Eocene outcrops may not represent the whole syn-rift section besides lack of wells encountered the section resulting in difficulty in defining the age.

The Tanjung vertical sequence is predominantly carbonaceous and laminated siltstones of the shallow marine reflecting a marine transgression during Middle to Late Eocene (Wain and Berod, 1989). The Late Eocene section could be already in the outer-shelf and deepwater bathyal as suggested by Chamber and Daley (1995). Thick carbonates were deposited on the remnant paleo-highs and around the basin margins. Towards the Lower Kutai, the facies is dominated by deltaic, near-shore facies prior to the shale dominated marine transgression of the deepwater bathyal depositional facies in Late Eocene to Late Oligocene (Rose and Hartono et al, 1978; and Chamber and Daley, 1995) during sag phase. The basin became a large depocentre for Neogene marine shale deposition.

In the Upper Kutai Basin, Wahau-1 (Lasmo, 1997) penetrated Middle Eocene lacustrine facies of the Kiham Haloq (or Beriun) Formation with a total depth of 4856 feet at the Mangkupa Formation. The facies is characterized by organic claystone, siltstones, and minor thin of fine-grained sandstones and coals. The well was drilled through the depocenter of an inverted Eocene half-graben structure (Laya et al, 2013). The Late Eocene transgression strata of the Batu Ayu were encountered by Tengkawang-1 (Lasmo, 1997), Wahau-1, and Tinjau-1 (Mobil, 1985). Tinjau-1 well is dry with a total depth of 9186 feet at the acid igneous rock. Tengkawang tested gas at the rate of 3,260 MMSCFD from the Upper Beriun Formation. Maau-1 (Lasmo, 1997) well reached a total depth at the Beriun Formation with oil and gas shows. The closest well to the Eocene sediment provenance is Batuq-1 (Elf Aquitaine, 1988) which is dry, encountered the Middle Eocene Batu Ayu sandstones at around 735 feet and reached a total depth of 3684 feet in the same formation.

Based on positive gravity anomalies as a combination of the uplift of high density syn-rift sediments and shallow basement rocks, Cloke et al (1997), Cloke et al (1999), and Chambers et al (2004) identified Neogene inversion of two anticlines (Gongnyay and Gergaji half-grabens) that are interpreted as Middle Eocene fault-bounded depocentres bounded by present-day steep reverse faults. The footwall of the fault forms a complex series of extensional faults (now reverse faults). The rifting led to development of a number of discrete asymmetrical half-grabens that switched polarity along strike. The extension was accommodated on NNE-SSW, N-S, and NE-SW trending faults. According to Cloke et al (1999), this inversion fold can be applied to other Middle Eocene depocentres identified throughout the Kutai Basin.

The potential of the Paleogene source rocks remain uncertain though some exploration wells were drilled in the Upper Kutai Basin and confirmed the presence of source rocks. Curiale et al (2006) believed that several of the coals collected in the Kutei Basin qualify as oil-prone potential source using conventional interpretive criteria, though no single coal is correlatable with any single oil in the basin suggesting that these coals cannot be used for oil-to-source correlation purposes.

Bachtiar et al (2013) visited West Sangatta region in the Upper Kutai and collected some Late Eocene rock samples of deltaic facies for source rock potential analysis. The coals have TOC of 45.65 wt% to 78.47 wt%. One of the carbonaceous shale samples has an excellent TOC of 12.62 wt%. The potential yield of the samples is 19.80 mgHC/g rock for carbonaceous shales and between 69.56 and 107.49 mgHC/g rock for coal samples indicating very good to excellent source rocks. HI of the coals range from 130 to 220 mgHC/g TOC. The presence of predominantly vitrinite macerals as well as non-fluorescent amorphous is an indicative of gas-prone sources. Lack of amorphous-fluorescent and low liptinitic materials suggest that the oil-prone kerogen is also present in the rock samples but it may be insufficient to generate oil as the hydrogen content is relatively low. Most of the sediments contain kerogen Type III and Type II. Pyrolysis gas chromatographic analysis of the two oil seepage samples indicate that the oils were associated with a mix of organic matter Type I and terrestrial higher plants of Type II/III. Algae and terrestrial higher plants may have been the source for the oil seepages. During Eocene time the depositional environment was dominated by terrestrial to deltaic settings.

Tengkawang-1 well discovered gas and condensate with oil shows in the Eocene and Oligocene sections (Guritno and Chambers, 1999), but it is not commercial. The TOC ranges from 0.5 wt% to 8.7 wt% in the organic rich shales. Hydrogen index is 100-470 mgHC/g TOC. The Eocene source rocks are lacustrine and fan delta origin and could generate a mix of oil and gas. This is categorized to be kerogen Type II/III.

Maturity of the syn-rift section ranges from late mature to over mature or Ro of 0.9 % to 1.8 % (Laya et al, 2013). The early migration began in Oligocene-Early Miocene and generation of hydrocarbon stopped by late Early-Mid Miocene at the time of basin inversion and regional uplift. In contrast, in the Lower Kutai Basin, the Paleogene has been buried by thick Neogene section in deep basin and is likely to be late over mature. It should be noted that the Miocene coaly source rocks occurred in the Delta Mahakam shelfal areas, are thermally post-mature in the Makassar Slope (Peters et al, (1999).

The hydrocarbon recoverable reserves in the Lower Kutai Basin (Mahakam Delta) are over 5.4 billion barrels of oil and condensate, and 70 TCF of gas mostly in the deltaic reservoir rocks (Lin et al, 2005). The hydrocarbon was sourced from mature Middle-Late Miocene coals and carbonaceous shales of the Mahakam Delta plain to delta front complex (Peterson et al, 1997). The source rocks have TOC of 20 wt% to 70 wt% with hydrogen indices up to 300 mgHC/g TOC. Oil generation occurred between Ro of 0.35% to 0.6% and gas generation of Ro>1.2%.

EOCENE SEQUENCE IN MAKASSAR STRAIT REGION

North Makassar Basin

Camp et al (2009) reported that the Early-Middle Eocene turbidite deposits were encountered by Makassar-A1 and Birah-1 wells and also exposed to surface in the area onshore nearby present-day Mangkalihat Peninsula. These wells encountered Early-Middle Eocene oil shows observed in the sidewall cores. Sampled surface oil seeps along the southern Mangkalihat indicate non-marine source rocks. Basin modeling shows the top of oil window (0.6 %Ro) at about 8200 feet indicating Eocene or older source rocks. Using the geothermal gradient of 2.2 °F/100 feet, the predicted top of dry gas window (1.3 %Ro) is at about 12,100 feet. Based on basin modeling, del Negro et al (2013) suggested that the deeper Eocene source rock is generally late to over mature in most of the basin.

Camp et al (2009) also interpreted two main turbidite facies types present around Mangkalihat Peninsula: thin-bedded, low net-to-gross distal turbidites; and thick-bedded, high net-to-gross proximal turbidites in both Makassar-A1 and Birah-1 wells. The transported coaly organic matter deposited in the Early-Middle Eocene turbidite deposits are thought to be the potential oil and gas source rocks based on analogy with the Late Miocene deepwater Kutei basin play (Camp et al, 2009). However, the source potential for the region remains uncertain.

Immediately to the south, in the present-day Kutei Basin deepwater, the best source rocks are sandstones, not shales (Saller et al, 2006). The Late Miocene organic material in the deepwater sandstones includes dominantly laminar coaly (leaf) fragments, pieces of wood, resinite, and other coaly debris. The fossil leaf fragments were apparently carried from the Mahakam Delta shelf into deepwater by turbidity currents (Dunham et al, 2000; and Guritno et al, 2003) during lowstands of sea level, concentrated in layers up to 50 wt% TOC and is interpreted to be the main source for deepwater oil and gas (Saller et al, 2006).

To the east, ExxonMobil drilled Rangkong-1 well (dry) in 2009 (Bacheller III et al, 2011; and Satyana et al, 2012). The well encountered sediments of latest Middle Eocene overlying unaltered volcanic paleo-basement high. Fluid inclusion analysis in the volcanic layers proved the presence of an active thermogenic hydrocarbon system with migrated wet gas and oil inclusions. Bravo-1 (Marathon, 2010) penetrated the Middle-Late Eocene carbonates of middle to outer neritic facies (Satyana et al, (2012).

Towards south, Kaluku-1 well (ConocoPhillips, 2011) successfully proved the presence of the Early Eocene syn-rift section with a total depth at volcanic tuff dated Late Cretaceous, Maastrichtian in age (Satyana, 2015) (Figure 4). The sequence consists of a 500-foot sequence of massive homogeneous shales with a 27-foot interval of argillaceous limestones at the base of the shales. The well also penetrated interbeds of shales, thin limestones, and occasional thin but clean sands. At the well location, the rocks at the base of the syn-rift, were deposited in deep lacustrine environment. Marine influence in late Early Eocene impacted to the change of depositional environment to be lower coastal plain and inner neritic in the shallower section. The water depth gradually continued to increase to be middle to outer neritic and upper bathyal in Middle Eocene.

The oil recovered in the Early and Middle Eocene sandstones in Kaluku-1 is very waxy with API gravity of 25.5° and 29.6º at 60° F. It has a pour point of 113ºF, sulfur content of 0.102 wt%, and a wax content of 17.23 wt%. The liquid chromatography indicates that the oil is paraffinic generated from a mature source rocks deposited in a shallow lacustrine environment with some terrestrial material input (Satyana, 2015).

Nur'aini et al (2005) and del Negro et al (2013) interpreted 2D seismic lines, gravity and well data to study the basement architecture and sedimentary basin fill in the eastern part of the basin. The results showed a system of NNW-SSE lineaments and faults intersecting the top basement seismic reflector. The lineaments and faults are arranged in en-echelon patterns and bound disconnected NNW-SSE trending depocentres. This syn-rift package was interpreted to be Middle to Late Eocene.

Further to south, current interpretation of 2D seismics, gravity and magnetic data indicated that the Middle Eocene syn-rifts are also present showing horst and graben structures. The structures are generally in northwest-southeast direction and remain well-preserved following major tectonics in the Plio-Pleistocene. The decollement surface and all thrust faults seem to slide on and die into the Oligocene deepwater shales (Argakoesoemah et al, 2016).

