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Depositional Environment and Source Rocks Potential of the Miocene Organic Rich Sediments, Balikpapan Formation, East Kutai Sub Basin, Kalimantan

Lingkungan Pengendapan dan Potensi Batuan Induk Sedimen Kaya Bahan Organik Berumur Miosen, Formasi Balikpapan, Sub Cekungan Kutai Timur Kalimantan

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Abstract- The fluvial to deltaic sediments of the onshore petroleum prolific of the Mahakam Delta in the East Kutai Sub-basin constrain organic rich sediments particularly within the Balikpapan Formation. This formation has been recognized as a source rocks of the conventional oil and gas production in the Kutai Basin. However, the geochemical studies to understand the origin of organic matter and paleo-environmental condition of this formation are still limited. A 390 selected samples of organic rich sediments from the Balikpapan Formation were analyzed by using organic petrographic and geochemical analyses. These analyses were used to define the sedimentary organic matter and moreover the paleo-environment conditions during deposition and their implication to the source rocks and hydrocarbon potential. The organic rich shales and mudstones of this sediment have high total organic content (TOC) values in range of 0.05% – 15.63% and coals are ranging from 2.25% to 57.11%. They are and mainly dominated by vitrinite maceral, with minor liptinite and inertinite. The minerals mostly consist of clay minerals, with minor pyrite and oxide minerals (quartz and carbonates). Rock Eval Pyrolisis analysis results show low hydrogen index (HI) values (4 to 248.52mgHC/g TOC) and predominance of vitrinite maceral reveal prevalence of terrestrially derived type III organic matter and their potential to generate gas. The max temperature values which is ranging from 411 to 435°C and Ro ranges 0.7% - 0.64% implies a low to moderate thermal maturation levels for an active source rocks. The organic matter accumulation is mainly associated with black shales and coals in the delta plain environment, derived from terrigenous organic matter.

Keyword: Depositional environment, source rocks, Balikpapan Formation, Kutai Basin.

Abstrak- *Batuan sedimen lingkungan fluvial sampai delta pada daratan penghasil hidrokarbon Delta Mahakam, Sub-cekungan Kutai Timur disusun oleh sedimen kaya bahan organik khususnya pada Formasi Balikpapan. Formasi ini telah diidentifikasi sebagai batuan induk yang menghasilkan minyak dan gas bumi di Cekungan Kutai. Namun demikian, kajian geokimia untuk mengetahui muasal material organik dan lingkungan pengendapan formasi ini masih sangat terbatas. Sejumlah 390 sampel terpilih berupa sedimen kaya bahan organik Formasi Balikpapan dianalisis petrografi organik dan geokimia. Kedua analisis tersebut dilakukan untuk mengetahui sedimentasi material organik, lebih jauh lagi kondisi lingkungan pengendapan pada saat diendapkan dan implikasinya sebagai batuan induk dan potensinya untuk hidrokarbon. Serpih dan batulumpur kaya bahan organik memiliki nilai total kandungan organik (TOC) antara 0,05% - 15,63% dan batubara berkisar antara 2,25% - 57,11%. Komposisi material organik pada batuan tersebut umumnya disusun oleh maseral vitrinit dan sedikit maseral liptinit dan inertinit. Mineral penyusun didominasi oleh mineral lempung dengan sedikit mineral pirit dan mineral oksida, (kuarsa dan karbonat). Hasil analisis rock eval pyrolysis memperlihatkan nilai indeks hidrogen 4 sampai 248,52 mgHC/gram TOC dan melimpahnya vitrinit yang menunjukkan material organik asal darat tipe-III yang berpotensi menghasilkan gas. Nilai Tmax berkisar 411-435 °C dan vitrinit reflektan (Ro) antara 0.7% sampai 0.64% menunjukkan tingkat kematangan batuan indeks dengan kategori rendah sampai menengah. Akumulasi material organik umumnya berasosiasi dengan serpih hitam dan batubara pada lingkungan dataran delta (delta plain) dimana umumnya berupa material organik asal darat.*

Kata kunci*: Lingkungan pengendapan, batuan induk, Formasi Balikpapan, Cekungan Kutai*

INTRODUCTION

Kutai basin is one the biggest prolific hydrocarbon potential in Indonesia, both conventional and unconventional hydrocarbons (Courtney et al. 1991 and Pertamina BPPKA, 1997). This basin is bounded to the north by the Mangkalihat High, to the south by Paternoster ridge, to the west by older sediment part of the Kuching High Central Ranges, and to the east by the Makasar Straits. This basin consists of the thick Neogene sequence which was derived from the inland of Kalimantan (Chambers and Daley, 1995; Hall and Nichols 2002). Miocene sediments were initially sourced from uplifted Paleogene or older sediments (Moss and Chambers 1999). During middle Miocene, the depocenter of this basin shifted to the Samarinda area. The stratigraphic succession of the Samarinda area consists of the Miocene organic rich sediments of the Balikpapan Formation. This formation dominantly comprises coarsening upward of prograding delta with shales, siltstone, and coals at the base and fine-coarse grained sandstones and carbonates at top of the section.

Preliminary source rock studies indicates that the Early Miocene Pamaluan Formation and the Miocene Balikpapan Formation were identified as source rocks potential. Bachtiar (2004) revealed that the best hydrocarbon source rocks in the Kutai Basin is mainly derived from the Early Miocene shales and coals succession in delta front environment, dominantly type III organic matter and associated with Lowstand System Tract (LST). However, the geochemical and petrological characterizations related to source rock hydrocarbon of the Miocene Balikpapan Formation are lacking and poorly understood. This paper provides the depositional environment and organic matter characterization of the organic rich sediments of the Balikpapan Formation, based on organic geochemical and petrological methods.

GEOLOGICAL SETTING

The Kutai Basin was formed during Early Tertiary and was filled-up with clastic sediments progressing from the western to the eastern part of the basin. This basin is subdivided into the West Kutai Sub-basin (Upper Kutai Basin), consisting Paleogene outcrops with Cenozoic volcanic rocks, and the East Kutai Sub-basin (Lower Kutai Basin) with Miocene deltaic sediments (Clay et al. 2000). Some researcher had showed the sedimentary evolution of the Kutai Basin and revealed that the Paleocene age were mainly as regressive sequences with a dominantly marine argillaceous sequences followed by a coal bearing deltaic and coastal plain succession of the Miocene shoreline progradation toward to the east (Samuel and Muchsin, 1975; Rose and Hartono, 1978). The studied area was located in the Samarinda area, near and around the Separi Anticline, in the East Kutai Sub-basin, Kalimantan (Figure 1).

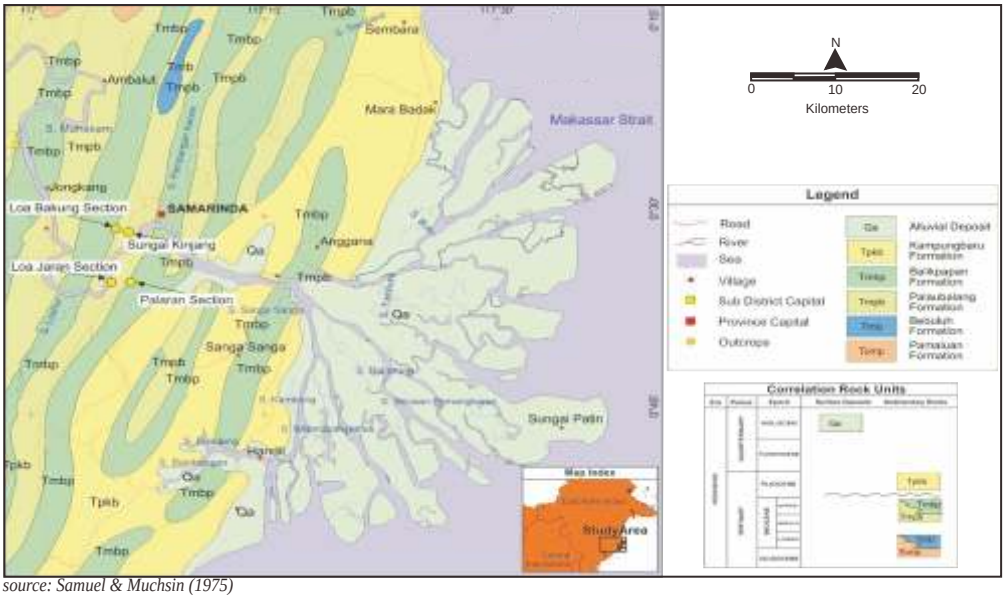
Supriatna and Rustandi (1986) showed the stratigraphy of the Neogen succession in the Kutai Basin, from bottom to tops: Pamaluan, Bebuluh, Pulau Balang, Balikpapan, Kampung Baru Formations and alluvial deposit (Figure 2). The Pamaluan Formation, up to 1500 m in thickness, which is mainly deep marine environment formed during Late Oligocene and Early Miocene, consists of sandstones with intercalations of claystone, shale, limestones, and siltstone. The Bebuluh Formation, up to 900 m in thickness, dominantly consists of Early Miocene limestones with interlamination of sandy limestones and argillaceous shale, and is interfingers with the Pamaluan Formation.

