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VARIABILITY OF PALEOGENE SOURCE FACIES OF CIRCUM-SUNDALAND BASINS, WESTERN INDONESIA: TECTONIC, SEDIMENTARY AND GEOCHEMICAL CONSTRAINTS – IMPLICATIONS FOR OIL CHARACTERISTIC

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ABSTRACT

Tertiary basins encircling Sundaland (circum-Sundaland Basins) of Western Indonesia (North Sumatra, Central Sumatra, South Sumatra, Sunda-Asri, West Java, East Java, Barito, Kutei, West Natuna, East Natuna, South Makassar, West-South Sulawesi Basins) were formed in the Mid-Eocene to Early Oligocene. The basins were formed mostly as tectonic responses due to collision of India to Eurasia, they were formed by: (1) trans-tensional rifting induced by regional post-collision tectonic escape or (2) back arc rifting induced by roll-back movement due to slower rate of Eocene subduction.

Thick intervals of Paleogene sediments were deposited in early, middle, and late phases of rifting, as well as early phase of post-rifting of the basins, covering depositional environments ranging from nonmarine, lacustrine, fluvio-deltaic, paralic, marginal- to shallow marine facies. These sediments are important hydrocarbon source rocks in the basins. Few wells or no well penetrated these sources, causing precise interpretation of the source facies is impossible due to the absence of samples for biostratigraphic analyses. However, interpretation of the source facies can be assessed by detailed examination of biomarkers of oils generated from these sources (geochemical inversion).

Varied biomarkers are encountered, revealing the variability of their source facies. Characteristic of oils generated are various caused by their various source facies, but the facies variability of each basin is typical and predictable, systematically expressing its tectonic and sedimentary settings on and around the Sundaland.

INTRODUCTION

Sedimentary basins around the Sundaland show roughly similar tectonostratigraphic history during the Paleogene and Neogene, basically including histories related to: pre-rifting, syn-rifting, post-rifting, sagging, and syn-inversion. Differences of these basins lay on the time initiation of each tectonostratigraphic unit and its sedimentary facies. The latter is determined by the position of the basin relative to the Sundaland.

These sedimentary basins (North Sumatra, Central Sumatra, South Sumatra, Sunda-Asri, West Java, East Java, Barito, and West Natuna) produce oils from Paleogene and Neogene reservoirs, but the oils were generated from Paleogene source rocks. Basins of South Makassar and West-South Sulawesi also have generated oils from their Paleogene sources as proved by testing of well/s or seeps. Kutei Basin produces oil generated from Neogene deltaic sources, whereas its Paleogene source is not proven yet generated oil due to these rocks are very deeply buried by stacks of Neogene deltaic sediments.

The facies variability of these Paleogene sources is best examined by biostratigraphic analysis of the rocks. However, these rocks are located within the kitchen of each basin and almost no well penetrate the kitchen. Therefore, the examination is based on oils generated from these sources through oil geochemistry analyses. A number of oil biomarkers are ample tool to reveal the source facies of oils.

METHODS

Tectonostratigraphic evaluation of Sundaland basins is based on published literatures. Tectonics and sedimentary facies of the Paleogene sequences on each basin will affect its source facies. Due to the absence of well penetrate these sources because they are deeply buried in the kitchens, the

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examination of the source facies is not based on biostratigraphic analysis, but on oil geochemistry analysis. The oil was generated from the source and oil characteristic will reveal its source.

In this paper, biomarkers of oils are used as tool to know the characteristic of source, this method is called geochemical inversion (Bissada et al., 1992). Biomarkers can extract specific information on the oil source. Inferences on such factors as organic matter make-up, depositional environment, lithology, age and maturity of the source can frequently be drawn.

RESULTS

Tectonics of the Sundaland Basins

Sundaland is the region of SE Asia that formed an exposed landmass during the Pleistocene sea level lowstand, comprising Indochina, the Thai–Malay Peninsula, Sumatra, Java, Kalimantan/ Borneo, and the shallow marine shelf (the ‘Sunda Shelf ’) between them. Sundaland is the continental core of SE Asia. It is now bordered to the west, south and east by subduction and collision zones. To the north it merges with the region deformed in the Cenozoic by India–Asia collision (Hall and Morley, 2004).

India-Asia collision in Eocene is widely accepted to be the major controlling mechanism for rift-basin development throughout the southeast Asia region during the Paleogene (Daly et al., 1987). They (1987) considered that the major effect of the India and Eurasia collision was to induce: clockwise rotation of Indochina, extension along the Sumatra margin and, presumably the development of rift-basins of South East Asia by mechanism of post-collision tectonic escape. Daly et al. (1987) also emphasized that the rate of the India-Eurasia collision was a factor controlling the plate-convergence rate along the margin of Sundaland. Rift-basin development during the Paleogene is explained to be also related to the decrease in the subduction rate along the margin of Sundaland (rifting related to subduction roll-back).

Paleogene tectonic setting of the basins will affect basin’s paleogeography which is important for its depositional facies. At the beginning of the Cenozoic (*Figure 1*, Hall and Morley, 2004) northern Sundaland was relatively high. Uplift in the Late Cretaceous–Paleogene extended from the Shan Plateau of Myanmar and northern Thailand through Laos into the Lanping–Siamo fold belt as the result of a diffuse, poorly defined orogenic event. Further south the region is interpreted to have been continental with the development of rifting containing continental fill or marine fill. Further south and east

In the Neogene, there were northeastward drifting of the Australian microcontinents, northward movement of the Australian continental plate and the westward movement of the Pacific plate. These plate movements were responsible for the collision of the microcontinents with the eastern margin of Sundaland, strike-slip movements, and basin inversions of the eastern margin of the Sundaland during the Neogene time onwards. The increase in the collision rate from 5 cm/year to 6.5 cm/year (Daly et al, 1987) during the late Miocene onwards resulted in compression along the subduction complex bordering the Sundaland margin, causing inversion of the many rift-basins developed during the Paleogene time.

Paleogene Sediments of the Sundaland Basins

The Paleogene time is marked by deposition of a syn-rift sedimentary package in a continental to marine setting. Although the Paleogene grabens and halfgrabens varied in depth and rate of subsidence, which in detail affected the depositional environment and type of sediment, the stratigraphic successions are remarkably similar. In terms of stratigraphic evolution, the rifting phase can be divided into three major phases, which are: early, middle and late phases of rifting. (Sudarmono et al., 1997). Stratigraphic succession of Sundaland basins both at the western and eastern margins of Sundaland is displayed on *Figure 2*.

The early-phase deposits of the Paleogene rift basins of Sundaland are predominantly non-marine, comprising volcaniclastics, fluviatile, alluvial-fan and shallow lacustrine freshwater deposits. In the Sunda Basin, the earliest basin fill is the early Banuwati Formation. In the South Sumatra Basin and the Ardjuna and Jatibarang Basins in northwest Java, the earliest basin fill typically is composed of alternating lacustrine clastics and volcanoclastics, Kikim volcanics in South Sumatra and Jatibarang volcanics in West Java Basins. In the West Natuna Basin, the Lama Formation is recognized as the earliest basin fill and is composed of lacustrine clastics interspersed with volcaniclastics.

During *the middle phase of rifting*, the depositional environment was commonly characterized by deep, broad lakes as earlier, smaller and separated lakes, which developed during the early-rift phase, coalesced as the rate of subsidence exceeded the rate of sedimentation. These broad and deep lakes at the depocentres tended to be restricted from large terrigeneous input and had low relief vegetated areas, which in humid climates are favorable sites for development of organic-rich lacustrine source facies. The Pematang lacustrine shales in the Central Sumatra Basin, the Late Banuwati lacustrine shales in the Sunda Basin, the Lama and Benua lacustrine shales in the West Natuna Basin are examples of the deep lacustrine development during the middle phase of rifting. In the Ardjuna Basin, shallow lakes with high volcanic sediment input rather than a restricted deep lake were likely developed during the deposition of the Jatibarang Formation.

At *the late stage of rifting*, lakes commonly were shallower and deposition dominated by coarse clastic fluvio-deltaic processes. Large and shallow embayments with restricted access to marine conditions likely occurred during this period throughout many of the Paleogene basins before the depositional setting gradually changed to fully marine. Marine incursions chronologically were slightly different from basin to basin and were controlled by the rate of subsidence, and access and closeness to the open marine system. The western margin of Sundaland was mostly occupied by marine conditions later than the eastern margin although the North Sumatra Basin likely was influenced by marine conditions as early as late Eocene. The East Java, Lombok and Barito basins were marine earlier than basins in Sumatra and West Java due to their closeness to the open Tethys Ocean. Parts of those basins were occupied by a marine setting since middle Eocene..

The post-rift phase is coincident with relative sea level rise resulting in a transgressive setting. There was a shift in provenance from sediment derived from a mixed metamorphic-granitic terrain of local basement highs/horst blocks and volcanic source terrain during early to middle rift-phase to a progressively more mature granitic/quartzose basement derived from the Sunda craton during the end of rifting to the post-rift.

Paleogene source facies of the Sundaland basins comprises sources from depositional phases of early phase of rifting, middle and late phases as well as post-rift phases. Paleogene source rocks that have generated hydrocarbons in Sundaland basins vary from organic-rich lacustrine facies of early and middle-phases of rifting, to carbonaceous shales and coals of fluvio-deltaic, paralic and marginal marine of late phases of rifting and post-rifting and marine facies of post-rifting.

Paleogene Sources of Sundaland Petroleum System Types

Presence of various source facies from lacustrine, fluvio-deltaic, paralic and marginal marine to marine facies will result in various petroleum system type (PST) because the system is based on the presence of source rock. Doust and Sumner (2007) proposed four petroleum system types for Sundaland and SE Asia-Austral-Asia, as below (*Figure 3*).

Early syn-rift lacustrine PST. This is strongly oil prone due to the widespread development of organic-rich lacustrine source rocks, and is common in basins in Thailand, Vietnam and western Indonesia. Most of the oils are derived from lacustrine and fluvio-lacustrine source rocks rich in algal organic material (Type I/II), while minor amounts of gas are contributed by Type III coals and coaly shale source rocks that occur in small marginal lake swamp facies.

Late syn-rift transgressive deltaic PST. Backstepping deltaic or paralic sequences typify this PST. Source rocks comprise oil and gas-prone Type II/III coals and coaly shales that are interbedded with fluvio-deltaic reservoirs and seals, often of excellent quality.

Early post-rift marine PST. Source rocks in this principally marine shale sequence are mainly lean and/or gas-prone. It is proposed that charge originates from mainly land plant material, transported into the marine environment where it has been buried and preserved as Type II/III terrestrial organic matter. Sometimes the organic material appears to have been transported by turbidity currents into deep water, but usually it is represented by dispersed Type II/III plant material in intra-deltaic neritic clays. Mangrove-derived organic matter found in association with carbonate sequences may also have minor source-rock potential, but this is not well documented.

Late post-rift regressive deltaic PST. This PST has similar environments and characteristics as the late syn-rift one except that it is typically progradational rather than retrogradational. In most cases it lies at depths too shallow for source-rock maturation and generation, but, where thick delta sequences are developed on continental margins, it represents the dominant system, as in the Baram, Kutei and Tarakan delta basins. Both reservoir and source material (typically terrestrial organic matter in the form of leaf litter) have been introduced into these bathyal environments by turbidity current processes.

