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Paleogene Deposits Distribution of the Kampar Block, Central Sumatra Basin

Distribusi Endapan Paleogen di Blok Kampar, Cekungan Sumatra Tengah

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Abstract- As the most prolific basin, Central Sumatra Basin is a very mature basin for hydrocarbon exploration. Most of the productive reservoir came from Neogen deposits therefore the stratigraphic reconstruction for depositional environment distribution mostly focused on these deposits. Meanwhile the Paleogene deposits distribution and gross depositional environment (GDE) has not been explore further especially on the southern part on the basin.

Paleogen deposits like Kelesa Formation is a synrift deposition which was deposited in the center of the basin. The lithofacies development of the Kelesa Formation consist of 3 (three) major lithofacies associations: (1) thick-bedded mudstone, (2) Interbedded sandstone and conglomerate, (3) Interbedded sandstones and mudstones. The thick-bedded mudstone is deposited in deep lake setting; interbedded sandstone and conglomerate is interpreted as alluvial fan deposit and interbedded sandstones and mudstones as a fluvial channel. Meanwhile the lower part of Lakat Formation consists of 2 (two) lithofacies association: (4) Thick-bedded sandstone as braided to meandering system deposits and (5) Interbedded sandstone and mudstone. Lakat interbedded sandstone and mudstone is a typical of floodplain complex in fluvial setting.

GDE map of Kelesa Formation indicate that sandstones facies developed in fluvial and alluvial fan setting near the basin boundary consider as a potential for future hydrocarbon exploration.

Keywords: Kelesa Formation; Lakat Formation; Paleogene, lithofacies; gross depositional environment.

Abstrak*-Sebagai cekungan paling produktif, Cekungan Sumatera Tengah merupakan cekungan yang sangat matang untuk eksplorasi hidrokarbon. Sebagian besar reservoir produktif berasal dari endapan Neogen sehingga rekonstruksi stratigrafi untuk sebaran lingkungan pengendapan lebih banyak difokuskan pada endapan ini. Sementara itu sebaran endapan Paleogen dan lingkungan pengendapan (gross depositional environment/GDE) belum tereksplorasi lebih jauh khususnya di cekungan bagian selatan.*

Endapan paleogen seperti Formasi Kelesa merupakan endapan synrift yang diendapkan pada bagian tengah cekungan. Perkembangan litofasies Formasi Kelesa terdiri atas 3 (tiga) asosiasi litofasies besar: (1) Batulumpur berlapis tebal, (2) Perselingan batupasir dan konglomerat, (3) Perselingan batupasir dan batulumpur. Batulumpur dengan lapisan tebal diendapkan di danau yang dalam; perselingan batupasir dan konglomerat diartikan sebagai endapan kipas aluvial dan perselingan batupasir dan batulumpur sebagai sungai fluvial. Sementara itu Formasi Lakat bagian bawah terdiri dari 2 (dua) asosiasi litofasies: (4) Lapisan tebal batupasir sebagai endapan sistem sungai menganyam hingga sungai berkelok dan (5) Perselingan batupasir dan batulumpur. Perselingan batupasir dan batulumpur Lakat adalah ciri khas kompleks dataran banjir di kondisi fluvial.

Peta GDE Formasi Kelesa menunjukkan bahwa fasies batupasir yang berkembang pada susunan kipas fluvial dan aluvial di dekat batas cekungan berpotensi untuk eksplorasi hidrokarbon di masa depan.

Kata kunci: Formasi Kelesa; Formasi Lakat; Paleogen; litofasies; lingkungan pengendapan.

INTRODUCTION

Central Sumatra Basin is the most hydrocarbon prolific basins in West Indonesia. The origin of accumulated hydrocarbons are mostly coming from structural trapping of Late Oligocene trough Miocene siliciclastic reservoirs (De Coster, 1974; Williams & Eubank, 1995; Wongsosantiko, 1976), where Minas and Duri fields are the examples of the giant fields in this area (Willis & Fitris, 2012; Wongsosantiko, 1976). Source rocks are thought from Paleogene deposits (Longley et al., 1990; Marpaung et al., 2010; Mertosono & Nayoan, 1974; Moulds, 1989; Rodriguez & Philp, 2015; Williams & Eubank, 1995), which its distributions are following relatively N-E and NW-SE orientations of Paleogene graben (Eubank & Makki, 1981; Mertosono & Nayoan, 1974; Moulds, 1989; Williams & Eubank, 1995), where Aman and Bengkalis Grabens are the biggest graben in Central Sumatra Basin (Fig. 1).