The Pamaluan and Bebuluh Formations are covered by (up to 900 m thick) the Early to Middle Miocene Pulau Balang Formation, which mainly consists of graywacke quartz sandstone, limestones, claystones, dacitic tuff and coal interlamination (3 to 4 m thick). This formation was mainly deposited in deltaic to shallow marine environments. Upward to the sequence, the Middle to Upper Miocene Balikpapan Formation (1000–1500 m thick) uniformly overlies the Pulau Balang Formation, which mainly consists of interbeded quartz sandstone, claystone, shale, and coal seams (5 to 10 m thick). This formation was mostly deposited in deltaic environment.

In the upper part section, the Upper Miocene to Pliocene Kampung Baru Formation discordantly overlies the Balikpapan Formation. This formation generally composes of (up to 900 m thick) quartz sandstone with interlamination of clay, shale, silt and coal (approximately 3m thick). The Kampung Baru Formation was deposited in deltaic environment and covered by alluvial deposit.

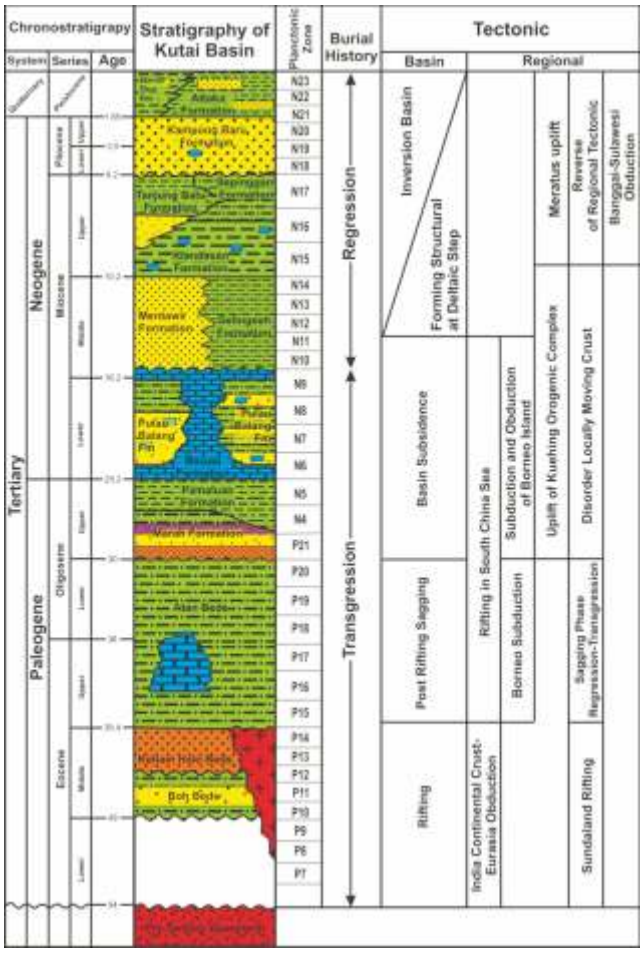
SAMPLES AND METHODS

This study was conducted on outcrop samples collected from 4 (four) locations around the City of Samarinda: Palaran, Loa Janan, Loa Bakung and Sungai Kunjang areas. The Miocene Balikapapan Formation is relatively well-exposed on that stratigraphical section. Fresh and representative samples were collected from outcrop and subjected to organic petrological and geochemical analyses for organic matter and source rocks hydrocarbon characterization. All samples were analyzed in the Batuan Sedimen Indonesia Laboratory (BSI Lab).



source: Samuel & Muchsin (1975)

Figure 1. Outline map of East Kutai Sub-basin, Kalimantan black square in the map index indicates the location of this study area. The Middle – Late Miocene Sediment of the Balikapapan Formation crops out in a section near and around the Samarinda City (yellow circles).



source: Supriana & Rustandi (1986)

Figure 2. Stratigraphic column of the Kutai Basin, showing Neogen succession which developed in the Lower Kutai Basin (East Kutai Sub-basin)

Total Organic Carbon (TOC)

A total of 390 selected samples were crushed into powder using mortar or mill and subsequently analyzed by multi elemental analyzer that provided for total carbon contents measurement. This samples consist of 144 samples from Palaran, 32 samples from Loa Janan, 94 samples from Loa Bakung, and 39 samples from Sungai Kunjang. Total organic carbon was analyzed by Leco Instrumentation.

Rock Eval Pyrolysis Analysis

In order to define the organic matter type and origin for source rock quality, 61 samples were crushed and subjected to rock eval pyrolysis equipment. Those 61 samples consisted of 29 (twenty nine) samples from Palaran, 7 samples from Loa Janan, 18 samples from Loa Bakung and 7 samples from Sungai Kunjang. The pyrolysis analysis was performed on 30 mg, which were heated to 600^{o}C in a helium atmosphere. Furthermore, several parameters such as the S1, S2, and temperature of maximum pyrolysis yield (Tmax) were measured to produced the calculation of hydrogen index (HI), production index (PI), and petroleum potential yield (PY) (Tissot and Welte, 1984; Espitalie et al., 1977).

Microscopic Studies

Ninety three (93) samples were polished (block) and identified under the organic petrography microscope (oil immersion in plane polarized reflected light). Those 93 samples consisted of 45 samples from Palaran, 12 samples from Loa Janan, 30 samples from Loa Bakung, and 6 samples from Sungai Kunjang. This analysis was carried out under oil immersion in plane polarized reflected light using Zeiss Axioplan with both white (100 W halogen) and blue violet (HBO) light sources; while the two oculars with magnifications of 25x and 50x were employed. Organic matter description used in this study follows the Australian Standard 2856.2 (Standards Australia, 1998). In this study, identification of different types of organic matter was mainly made on the basis of morphology and reflectance.

RESULTS

Lithological Facies and Depositional Environment

The section studied begins from the east to the west, adjacent to the core of the Samarinda Anticlinorium. The lithological succession has been divided into four stratigraphic sections, the Palaran, Loa Janan, Sungai Kunjang, and Loa Bakung Sections. The description of each section is outlined below.

Palaran Section

This section represents the complete cycles of fluvio-deltaic environment in study area (Figure 3), shows a wide ranges variation from fluvial to deltaic facies association. A complete prograding deltaic cycles in this section are well distinguished by the presence of prodelta shales facies series at the bottom which then followed by the delta front mouth bars, and then the thin silt layer alternating organic rich shales of marsh facies, then fine-grained sands follow in upper part, organized in thicker, and more continuous layers afterwards. The grain size of this sediment has a coarsening and thickening upward pattern, and shale content decreases upwards, while some spot have an erosional base contact representing fluvial channel sandstones.