Biomarker as Clue to Know Source Facies of Oils

The organic matter accumulating in the potential, source sediments possesses distinctive biochemical characteristics inherited from the specific combination of organisms within the original ecosystem.

These characteristics, in turn, are transferred to the generated oils in the form of molecular geochemical "fossils" or biomarkers. Among these are the series of compounds known as "isoprenoids", derived mainly from the side chain on the chlorophyll molecule, a series known as "triterpanes", derived mainly from cell membranes of prokaryotic organisms (bacteria and blue-green algae), and a series known as "steranes", derived mainly from steroids of algae and higher organisms. The identification of more specific biomarker compounds in an oil can be very useful in inferring many attributes of the parent source rock. Interpretation of such traces unravels a lot of the mystery surrounding the origin of a crude.

Some usages of biomarkers to interpret the source facies are as follows. The ratio of pristane (Pr) to phytane (Ph) in a crude oil has frequently been used as an indicator of either relative importance of higher-plant input vs. bacterial inputs or redox conditions within the depositional system. The dominance of tricyclic over pentacyclic triterpanes (ratio > 1) in the crude provides a criterion to establish the dominance of the microbial or algal contribution because tricyclics are characteristically absent in extracts from higher plant kerogens. Oils enriched in tricyclics should be interpreted to have originated in a distal marine facies far removed from any terrestrial input, or in lacustrine shales containing Type I kerogen. The lower pentacyclic terpane (hopanes) abundance relative to the steranes, reflects the strong influence of the autochthonous algal input to the source. The C-27 to (2-29 sterane ratio in a crude oil is traditionally used as an indicator of the relative importance of marine (dominantly C-27) versus terrestrial (dominantly C-29) organic matter into the source.
The product hydrocarbon retains the majority of the structure that was in the original complex organic molecule. Thus, by examining the encountered hydrocarbons, it is possible to glean what type of organic matter originally contributed to the petroleum. To examine the characteristics of hydrocarbons to infer the characteristics of their sources is called *geochemical inversion*.

Paleogene Source Facies of the Sundaland Basins: Clues from Biomarkers

Paleogene source rocks that have generated hydrocarbons in Sundaland basins vary from organic rich lacustrine facies to carbonaceous shales and coals of fluvio-deltaic, paralic and marginal marine and marine facies. Most of the lacustrine source rock facies were deposited during the middle-phase to the end of post-rift phase while other source rock types were developed at the end of the post-rift phase concurrently with marine incursion events. Multiple source rock facies are possible in a single Paleogene basin, but commonly only a single major source rock facies is present in any one basin (Sudarmono et al., 1997).

Basins with source facies of lacustrine to fluvio-deltaic

Central Sumatra Basin (*Figures 4, 5*). Lacustrine facies dominates the sources of this basin. The characteristics are bimodal to broad n-alkane distribution due to input of C15-C19 and C23-C33 n-alkanes from non-marine algae, low Pr/Ph ratios < 3.0 and have low Pristane/nC17 ratios. Lacustrine oils are typically high wax (C31/C19 > 0.4). Deep lacustrine sourced-oils tend to have simple triterpane distributions containing only pentacyclic 17α hopanes from C27-C35 plus moretanes and little else. The Tm/Ts ratio, which is maturity and organic facies influenced, is low and enriched in tricyclic terpanes. Steranes relative to hopanes tend to be in low concentrations. Deep lacustrine oils usually contain the full range of C27-C29 steranes and diasteranes, albeit in very low concentrations, and usually have a roughly equal concentration of C27 and C29 steranes. However, a characteristic of deep lacustrine oils in Indonesia is the unusually high concentration of C30 4-methyl steranes in many of the oils. These can be identified from m/z 231, 414 scans and are also present on the m/z 217 scan (Robinson, 1987). These compounds are believed to be derived from dinoflagellates, but are also probably derived from non-marine planktonic algae. Presence of high Pr/Ph (> 6.0, MSCQ-1 oil) shows the presence of fluvio-deltaic source in addition to predominating lacustrine shales. The

Oligocene synrift Pematang shales are the sources of Central Sumatra Basin.

Sunda- Asri and West Java Basins (*Figure 6*). Zelda oil from Sunda-Asri Basin shows lacustrine oil. It is bimodal distribution of GC. low Pr/Ph (< 3.0), enriched in C23-C27, and high wax ratio C31/C19 > 0.4. Triterpane m/z-191 of Sunda oils show low Tm/Ts ratio (0.5). West Java Basin generated fluvio-deltaic oils as shown by high Pr/Ph ratio of oils Ardjuna MQ-1 and Cemara Selatan-2 (6-8). They characteristically have high pristane/phytane ratios (>3.0) due to deposition of the source rock in an oxic environment. Triterpane of Ardjuna shows high Tm/Ts ratio, and presence of biomarkers oleanane and bicadinane. Fluvio-deltaic oils have very characteristic Triterpane distributions with high concentrations of C30 higher plant resin derived cyclic alkanes and the C30 compound 18α oleanane. Bicadinane derives from angiosperm dammar resins of some SE Asian higher land plants (Peters and Moldowan, 1993), characterizing fluvio-deltaic environment. The Oligocene synrift Banuwati shales are the sources of Sunda-Asri Basin. The Oligocene late synrift Talang Akar coals and coaly shales are the sources of West Java Basin.

West Natuna Basin (*Figure 7*). Both lacustrine and fluvio-deltaic or shallow lacustrine source facies exist in the basin. Lacustrine source facies is characterized by bimodal distribution of GC and < 3.0 Pr/Ph like in Alu-Alu oil, as well as abundant tricyclic terpane of Belanak oil. Fluvio-deltaic, terrestrial higher plant-sourced oils also occur in Alu-Alu as shown by high ratio of Tm/Ts and presence of oleanane and bicadinane. Michael and Adrian (1996) investigated that oils proposed to have a terrestrial dominated source rock origin from coal and/or coaly shale sources (i.e. Belida, Kakap, Terubuk, Kerisi DST-2) also contain high concentrations of cadalene (500 - 1,250 ppm), higher C29 steranes and resin-derived diterpoids (123 m/z) and terpanes (e.g. oleanane, des-A-oleanane) which are not present or have lower concentrations in oils more likely sourced from lacustrine algae. Based on crossplot of Pr/Ph and 13-carbon isotope from saturate fraction, Michael and Adrian (1996) grouped oils in West Natuna Basin of area Block B into source facies of (with diminishing predominance): terrestrial organic matter, mixed algal and terrestrial organic matter, and fresh to brackish lacustrine. Oligocene Synrift Benua/Belut and late-synrift Lower Gabus shales, as well as Early Miocene postrift Barat/Lower Arang coals and coaly shales are proven and possible sources of the West Natuna Basin.

Basins with source facies of predominating fluvio-deltaic

South Sumatra Basin (*Figure 8*). Fluvio-deltaic source facies dominates the oils of this basin. Bicadinane and oleanane, deriving from angiosperm dammar resins of some SE Asian higher land plants exist in oils. Tricyclic terpane is minimum, showing nonmarine or non-lacustrine algal association for oils. Sterane distribution with dominant C29 show significant terrestrial/fluvio-deltaic input. Fluvio-deltaic oils have a very characteristic m/z 217 scan usually containing only C29 steranes and diasteranes. The dominant compounds on the scan are C30 resin derived cyclic alkanes, which are also present on the m/z 191 triterpane scan. Robinson (1987) compared triterpane and sterane distributions of fluvio-deltaic oils from South Sumatra, Kutei and Tarakan Basins shows little variation between them, suggesting the organic facies and original higher plant input is similar in all these basins although source age of South Sumatra (Paleogene Talang Akar) is different with those Neogene sources from Kutei and Tarakan Basins. GC of Bentayan oil may indicate the presence shallow lacustrine source facies in this basin with enriched C23-C29 and Pr/Ph < 3.0. Proven sources of the South Sumatra Basin are believed Early Oligocene synrift Lemat shales and Late Oligocene late synrift-early postrift Talang Akar coals and coaly shales.

East Java Basin (*Figure 9*). Fluvio-deltaic source facies dominates the oils of East Java Basin. It is characterized by high Pr/Ph and Pr/nC17 ratios, indicating terrestrial input and deposition in a relatively oxidizing environment. Abundant presence of terrestrial plant biomarkers such as bicadinane and oleanane indicate source rocks rich in terrestrial plant kerogen. The presence of C30 marine steranes together with abundant oleanane suggests a marine-influenced deltaic source facies-probably lower delta plain coals and/or organically rich interdistributary bay mudstones. Marine-influenced of deltaic source facies may also be indicated by significant tricyclic terpane of Kawengan oil. Satyana and Purwaningsih (2003) investigated regional oil geochemistry of East Java oils. GC of East Java oils show pronounced waxy alkanes of C20 and above, indicating derivation from land plants. Pristane/phytane ratios of the oils are roughly similar (average 4.97 for onshore oils, 5.36 for offshore oils) and are interpreted as a terrestrially derived type III kerogen from a moderately oxic environment. The wax content in the oils is variable but is generally moderately high to high (nC31/nC19 often > 0.30). The oils show a cyclic hump in the C13-C15 range interpreted as showing significant angiosperm terrestrial resin input to the oils. The GC scans for the oils are fairly typical of Indonesian oils sourced from fluvio-deltaic shales and coals containing a mainly terrestrial/minor algal organic facies. The biomarker composition of oils suggest generation from a predominantly terrestrial/minor algal organic facies. All the data is consistent with deposition of the source rock in a fluvio-deltaic to near shore marine environment. The high 18α oleanane content is suggestive of angiosperm resin input. A C24 tetra cyclic content is indicative of significant terrestrial input. Low concentrations of tricyclic terpanes and relatively low concentrations of C27 steranes (average C27/C29 steranes for onshore oils 1.04 for offshore oils 0.36) show only minor or moderate algal input. High hopane/sterane ratios are typical of predominantly sub-oxic to oxic terrestrial sourced oils.Mid-Late Eocene synrift to late syn-rift Ngimbang shales, coals, and coaly shales are proven source rocks of East Java Basin.

Barito Basin (*Figure 10*). High Pr/Ph ratios (> 5.0) of oils show deposition of sources in oxic terrestrial related to fluvio-deltaic environment. Oils reservoired in Tanjung sandstones (Tanjung Field) are slightly differ from oils reservoired in Warukin sandstones (Tapian Timur and Warukin Selatan Fields). The difference may relate to different maturity level or source facies. Tanjung oils may also come from shallow lacustrine. Tanjung oils are moderately mature terrestrial oils, being slightly more mature that the Warukin oils. The terrestrial nature of Tanjung oils is illustrated by their high wax content (C31/C19), high Pr/Ph and Pr/nC17 ratios, high resin content shown by anomalous peaks in the C13 to C16 range, and the dominance of C29 isomers in the sterane component of the GC/MS scans. Warukin oils are low to moderately mature terrestrial oils. Depletion of light end alkanes in the C8 to C13 range may relate to biodegradation since the Warukin Formation is hydrodynamically active, and meteoric water flushing would provide an avenue for the introduction of bacteria. Also, the reservoir temperatures where these oils trapped are low enough not to preclude biodegradation. The terrestrial nature of the oils is illustrated by their high wax content, high Pr/Ph, Pr/nC17 ratios, high resin content (C13-C16 content), and the dominance of C29 isomers in the sterane component. Mid-Eocene synrift to late synrift Lower Tanjung shales, coals and coaly shales are proven source rocks of the Barito Basin. Upper early Miocene Lower Warukin coaly shales are considered by Rotinsulu et al. (1993) have generated oils, but maturity analysis on this is dubious.