South Makassar Basin

In Middle Eocene, the development of a series of localized half-grabens of fluvio-lacustrine source rocks was deposited in predominantly northwest-southeast orientation (Kupecz et al, 2013). Taka Talu-1 (Union Carbide, 1970) and Pangkat-1 (Gulf, 2000) were drilled in the Pangkat Graben. Total depth of Taka Talu-1 is at the Late Eocene tight sandstones and coarse grained conglomerates of the Toraja Formation. In this well, the basal Eocene clastics have very lignitic interval over the interval 9,810-10,270 feet. In Taka Talu-2 (Ashland, 1970) well the conglomerates rest directly on the crystalline basement. These coarse clastics grade upward into sandy shales with coals suggesting a paralic depositional environment (Samuel and Muchsin, 1975). In the Pangkat Graben, the dominant organofacies of the Middle Eocene are Type D/E fluvio-deltaic coals and minor Type C lacustrine shales while the Late Eocene section has little or no source potential (Ariyono et al, 2013). The hydrocarbon generation and expulsion in the South Makassar Basin began at approximately 20 mya while in Pangkat was about 12 mya.

Pangkat-1 penetrated Middle-Late Eocene syn-rift clastics with very limited reservoir potential, was tested and discovered non-commercial oil in the Cretaceous andesitic fractured basement (Lunt and van Gorsel, 2013) with one DST unable to flow to surface but had an estimated flow rate of 100 BOPD (Ariyono et al, 2013; and Kupecz et al, 2013). Curiale et al (2003) suggested that oils in Pantai-1 (Union Oil, 1982) and Pangkat-1 contain elevated levels of 4-methylsteranes and lacustrine-definitive tetracyclic hydrocarbons. Pangkat-1 oil also contain beta-carotane, elevated sulfur levels (S=2.1%) and unusually light carbon isotope ratios (d13C=-30.3 o/oo) suggesting a product of early generation from a Type I-S kerogen deposited in a hypersaline setting. Paleogene rifting in this region appears to have provided appropriate environments for lacustrine deposition and the potential development of oil-prone lacustrine source rocks. Pantai-1 tested gas and condensate in the Late Miocene sandstones of the Balikpapan Group with the gas flow rate of 12.5 MMSCFD.

Martaban-1 (Aquitaine, 1976) wells encountered several thick Eocene coals and coaly shales with a total depth at the Cretaceous basement. The coals in this well are Type D/E fluvio-deltaic. Rock Eval pyrolysis analysis results of the Eocene section shows TOC of 20 wt%-43 wt%, HI values of 181-293 mgHC/g TOC, and Tmax of 420ºC indicating oil- to gas-prone source rocks with excellent pyrolysis yield of 42.35 mgHC/g rock (Pireno and Darussalam, 2010; and Ariyono et al, 2013). Martaban-1 also penetrated the Eocene shelf carbonates (Kupecz et al, 2013).

Courel et al (2011); and Lunt and van Gorsel (2013) suggested that possible source rocks in the basin are fluvio-deltaic coals and shales, and lacustrine shales. Rousseau et al (2015) also believed that the primary source rocks in the basin are the Eocene fluvio-deltaic coals and shales containing land plant organic matter as observed in the onshore outcrops. Ariyono et al (2013) and Kupecz et al (2013) also believed that the source potential is indicated by Eocene lacustrine shales (90-foot thick) in Pangkat-1, and fluvio-deltaic shales and coals from Pangkat-1 and Martaban-1. Pireno and Darussalam (2010) reported that the Eocene shallow lacustrine shales in Pangkat-1 have TOC of 4 wt%-6 wt%, Tmax of 436ºC, and HI of 294-456 mgHC/g TOC suggesting oil-prone kerogen Type II. The maturity (Ro) is 0.5% and expecting to be mature in the deeper section. Carbon isotope analysis of the oil sample suggests that the shales contain primarily terrestrial organic matter with a subordinate algal component. The fluvio-deltaic interval exhibits the TOC of 0.74 wt%-2.54 wt%, Tmax of 436°C and HI of 121-148 mgHC/g TOC suggesting fair source rock potential of gas-prone kerogen Type III to primarily generate gas.

ExxonMobil drilled Sultan-1 in 2009 and Kris-1ST in 2010 (Bacheller III et al, 2011; and Satyana et al, 2012). Sultan-1 well penetrated thick Middle Eocene to Late Oligocene pinnacle reef carbonates sitting on the older, non-marine pyroclastic volcanics horst. The top of the pinnacle reef contains a 102 m column of 97% methane gas but uneconomic (Bacheller III et al, 2011). The gas could be biogenic in nature. Lempuk-1 (Talisman, 2011) was dry (Satyana et al, 2012; and Satyana, 2015). Kris-1ST well penetrated the Middle to Late Eocene carbonates characterized by dolomitized larger benthic *Foraminifera*, red algae, and skeletal packstone. The well is dry due to tight and lack of reservoirs.

Makassar Straits-1 (Ashland, 1974) discovered 460-foot gas column in the good-quality platform of the Early Miocene Berai carbonates (Kupecz et al, 2013) with potential for a down-dip oil leg. Bottom-hole of Makassar Straits-1 is at the Middle-Late Eocene section at a final depth of 9035 feet. The gas is a mix of thermogenic with a minor biogenic component (Ariyono et al, 2013). The Late Eocene section has a little or no source potential with the TOC of 0.3 – 2.3 wt%. Pearl (2006) drilled appraisal well Makassar Straits-2 which were successful and followed by drilling two additional successful appraisal wells for a plan of development (POD) of the Ruby Gas Field (278 BCF 1P in-place).

Further to the south towards offshore southwest Sulawesi, Curiale et al (2002) suggested that lacustrine, oil-prone sources in Selayar Basin were deposited during Paleocene and that the hydrogen-rich, oil-prone coaly sequences occurred in Middle Eocene. SSA-1X (Gulf, 1971) encountered several thick Eocene coals and shales with a total depth at the early Early Eocene conglomerates of the Toraja Formation. Gas and minor shows were observed in the sidewall core samples of the Early Eocene section.

At the southern end of the basin, Kelara-1 (Amoseas, 1993) is dry but encountered the Early-Middle Eocene Malawa Formation. The total depth is 7431 feet at the Cretaceous metamorphic basement. This Eocene has Type D/E fluvio-deltaic shales with TOC of 2-3 wt% and HI < 200 mgHC/g TOC indicating the source is lean and gas-prone. The well also encountered Type C lacustrine shales having good source potential with TOC of 4-6 wt% and HI of 300-500 mgHC/g TOC indicating oil-prone source rocks (Ariyono et al, 2013). Curiale et al (2002) suggested that the Eocene "Kelara limestone" unit is interpreted as a source for low-wax, low-asphaltene oil. The underlying Middle Eocene coals and coaly shales are analogous to the oil-generative sapropelic coals in the Barito Basin, and are responsible for high-quality oils seeping in the adjacent areas of onshore southwest Sulawesi.

Lombosang-1 well (Unocal, 2003) penetrated about 4600 feet of the Middle to Late Eocene section prior to reach a total depth of 11,828 feet at ?Cretaceous basement in the Spermonde-Salayar Basin (Lunt and van Gorsel, 2013). The Middle Eocene section was deposited in the fluvial-coastal plain to paralic while the Late Eocene was in the outer neritic to upper bathyal depositional environment. Well bedded coals are seen in the upper part of the Middle Eocene sequence. Thin clastic and coal section over weathered Createceous lavas at the total depth of pre-Tertiary basement, was encountered in Bone-1 (Amoseas, 1972).

EOCENE SEQUENCE IN WEST SULAWESI REGION

Lariang and Karama Region

The Tanjung Formation is lithostratigraphically equivalent to the Kalumpang Formation in the Lariang and Karama Basins. The oldest interval as an initial basin fill consists of a swampy marginal marine sequence of shales, coal beds and metre-thick quartzose sandstones (Calvert, 1999; Calvert and Hall, 2003 and 2007). The thick sandstones represent broad fluvio-deltaic channels. The oldest dated sediments were deposited in a marginal marine succession in the NE-SW trending half-graben during extensional phase. It post-dated the non-marine rift initiation. The formation passes laterally and conformably overlain by Middle Eocene to Late Oligocene post-rift Budung-budung limestone shoals as a result of a relatively rise of sea level and/or basin subsidence. The Budung-budung Formation was deposited in an inner to outer neritic or upper bathyal (Raharjo et al, 2012).

Hydrocarbon exploration has actually been conducted since 1898-1900 in the Lariang region. The most recent wells are Karama-1 and Lariang-1 (Gulf, 1973), Tike-1 ((BP, 1979), and LG-1 and KD-1 (Tately, 2011), but none of the wells penetrated the Kalumpang Formation. KD-1 encountered thick section of mudstones with interbedded sandstone, siltstone and limestone of the Budung-budung Formation.

Geochemical analysis of oil seep samples from Lariang and Karama areas, onshore southwest Sulawesi indicates that the oil is paraffinic, low sulfur content (0.15 - 0.19 wt%) with moderate (0.49 - 2.03 wt%) low wax and waxy oils (Raharjo et al, 2012). The oil seep samples from Doda, Poluhu, and Paniki areas show terrestrial oil characterization with Ro of 0.8 – 1.0 %. The calculated maturity of the Bantaya oil seepage sample has Ro of 1.2 – 2.0 %. The GC-MS biomarker data indicate organic assemblage dominated by terrestrial higher plant material with some minor algal input. Hence, the oils could be generated from estuarine, shallow lacustrine, open marine and/or deep lacustrine of the Middle Eocene Kalumpang shales. It should be noted that another source potential is present in the Early Miocene section based on the geochemical screening of the KD-1 cuttings.

Onshore SW Sulawesi and Sengkang Basin

The syn-rift deposition in the onshore southwest Sulawesi is interpreted to begin in Middle Eocene. The lithostratigraphic equivalent to the Tanjung Formation is the Toraja (Malawa) Formation. The upper part of the Toraja consists of a mix of clastics and carbonates interpreted to be the product of deltaic and marginal marine conditions (Coffield et al, 1993; and Guritno et al, 1996). It is rich in fluvio-deltaic coals associated with oil-prone kerogen but the distribution remains unknown. These Eocene carbonaceous shales and coals of the Toraja could be possibly the source for hydrocarbon. The coals could generate some gas. Maturation modeling in this region indicates that the early hydrocarbon generation could start at approximately 5000 feet and migrate in Late Pliocene (Yulihanto, 2004).

In the southwestern corner of Sulawesi, the Middle-Late Eocene Malawa Formation and Langi Volcanics have cropped-out in the west of Walanae Depression. These deltaic-marginal marine clastics passed transgressively into shallow marine carbonates of the Tonasa Formation (Wilson, 1996; and Wilson et al, 2000) and extended immediately to the east. The carbonate gradually changed eastward to an open marine environment (Yulihanto, 2004) towards the region where the Middle Miocene Sengkang Basin located. The sequence comprises claystones, sandstones, conglomerates, coals, limestones, and interbedded with Langi Volcanics. Distribution of the facies was strongly controlled by north-south orientation on an extensional graben system of the Walanae Graben.