The Palaran section has a 159 m thick contains of shale-coal and sandstones cycles. The first 7 m of this section can be characterized by its thick light grey fluvial sandstone bodies, fining upward pattern, and medium to very coarse grained. Low angle trough cross beddings are dominating the sedimentary structures, with the oriented coal fragment and carbon streak parallel to bedding insides which probably as debris of terrestrial organic matter. Around 152 m above the fluvial sandstones, this section contains of relatively thin and infrequent sandstones beds, with the thick clay-shale facies interbedded with coal beds around 50 cm to 2 m in thickness. The shale beds can be characterized by its dark grey colour and contains organic rich black shales, alternating with very fine sandstone, flasser, and lenticular beds sedimentary structures in some part. The lower shales bed contains coal fragment, leaves, and root fossil. Coals segment has a dull to bright banded, hard and thickening upward on the upper part of this section. The deposition environment of this lithological succession is interpreted on fluvial to delta plain.

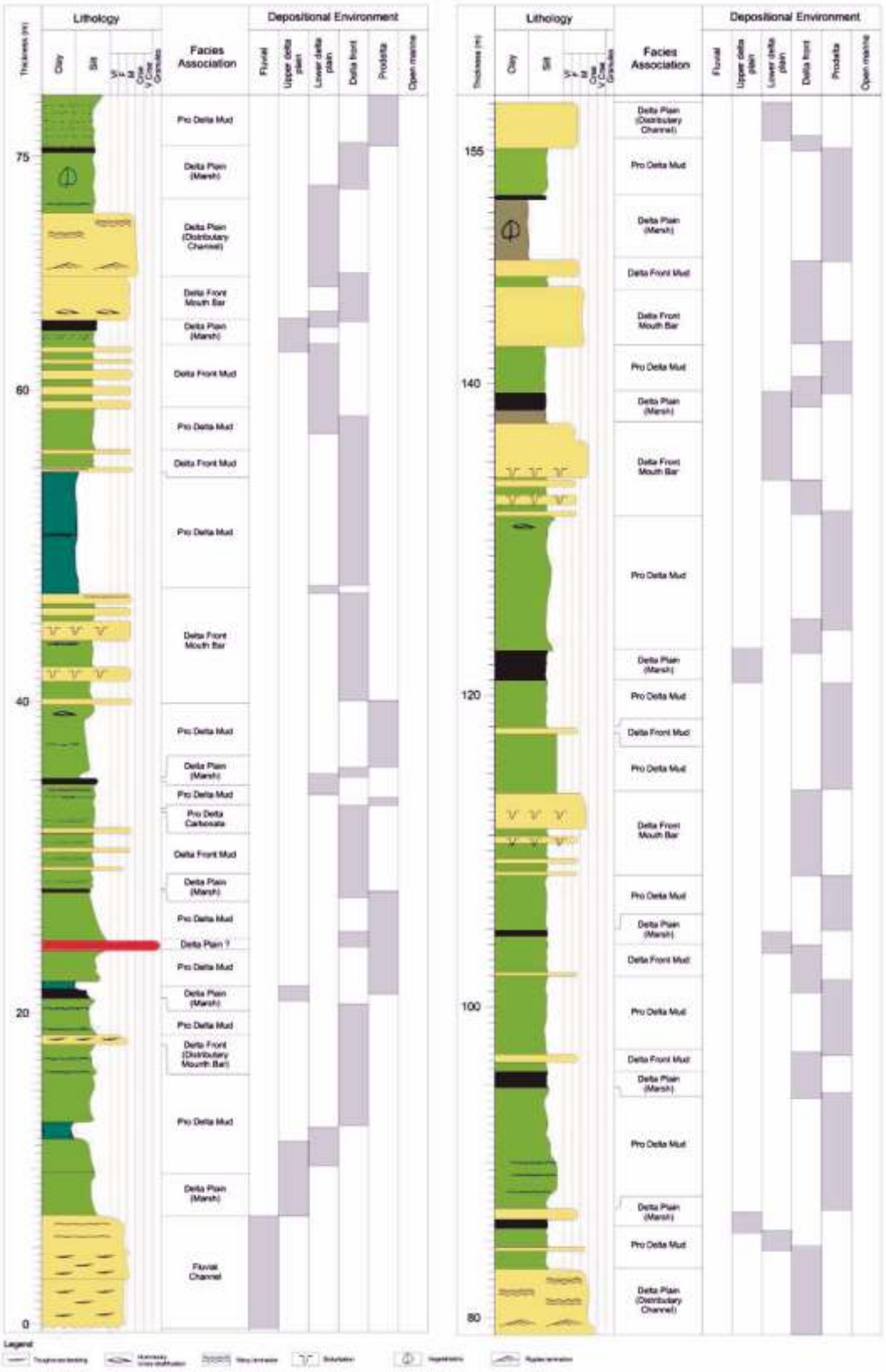


Figure 3. Stratigraphic measured section of the Palaran area, showing lithological variation, contains of shale-coal and sandstones cycles, represent complete cycles of fluvio-deltaic depositional environment in the studied area.

Loa Janan Section

The Loa Janan section has thickness about 47 m and contains thick shale-coal facies interbedded with thin sandstones facies. At first 25 m of this section contains thick shales facies interbedded with relatively thin sandstones facies and coal beds. The least two sandstones intervals of this section has a coarsening and thickening upward trends represent the mouth bar facies association (Figure 4). Shales section has a grey to relatively dark grey colour, thick and massive structure in the lower part, thinning upward, contains alternating of very fine sandstones and siltstones, as well as lenses and nodul of very fine sandstones and limestones also observed in some part of section. Above this unit has a 5 m of thick sandstones beds with a fining upward trend, fine to medium grained, with wavy and cross lamination structures, extensive bioturbation, and thin layer oriented coal fragment parallel to bedding. Around 17 m in the upper part of this section can be characterized by its thick clay shales facies interbedded by thinner sandstones and coal beds, with well-developed of lenticular and flasser bedding sedimentary structures represents delta front mud facies (Figure 5). This lithological unit is interpreted as deltaic depositional environment which mainly developed in delta plain to delta front setting.

Sungai Kunjang Section

The Sungai Kunjang section is located in the west of Samarinda City that about a 58 m of sandstones and shales cycles with alternating thin limestones beds are well exposed. The first 38 m of this section contains at least two intervals of interbedded thick sandstones bodies and shales represents the fluvial and distributary channel facies association (Figure 6), which the sandstones has a light grey to dark grey colour, finning upward, medium to coarse grained, sharp erosional base, extensive bioturbation, flasser, lenticular and cross bedding sedimentary structures. Furthermore, the shale section has a layer oriented coal fragment parallel to the shale bedding, grey to relatively dark grey colour, well bedded, with thin layer of fine sandstones and limestone nodules, and containing leaves and root remnant. The rest 20 m of this section contains more thin and fine sandstones covered with thin limestones bed. Limestones has a light grey to white colour, very hard texture, containing microfossils, corals and mollusks. This unit is interpreted has deposition environment similar to the Loa Janan Section, the deltaic environment mainly in delta front setting.