Kutei Basin (*Figure 11*). Oils of Kutei Basin are sourced by Neogene coals and coaly shales of deltaic facies. It is discussed here for a comparison for similar source facies (coals and coaly shales) of Paleogene sources mainly in South Sumatra, West Java, East Java, and Barito Basins. GC alkane and GC/MS of triterpane m/z 191 and sterane m/z 217 show typical terrestrial fluvio-deltaic oils like their Paleogene counterparts: high Pr/Ph and Pr/nC17 ratios, presence of bicadinane and oleanane, dominance of C29 isomers in the sterane component, and minimum presence of tricyclic terpane. Neogene deltaic coals and coaly shales of Kutei Basin are the proven source rocks of Kutei oils, and their transported materials into deep-water area of Kutei-North Makassar Basins also sourced the oils of deep-water reservoirs like in West Seno and Ranggas Fields. Lin et al. (2005) investigated this and shows that oils in deep-water fields are similar in nature with oils in deltaic fields. Similar characteristics including: (1) high pristane/phytane, oleanane/hopane and bicadinane/hopane ratios, (2) a C29-sterane dominance and the general lack of C30-steranes, (3) high lupanoids - another suite of molecular markers indicative of land plant precursors, (4) low sulfur and asphaltene, and (5) variable wax content.

West Sulawesi Seeps (*Figures 12, 13*). West Sulawesi, geologically shares similar tectono-stratigraphic setting with sedimentary basins of Sundaland. West Sulawesi is the easternmost margin of the Sundaland that drifted away from the Sundaland by opening of the Makassar Straits. There are numerous oil and gas seeps in onshore West and South Sulawesi, and have been characterized geochemically. All oil seeps were sourced by Eocene terrestrial coals or coaly shales of Toraja or Kalumpang Group. Slight biodegraded oil seeps show GC alkane scan typical of terrestrial oils with high Pr/Ph (> 5.0) and Pr/nC17 (> 0.5) ratios. The Eocene coal samples have been characterized and show similar GC alkane distribution. Sources of these seeps are similar in nature with Paleogene coals and coaly shales of South Sumatra, West Java, East Java and Barito Basins.

Basin with source facies of predominating marginal-shallow marine

North Sumatra Basin (*Figure 14*). Different with other basins encircling Sundaland, North Sumatra oils show predominating marine oils as indicated by their GC alkane, triterpane and sterane scans. GC scans show decreasing concentration of higher molecular weight n-alkanes (low wax content), Pr/Ph < 3.0, Pr/ C17 ratio < 1.0, low wax (< 0.4 C31/C19). Triterpane scans have relatively simple hopane and moretane distributions, Tm/Ts values range from 3.0 to 1.0. There is content of 18α oleanane, indicating transportation of resistant higher plant resins into marine basin and not indicative of a terrestrial source for the oil. Noticeable other C30 resin derived compounds, commonly found in association with oleanane, are absent or in very low concentrations. Marine oils of North Sumatra are also indicated by relatively high concentrations of tricyclic terpanes. Based on steranes, isomer C27 dominates the distribution, indicating marine facies. The more abundance of C27 steranes is often associated with an algal input. Pentacyclic terpane of TJ-1 oil also shows C30 hopane/C29 norhopane ratio < 1.0, indicating carbonate source in addition to marine shales as indicated by C30 hopane/C29 norhopane ratio >1.0 (BM-1 and NSB-H1 oils). Subroto et al. (1992) investigated this matter and considered that TJ-1 crude oil is most likely to have been derived from carbonate-rich source rock with similar characteristics to the sediments of the Early Miocene Peutu/Arun Formation at Rayeu-B1. The maturity of the Peutu Formation also appears to be sufficient to have generated the TJ-1 crude oil. While the BM-1 and NSB-H1 have biomarker characteristics clearly relating them to similar source and depositional conditions to the shale sample of the Mid-Miocene upper Baong Formation at Rayeu-B1, the maturity of these formations for crude oil formation is questionable. If these formations have not reached sufficient maturity in the basin, then deeper and more mature sources with similar source and depositional conditions must be sought as a source of these crude oils. Such a source may be the Oligocene Bampo Formation which comprises mainly shales deposited in shallow to deep marine conditions.

CONCLUSIONS

Based on biomarkers of oils, and referred to tectonic and sedimentary setting of each basin of the Sundaland, it can be concluded that there is one dominating type of source facies in each basin, but totally there is mixture with other subordinate source facies. Map of Paleogene source facies of the Sundaland Basins is illustrated at *Figure 15*.

Totally, there are three major types of source facies are characterized for the Paleogene rift basins. The first type is organic rich lacustrine shales that are the most significant source rocks in Western Indonesia. Paleogene basins that contain this important source facies are mainly Central Sumatra, Sunda-Asri and may be West Natuna. Other basin indicates the presence of lacustrine facies is South Sumatra. A second type is terrestrial source rocks comprising carbonaceous shales and coals deposited in fluvio-deltaic, paralic to marginal marine settings. The depositional setting for this type commonly occurred during the end of rifting to the post-rift phase. Paleogene basins that have this type include South Sumatra, West Java, East Java, Barito, and West Sulawesi Basins. A third type is marine source facies that includes only the North Sumatra Basin (Bampo and Baong marine shales and Peutu carbonates).

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REFERENCES CITED

Bissada, K.K., Elrod, L.W., Darnell, L.M., Szymczyk, H.M., and Trostle, J.L., 1992, Geochemical inversion – a modern approach to inferring source-rock identity from characteristics of accumulated oil and gas, Proceedings Indonesian Petroleum Association, 21st Annual Convention, Jakarta.

Daly, M.C., Hooper, B.G.D, and Smith, D.G., 1987, Tertiary plate tectonics and basin evolution in Indonesia, Proceedings Indonesian Petroleum Association, 16th Annual Convention, Jakarta.

Doust, H. and Sumner, H.S., 2007, Petroleum systems in rift basins – a collective approach in Southeast Asian basins, Petroleum Geoscience, 13, 127–144.

Hall, R. and Morley, C.K., 2004, Sundaland Basins, in: Clift, P. Wang, P. Kuhnt, W. & Hayes, D.E., (eds), Continent–Ocean Interactions within the East Asian Marginal Seas, AGU Geophysical Monograph, 149, 55–85.

Lin, R., Saller, A., Dunham, J., Teas, P., Kacewicz, M., Curiale, J., Decker, J., 2005, Source, generation, migration and critical controls on oil versus gas in the deepwater Kutei petroleum system, Proceedings Indonesian Petroleum Association, 30th Annual Convention, Jakarta.

Longley, I.M., Barraclough, R., Bridden, M.A., and Brown, S., 1990, Pematang lacustrine petroleum source rocks from the Malacca Strait PSC, Central Sumatra, Indonesia, Proceedings Indonesian Petroleum Association, 19th Annual Convention, Jakarta.

Michael, E. and Adrian, H., 1996, The petroleum systems of West Block 'B' PSC, South Natuna Sea, Indonesia, Proceedings Indonesian Petroleum Association, 25th Annual Convention, Jakarta.

Peters, K.E. and Moldowan, J.M., 1993, The Biomarker Guide: Interpreting Molecular Fossils in Petroleum and Ancient Sediments, Prentice-Hall, Inc., Englewood Cliffs.

Pramono, H., Charlie Wu, C.H., and Noble, R.A., 1990, A new oil kitchen and petroleum bearing subbasin in the offshore Northwest Java area, Proceedings Indonesian Petroleum Association, 19th Annual Convention, Jakarta.

Robinson, K.M. and Kamal, A, 1988, Hydrocarbon generation, migration and entrapment in the Kampar block, Central Sumatra, Proceedings Indonesian Petroleum Association, 17th Annual Convention, Jakarta.

Robinson, K.M., 1987, An overview of source rocks and oils in Indonesia, Proceedings Indonesian Petroleum Association, 16th Annual Convention, Jakarta.

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 Indonesian Petroleum Association, 22nd Annual Convention, Jakarta.

Satyana, A.H. and Purwaningsih, M.E.M., 2003, Geochemistry of the East Java Basin: new observations on oil grouping, genetic gas types and trends of hydrocarbon habitats, Proceedings Indonesian Petroleum Association, 29th Annual Convention, Jakarta.

Satyana, A.H. and Purwaningsih, M.E.M., 2012, Variability of Paleogene source facies of circum- and drifted Sundaland Basins, Western Indonesia: constraints from oil biomarkers and carbon-13 isotopes - abstract, American Association of Petroleum Geologists, International Conference and Exhibition, September 2012, Singapore.

Subroto, E.A., Alexander, R., Pranjoto, U., and Kagi, R.I., 1992, The use of 30-norhopane series, a novel carbonate biomarker, in source rock to crude oil correlation in the north Sumatra Basin, Indonesia, Proceedings Indonesian Petroleum Association, 21st Annual Convention, Jakarta.

Sudarmono, Suherman, T., Eza, B., 1997, Paleogene basin development in Sundaland and its role to the petroleum systems in Western Indonesia, in Howes, J.V.C. and Noble, R.A. (eds), Proceedings of the Petroleum Systems of SE Asia and Australasia Conference, May 1977, Indonesian Petroleum Association, Jakarta, 545-560.