Although tectonic and stratigraphic evolution of Central Sumatra Basin have been discussed by previous workers (e.i. De Coster, 1974; Eubank and Makki, 1981; Heidrick and Aulia, 1993; Mertosono and Nayoan, 1974; Shaw et al., 1997; Sudarmono et al., 1997; Williams and Eubank, 1995), the studies were beneficially for regional purpose. Detail facies distribution of sediment infill into the basin during Paleogene, especially for synrift reservoirs target in the southern part of this basin (Bengkalis Trough) is not yet inform detailly. Synrift deposits, the main source rocks in this basin, are also contains coarse-grained terrigenous sedimentary rocks that deposited in terrestrial settings. Those coarse-grained are important reservoirs for the current exploration target.

In the southern part of Central Sumatra Basin, Kampar Block, hydrocarbons are produced mostly from Neogene deposits of several fields, lie above or adjacent to BengkalisTrough, and its distributions are following the youngest NW-SW structural orientations. There are available data of hundreds of 2D seismic sections and wells within the block. Toward southwest, Paleogene deposits are exposed around Pegunungan Tigapuluh. Those situations give an opportunity to reconstruct basin evolution for identifying the possibility of hydrocarbon accumulation in the coarse-grained sandstones of stratigraphic traps.

The primary purpose of this paper is to map the distribution of Paleogene deposits in the study area, at the southern part of Central Sumatra Basin, in term of reservoirs facies which is the key of exploration in this mature basin. The principal method of investigation was description and interpretation of well log, seismic sections and outcrops analogue. The aims of this study are: (1) to document lithofacies variations, and to interpret the depositional setting, (2) to reconstruct stratigraphic evolution and distribution, and (3) to suggest the potential exploration for Paleogene deposits target.

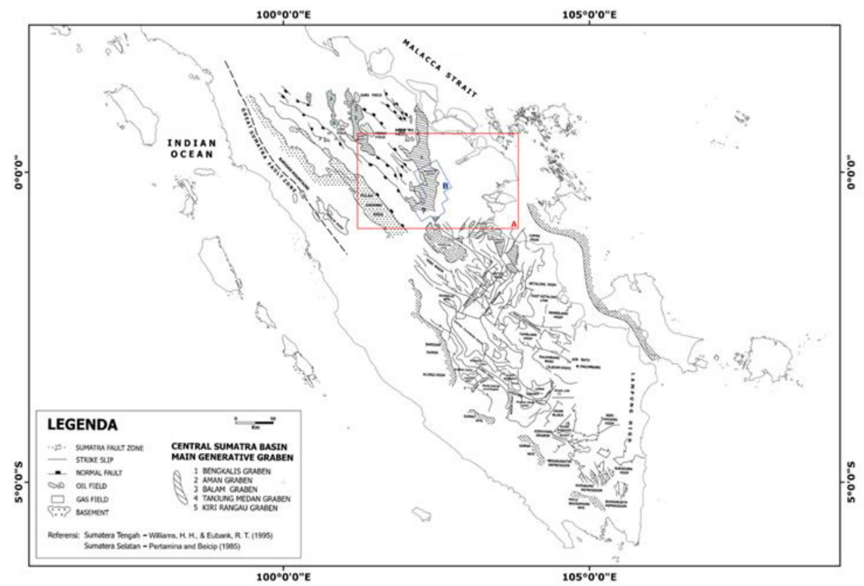

Figure 1. Outline of Paleogene deep & NW-SE structural grains of Central Sumatra Basin in the northern part, and NW-SE and NE-SW structural grains of South Sumatra Basin in the southern part, where Pegunungan Tigapuluh in between modified mainly from Pertamina 7 Beicip (1985) and William & Eubank (1995). Rectangular block (A) is outline general paleogeography map, while asymmetric block (B) is an area for detail GDE map in study area.