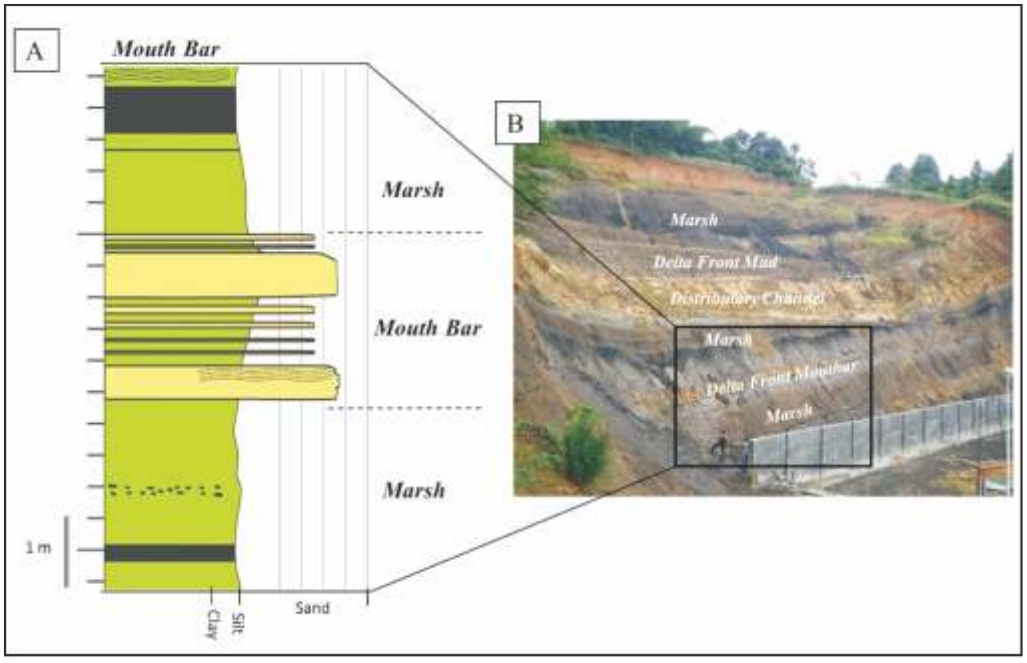


Figure 4. Outcrop expressions of cyclicity of facies association in the lower part of the Loa Janan section; A) stratigraphic log showing upper delta plain marsh and delta front mouth bar facies association; delta plain marsh comprise of thick facies interbedded by thin coal bed seam, while the delta front mouth bar composed of fine to medium grained sandstones, with coarsening and thickening upward trends; B) outcrop photograph represent deltaic cycle environment, facies changes from the fluvial dominated upper delta plain marsh, to tidal influence lower delta plain and delta front.

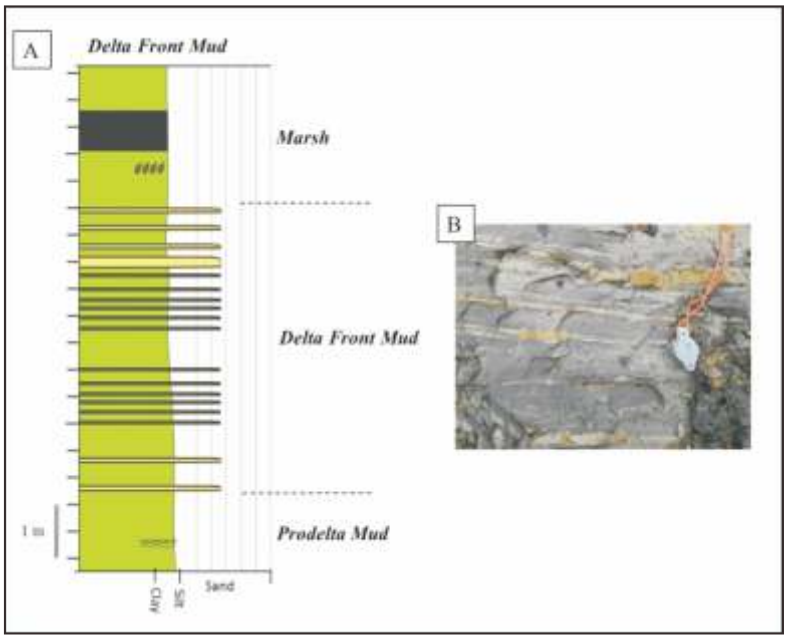


Figure 5. Outcrop expression of delta front mud associated with high siliciclastic input at the upper part of the Loa Janan section, A) stratigraphic log showing delta front mud facies association, consist thick clay-shales facies interbedded with coal beds, with well-developed of lenticular and flaser bedding sedimentary structures indicate tidal dominated influenced; B) close up photograph of delta front mud facies showing lenticular and flaser bedding sedimentary structures.

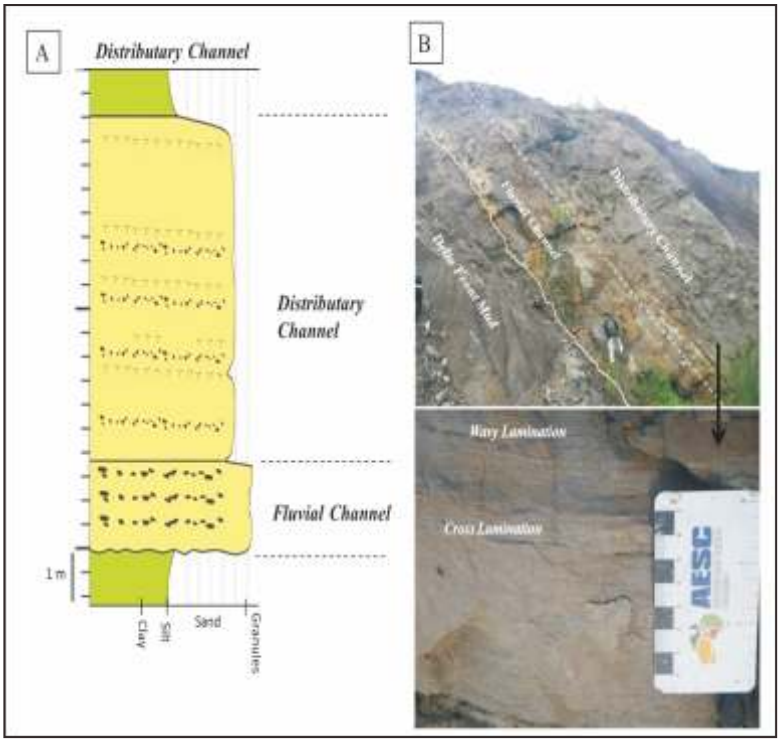


Figure 6. Outcrop expressions of the fluvial and distributary channel facies association in the Lower to the middle of the Sungai Kunjang section; A) stratigraphic log showing fluvial channel and distributary channel characteristics; fluvial channel composed of medium - coarse grained sandstones, fining upward with erosional contact on the channel base and trough cross bedding sedimentary structures, while distributary channel composed fine to medium grained sandstone, with ripple sedimentary structures, burrowed and cross to wavy lamination at the top; B) outcrop photograph of changes facies architecture, prograding succession of delta front mud at base to distributary channel at the top with cross and wavy lamination suggest the strong tidal influence.

Loa Bakung Section

The Loa Bakung section has a 110 m thickness contains of thick shales and sandstones cycles interbedded with thin coal, coaly shales, and limestones beds. The first a 10 m of the section is composed by thick bodies of fluvial channel interbedded thin layer shales. The sandstones can be characterized by its brownish grey colour, fining upward trend, medium to very coarse grain, sharp erosional base, low and trough cross bedding dominated sedimentary structures, and several oriented coal fragment and carbon streak parallel to bedding. Furthermore, around 15 m thick above the first unit is well exposed which consist of two sandstones intervals with thick shales facies. The sandstones has a grey to light grey colour, coarsening and thickening upward, fine to medium grain, cross, wavy, until parallel lamination dominant sedimentary structures.While the shales part has a thick bedded and grey to dark grey colour. Above this unit, around 39 m is composed by sandstones beds which are more frequent but much thinner. This unit is characterized by interbedded of thick shales which punctuated by thin wackstone - packstone beds in some intervals indicates marine influenced condition (Figure 7). Shales has a thick bedded, grey to dark grey colour, massive structure, alternating of very fine sandstones and siltstones, as well as lenses and nodul of limestones observed in upper part. The upper part of this succession consists of three intervals of shales interbedded channel sandstones, thin coal, and coaly shale beds. Sandstones interval has a grey colour, fine to medium grain, sharp base, extensive bioturbation, cross, wavy and paralel lamination sedimentary structures. The shales interval has a grey to dark grey colour, massive, and contains of layered oriented coal fragment parallel to bedding plane. This lithological unit is interpreted to be mainly as deltaic environment, but part of the limestone succession may reflects to be influenced by marine conditions, thus this unit may deposited in prodelta to marine environment.