The Late Eocene sequence was penetrated by Kampung Baru-1 (Gulf, 1976) with a total depth of 5900 feet at the Eocene Langi Volcanics. DST#5 (2423-2462 feet) flowed 3,500 MSCFD from the Late Miocene Tacipi limestones (around 312-foot thick). BP discovered four separate accumulations of gas totaling about 0.75 TCF in the Late Miocene knoll reefs of the Tacipi Formation (Grainge and Davies, 1983; and Coffield et al, 1997). Energy Equity is now producing the gas from Kampung Baru Gas Field, the largest field in the area containing almost half of the total reserves. The methane is not of biogenic origin (Grainge and Davies, 1983). Kampung Baru Gas Field has 94% CH4, Sampi-Sampi and Walanga has 95% CH4, and Bonge to the east has 97% CH4 or dryer and not full to spill. The most likely source of the thermogenic gas is the Eocene coals to the west, which are now deeply buried in the Walanae Trough (Coffield et al, 1997).

In the Kalosi area, the Middle-Late Eocene Toraja sequence is dominated by red argillaceous claystones deposited in fluvial and shallow lacustrine environments. Conglomerates and sandstones are also present. Marine incursion occurred in Middle Eocene and is represented by thin *Nummulitic* limestone interval (Coffield et al, 1993). Coals and carbonaceous claystones deposited in fluvio-deltaic depositional environment are present in the upper part of the Toraja Formation and are considered to be the primary source rocks.

Many gas and oil seepages are present in the Kalosi area. All of the oils are fully to late mature. These oils from seeps have been typed to the Eocene source rocks (Coffield et al, 1993). Kerogen types of the Eocene outcrop samples are Type II/III with the TOC values range from 30 wt% to 80 wt%; and hydrogen index of 150-600 mgHC/gTOC. The outcrop samples are immature to early mature with Tmax < 440°C. Results of the geochemical analysis indicate that the oil seepages are paraffinic, low sulfur, moderately low to waxy oils with API gravity (where not biodegraded) of 35° to 40°.

MIDDLE EOCENE PALAEOGEOGRAPHY AND SOURCE ROCK DISTRIBUTION

Review of the Eocene sequences in the Greater Makassar Strait region indicates that all of the basins in the region have a strong geological similarity both in structural development and stratigraphic succession. The oldest sediments in this region are the Early-Middle Eocene syn-rift sequences deposited directly on the pre-Tertiary basement rocks in peripheral foreland basins rather than extensional basins. This is in line mainly with the seismic interpretation and well data, and other additional data such as geological fieldwork on onshore, and laboratory analysis results of the outcrop fluid and rock samples which have proven that the underneath crust of the Greater Makassar Strait region is a continental crust of the Sundaland Craton (Figure 5).

Seismic interpretations indicate that the syn-rift structure probably began in Late Paleocene or Early Eocene. These Eocene deposits are likely to be present in all basins in the Greater Makassar Strait region. Lack of deep wells drilled in the region encountered syn-rift section, incomplete syn-rift sequence in the outcrops onshore, non-marine Eocene facies development, and limited published references, all together have caused the difficulty to properly date the syn-rift interval in the region. Hence, the syn-rift deposition has been interpreted to consistently begin in Early-Middle Eocene.

The sequence widely consists of sandstones, claystones, and coals with carbonates on the remnant paleo-basement highs. Part of the deposits have been identified and dated both in outcrop and borehole rock samples, but many of them remain in questions due to limited data. Therefore, it is not surprising if the understanding of the sequence development is still confusing. One of the examples is the syn-rift sequence interpreted in the Kutai Basin specifically those deposited in the Lower Kutai Basin to the east.

The previous researchers tend to define the syn-rift sediments in the Lower Kutai Basin were deposited in the deepwater settings. As there are limited access to the well data and incomplete outcrops, the interpretation could mix-up with the Late Eocene post-rift section which was rapidly and widely deposited in the deeper water depth due to basin sag and perhaps in a combination with relatively sea level rise beginning in Late Eocene (Figure 5). For example, Lunt and van Gorsel (2013) observed the presence of the Late Eocene deepwater planktonic and benthic bathyal *Foraminifera* in Pangkat-1 well. The early Late Eocene post-rift bathyal marine transgression is also present in Bone-1, Doang-1 (Amoseas, 1972), ODB-1X (Gulf, 1971), and Lombosang-1 further to the south. Doang-1 reached a total depth at the Campanian basement. The intra-Late Eocene marine transgression was also observed in Taka Talu-2 well. This is consistent with those encountered in the late Middle Eocene section in Kaluku-1 well to the north. A sudden intra-Late Eocene transgression was observed in Kris-1 though no significant subsidence in Late Eocene times in Sultan-1 has been reported (Bacheller III et al, 2011; and Lunt and van Gorsel, 2013).

Lithology, seismic and log responses of the syn-rift section could easily be interpreted interchangeably with those in the Late Eocene post-rift section as the top syn-rift in most of the wells is not very obvious separating with the base part of the post-rift. For the purpose of the palaeogeography reconstruction discussed in this paper, the Early-Middle Eocene syn-rift sequences are interpreted to have been deposited mostly in the non-marine to restricted shallow marine depositional environments. The only exception is that described for the deepwater syn-rift in the northern end of the North Makassar Basin near the present-day Mangkalihat Peninsula. Hence, towards the northern end area across Sangkulirang escarpment into the proto-Sulawesi Sea, the depositional environment generally tends to gradually deepen from non-marine fluvio-deltaic-lacustrine to be deepwater (Figure 6). Further to the south, a shallow marine setting seems to occur in the southeastern end of the region around the present-day southwestern Sulawesi.

In addition to the local sediment sources, most of the sediment provenance for the syn-rift is interpreted to be in the western end of the region which are in the areas near Central Kalimantan Ranges, Schwaner Mountains, and Karimunjawa Arch. Deposition direction is generally to the east, partially to the east-northeast for the area south of Barito and southwest Sulawesi, and to the north-northwest for the North Makassar Strait. All of these syn-rift sediments are interpreted to have been deposited in the proto-Barito Basin, proto-Kutai Basin, proto-North Makassar Basin, proto-South Makassar Basin, and southeastern end of the region (Figure 6).

Orientation of the syn-rift horst and graben structures varies in each basin depending on the tectonic nearby. In the Barito Basin, the structure orientation is in northwest-southeast direction (Kusuma and Darin, 1989; and Awang and Silitonga, 1994). The syn-rift lineaments function as the sediment deposition path across the present-day Meratus-Asem Asem area and may in contact to those half-grabens in the east-northeast region including the productive Pangkat Graben (Figure 6). In the Kutai Basin, the horsts and grabens are asymmetrical and vary in NNE-SSW, N-S, and NE-SW trend. In the North and South Makassar Basins, the structural trends also vary in each local highs and lows. In the southern and eastern part of the North Makassar Basin, the Eocene lineament of narrow normal faults is in NNE-SSW and NW-SE directions (Nur'aini et al, 2005). The Eocene fault orientation has been well-preserved as the Plio-Pleistocene thrust faults do not have significant impact to the Eocene horst and graben structures (Argakoesoemah et al, 2016) (Figure 7). In the South Makassar Basin, the horsts and grabens are in northwest-southeast direction including the Pangkat Graben (Kupecz et al, 2013). The major Eocene structural features could extend towards south-southwest to the northeastern part of East Java region (Bransden and Matthews, 1992; Manur and Barraclough, 1994; Gross et al, 2006; and Courel et al, 2011). In the west and southwest Sulawesi, the structures have north-south orientation specifically in the area western Walanae Trough.

The Adang fault escarpment initiation is interpreted to be present in Middle-Late Eocene and has separated proto-Barito and proto-South Makassar Basins in the southwest and proto-Kutai and North Makassar Basins in the northeast (Figure 6). The main activity of the Adang normal fault is interpreted to occur in Early Oligocene at the time of the Paternoster Platform uplift and erosion with a normal component towards north-northeast (Argakoesoemah et al, 2016).

Another large escarpment is also interpreted to take place in the northern most of proto-North Makassar Basin, called the Sangkulirang fault escarpment, seems to be present in Middle Eocene separating the basin in the south and proto-Sulawesi Sea in the north (Figure 6). The fault should have dip components to the northeast. Thick Early-Middle Eocene deepwater syn-rift clastics were penetrated in wells up-thrown (north) of the fault (Camp et al, 2009). This is also consistent with the gravity and magnetic images (Decker et al, 2004).

The eastern boundary of the Greater Makassar Strait is the location of Palu-Koro Fault separating the region in the west and accreted Late Miocene terrane of East Sulawesi to the east (Rose and Hartono, 1978; and Hall, 2012). This fault position is likely to be the eastern-southeastern end of the Sundaland Craton or Greater Makassar Strait in Middle Eocene as indicated by the reconstruction for 40 mya by Hall (2012) (Figure 8). The terrane was detached and merged with the Western Sulawesi Plutono-Volcanic Arc (Wilson and Moss, 1999) in Late Miocene (Hall, 2012).

The primary Eocene source rocks seem to be the carbonaceous-rich shales and coals deposited in non-marine fluvio-deltaic-lacustrine depositional environments, and deepwater settings in the northeastern most North Makassar Basin around present-day Mangkalihat Peninsula. Kerogen type is generally Type II/III that could generate significant oil and gas accumulation. Although there is lack of major discovery in the syn-rift section with an exception of the Tanjung Oil Field, there is a strong possibility of oil and gas accumulation present in the syn-rift and post-rift section. Further efforts are obviously needed including a better technology to image deeper section in the basins.

CONCLUSIONS AND RECOMMENDATIONS

Some conclusions and recommendations are as follow:

(1) The Greater Makassar Strait includes basins in Barito, Kutei, North and South Makassar, Lariang and Karama, Sengkang, and onshore southwest Sulawesi regions as part of the southeastern most Sundaland continental crust, have similar Eocene geological structure and physiographic basin features receiving the sediments from the highlands and local highs surrounding the basins.

(2) Review of the Paleogene sequence indicates that the Eocene stratigraphy in each basin is common and very similar widespread across the Greater Makassar Strait region.

(3) Syn-rift deposition was likely initiated at the same time in Middle Eocene and occurred in the peripheral foreland basin. This is in line and response to the findings that underneath of the Greater Makassar Strait region is a continental crust.

(4) The Early-Middle Eocene syn-rift sediments were consistently deposited in the non-marine and/or shallow marine environments. However, deeper water depth could occur in the distal area toward east and northeast.