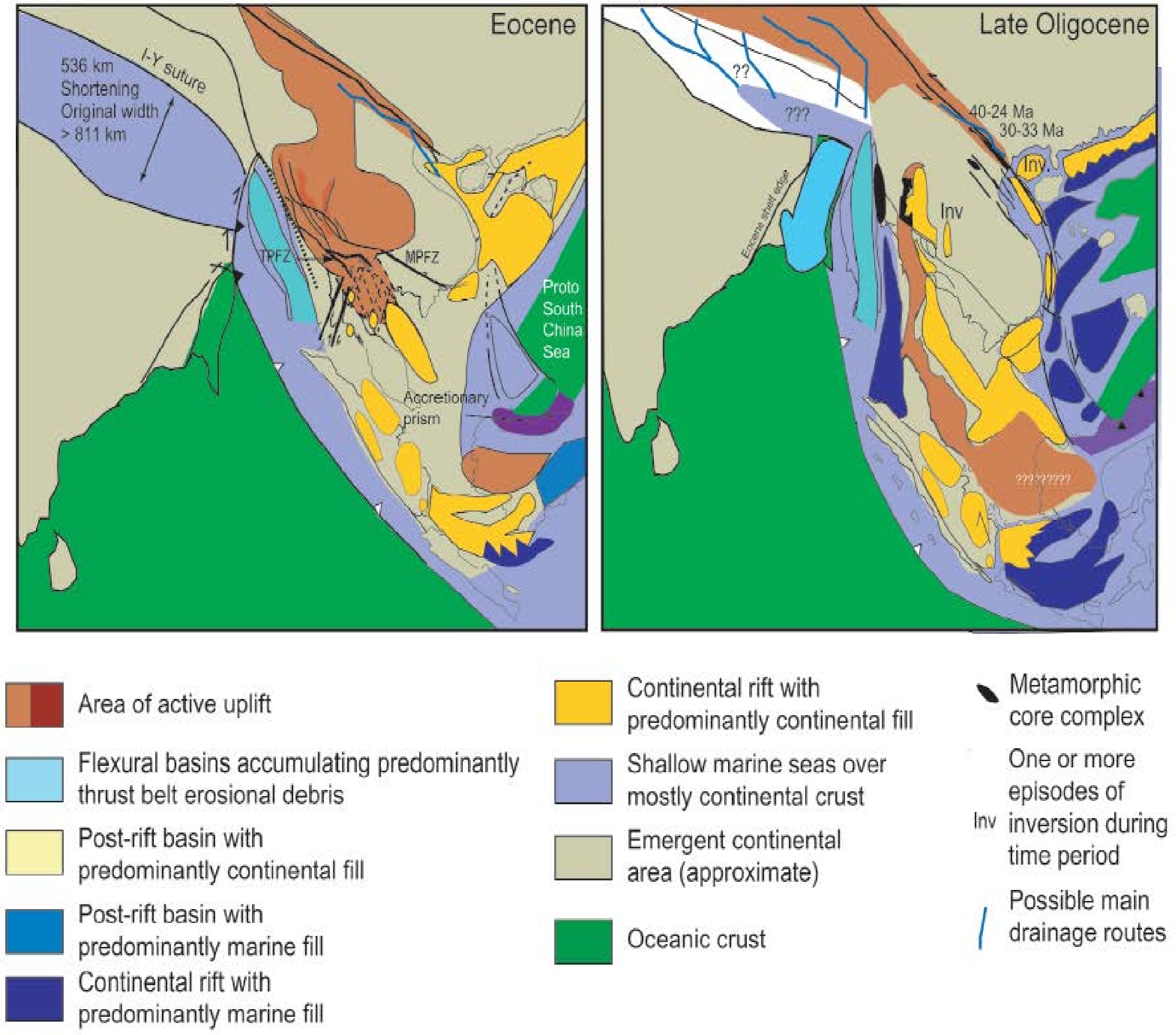


Figure 1 - Reconstruction of SE Asia and Facies of Basin Fills (Hall and Morley, 2004).

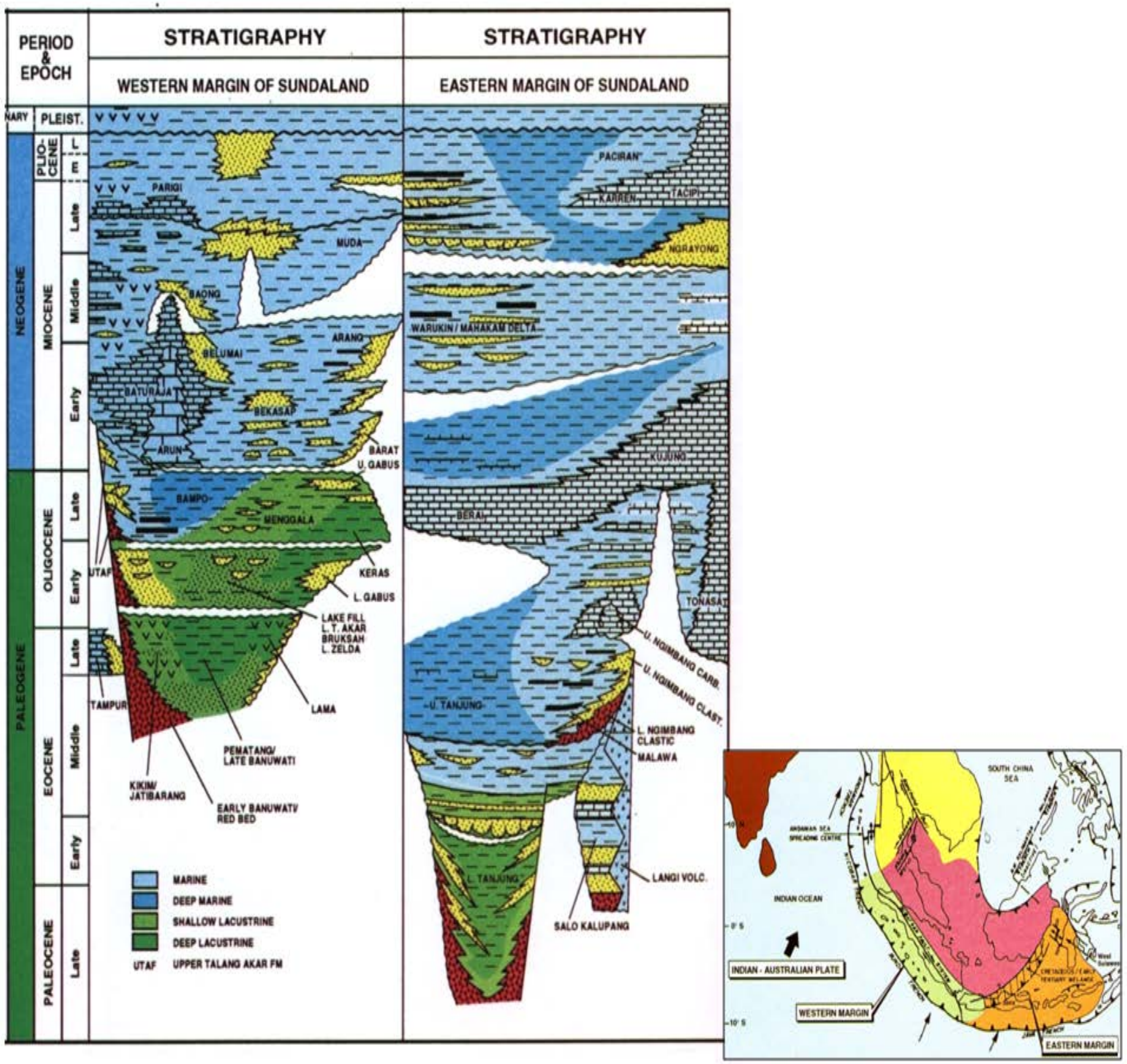


Figure 2 - Comparative stratigraphy of western and eastern margins of Sundaland (Sudarmono et al., 1997).

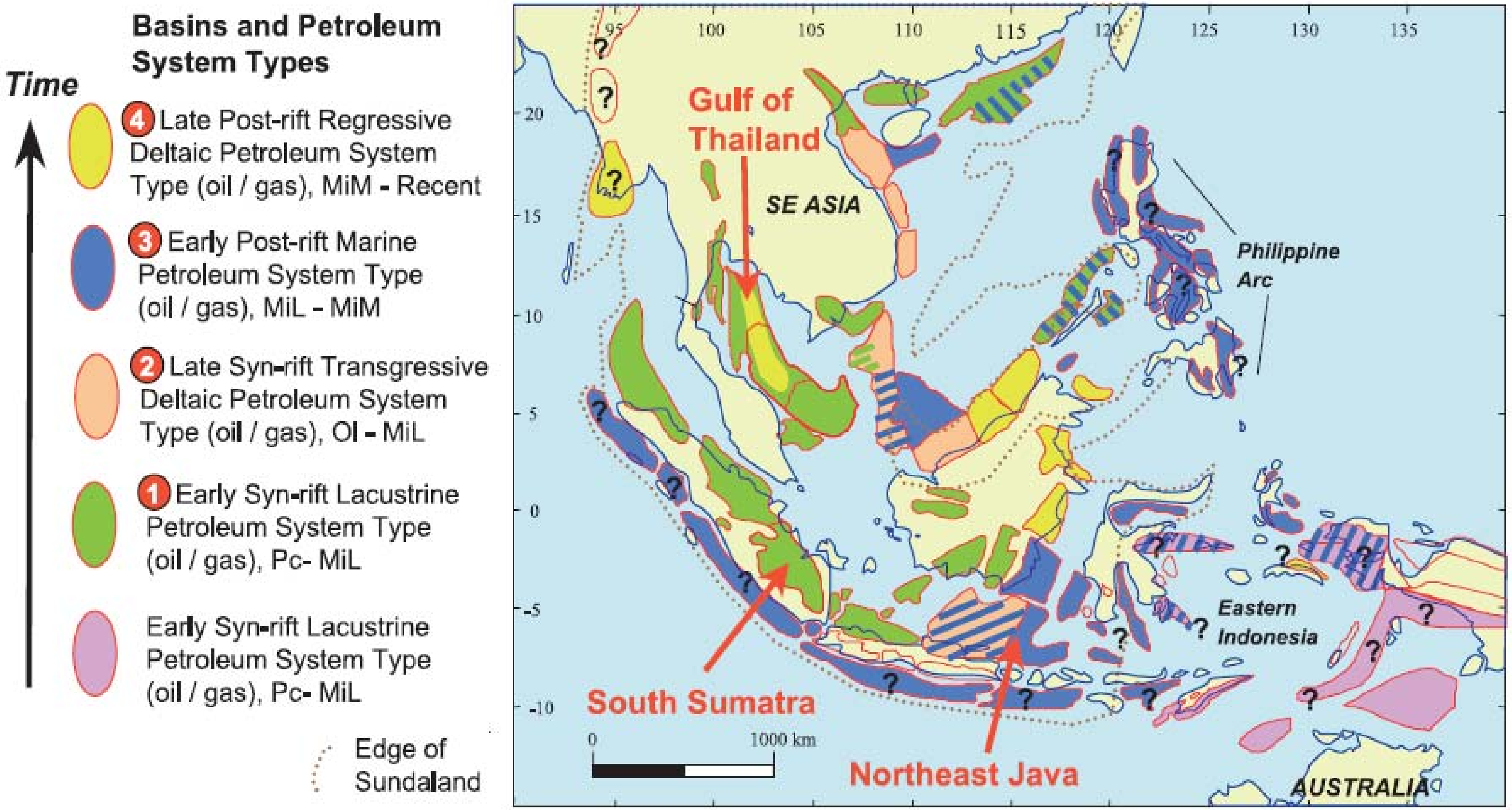


Figure 3 - Tertiary basins of Southeast Asia, showing the predominant petroleum system type or types represented (Doust and Sumner, 2007).

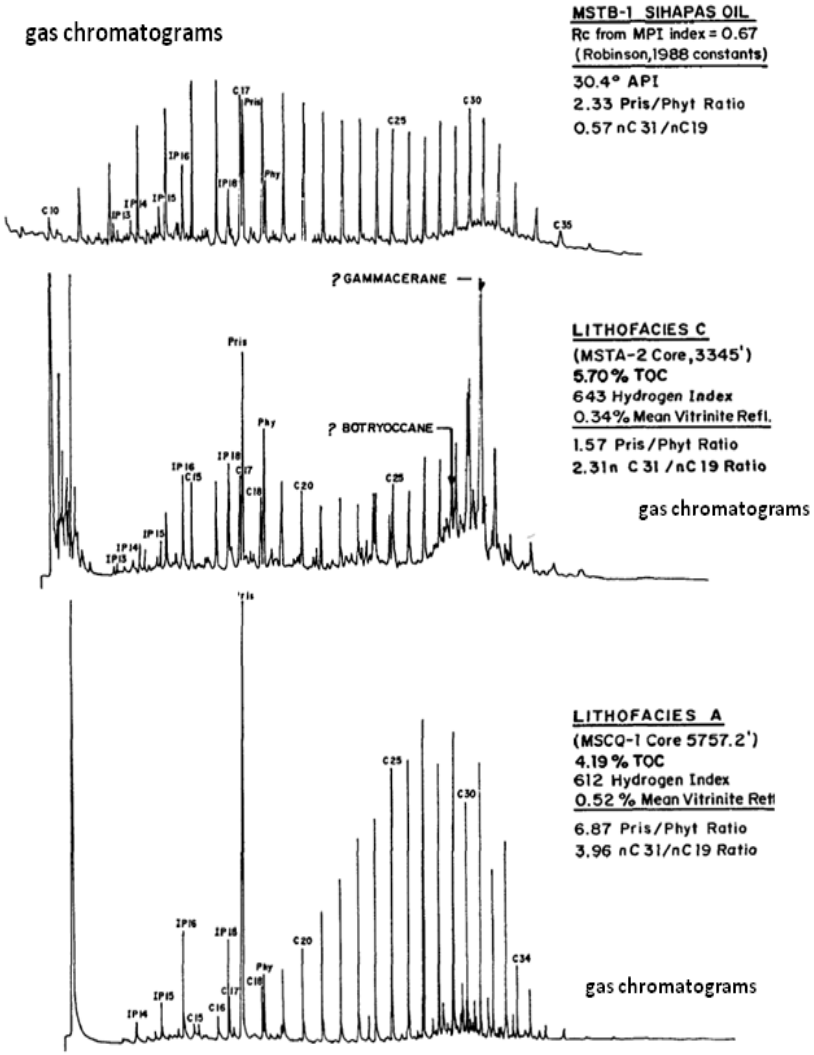


Figure 4 - Biomarker characteristics of Central Sumatra oils: lacustrine and fluvio-deltaic source facies (Longley et al., 1990).