GEOLOGIC SETTING

The studied area is located in the southern part of Central Sumatra Basin, sitting on the southern part of Bengkalis Trough, which has N-S orientation and then turning orientation into NW-SE of South Sumatra Basin (De Coster, 1974). In between CSB and SSB in the western part of those trough orientation is Pegunungan Tigapuluh, where basement and Paleogene deposits are locally exposed (Fig. 2).

Bengkalis Trough was infilled by Cenozoic sedimentary rocks, overlaid the basement that consists of a complex of Mesozoic igneous rocks, and Paleozoic and Mesozoic metamorphics and carbonates (De Coster, 1974). Bengkalis Trough is N-S regional rift system, extent over 250 km from the north near Bengkalis Strait, to the south near Pegunungan Tigapuluh, which is segmented into three compartments; (1) Butun (in the north), Metas (in the middle) and Petodak (in the south). The thickest sediment of Eo-Oligocene deposits is reaching up to 12,000 ft in Butun area (Heidrick & Aulia, 1993).

In the study area, the seismic sections, especially for E-W sections, are representing a main bounding fault that controlled the basin, and some synthetic and antithetic faults, which are mostly developed in lower intervals near the basement. The faults are contractional structure styles, typified by folds and inverted faults (Figure 2). Reflector's characteristic of seismic sections over the basement can be grouped into two units, upper and lower units. Upper unit have relatively parallel, continues and homogenous in thickness, while the lower unit represents a discontinuity by faults and locally in lower interval onlap to the flex margin. Contact of both units is party representing erosional truncation (Fig. 3). The development of lower unit is interpreted to have been controlled by extensional main fault, which is also known as synrift deposits, while the upper unit is postrift deposits (e.g. Lambiase and Bosworth, 1995; Lambiase and Morley, 1999; Leeder and Alexander, 1987; Perner et al., 2018; Prosser, 1993; Smyrak-Sikora et al., 2019).

Cenozoic stratigraphic evolution was begun by deposition of siliciclastic sediments into the basin, which its distributions are following the trough during Eocene–Oligocene time. This deposit is called by Kelesa Formation, representing synrift deposits in this study area, and reached up to 1500 m in thickness. Post synrift period, a phase of contractional tectonic occurred, it induced Kelesa Formation underwent folded and eroded in the most upper part interval locally. In Central Sumatra Basin (Central Deep part), this synrift deposits is the oldest sedimentary unit, and is also known as Pematang Formation (Cameron, 1983; Mertosono & Nayoan, 1974), which is characterized by terrestrial deposits that developed in fluvial, alluvial fan and lacustrine sedimentary settings (Fig. 4). Post folding and erosion, the basin was infilled by transgressive succession deposits from terrestrial to shallow marine of Lakat and Tualang Formations during Late Oligocene–Middle Miocene time.

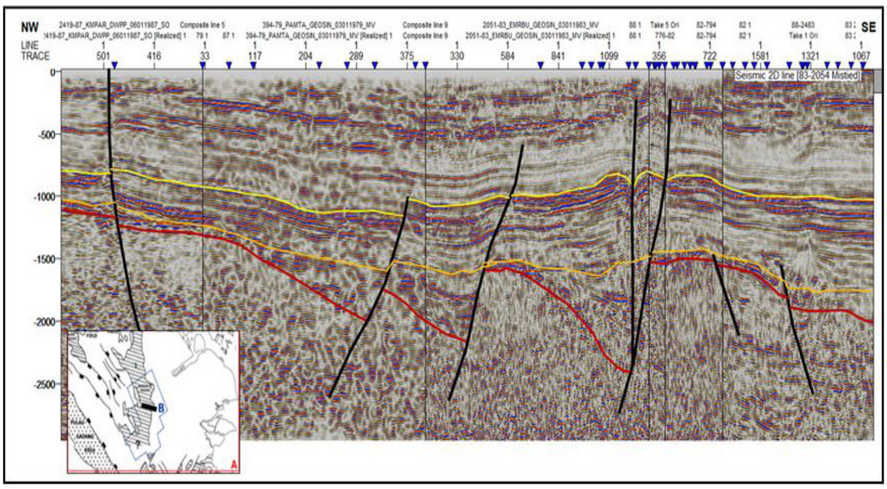

Figure 2. Relatively NW-SE composite seismic sections from study area representing inverted rift basin, where the lower part characterized by thickening toward the major faults, while the upper part the succession is characterized by relatively homogenous in thickness.