From the above discussion and analysis, it indicates that the Balikpapan Formation was deposited on mixed fluvial-deltaic systems. Moreover, the study area has a variation depositional environment in lateral, especially from northwest to the southeast (Figure 1). On those northwest – southeast orientation, it is determined that was depositedin the Early to Middle Miocene while the paleoenvironment changes from prodelta in Loa Bakung and getting more shallow towards Sungai Kunjang (delta front), Loa Janan (delta front to delta plain), and Palaran (almost entirely delta plain to fluvial).

Based on lithological description and its facies association, the Miocene organic rich sediments of the Balikpapan Formation contain at least 7 (Seven) association facies, which are summarized bellows (Table 1, Figure 4-7):

(1) Fluvial channel, mainly composed of medium - coarse grained sandstones, fining upward trend, with erosional contact on the channel base and trough cross bedding sedimentary structures.

(2) Distributary channel, dominantly consist of fine to medium grained sandstone, with ripples sedimentary structures, burrowed and cross to wavy lamination.

(3) Marsh, composed of thick facies of clay and siltstone interbedded by thin coal bed seam

(4) Delta front mouth bar, mainly consist of fine to medium grained sandstones, with coarsening and thickening upward trends, bioturbation and hummocky cross stratification.

(5) Delta front mud, composed of interlamination of fine sandstone and clays, with thickening upward trends of sandstones facies, wavy lamination.

(6) Delta front carbonate, consist of muddy fine to medium bioclastic sandstones, rich of foraminifera as well as large of fossil fragment of molusc and corral.

(7) Prodelta mud, composed of thick marine clay to siltsone facies in prodelta to shallow marine environment.

Organic Petrography

The petrographic examination revealed that two types of organic rich sediment are identified in the fluvio-deltaic of the Balikapapan Formation: the coals and shales or mudstones. Coal samples are dominated by vitrinite with minor inertinite, liptinite and mineral matter (Figure 8). The vitrinite maceral are mainly textinite, texto-ulminite and telocollinite. Inertinite are dominated by fusinite and semifusinite and some funginite. Liptinite are mainly as sporinite and cutinite. Most of shales samples are mainly consist of mainly detritus clay size-minerals, with minor vitrinite (huminite), and rarely inertinite macerals. The shales or/and mudstones are dominated by clay and oxide minerals, with significant amount of densinite, attrinite and bituminite. The mineral content in coals is relatively low which less than 3.2 %, while in the shales are very high which over 93% (from micrsoscopical analysis). Mineral is predominantly composed by clay minerals, with minor pyrite and carbonate minerals.

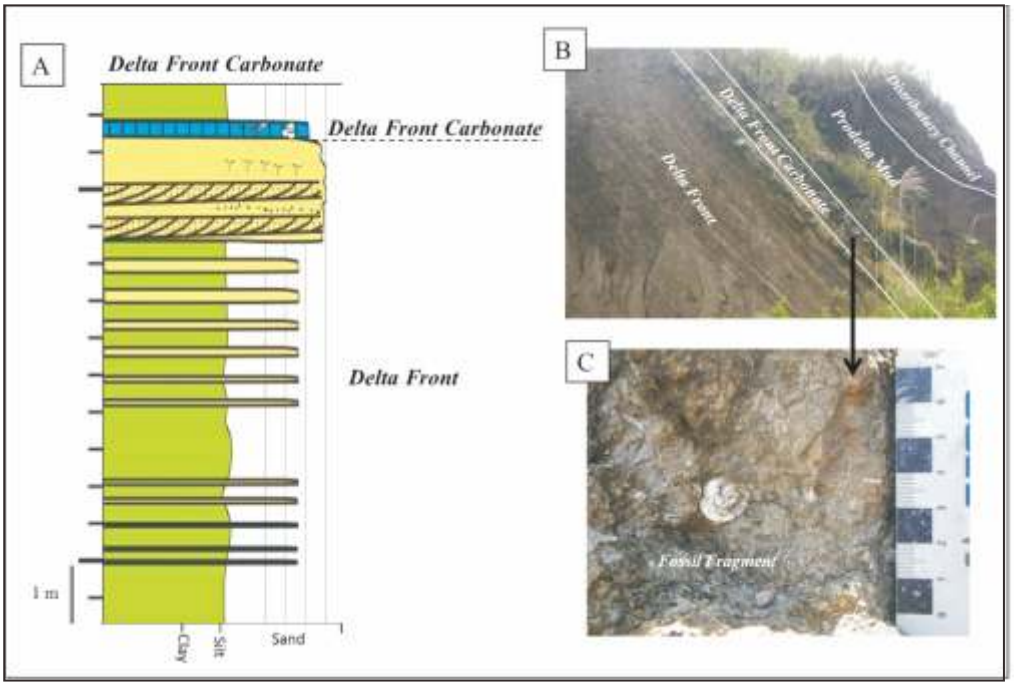


Figure 7. Outcrop expressions of delta front facies associated or influenced by marine depositional condition at the middle part of the Loa Bakung Section; A) stratigraphic log showing delta front facies association; at the base consists interlamination of fine sandstone and clays, with thickening upward trends of sandstones facies, this facies covered by muddy fine to medium bioclastic sandstone (wackstone-packstone), abundant of foraminifera as well as large of fossil fragment of molusc and corral; B) outcrop photograph showing facies succession in the Sungai Kinjang section, delta front facies covered by delta front carbonate, further deeper to prodelta setting, then cross cut by distributary channel fill deposit, C) close up photograph of delta front carbonate facies, shows mollusk and coral fragment.

Tables 1. Summary of lithofacies description of the Balikpapan Formation

Lithofacies Association	Characteristics	Depositional Environment
Fluvial Channel	medium - coarse grained sandstones, fining upward, With erosional contact on the channel base and trough cross bedding sedimentary structures	Fluvial
Distributary Channel	fine to medium grained sandstone, with riplles sedimentary structures, burrowed and cross to wavy lamination	Delta (Upper - Lower Delta Plain)
Marsh	thick facies of clay and siltstone interbedded by thin coal bed seam	Delta (Upper Delta Plain)
Delta Front Mouth Bar	thick facies of clay and siltstone interbedded by thin coal bed seam	Delta (Delta Front)
Delta Front Mud	interlamination of fine sandstones and clays, with thickening upward trends of sandstones facies, wavy lamination	Delta (Delta Front)
Delta Front Carbonate	muddy fine to medium bioclastic sandstones, rich of foraminifera as well as large of fossil fragment of molusc and corral	Delta (Delta Front)
Prodelta Mud	thick marine clay to siltsone facies	Prodelta - Shallow Marine