(5) The Paleogene transgression seems to be initiated in the late Late Eocene by depositing widespread of marine deepwater shales and partial carbonate deposition over the remnant basement highs. The shales are functioned as a top seal for the Eocene hydrocarbon accumulation.

(6) The Early-Middle Eocene shales and coals have been widely spread out across the region in the syn-rift structures and have proven to be potential and productive source rocks. Most of the kerogens are Type III and Type II/III.

(7) Lack of discovery in the Paleogene plays is possibly caused by a series of Neogene uplifts resulting in thief zones, sedimentary provenance causing variation of the source rock and reservoir quality, and possible excessive source rock maturity. Other possible economic risks are the location of the exploration prospects in the deeply buried position in the basin, surface physiography, and present-day ultra-deepwater settings. Further geological evaluation should be conducted by optimizing current technology to image better geological features. At present, lack of subsurface data has hampered further exploration efforts in the region.

ACKNOWLEDGEMENTS

The author would like to thank Management of PTTEP Indonesia, Ditjen Migas, and SKK Migas for permission to publish this paper. I would thank the IPA Technical Program Committee 2017 for selecting this paper to be presented in the Convention. I would also thank Kuntadi Nugrahanto and Prasiddha Hestu Narendra for the review and comments. I also thank my colleagues to provide some reading materials and help generate graphical work for some figures.

REFERENCES

Argakoesoemah, RM.I., Nainggolan, H.B., Wahyudi, I., Hidayat, A., and Shahab, M.F., 2016, Fluvial-to-deepwater stratigraphy and structural development of the southern part of North Makassar Basin, Indonesia, Proceedings of the Indonesian Petroleum Association, 40th Annual Convention and Exhibition, paper IPA16-728-G, 8 pp. and 15 figs.

Ariyono, D., Kupecz, J., Sayers, I., Tanos, C., and Hilman, A., 2013, Generation and expulsion from Middle Eocene source in the South Makassar Basin, Indonesia, Proceedings of the Indonesian Petroleum Association, 37th Annual Convention and Exhibition, paper IPA13-G-160, 6 pp., 13 figs, and 1 tab.

Bacheller III, J., Buck, S.P., Cahyono, A.B., Polis, S.R., Helsing, C.E., Zulfitriadi, de Man, E.M., Hillock, P.M., Ruf, A.S., and Toxey, J.K., 2011, Early deepwater drilling results from a new exploration play, offshore West Sulawesi, Indonesia, Proceedings of the Indonesian Petroleum Association, 35th Annual Convention and Exhibition, paper IPA11-G-243, 7 pp., 8 figs.

Bachtiar, A., Heru N., D.W., Azzaino, Z., Utomo, W., Krisyunianto, A., and Sani, M., 2013, Surface data re-evaluation, Eocene source rock potential and hydrocarbon seepage, and Eocene sand reservoir prospectivity in West Sangatta, Northern Kutai Basin, Proceedings of the Indonesian Petroleum Association, 37th Annual Convention and Exhibition, paper IPA13-G-087, 10 pp., 18 figs, and 3 tabs.

Bon, J., Fraser, T.H., Amris, W., Stewart, D.N., Abubakar, Z., and Sosromihardjo, S., 1996, A review of the exploration potential of the Paleocene Lower Tanjung Formation in the South Barito Basin, Proceedings of the Indonesian Petroleum Association, 25th Silver Anniversary Convention, vol.1, p. 69-79.

Bransden, P.J.E., and Matthews, S.J., 1992, Structural and stratigraphic evolution of the East Java Sea, Indonesia, Proceedings of the Indonesian Petroleum Association, 21st Annual Convention, vol.1, p. 417-453.

Calvert, S.J., 1999, The Cenozoic evolution of the Lariang and Karama Basins, Sulawesi, Proceedings of the Indonesian Petroleum Association, 27th Annual Convention and Exhibition, paper IPA99-G-046, 3 pp. and 4 figs.

Calvert, S.J., and Hall, R., 2003, The Cenozoic geology of the Lariang and Karama regions, Western Sulawesi: New insight into the evolution of the Makassar Straits region, Proceedings of the Indonesian Petroleum Association, 29th Annual Convention and Exhibition, paper IPA03-G-036, 13 pp. and 4 figs.

Calvert, S.J., and Hall, R., 2007, Cenozoic evolution of the Lariang and Karama regions, North Makassar Basin, western Sulawesi, Indonesia, Petroleum Geoscience, vol.13, p. 353-368.

Camp, W.K., Guritno, E.E., Drajat, D., Wilson, M.E.J., 2009, Middle-Lower Eocene turbidites: A new deepwater play concept, Kutei Basin, East Kalimantan, Indonesia, Proceedings of the Indonesian Petroleum Association, 33rd Annual Convention and Exhibition, paper IPA09-G-001, 8 pp. and 7 figs.

Chambers, J.L.C., Carter, I., Cloke, I.R, Craig, J., Moss, S.J., and Paterson, D.W., 2004, Thin-skinned and thick-skinned inversion-related thrusting – A structural model for the Kutai Basin, Kalimantan, Indonesia, *in* K. R. McClay (ed.), Thrust tectonics and hydrocarbon systems, AAPG Memoir 82, p. 614– 634.

Chambers, J.L.C., Daley, T.E., 1995, A tectonic model for the onshore Kutai Basin, East Kalimantan, based on an integrated geological and geophysical interpretation, Proceedings of the Indonesian Petroleum Association, 24th Annual Convention, vol.1, p. 111-130.

Clements, B., and Hall, R., 2008, U-Pb dating of detrital zircons from West Java show Complex Sundaland provenance, Proceedings of the Indonesian Petroleum Association, 32nd Annual Convention and Exhibition, paper IPA08-G-115, 10 pp. and 8 figs.

Clements, B., and Hall, R., 2011, A record of continental collision and regional sediment flux for the Cretaceous and Palaeogene core of SE Asia: Implications for early Cenozoic palaeogeography, Journal of the Geological Society, London, vol. 168, p. 1187–1200.

Cloke, I.R., Moss, S.J., and Craig, J., 1997, The influence of basement reactivation on the extensional and inversional history of the Kutai Basin, East Kalimantan, SE Asia, Journal of the Geological Society, London, vol.154, p. 157-161.

Cloke, I.R., Moss, S.J., and Craig, J., 1999, Structural controls on the evolution of the Kutai Basin, East Kalimantan, Journal of Asian Earth Sciences, vol.17, p. 137-156.

Coffield, D.Q., Bergman, S.C., Garrard, R.A., Guritno, N., Robinson, N.M., and Talbot, J., 1993, Tectonic and stratigraphic evolution of the Kalosi PSC area and associated development of a Tertiary petroleum system, South Sulawesi, Indonesia, Proceedings of the Indonesian Petroleum Association, 22nd Annual Convention, p. 679-706.

Coffield, D., Guritno, N., Wilson, M., and Ascaria, N.A., 1997, Petroleum systems of South Sulawesi, Indonesia: Field trip summary, Proceedings of the Petroleum Systems of SE Asia and Australasia Conference, Indonesian Petroleum Association, p. 1001-1010.

Courel, R., Hollomon, G., Kim, M., Richert, D., Tiranda, C., and Tognini, P., 2011, A re-evaluation of the South Makassar Basin using an integrated multi-discipline approach, 11 pp. Staff of Talisman Energy, Makassar Straits: Deepwater basins with major gas/condensate potential (Abstract), Proceedings of the South East Asia Petroleum Exploration Society (SEAPEX) Conference, 32 pp.

Curiale, J.A, and Decker, J., 2010, Eocene oil-prone source rock potential of Central Indonesia, Abstract of the AAPG Annual Convention and Exhibition, AAPG Search and Discovery Article # 90104.

Curiale, J.A, Decker, J., Lin, R., and Morley, R.J., 2006, Oils and oil-prone coals of the Kutei Basin, Indonesia, Abstract of the AAPG Annual Convention and Exhibition, AAPG Search and Discovery Article # 90061.

Curiale, J.A, Decker, J., Caughey, C.A., and Schwing, H.F., 2003, Oil-prone lacustrine source rock potential in Central Indonesia, Abstract of the AAPG Annual Meeting, AAPG Search and Discovery Article # 90013.

Curiale, J.A, Lumadyo, E., and Lin, R., 2002, Petroleum and source rock geochemistry of the Selayar Basin (offshore Sulawesi), Indonesia, Abstract of the AAPG Annual Meeting, AAPG Search and Discovery Article # 90007.

Decker, J., Teas, P.A, Curiale, J.A., Johnson, E.A.E., and Orange, D.L., 2004, Multibeam exploration in the Makassar Strait, Proceedings of the Deepwater and frontier exploration in Asia and Australasia Symposium, Indonesian Petroleum Association, 7 pp. and 13 figs.

del Negro, R., Castellano, P., Kuhfuss, A., Mattiono, L., Moss, J., and Vialla, M., 2013, Structural styles and petroleum system modeling of the North Makassar Straits, Indonesia, Proceedings of the Indonesian Petroleum Association, 37th Annual Convention and Exhibition, paper IPA13-G-077, 9 pp. and 11 figs.

Dunham, J.B., Brown, T.J., Lin, R., Redhead, R.B., Schwing, H.F., Shirley, S.H., 2000, Transport and concentration of gas- and oil-prone kerogens into deep water sediments of the Kutei Basin, East Kalimantan, Indonesia, Abstract of the AAPG International Conference and Exhibition, AAPG Search and Discovery Article # 90913.

Grainge, A.M., and Davis, K.G., 1983, Reef exploration in the East Sengkang Basin, Sulawesi, Proceedings of the Indonesian Petroleum Association, 12th Annual Convention, vol.1, p. 207-227.

Gross, O.P., Drevet, R.J., Sulaeman. A., Johnstone, E.M., McPherson, J.G., Stevens, J., and Johnstone, D.C., 2006, A new look at the East Java Basin using a genetic basin analysis approach, Proceedings of the Jakarta 2006 International Geosciences Conference and Exhibition, paper Jakarta06-PG-31SS, 4 pp. and 1 fig.

Guritno, E.E., and Chambers, J., 1999, North Runtu PSC: The first proven Eocene petroleum play in the Kutai Basin, Proceedings of the Indonesian Petroleum Association, 27th Annual Convention and Exhibition, paper IPA99-G-092, 7 pp. and 13 figs.

Guritno, E., Salvadori, L., Syaiful, M., Busono, I., Mortimer, A., Hakim, F.B., Dunham, J., Decker, J., and Algar, S., 2003, Deep-water Kutei Basin: A new petroleum province, Proceedings of the Indonesian Petroleum Association, 29th Annual Convention and Exhibition, vol.1, 7 pp. and 15 figs.