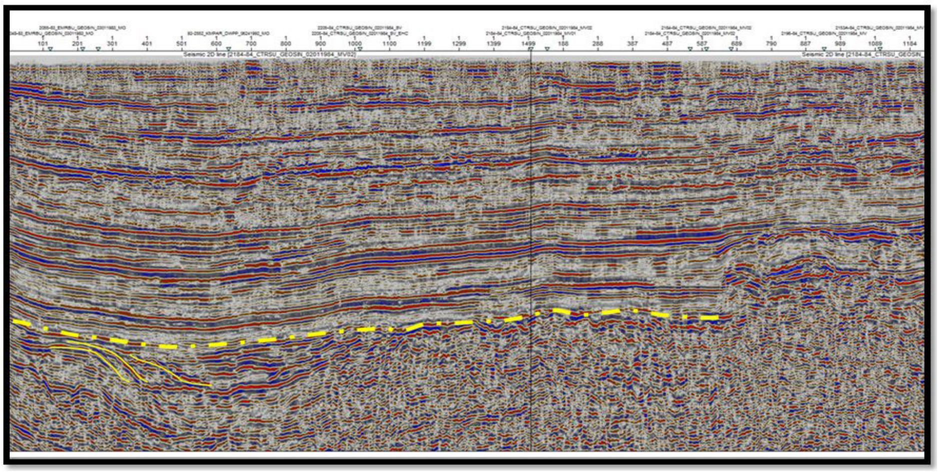

Figure 3. Erosional truncation contacts between synrift deposits (Kelesa Formation) and post rift deposits (Lakat Formation).

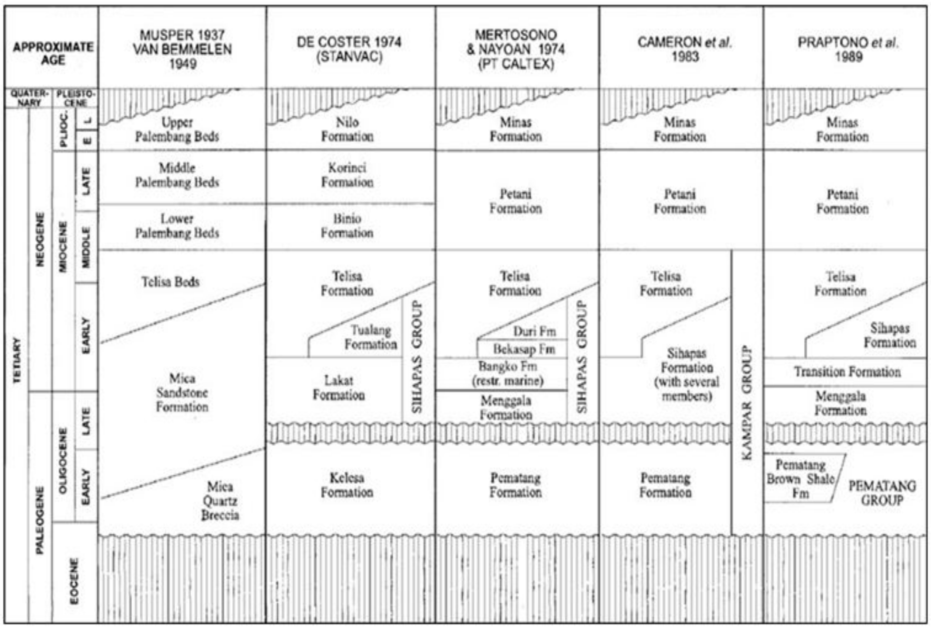

Figure 4. Regional stratigraphy of CSB, nomenclature and terminology (De Smet & Barber, 2005)

PALEOGENE DEPOSITS

There are two formation units in the study area that represent Paleogene age, Kelesa and Lakat Formations. Both formations are bounded by unconformity due to uplifted tectonic processes.