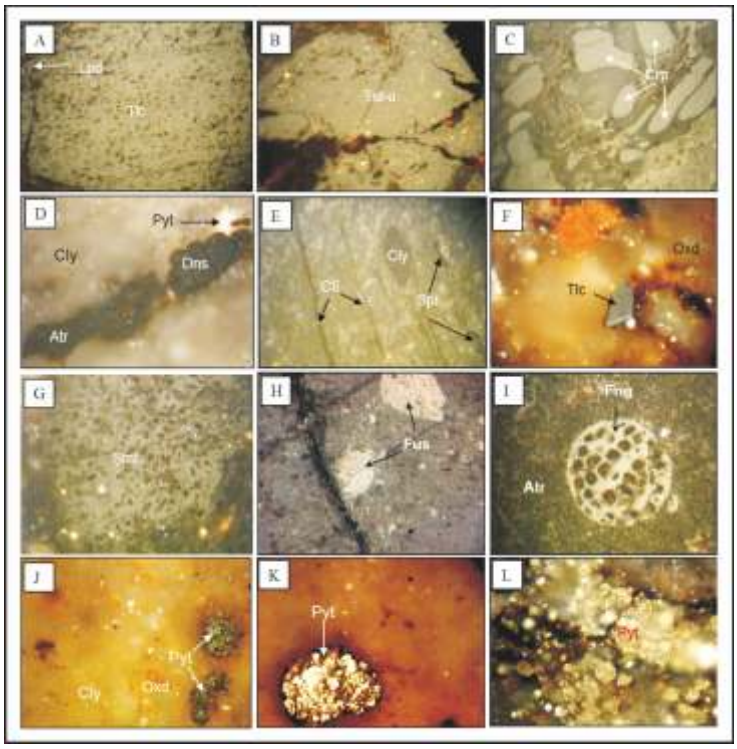


Figure 8. Photomicrographs taken under the organic petrography microscope of the samples from study area; A) Telocollinite (tlc) associated with liptodetrinite (lpd), coal samples from Palaran, 15 AP 01LL; B) Massive Texto-ulminite (txt-u), coal samples from Palaran 15 AP 01DT; C) Oval to rounded of corpogelinite (crp) macerals, coal samples from Loa Janan 15 AP 12AL; D) Densinite (dns) and Atrinite (atr) macerals, with clay minerals (cly) as groundmass, shales sampels from Sungai Kinjang 15 AP14I; E) Desmocollinite macerals associated with cutinite (Cti), sporinite (spr) and oval clay minerals (cly) lense, coal sampels from Palaran 15 AP01BP; F) Telocolonite (tlc) sorounded by clay (cly) and carbonates (oxd), Sandstones samples from Palaran 15 AP01BL; G) Semifusinite macerals, coal samples from Loa Janan 15 AP12P; H) Fusinite (fus) associated with telocolinite macerals, coal samples from Palaran 15 AP01J; I) Rounded funginite (fng) with atrinite (Atr) macerals, coal samples from Palaran 15 AP01DB; J) replacement pyrite (pyt) in clay minerals (Cly) and oxide minerals as geoundmass, shale samples from Loa Bakung 15 AP13K; K) Euhedral crystaline pyrite (pyt), shales samples from Palaran 15 AP01X; L) Framboidal pyrite (pyt), shales samples from Palaran 15 AP01CZ.

The vertical variation of maceral groups and mineral matter of the organic rich sediment of the Balikpapan Formation are represented in the Palaran section (as shown in Figure 9). In general, maceral composition has a little variation from the bottom to the top of the section. Vitrinite/huminite shows a relatively high concentration through the section, although a lesser composition in the middle part, while inertinite and liptinite have a moderate variation, they show a relatively high concentration in the bottom and upper part of the section, and eventually in some part of the section are associated with mineral matter occurrence and pro-delta facies. Mineralogical variation has no specific trends, yet pyrite and oxide mineral (quartz and carbonates) show a significant correlation with the occurrences of coal facies in delta plain environment. Thus, this may indicate that the maceral and mineral variations are associated with the environmental conditions during the depositional setting.

Organic Carbon and Bulk Kerogen Characteristics

The organic rich sediment has a relatively high total organic content (TOC) values. The shales or mudstones has a 0.05 wt% to 15.63wt% TOC, while coals are ranging from 2.25 wt% to 57.11 wt%. The vertical variation of TOC's values has an irregular trend from the bottom to the top of the section. The relatively high TOC's values are commonly associated with the occurrence of dark shales and coal beds facies in delta plain environment; therefore, they are getting high from prodelta to delta plain facies. The TOC's values also changes in lateral variation, they are decreasing from northwest (Palaran Section) towards southeast (Loa Bakung Section).

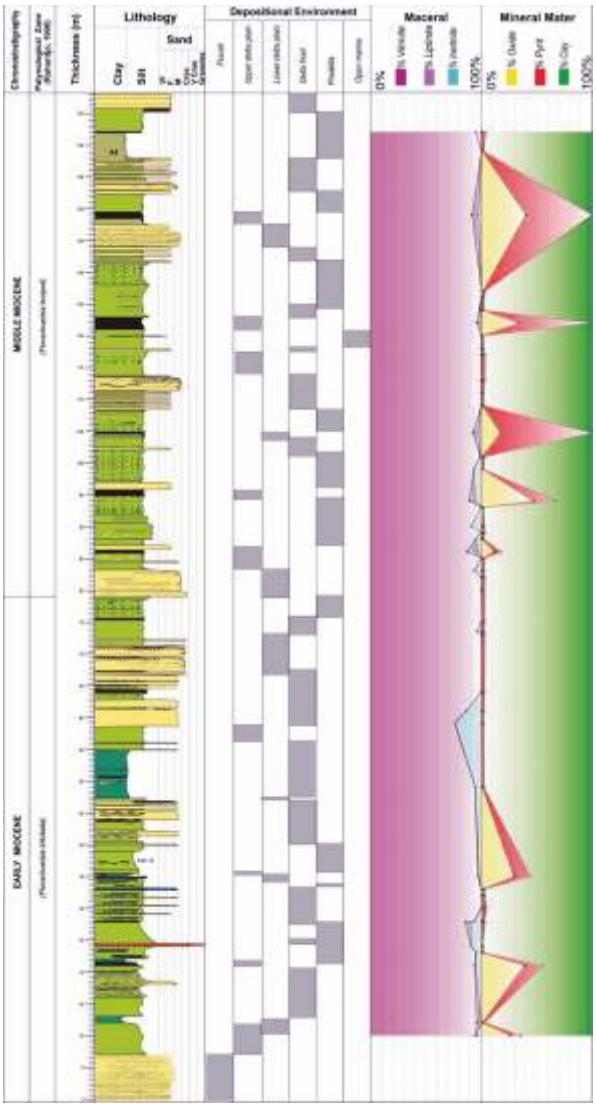


Figure 9. Vertical variations of maceral and mineral matter compositions within the organic rich sediments of the Balikpapan Formation in the Palaran section.

The analytical results of rock eval pyrolysis of the organic rich sediment (Table 2) show that HI (Hydrogen Index) values varies from 4 mgHC/g TOC to 248.52 mgHC/g TOC, while the OI (Oxygen Index) values ranges from 7 mgCO2/g TOC to 183 mgCO2/g TOC. The thermal maturity of organic matter is commonly derived from Rock Eval Tmax, while the Tmax values of samples from the study ranges 411°C – 435° C. The potential yield as hydrocarbon generation potential parameter shows wide ranges variation, which is varies from 0.05 mgHC/g rock TOC to 130.13 mgHC/g rock TOC. The vertical variation of the rock eval data from the base to the top of the sections shows an irregular trend, that HI and OI values are relatively low with some high spike in the lower and middle part of the section. T max values are relatively high in lower part of the section, then decreases toward to the top.

Those above parameters can be used for source rocks generative potential characterization (Tissot and Welte, 1984; Bordenave, 1993). For an instance, a plot of Hydrogen Index (HI) and Pyrolysis Tmax can be used to classify the maturity and type of organic matter (Mukhopadhyay et al., 1995). Considering this term, the cross plot results shows that the shales and mudstone are mainly as type-III kerogen, with organic maturation reflects immature to early peak mature (Figure 10). Another cross plot of Total Hydrocarbon Generation (S1+S2 mg HC/g rocks) and TOC shows that the samples from the study area are considered as good to excellent source rocks potential (Figure 11).