Guritno, N., Coffield, D.Q., and Cook, R.A, 1996, Structural development of Central South Sulawesi, Indonesia, Proceedings of the Indonesian Petroleum Association, 25th Silver Anniversary Convention, p. 253-266.

Hall, R., 2012, Late Jurassic-Cenozoic reconstructions of the Indonesian region and the Indian Ocean, Tectonophysics, vols. 570-571, p.1-41.

Heriyanto, N., Nawawi, A., Mason, A.D.M., Ingram, F.T., Pedersen, D.E, and Davis, R.C., 1996, Exploratory update in the North Tanjung, South Kalimantan, Proceedings of the Indonesian Petroleum Association, 25th Silver Anniversary Convention, vol.1, p. 55-68.

Kupecz., J., Sayers, I., Tognini, P., Hilman, A., Tanos, C., and Ariyono, D., 2013, New insights into tectono-stratigraphic evolution of the South Makassar Basin, Proceedings of the Indonesian Petroleum Association, 37th Annual Convention and Exhibition, paper IPA13-G-158, 13 pp., 27 figs, and 1 tab.

Kusuma, I., and Darin, T., 1989, The hydrocarbon potential of the Lower Tanjung Formation, Barito Basin, S.E. Kalimantan, Proceedings of the Indonesian Petroleum Association, 18th Annual Convention, vol.1, p. 107-138.

Laya, K.P., Nugroho, B., Hadiyanto, N., and Tolioe, W., 2013, Paleogeographic reconstruction of Upper Kutei Basin: Implications for petroleum systems and exploration play concepts, Proceedings of the Indonesian Petroleum Association, 37th Annual Convention and Exhibition, paper IPA13-G-106, 9 pp. and 7 figs.

Lin, R., Saller, A., Dunham, J., Teas, P., Kacewicz, M., Curiale, J., and Decker, J., 2005, Source, generation, migration and critical controls on oil versus gas in the deepwater Kutei petroleum system, Proceedings of the Indonesian Petroleum

Association, 30th Annual Convention and Exhibition, vol.1, p. 447-466.

Lunt, P., and van Gorsel, J.T., 2013, Geohistory analysis of South Makassar, Berita Sedimentologi (Indonesian Journal of Sedimentary Geology), no.28, p. 14-24.

Manur, H., and Barraclough, R., 1994, Structural control on hydrocarbon habitat in the Bawean area, East Java sea, Proceedings of the Indonesian Petroleum Association, 23rd Annual Convention, vol.1, p. 129-144.

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

Moss, S.J., and Chambers, J.L.C., 1999a, Depositional modeling and facies architecture of rift and inversion episodes in the Kutai Basin, Kalimantan, Indonesia, Proceedings of the Indonesian Petroleum Association, 27th Annual Convention and Exhibition, paper IPA99-G-188, 10 pp. and 12 figs.

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

Nur'aini, S., Hall, R., and Elders, C.F., 2005, Basement architecture and sedimentary fill of the North Makassar Straits Basin, Proceedings of the Indonesian Petroleum Association, 30th Annual Convention and Exhibition, p. 483-497.

Peters, K.E., Snedden, J.W., Sulaeman, A., Sarg, J.F., and Enrico, R.J., 1999, New deepwater geochemical model for the Mahakam Delta and Makassar Slope, Kalimantan, Proceedings of the Indonesian Petroleum Association, 27th Annual Convention and Exhibition, paper IPA99-G-094, 12 pp. and 5 figs.

Peterson, D.W., Bachtiar, A., Bates, J.A., Moon, J.A, and Surdam, R.C., 1997, Petroleum system of the Kutei Basin, Kalimantan, Indonesia, Proceedings of an International Conference on Petroleum Systems of SE Asia and Australasia, Indonesian Petroleum Association, p. 709-726.

Pireno, G.E., and Darussalam, D.N., 2010, Petroleum system overview of the Sebuku Block and the surrounding area: Potential as a new oil and gas province in South Makassar Basin, Makassar Straits, Proceedings of the Indonesian Petroleum Association, 34th Annual Convention and Exhibition, paper IPA10-G-169, 6 pp. and 10 figs.

Raharjo, S., Seago, R., Jatmiko, E.W., Hakim, F.B., Meckel, L.D., 2012, Basin evolution and hydrocarbon geochemistry of the Lariang-Karama Basin: Implications for petroleum system in onshore West Sulawesi, Proceedings of the Indonesian Petroleum Association, 36th Annual Convention and Exhibition, paper IPA12-G-135, 10 pp. and 12 figs.

Rose, R., and Hartono, P., 1978, Geological evolution of the Tertiary Kutei-Melawi Basin, Kalimantan, Indonesia, Proceedings of the Indonesian Petroleum Association, 7th Annual Convention, p. 225-251.

Rotinsulu, L.F., Sardjono, S., and Heriyanto, N., 1993, The hydrocarbon generation and trapping mechanism within the northern part of Barito Basin, South Kalimantan, Proceedings of the Indonesian Petroleum Association, 22nd Annual Convention, p. 607-633.

Rousseau, M., Guerin, V., Sapin, F., Restiadi, D., Malla-Meidianna, C., and Gaulier, J-M., 2015, South Makassar basin: 3D thermal modeling – implication for future exploration, Proceedings of the Indonesian Petroleum Association, 39th Annual Convention and Exhibition, paper IPA15-G-262, 7 pp. and 8 figs.

Saller, A., Lin, R., and Dunham, J., 2006, Leaves in turbidite sands: The main source of oil and gas in the deep-water Kutei Basin, Indonesia, AAPG Bulletin, vol. 90, p. 1585-1608.

Samuel, L., and Muchsin, S., 1975, Stratigraphy and sedimentation in the Kutai Basin, Kalimantan, Proceedings of the Indonesian Petroleum Association, 4th Annual Convention, vol.2, p. 27-39.

Satyana, A.H., 1995, Paleogene unconformities in the Barito Basin, Southeast Kalimantan: A concept for the solution of the "Barito Dilemma" and a key to the search for Paleogene structures, Proceedings of the Indonesian Petroleum Association, 24th Annual Convention, p. 263-275.

Satyana, A.H., 2015, Rifting history of the Makassar Straits: New constraints from wells penetrating the basement and oils discovered in Eocene section – implications for further exploration of West Sulawesi offshore, Proceedings of the Indonesian Petroleum Association, 39th Annual Convention and Exhibition, paper IPA15-G-104, 17 pp. and 17 figs.

Satyana, A.H., Damayanti, S., and Armandita, C., 2012, Tectonics, stratigraphy and geochemistry of the Makassar Straits: Recent updates from exploring offshore West Sulawesi, opportunities and risks, Proceedings of the Indonesian Petroleum Association, 36th Annual Convention and Exhibition, paper IPA12-G-156, 13 pp. and 8 figs.

Satyana, A.H., and Silitonga, P.D., 1994, Tectonic reversal in the East Barito Basin, South Kalimantan: Consideration of the types of inversion structures and petroleum significance, Proceedings of the Indonesian Petroleum Association, 23rd Annual Convention, vol.1, p. 57-74.

Setiawan, N.I., Osanai, Y., Nakano, N., Adachi, T., Setiadji, L.D., Wahyudiono, J., 2013, Late Triassic metatonalite from the Schwaner Mountains in West Kalimantan and its contribution to sedimentary provenance in the Sundaland, Berita Sedimentologi (Indonesian Journal of Sedimentary Geology), no.28, p. 4-12.

Siregar, M.S. and Sunaryo, R., 1980, Depositional environment and hydrocarbon prospects, Tanjung Formation, Barito Basin, Kalimantan, Proceedings of the Indonesian Petroleum Association, 9th Annual Convention, p.379-400.

van de Weerd, A., Armin, R.A., Mahadi, S., and Ware, P.L.B., 1987, Geological setting of the Kerendan gas and condensate discovery, Tertiary sedimentation and paleogeography of the northwestern part of the Kutei Basin, Kalimantan, Indonesia, Proceedings of the Indonesian Petroleum Association, 16th Annual Convention, vol.1, p.317-338.

Wain, T., and Berod, B., 1989, The tectonic framework and paleogeographic evolution of the Upper Kutei Basin, Proceedings of the Indonesian Petroleum Association, 18th Annual Convention, vol.1, p. 55-78.

Wilson, M.E.J., 1996, Evolution and hydrocarbon potential of the Tertiary Tonasa Limestone Formation, Sulawesi, Indonesia, Proceedings of the Indonesian Petroleum Association, 25th Silver Anniversary Convention, p. 227-240.

Wilson, M.E.J., Bosence, D.W.J., and Limbong, A., 2000, Tertiary syntectonic carbonate platform development in Indonesia, Sedimentology, vol. 47, p. 395-419

Wilson, M.E.J., and Moss, S.J., 1999, Cenozoic palaeogeograhic evolution of Sulawesi and Borneo, Palaeogeography, Palaeoclimatology, Palaeoecology, vol.145, p. 303-337.

Witts, D., Davies, L., and Morley, R., 2014, Uplift of the Meratus Complex: sedimentology, biostratigraphy, provenance and structure, Proceedings of the Indonesian Petroleum Association, 38th Annual Convention and Exhibition, paper IPA14-G-082, 8 pp., 12 figs, 1 tab.

Witts, D., Hall, R., Morley, R.J., and BouDagher-Fadel, M.K., 2011, Stratigraphy and sediment provenance, Barito Basin, Southeast Kalimantan, Proceedings of the Indonesian Petroleum Association, 35th Annual Convention and Exhibition, paper IPA11-G-054, 10 pp., 8 figs.

Yulihanto, B., 2004, Hydrocarbon play analysis of the Bone Basin, South Sulawesi, Proceedings of the Deepwater and Frontier Exploration in Asia and Australasia Symposium, Indonesian Petroleum Association, paper DFE04-OR-003, 8 pp. and 8 figs.