Kelesa Formation in the study area from penetrated well data is consisting of various lithology, e.i: conglomerates, coarse quartz sandstone, variegated shales, coals and tuffaceous material, which were constantly deposited at the terrestrial environments. Coarse-grained sandstones and conglomerates are slightly penetrated by wells that seated close the basin boundaries (c.f. Panduk, Talayap and Aghya fields), while finer-grained sediments are mostly observed in the center part of basin (c.f. Kayuara, Gemuruh fields). Although detailly lithofacies of Kelesa Formation is not available in well data, the outcrops of this formation are well exposed in several area around Pegunungan Tigapuluh, and provide an opportunity to examining the lithofacies and depositional environments. In general, Kelesa Formation in the outcrops is consisting of terrestrial deposits, and can be grouped into 3 major lithofacies associations: (1) Thick-bedded mudstone, (2) Interbedded sandstone and conglomerate, (3) Interbedded sandstones and mudstones.

(1) Thick-bedded mudstone consists of thick claystone, locally thin- to very thin bedded fine-grained sandstones and tuffaceous mudstones. Claystone is thick, massive, non-calcareous, with thickness up to 160 cm. The sandstone occasionally observed within the thick mudstone facies, typified by thin- to very thin bedded of very fine-grained sandstone, parallel and cross ripple lamination with sharp top and bottom contact. Tuffaceous mudstones in the most upper part of thick-bedded mudstone, typified by very thick-bedded, white with locally reddish brown when weathered. Locally, the tuffaceous mudstones interbedded with coarse-grained sandstones and conglomerates (Fig. 5)

Thick-bedded mudstones are interpreted to have been deposited at quiet and low sedimentation, possibly in the deep water situation of terrestrial settings. Fine-grained sandstone materials occasionally delivered by turbidity currents. Those deposits are interpreted to have been developed in deep lake settings. Tuffaceous materials are possibly product of ash volcanic falls, or re-transported by fluvial erosion from hinterland.

(2) Interbedded sandstone and conglomerate are characterized by thick-bedded of medium- to coarse-grained sandstones, and conglomerates. Sandstones are medium- to well sorted, mostly medium- to coarse, with the thickness is ranging 20 to 60 cm of single bed. Locally the sandstones contain fragments. Conglomerates are component supported, consist of various lithology of igneous and metamorphic rock fragments. Both sandstones and conglomerates are not representing distinct sedimentary structure, except long axis of conglomerate fragment are slightly parallel to bedding surfaces. The bedding surfaces are scouring and irregular, and the beds are impersistent in thickness (Fig. 5).

Since there is no distinct sedimentary structure from the sandstone and conglomerate lithofacies, the deposits are interpreted to have been developed by irregular event of transport by waters. Interbedded sandstone and conglomerate are signal of various of sediment discharge and flow orientations. Those deposits are interpreted to have been developed in alluvial settings. Since these facies also sometimes observed interbedded with tuffaceous mudstones indicate that it's possibly developed near the lake area, where the increasing of supply sediment would produce lake delta of alluvial fan.

(3) Interbedded sandstone and mudstone is observed in many spot areas of eastern part of Pegunungan Tigapuluh. Good exposures are found along Tembulun River, with the total succession of amalgamated sandstones is up to 300 m. It is characterized by thick- to very thick- bedded of coarse- to very coarse-grained sandstones. The mudstone facies in only observed in the lower interval of this sandstone succession. The sandstones are medium- to well sorted, representing cross and parallel bedding, with the single sandstone bed up to 70 cm in thickness. Beds are commonly sharp with scoring in bottom contacts. Interbedded sandstones with parallel and cross bedding are interpreted to have been developed as fluvial channel in terrestrial settings (Fig. 6).

Figure 5. Outcrop photograph of Kelesa Formation represents mudstone dominated facies (A), with very thin-bedded fine-grained sandstones (B), gravelly coarse-grained sandstone overalaid tuffaceous mudstone (C), and interbedded coarse-grained sandstones and conglomerates.