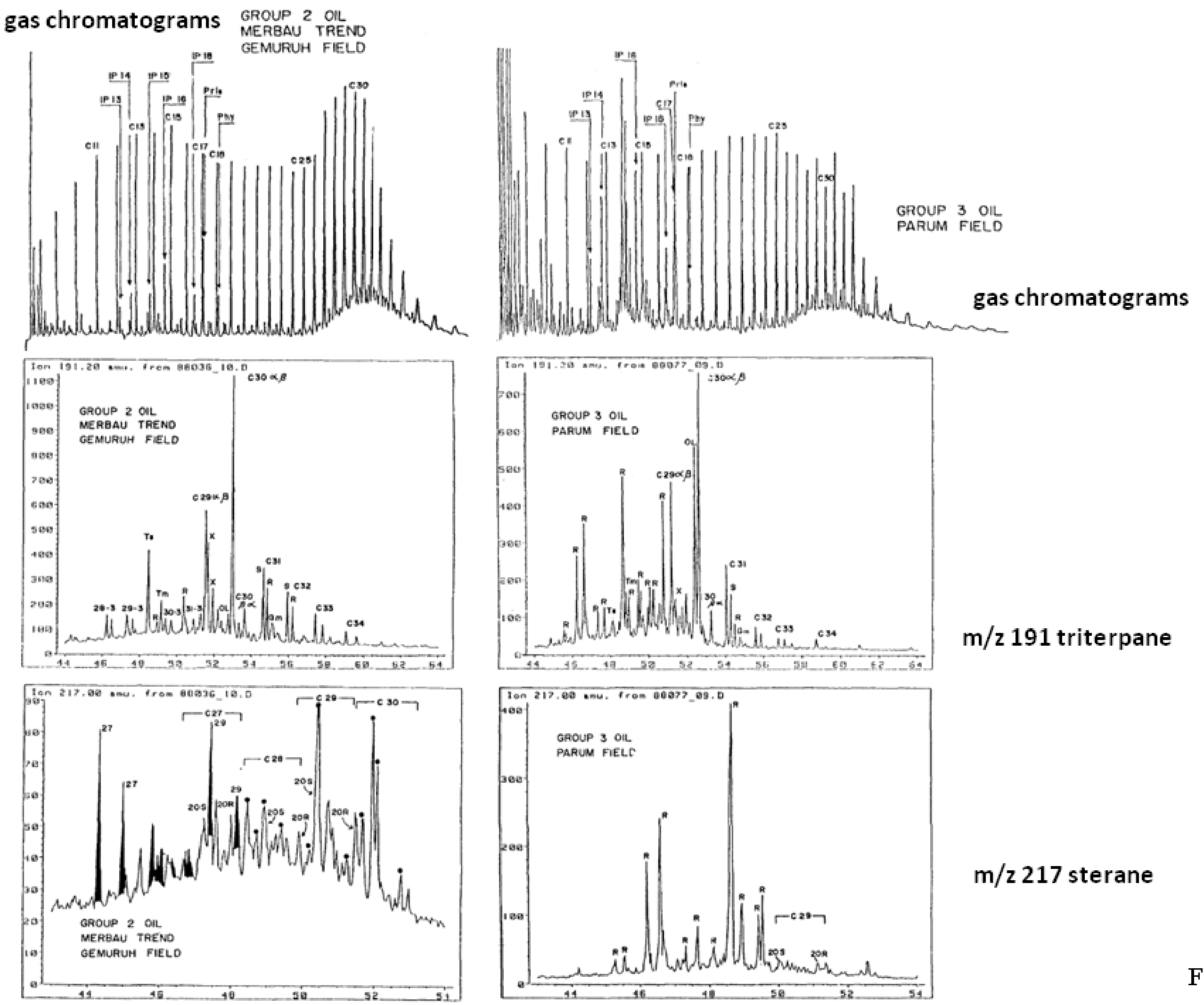


Figure 5

Figure 5 - Biomarker characteristics of Central Sumatra oils: lacustrine & fluvio-deltaic source facies (Robinson and Kamal, 1988).

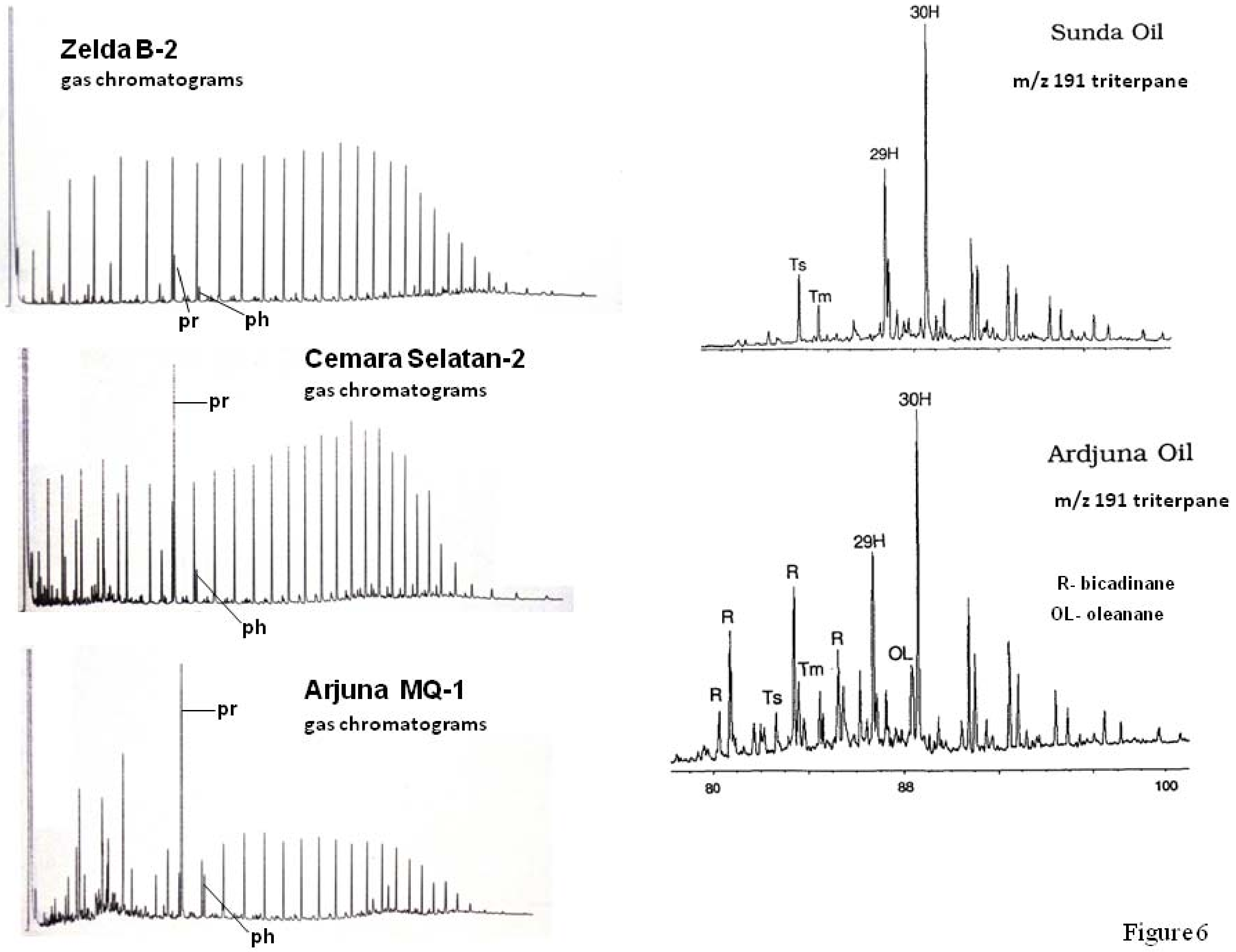


Figure6

Figure 6 - Biomarker characteristics of Sunda, Asri, NW Java oils: lacustrine - fluvio-deltaic source facies (Pramono et al., 1990).