Tables 2. Summary of organic geochemical data (Rock Eval Pyrolisis) from the Balikpapan Formation samples

	Rock Eval Pyrolisis											
	Tmax			Potential Yield			Potential Yield			Potential Yield		
Location	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg
Palaran Section	411	431	423	0.08	130.13	9.42	4	248.52	44.36	13	183	43.6
Loa Janan Section	419	430	425	0.05	5.46	2.02	2	97	41.78	18	108	42.22
Sungai Kujang Section	422	435	428	0.11	7.23	1.64	13	118	41.3	7	39	17.7
Loa Bakung Section	427	435	430	0.05	0.88	0.52	6	51	32.56	10	30	19.1

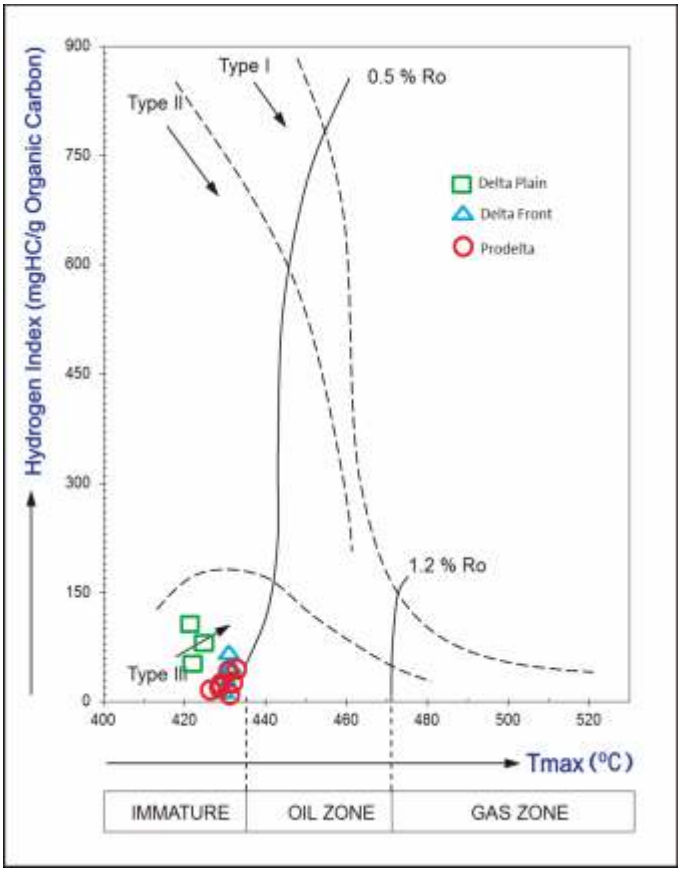


Figure 10. Classification of kerogen from different facies in the Balikpapan Formation (base on Mukhopadhyay et al., 1995), shows predominantly type-III kerogen and immature to early peak mature of organic maturation.

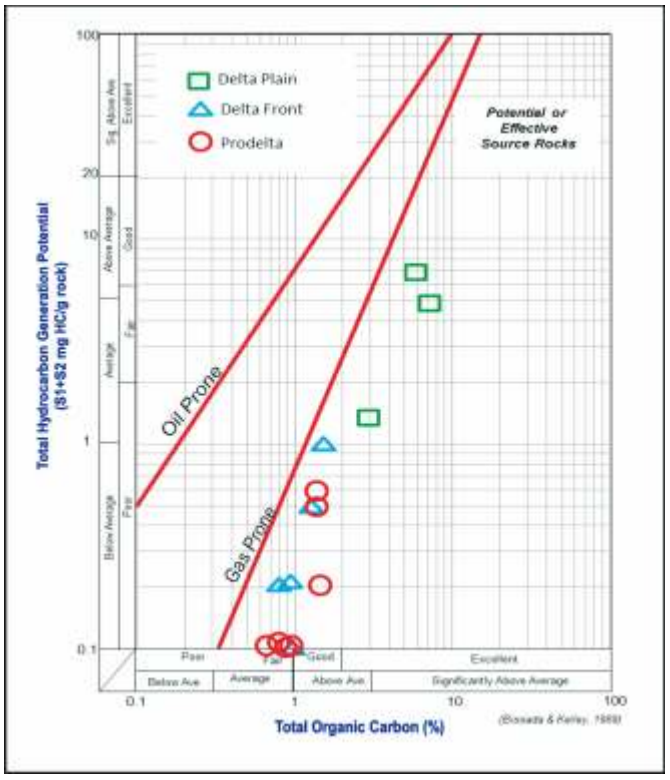


Figure 11. Classification of source rocks generative potential from different facies of the Balikpapan Formation, show good to excellent category of source rocks potential.

DISCUSSION

Depositional Environment, Type and Accumulation of Organic Matter

The organic rich sediment of the Balikpapan Formation as determined before was deposited in mixed fluvial-deltaic systems which ranged from fluvial, upper delta plain, to prodelta facies setting. It shows that during the Miocene, the depositional setting of the study area changes by prograding system from marine and extensive deltaic setting to fluvial deposition. Previous studies by some researchers (Moss et al., 1997; Tanean et al., 1996, Ahmad and Samuel, 1984; Moss and Wilson, 1998; Netherwood and Wight, 1992; Van de Weerd and Armin, 1992), have been revealed that this prograding sequence occurred on the eastern side of Kalimantan, particularly in the Kutai, Tarakan-Muara and Barito Basins, suggests that sediment supply was very high and actively subsiding kept pace with base level fall, providing accommodation space to bury and preserve the large amount of sediment input into these areas. The abundant detritus sediment was might be supplied from the uplift and denudation of the center of the Borneo Island and coeval volcanism.

The proportion and type of maceral in coals and shales reflect the origin of organic matter and conditions during the accumulation. Littke (1993) shows that the concentration of organic matter in fluvio-deltaic sediment are highly varied due to the high differences in climate and exposures to either sub aerial or sub aquatic condition after deposition. The organic content of Miocene organic rich sediments of the Balikpapan Formation is started to be 0.05 wt% to 57.11 wt%. Its value varies between 0.18 wt% - 57.11% wt% in delta plain and ranges 0.16 wt % - 7.77wt% in delta front, and further decreases at around 0.05 wt% - 1.97 wt % in prodelta. This trend may be similar in recent sediment of Mahakam Delta (Allen et al., 1976), which is showing that the organic contents in deltaic sediment decreasing from the inner part of deltas to the outer offshore areas. This variation may be due to the dilution of the organic matter by the mineral phases, as high organic periods correspond to low rates of sedimentation and progradation (Bustin, 1988).

In fluvial and deltaic sequences, the bulk of organic matter consists of part of higher land plants most of which are deposited close to but not exactly at the place of plant growth (Scheihing and Pfefferkorn, 1984). In

fluvial and deltaic sequences, terrigenous organic matter are more dominant that the marine or aquatic organic matter (Scheidt and Littke, 1989 and Smyth, 1989). The petrographic composition of organic rich sediment in the study area is composed by a mixture of different macerals. Vitrinite is the most frequent maceral group in organic rich sediment (coals and shales), followed by inertinite and liptinite macerals. The vitrinite group components are mainly textinite, texto-ulminite and telocollinite. The inertinites group consists of fusinite, semifusinite and funginite, whereas liptinites are mainly sporinite and cutinite. The vitirnite and inertinite maceral are dominated by organic particle derived from higher plant structure. They correspond to terrestrial higher plant of type III kerogen.

During the Early - Middle Miocene time the depositional environment of study area was dominated by fluvial to deltaic settings. In detailed description, the lower part sequence represents prodelta facies which has lower concentration of organic matter, while in the upper part sequence represents proximal delta (delta plain to delta front) which are richer in organic matter. The preservation and accumulation of organic matter in this area are mainly due to a biological activity which produces large amount of organic matter on delta plain. The organic matter is composed by vegetal debris such as bark, wood and leaves which accumulated insitu, preserved, protected by sedimentation forming thick layer shales and coal beds. This terrestrial organic debris then may be transported further to the basin setting in prodelta facies.

Source Rocks Generative Potential

Source rocks generative potential was evaluated by using total organic carbon content (TOC) and rock eval pyrolysis. As expected, the organic rich sediment of the Balikpapan Formation contain high organic material content, which are ranges from 0.05 wt% to 57.11 wt% TOC, mainly as type –III kerogen, and the terrestrial organic matter is associated with the occurrence of dark shales and coal beds facies in delta plain environment. In the pyrolysis analysis, Tmax values range from 411°C – 435° C and Hydrogen Index values range from 2 – 248.52 mg HC/g TOC. Plot of Tmax vs HI shows the organic maturation of the samples from the study area ranges immature to early peak mature. The potential yield (PY) values range from 0.05 – 130.13 mg HC/g rocks. The cross plot PY values vs TOC indicate the material organic is considered as good to excellent source rocks potential.