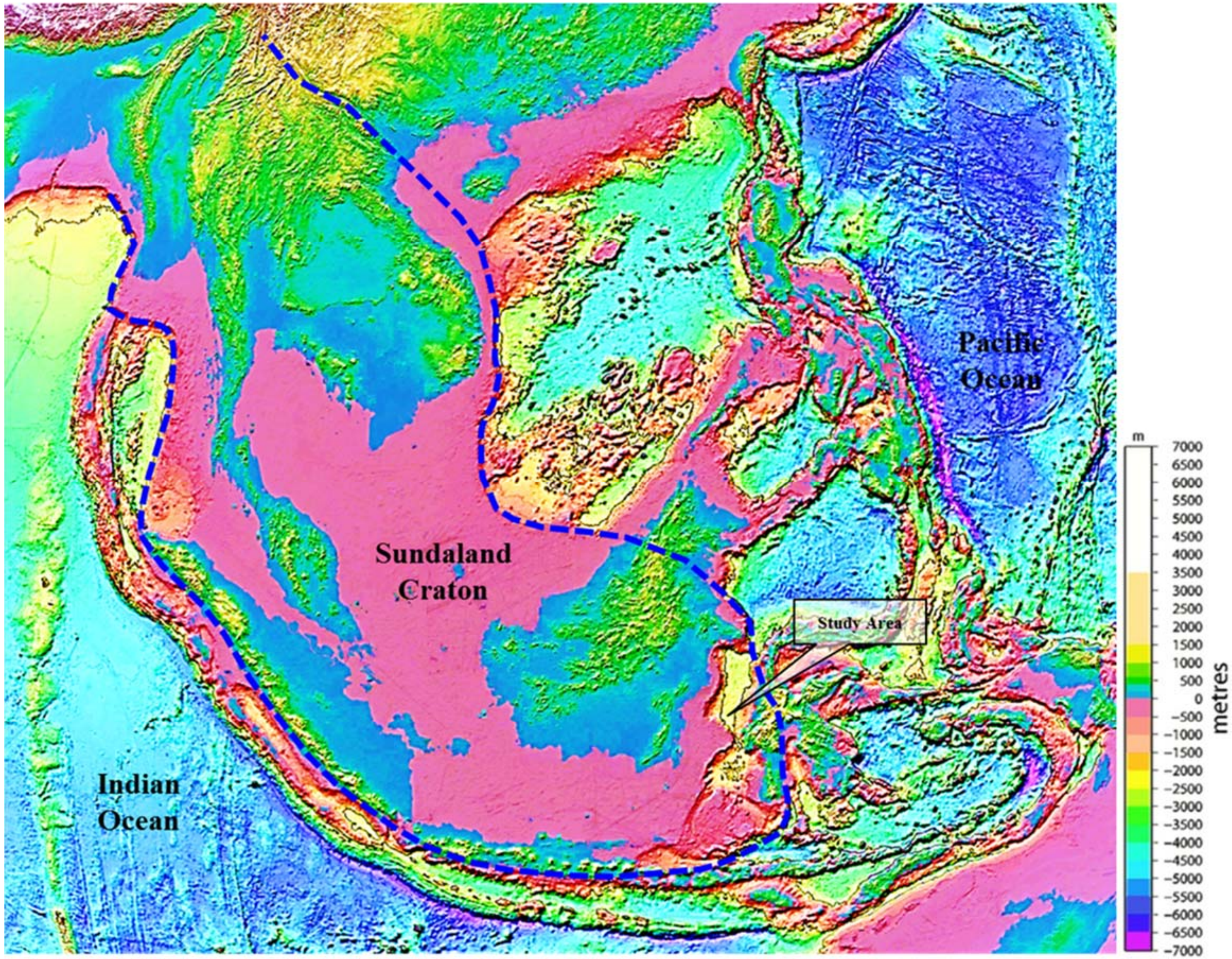

Figure 1 - Shuttle Radar Topography Mission (SRTM) map plotted in Google Earth showing the Sundaland Craton outlined by dashed blue line (http://topex.ucsd.edu/kml/topo_srtm/topo_srtm.kml). The study area is in the southeastern end of the craton (Argakoesoemah et al, 2016).

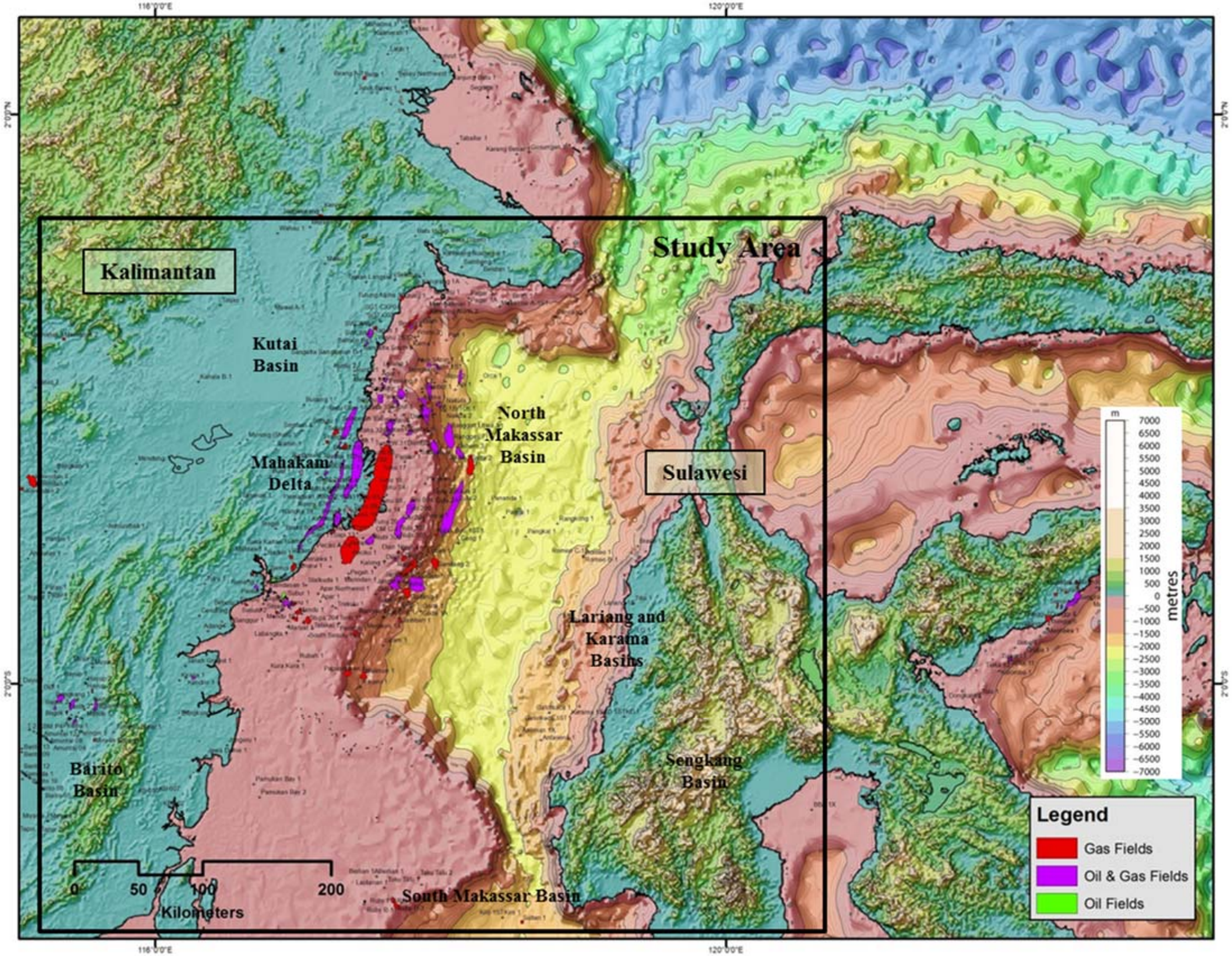

Figure 2 - Topographic and bathymetric map showing the Greater Makassar Strait region including the relative location of Barito Basin, Kutai basin, North Makassar Basin, South Makassar Basin, Lariang Basin, Karama Basin, Sengkang Basin, and onshore southwest Sulawesi. These are overlain with the current existing oil, condensate, and gas discoveries in the region (http://www.bandaarcgeophysics.co.uk/ei-topo.htm).

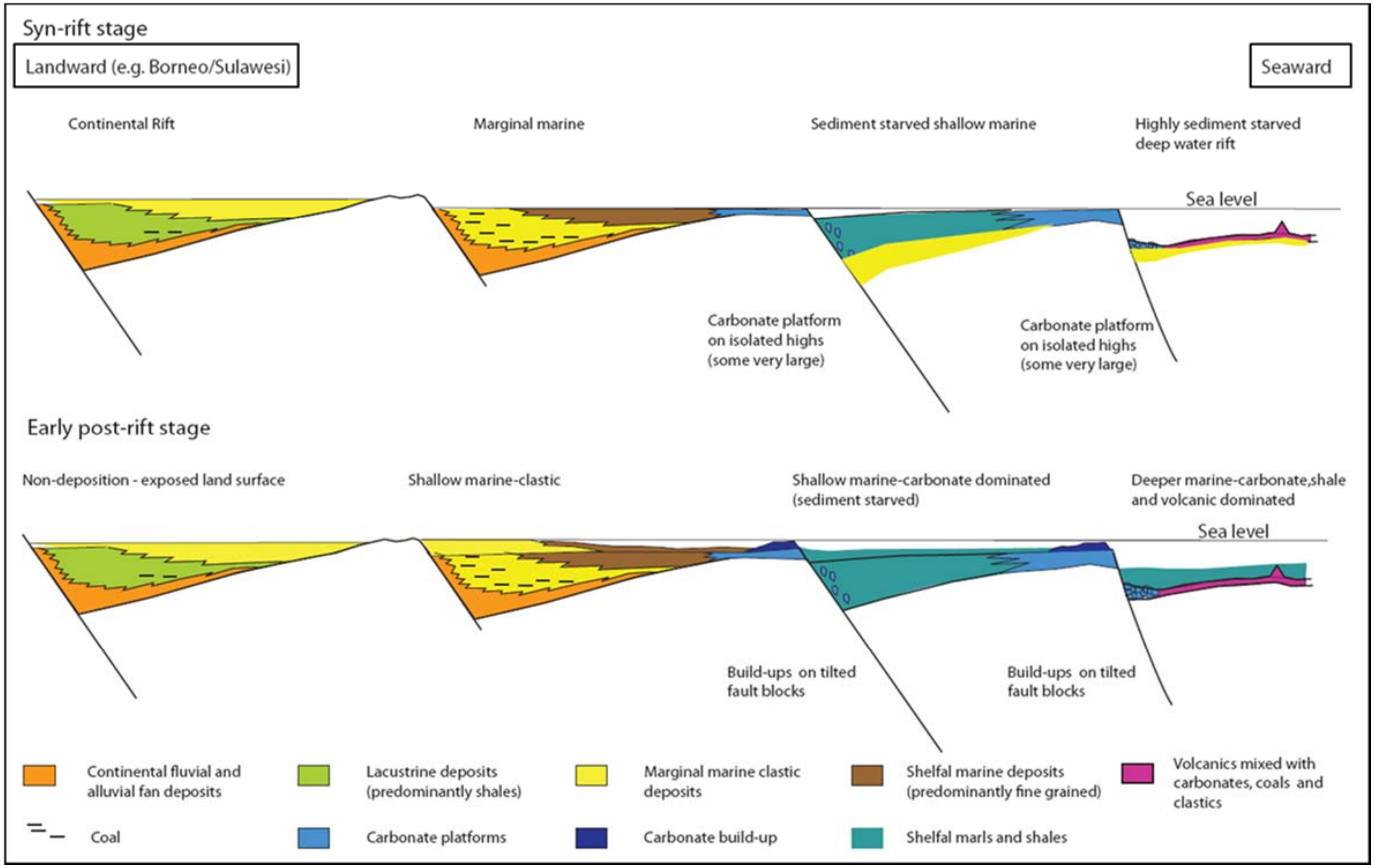

Figure 3 - A sketch illustrating variation of depositional sequences in syn-rift and early post-rift stages from non-marine to shallow marine to deepwater settings (Argakoesoemah et al, 2016).