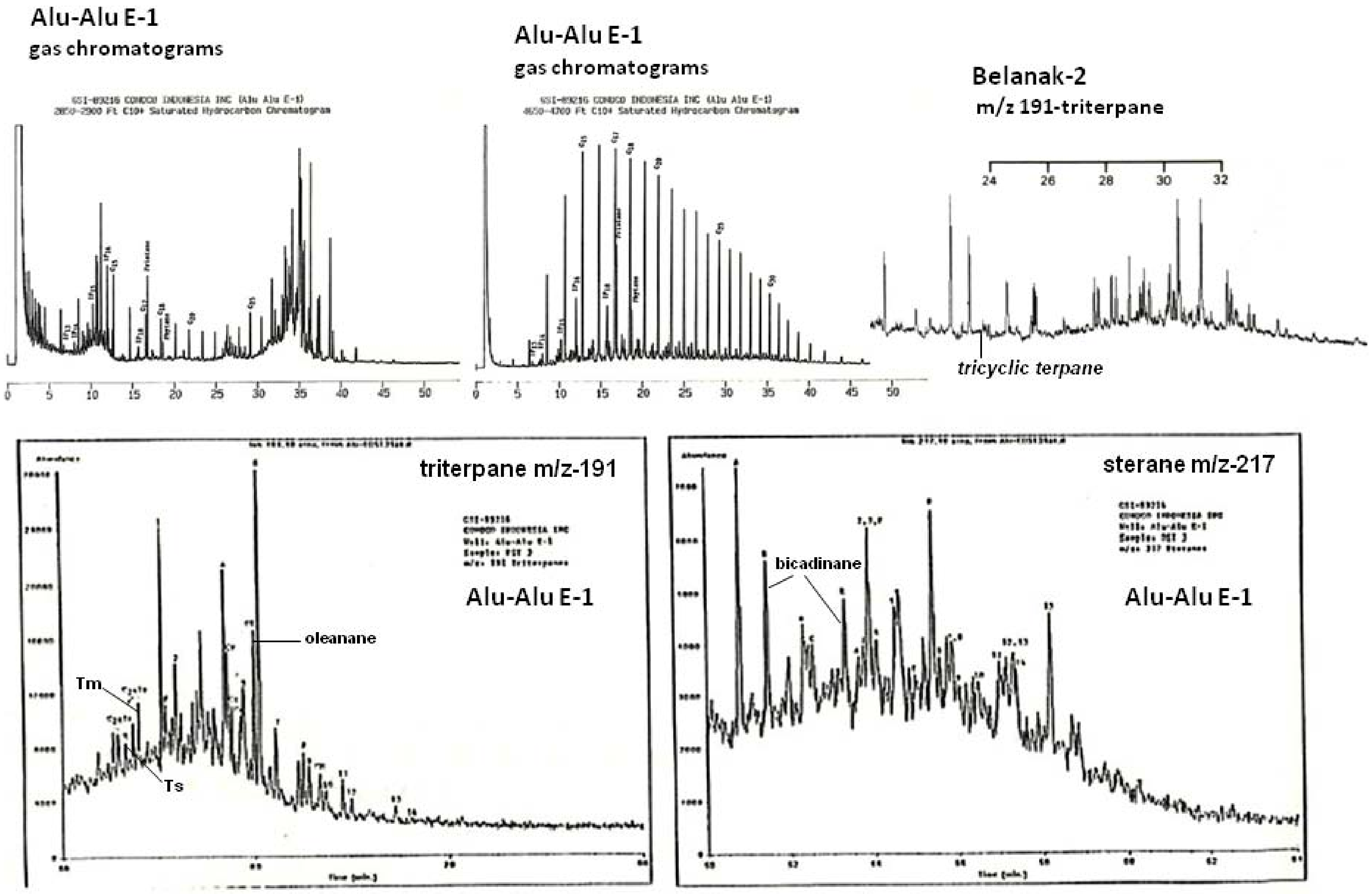


Figure 7 - Biomarker characteristics of West Natuna oils: lacustrine and fluvio-deltaic source facies (Satyana and Purwaningsih, 2012).

Figure 8

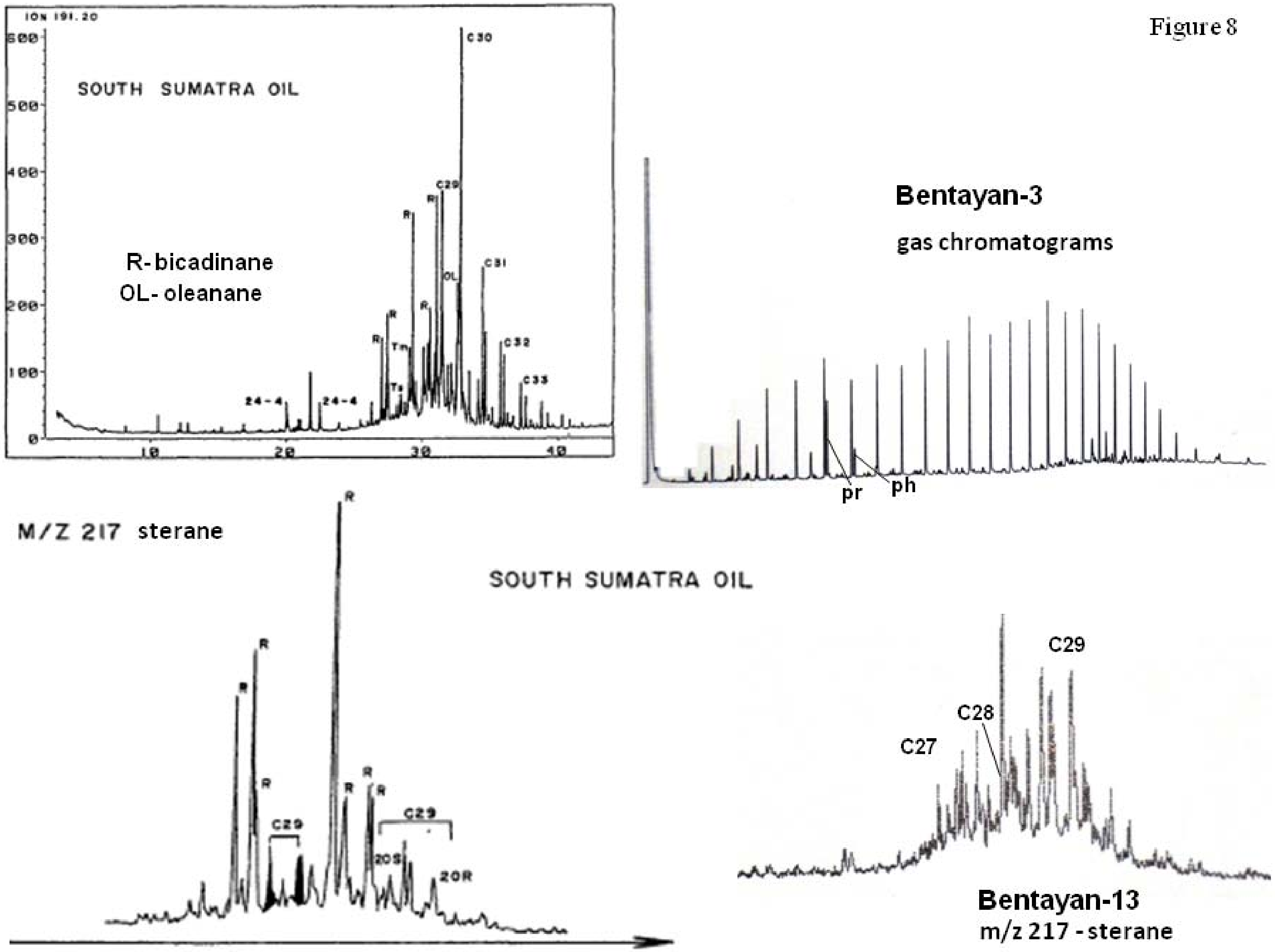


Figure 8 - Biomarker characteristics of South Sumatra oils: fluvio-deltaic and lacustrine source facies (Robinson, 1987).

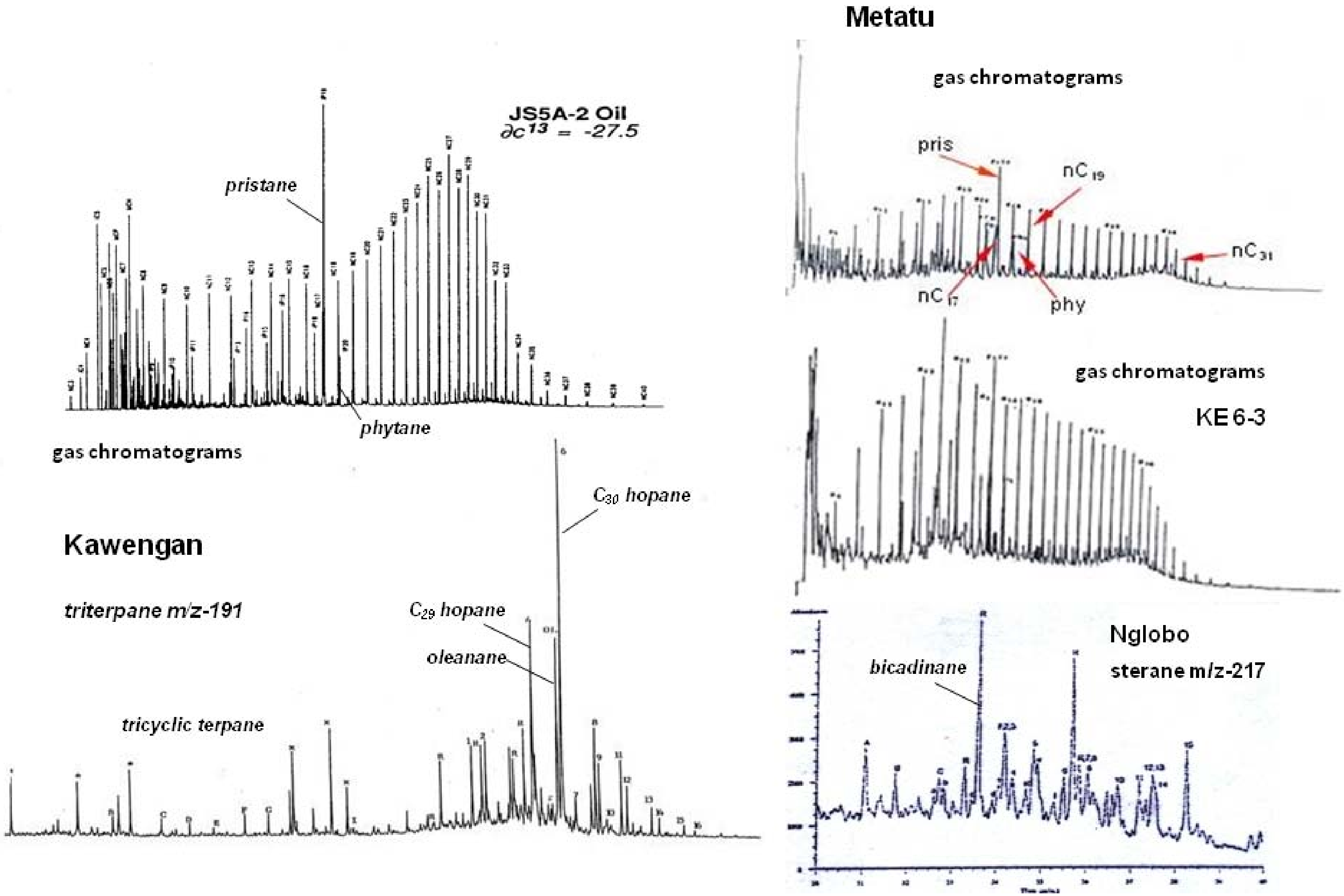


Figure 9 - Biomarker characteristics of East Java oils: fluvio-deltaic source facies (Satyana and Purwaningsih, 2003).