The primary source rocks in the Upper Kutai Basin (West Kutai Sub-basin) seem to be the Paleogene carbonaceous-rich shales and fluvio-deltaic-lacustrine coal. This results has been proved by some exploration well which were drilled in the Upper Kutai Basin and confirmed the presence of source rocks (Curiale et al, 2006). Previous researcher also reveals that Paleogene source rocks has a good source rocks generative potential. Bachtiar et al (2013) have been collected some Late Eocene rock samples of deltaic facies for source rock potential analysis. The coal and carbonaceous shales has an excellent organic matter composition (45.46 wt % to 78.47wt% TOC for coals and 12.62wt% TOC for carbonaceous shales). Moreover, the Potential Yield from the Rock Eval Pyrolisis of those samples also indicating very good to excellent source rocks.

In the Lower Kutai Basin (East Kutai Sub-basin), however, it might be different than the source rock generative potential results is the Neogen sequence, which is mainly the Early to Late Miocene of carbonaceous-rich shales and fluvio-deltaic coal. The Paleogene source rocks have been buried by very thick Neogene sediment in the Lower Kutai Basin and is likely to be late over mature. Peters et al. (1999) noted that the Miocene coaly source rocks which found in the Makaham Delta shefal area are thermally matured until post-mature in the Makasar Slope.

The Miocene source rocks in the Lower Kutai Basin have been identified by Patterson et al. (1997). They believed that the hydrocarbon in this area was originated from Middle to Late Miocene coals and carbonaceous shales of the Mahakam delta plain to delta front complex. Geochemical and petrological analyses of the Miocene organic rich sediment from the study area shows that the possible source rocks are delta plain-delta front coals and shales containing predominantly of vitrinite maceral, derived from terrestrially type III kerogen organic matter, with early peak maturation, and considered as good until excellent gas source rocks potential.

CONCLUSIONS

The investigated sections of the Miocene organic rich sediments of the Balikpapan Formation consist of thick prograding deltaic sediment to fluvial sequences, with sand, shale, and coal-rich sequences in the proximal fluvio-deltaic facies and an underlying thick shale-dominated sequence in the distal marine prodelta facies. They are divided into seven facies association; fluvial channel, distributary channel, marsh, delta front mouth bar, delta front mud, delta front carbonate, and prodelta mud.

The source rocks has a moderate to excellent content in organic matter. This result is considered from rock-eval pyrolysis and maceral analysis data that has type III kerogen, and indicating substantial contribution from terrestrial source and potential to generate gas. Most of the source rocks in the area has a fair to excellent hydrocarbon potential yields. Therefore it can be considered as a good potential source rocks. However, thermal maturity result indicates an immature to early peak mature level for the source rocks. At present outcrop level, hydrocarbons have not been generated yet.

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REFERENCES

Ahmad, Z., and Samuel, L., 1984. Stratigraphy and depositional cycles in the N.E. Kalimantan Basin. Indonesian Petroleum Association Proceedings 13th Annual Convention, pp. 109–120.

Allen, G.P., Laurier, D., and Thouvenin, J., 1976. Sediment distribution patterns in the modern Mahakam delta. Proceedings Indonesian Petroleum Association, 5: 159-178.

Bachtiar, A., 2004. Kerangka Stratigrafi Sikuen dan karakter batuan induk Miosen Awal di Cekungan Kutai Hilir, Kalimantan Timur. Disertasi, Institute Teknologi Bandung, 259 h.

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 p.

Bordenave, M. L., 1993. Applied petroleum geochemistry. Imprimerie Nouvelle, Paris, France, Edition Technip, 524 p.

Bustin, R.M. 1988. Sedimentology and characteristics of dispersed organic matter in Tertiary Niger Delta: origin of source rocks in a deltaic environment. American Association of Petroleum Geologists Bulletin, 72: 98-277.

Chambers, J.L.C. and Daley, T. 1995. A tectonic model for the onshore Kutai Basin, East Kalimantan, based on an integrated geological and geophysical interpretation. Indonesian Petroleum Association, Proceddings 24th annual convention, Jakarta, 1995, 1: 111-130.

Clay, K.Mc., Dooley, T., Ferguson, A., and Poblet, J., 2000. Tectonic evolution of the SangaSanga Block, Mahakam Delta, Kalimantan, Indonesia. AAPG Bulletin, 84: 765-786.

Courtney, S., Cockcroft, P., Lorentz, R., Miller, R., Ott, H.L., Prijosoesilo, P., Suhendan, A.R., Wight, A.W.R., and Wiman, S.K. (Eds.), 1991, Indonesia – oil and gas field atlas volume V: Kalimantan, Indonesian Petroleum Association, Jakarta.

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

Espitalié, J., Madec, M., Tissot., B., Menning, J.J., and Lepat, P. 1977. Source Rock Characterization Method for Petroleum Exploration. Proceedings from the 9th. Annual Offshore Technology Conference, May 2-5, Houston, Texas, p. 439-445.

Hall, R., and Nichols, G., 2002. Cenozoic sedimentation and tectonics in Borneo: climatic influences on orogenesis, in Jones, S.J., and Frostick, L., eds., Sediment Flux to Basins: Causes, Controls and Consequences: Geological Society, London, Special Publications, 191: 5-22.

Littke, R., 1993. Deposition, diagenesis and, weathering of organic matter-rich sediments. Springer-Verlag, Berlin, Germany, 216 p.

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, 126: 395-416.

Moss, S.J., and Wilson, M.E.J., 1998, Biogeographic implications of the Tertiary paleogeographic evolution of Sulawesi and Borneo,in Hall, R., and Holloway, J.D., eds., Biogeography and Geological Evolution of Southeast Asia: Leiden, Backhuys Publishers, pp. 133–163.

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

Mukhopadhyay, P.K., Wade, J.A., and Kruge, M.A., 1995b. Organic facies and maturation of Cretaceous/Jurassic rocks and possible oil–source rock correlation based on pyrolysis of asphaltenes, Scotian Basin, Canada. Organic Geochemistry, 22: 85-104.

Netherwood, R., and Wight, A., 1992. Structurally controlled, linear reefs in a Pliocene deltafron setting, Tarakan Basin, Northeast Kalimantan. In: Siemers, C.T., Longman, M.W., Park, R.K., Kaldi, J.G. (Eds.), Carbonate Rocks and Reservoirs of Indonesia: A core workshop held in conjuction with 1992 Indonesian Petroleum Association Annual Convention, 1: 3.1.3–3.1.36.

Pertamina BPPKA., 1997, Petroleum Geology of Indonesian Basins: Principles, Methods and Application, volume XI, Kutai Basin, 134 p.

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 p.

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

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

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

Scheidt, G. and Littke, R. 1989. Comparative organic petrology of interlayered sandstones, siltstones, mudstones and coals in the Upper Carboniferous Ruhr basin, northwest Germany, and their thermal history and methane generation. Geol. Rundschau, 78: 375-390.

Scheihing, M.H. and Pfefferkorn, H.W. 1984. The taphonomy of landplants in the Orinoco delta: a model for the incorporation of plant parts in clastic sediments of Late Carboniferous age of Euramerica. Rev. Palaeobot. Palynol., 41: 205-240.

Smyth, M., 1989. Organic petrology and clastic depositional environments with special reference to Australian coal basins. Intern. Journ. Coal. Geol., 17: 635-656.

Supriatna, S., and Rustandi, E., 1986. Peta Geology Lembar Samarinda, Pusat Penelitian dan Pengembangan Geology, Bandung.

Standards Australia, 1998. Coal petrography-maceral analsyis. Australian Standards 2856-2, 32p.

Tanean H., D.W.Paterson, and M. Endharto, 1996, Source provenance interpretation of Kutai Basin sandstones and the implicationsfor the tectono-stratigraphic evolution of Kalimantan, Proceedingsof Indonesian Petroleum Association 25th, pp. 333-345.

Tissot B.P., Welte D.H., 1984. Petroleum Formation and Occurrence, second ed., Springer, New York, , 699 p.

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