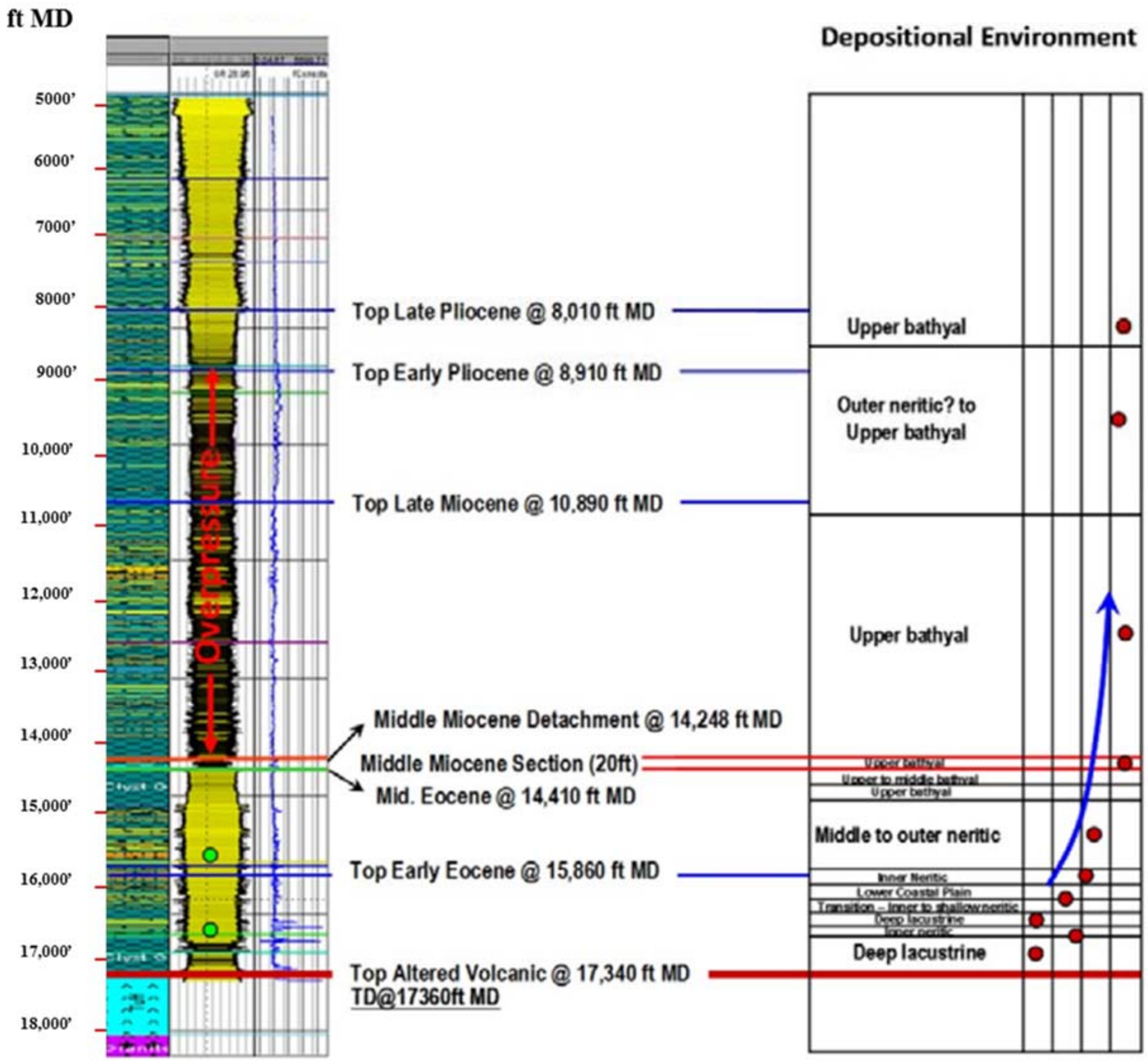

Figure 4 - Kaluku-1 post-drill lithology and biostratigraphic analysis results (Satyana, 2015). The depositional environment of Middle Eocene sequence rapidly changed from outer neritic to be upper bathyal in Middle Miocene. The Oligocene to Early Miocene interval seems to be too thin to be recognized in this well location.

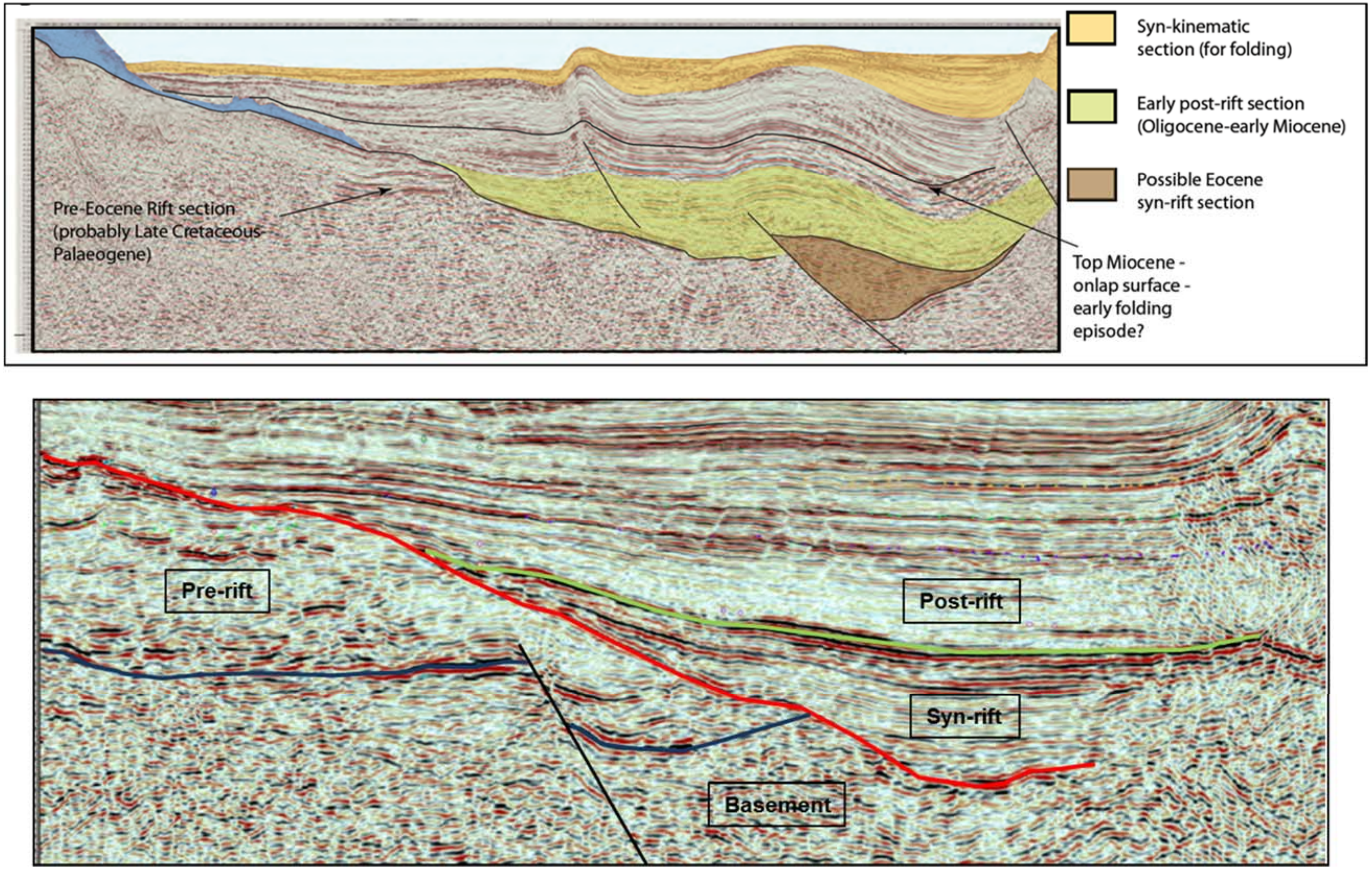

Figure 5 - An example of 2D seismic interpretation showing the development of a syn-rift in the Greater Makassar Strait region. Internal seismic characters show that the basement rocks underneath the region is a continental crust.