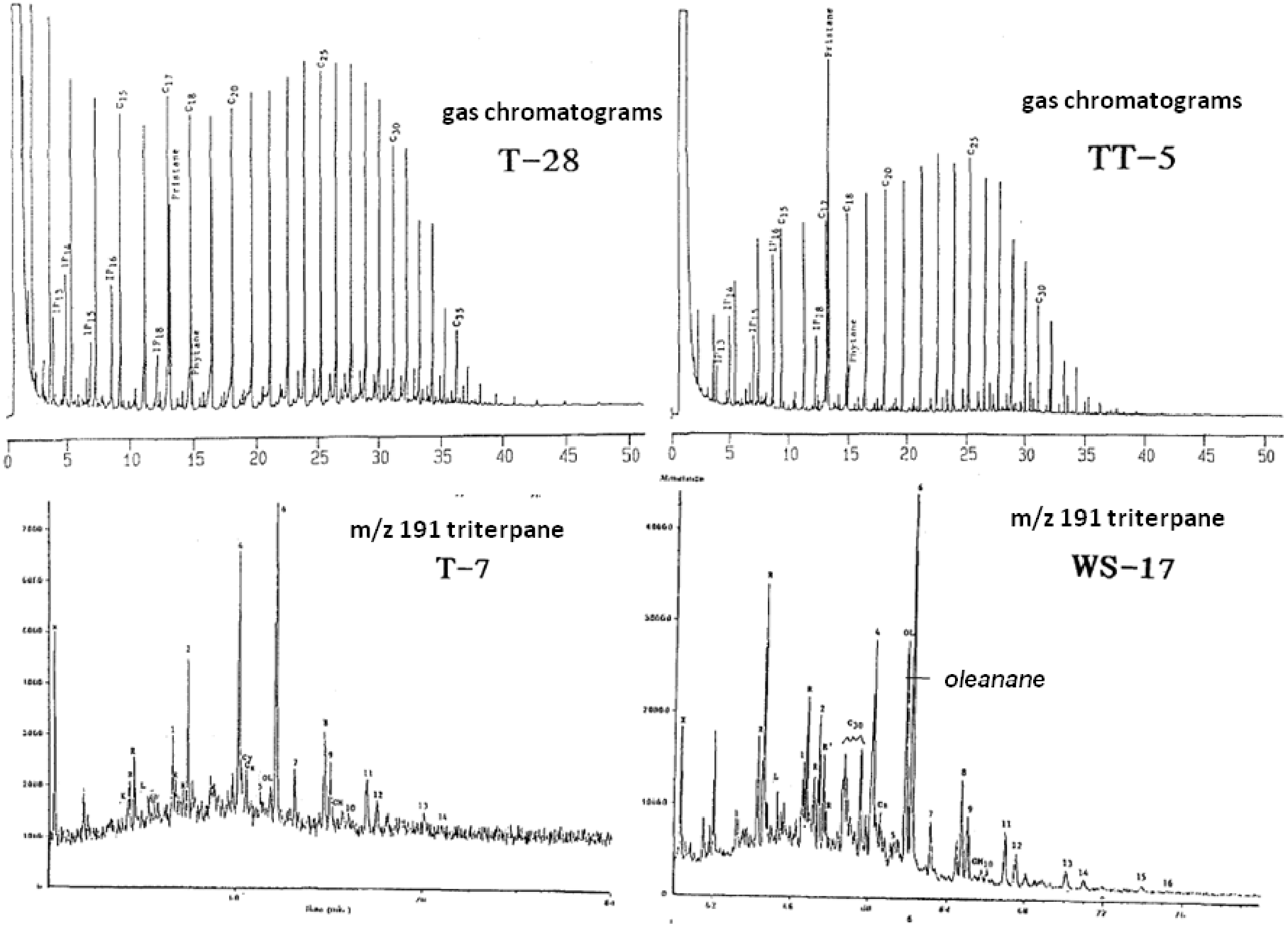


Figure 10 - Biomarker characteristics of Barito oils: fluvio-deltaic source facies (Rotinsulu et al., 1993).

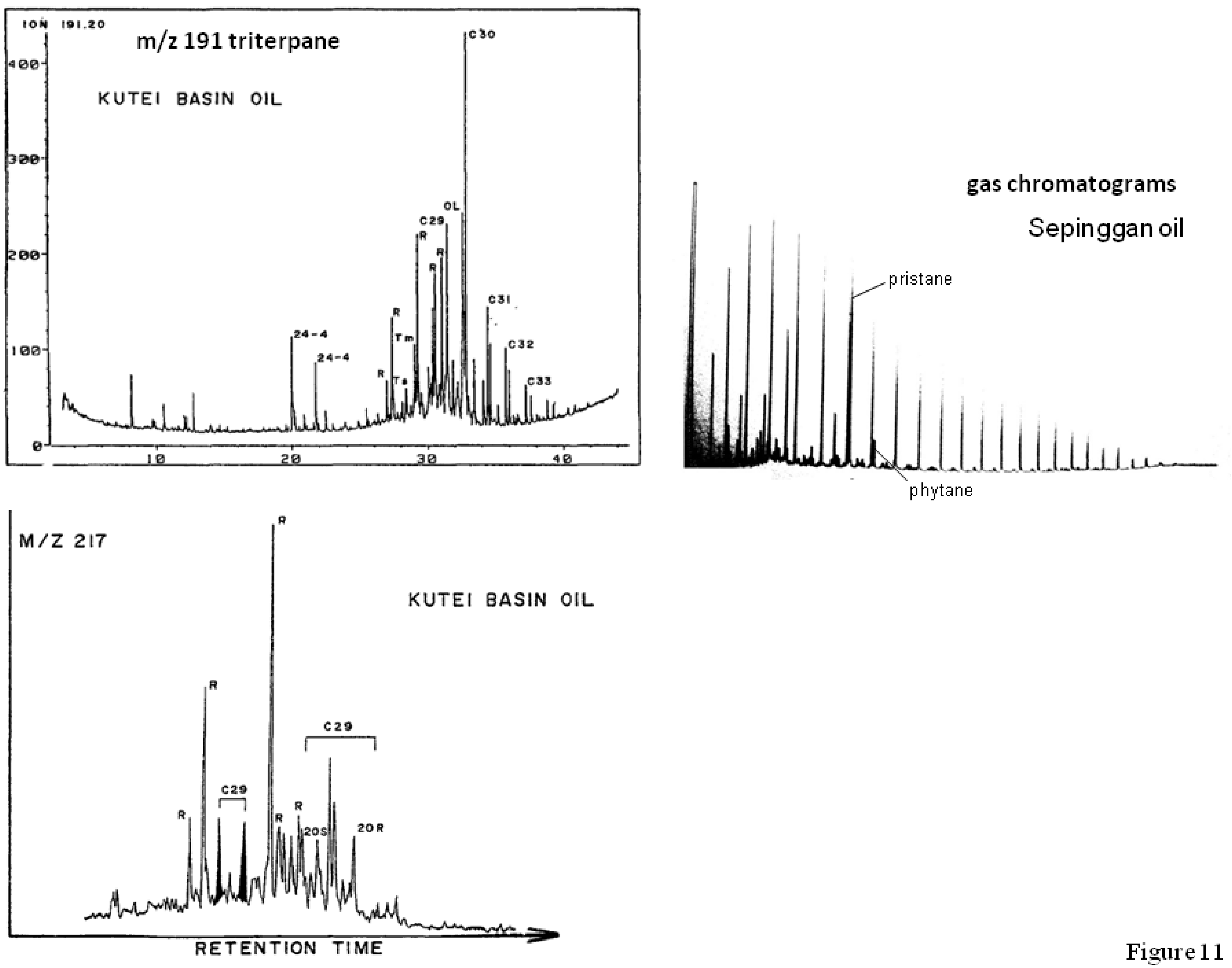
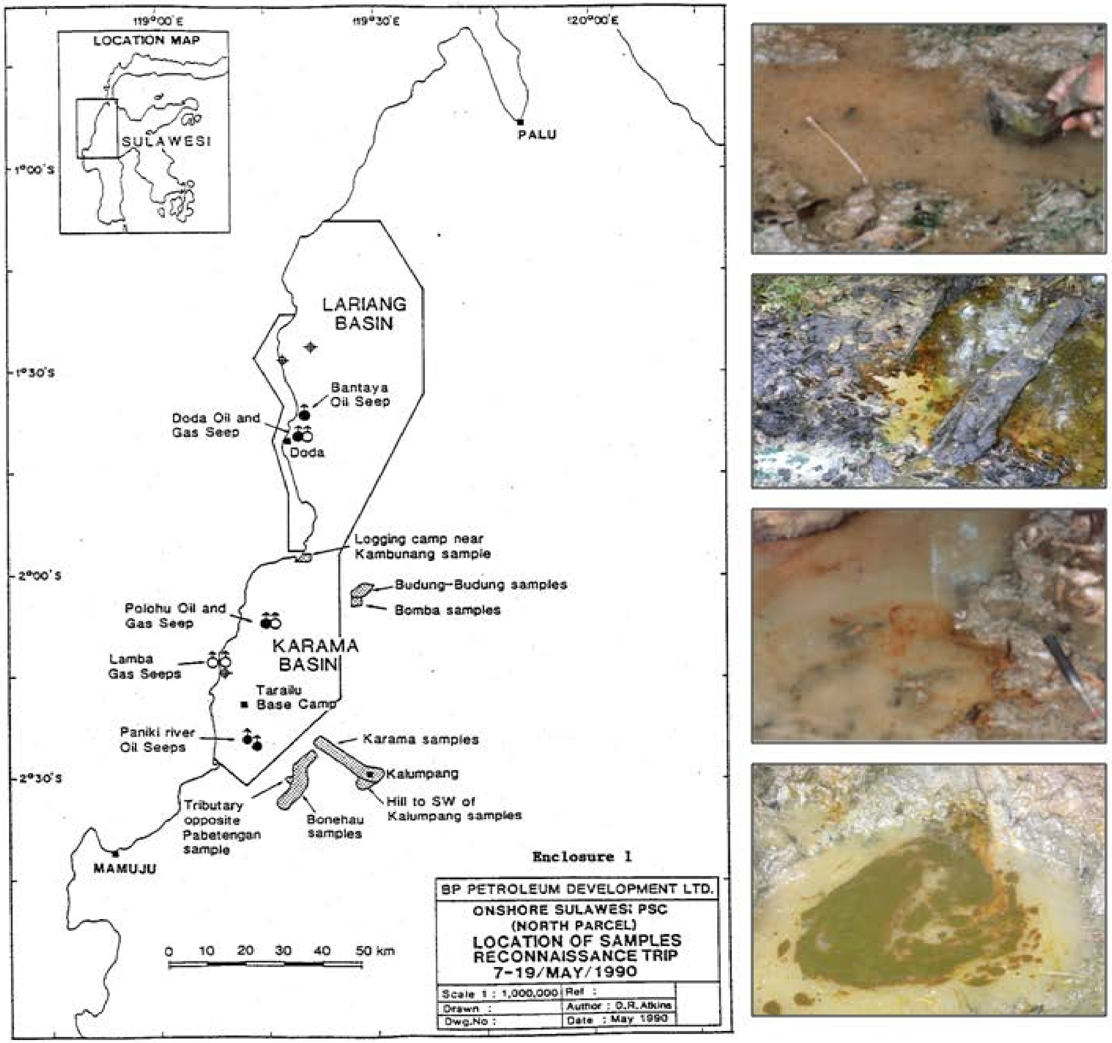


Figure 11

Figure 11 - Biomarker characteristics of Kutei oils: fluvio-deltaic source facies (Robinson, 1987).



Bantaya Oil Seep
(Ro = 1.2 – 2.0%)

Doda Oil Seep
(Ro = 0.8 – 1.0%),
Terrestrial Oil Characterization,
Eocene Coals and Coaly Shale
Predicted Source

Poluhu Oil Seep
(Ro = 0.8 – 1.0%)
Terrestrial Oil Charateization,
Eocene Coaly and Coaly shale
Predicted Source

Paniki River Oil Seep
(Ro = 0.8-1.0%),
Terrestrial Oil
Characterization

Figure 12

Figure 12 - Location and photographs of oil seeps in West Sulawesi, oils were sourced by Eocene source rocks, generated at shown calculated vitrinite reflectance (Satyana and Purwaningsih, 2012).

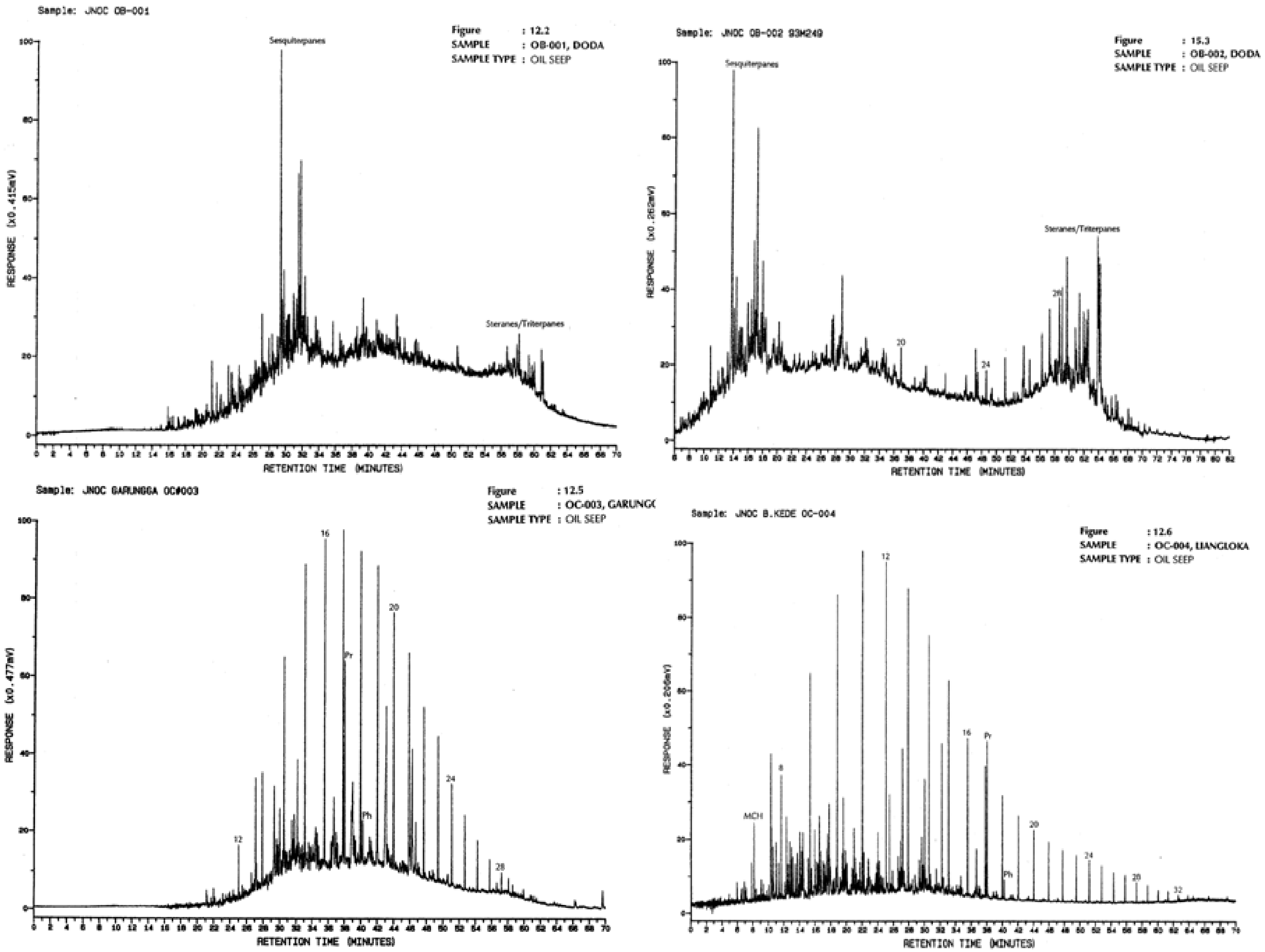
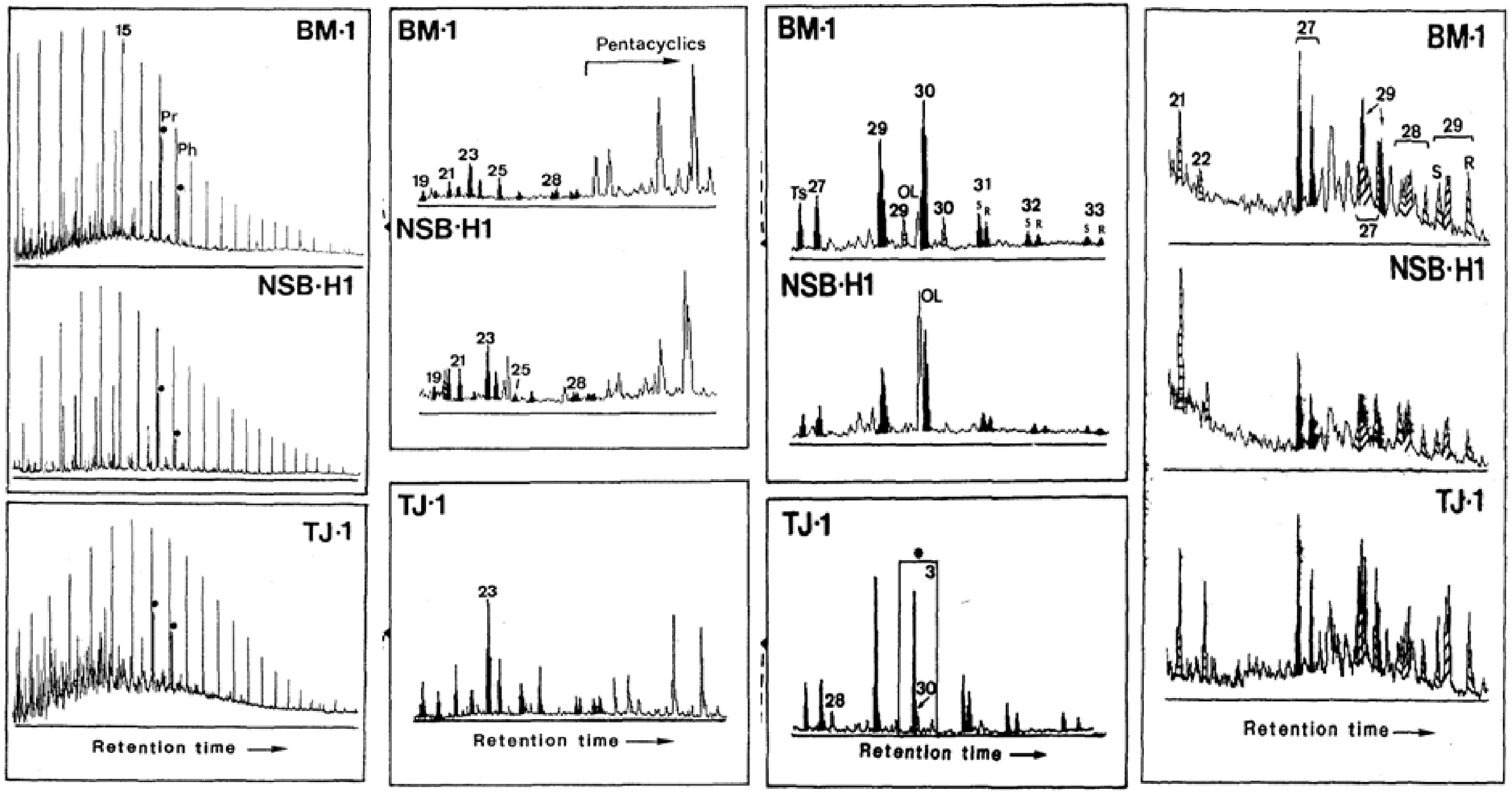


Figure 13 - Biomarker characteristics of West Kutei oil seeps: fluvio-deltaic source facies (Satyana and Purwaningsih, 2012).



gas chromatograms

tricyclic terpanes m/z 191

pentacyclic terpanes m/z 191

steranes m/z 217

Figure 14 - Biomarker characteristics of North Sumatra oils: marine shales and carbonates source facies (Subroto et al., 1992).

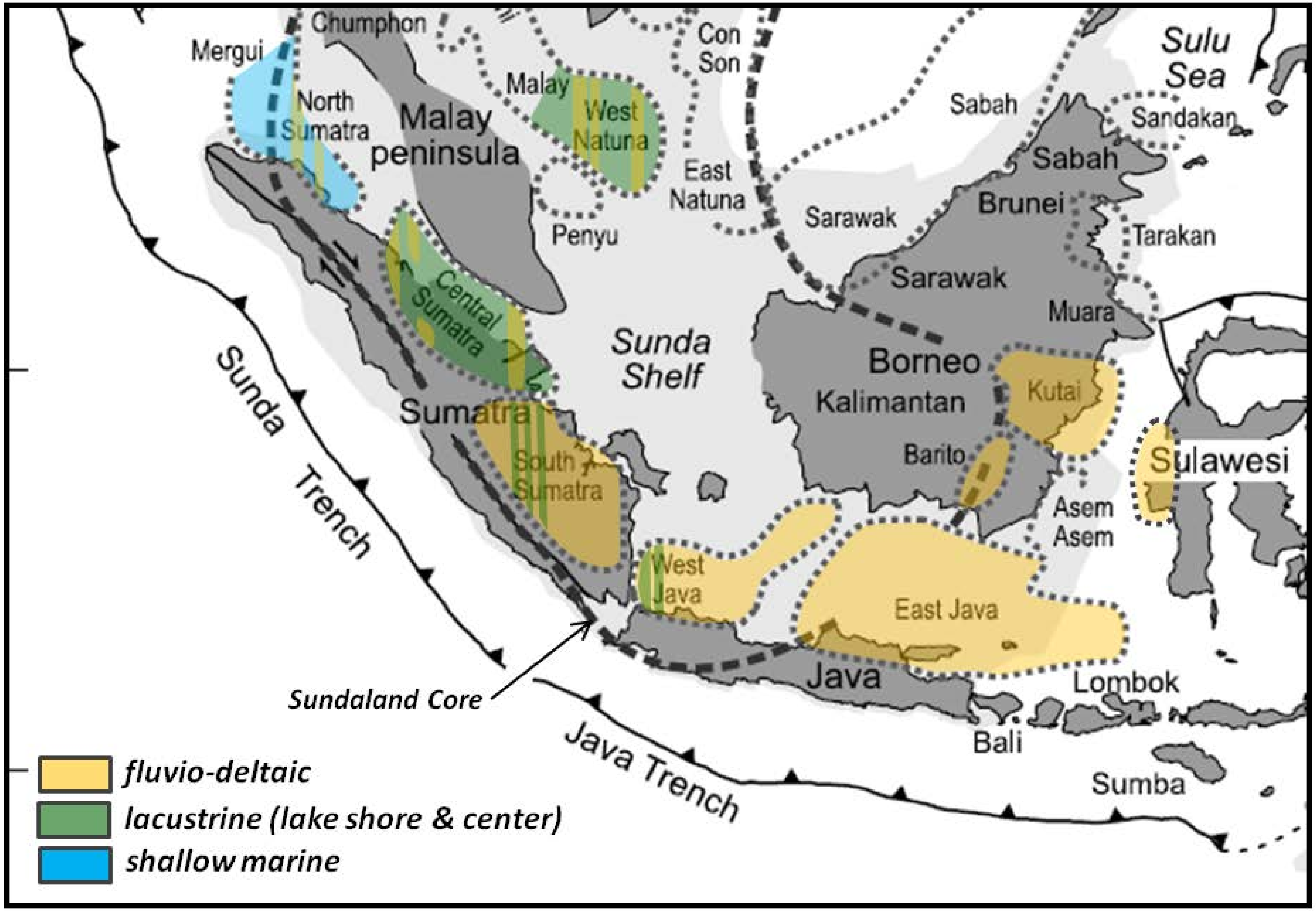


Figure 15 - Major Paleogene source facies of circum- Sundaland basins.