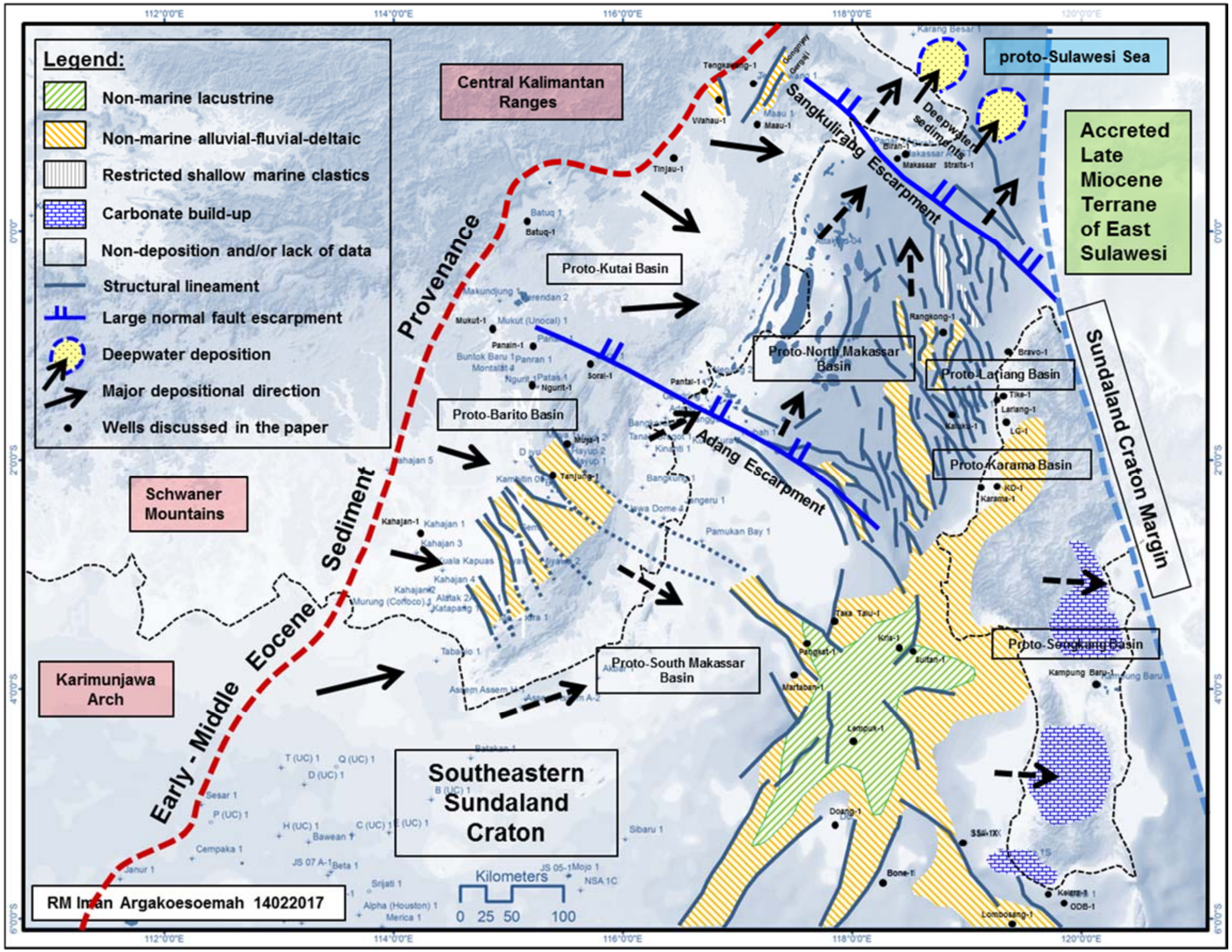

Figure 6 - Palaeogeography of Middle Eocene showing distribution of syn-rift sequences over the Greater Makassar Strait region. The map is overlain with the present-day structure.

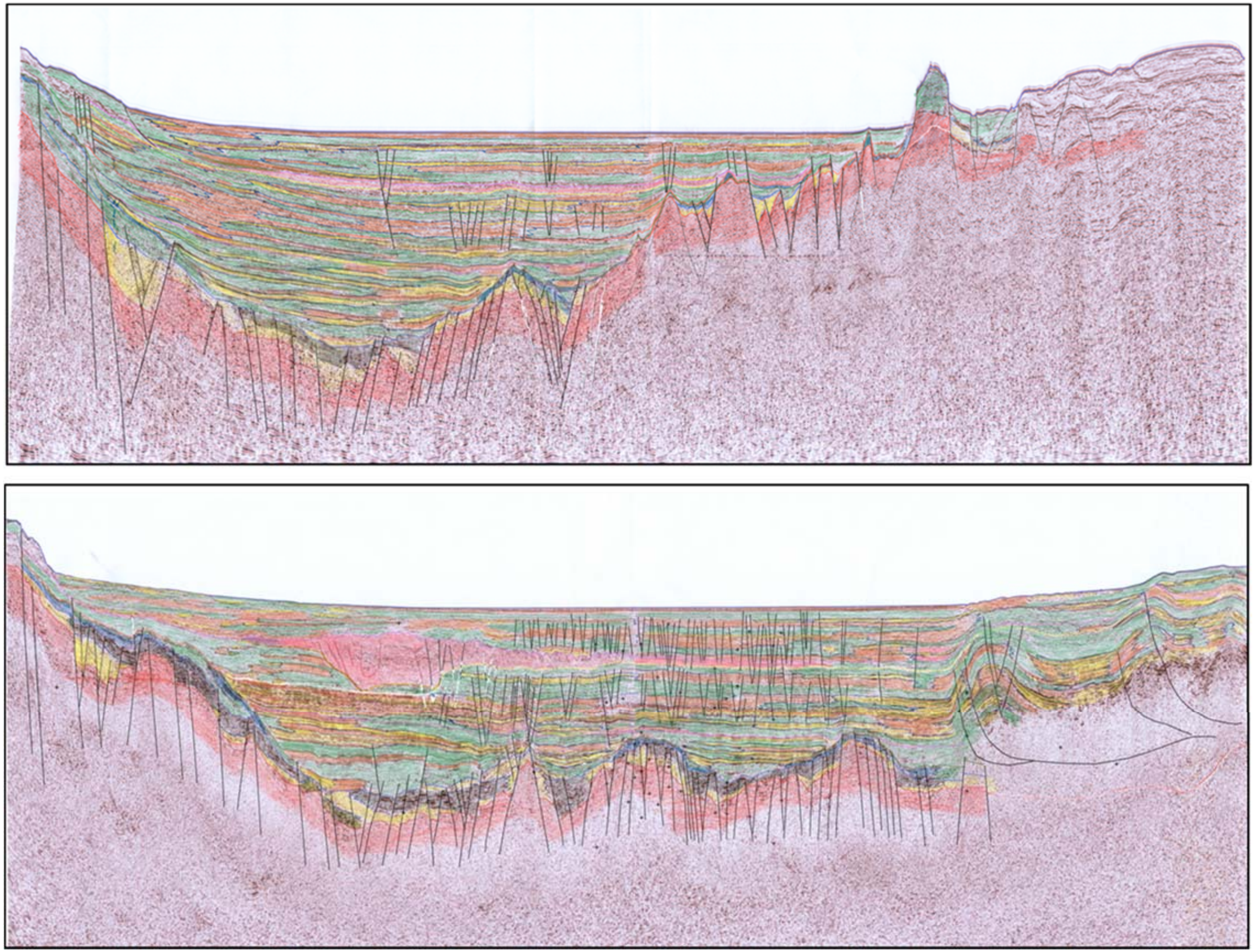

Figure 7 - 2D seismic interpretation showing horsts and grabens of the Early-Middle Eocene syn-rift sequence. The Plio-Pleistocene compressional and uplift do not have significant impact to the syn-rift structures.

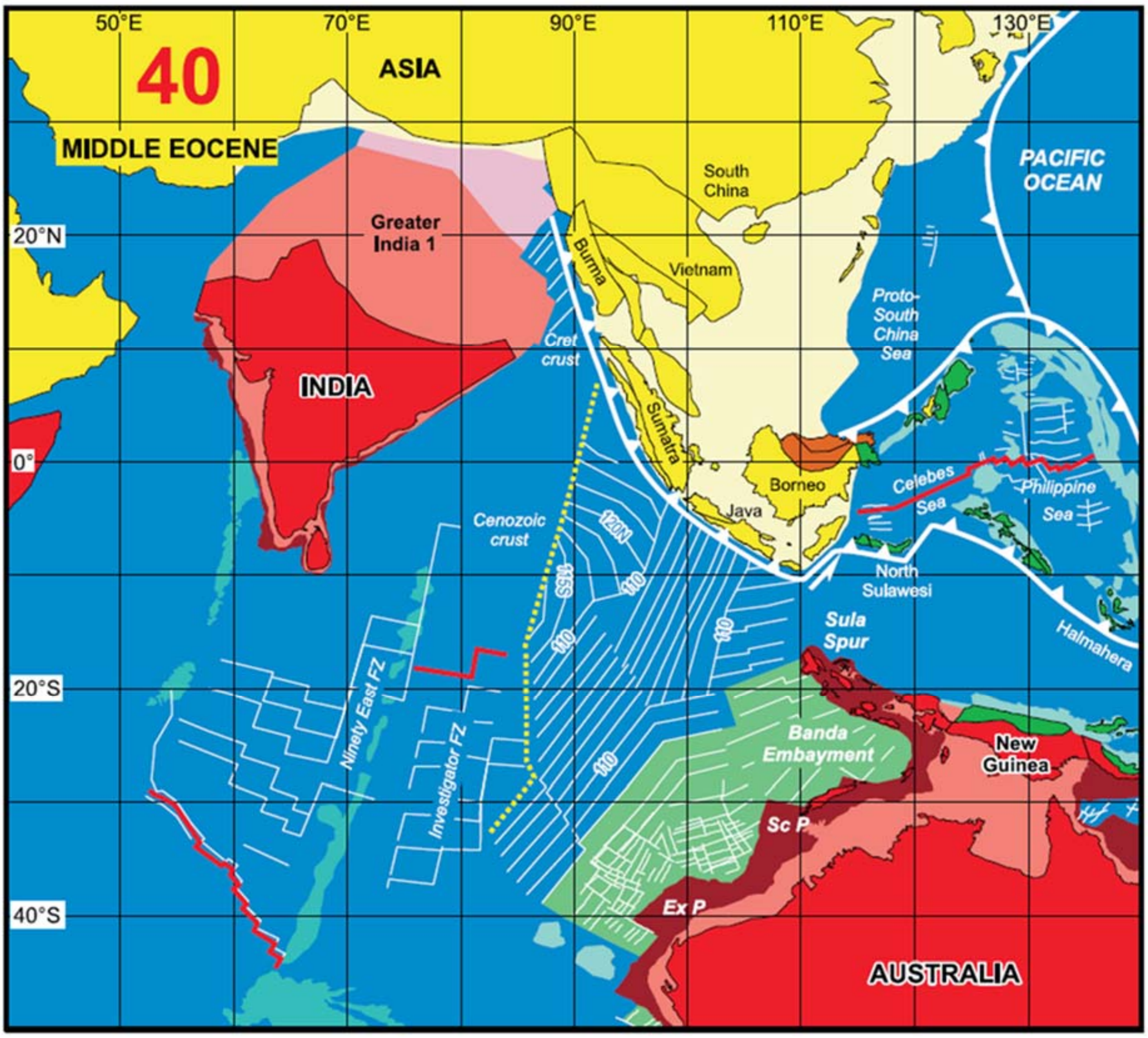

Figure 8 - Tectonic reconstruction at 40 mya (Middle Eocene) showing the southeastern end of Sundaland Craton and Greater Makassar Strait region (Hall, 2012).