Figure 6. Channel-fill deposits of Kelesa Formation exposed in the eastern part of Pegunungan Tigapuluh. Erosional basal contact (A), outcrop situation in Tembulun River (B), trough cross-bedding sandstones (C), and planar cross-bedding sandstones (D)

Lakat Formation is the main hydrocarbon reservoir unit in this study area, therefore many wells have penetrated this formation and provide adequate data, such as well log, core, cutting and biostratigraphy analysis.

Lakat Formation deposited from Late Oligocene-Early Miocene (De Coster, 1974) and lies unconformably above Kelesa Formation. Biostratigraphy data (nannoplankton & palynology) shows that the lower and middle part of formation represent terrestrial fluvial setting, that while the upper part indicate of paralic setting. Overall, Lakat Formation represents transgressive deposits from terrestrial fluvial into paralic setting of Oligocene through Lower Miocene in ages.

The lower part of Lakat Formation consists of 2 (two) lithofacies association: (4) Thick-bedded sandstone and (5) Interbedded sandstone and mudstone.

(1) Thick-bedded sandstone lithofacies association mostly developed on the north and middle part of the study area. This lithofacies is characterized by thick-bedded of sub angular- to sub-rounded medium- to very coarse-grained sandstone with streaks of silty light grey to light brown shales, locally these sandstones also interbedded with mudstone and coal. Gamma ray log characterized by blocky shapes low API GR with thickness of individual bed range from 10 – 200 feet.

The characteristics of lithology in this lithofacies associations, the absence of foraminifera and electrofacies pattern (blocky shapes pattern), this lithofacies is interpreted as fluvial deposits in a braided to meandering system.

(2) Interbedded sandstone and mudstone lithofacies are characterized by funnel shape of gamma ray log with sandstones of medium- to very coarse-grained size, abundant cross bedding with thin carbonaceous material and coal layer are present in between cross bedded, medium- to well sorted. Mudstone are dark brown consist of silt lenses with the present of parallel laminations and load structures. This lithofacies associations is a typical of floodplain complex in fluvial setting.

Gross Depositional Environments (GDE)

GDE map represents the environments in which the rocks were deposited at considered time period. In this study, we reconstruct three GDEs that represent Kelesa, Lakat and Tualang units from Paleogene synrift phase through Neogene postrift phase.

The interpretation of depositional environments is subject to mainly available well and seismic data, and supported by outcrops analogue and model. Well data in the study area are complete to support the interpretation for Lakat and Tualang Formation, by combining of stacking log pattern and cutting description, and supported by the outcrops data that provide more detail of lithofacies description. Due Kelesa Formation is not penetrated by wells as much as both formations, the depositional interpretation was guided by outcrops analogue and model for rift basin depositional settings (e.g. Lambiase & Bosworth, 1995; Lambiase & Morley, 1999; Leeder & Gawthorpe, 1987; Prosser, 1993b).

GDE map of Kelesa Formation is very important, because these deposits are representing of synrift period, further target exploration (Williams & Eubank, 1995), especially to figure out the possibility of siliciclastic reservoirs distribution and variation. The map will guide also for probabilistic ratio for reservoir availability.

Kelesa GDE Map

During Oligocene (possibly latest Eocene to early Oligocene) time sediment accumulated in Bengkalis Trough, in what developed to be a small linear and structurally controlled basin. This deposits, the distribution and thickness, are controlled by local normal faults and are known as Kelesa Formation. Since Kelesa Formation was not observed from well or seismic data, the eastern area was interpreted to be the hinterland area, while the lower area, where sediments deposited can be grouped into lacustrine and alluvial or fluvial settings. Outline of deeper area followed relatively N-S orientation of Bengkalis Trough, where the hinterland area ceased in the west and in the east area (Fig. 7). More detail sedimentary setting interpretation from seismic and well in the study area represents lacustrine, fan delta an alluvial fan/talus. An outcrop analogue of lacustrine deposits is also exposed in Bukit Susah, located on the south of the study area (Hermiyanto & Panggabean, 2008).

Lakat GDE Map

Post Kelesa Formation deposited; the deformation occurred due to tectonic activity that then this formation underwent to folded and eroded at the most upper part of the succession. Sediments of Lakat Formation then deposited over this layer of unconformity in terrestrial setting (Fig. 3).

Lakat Formation is typified thick to very thick-bedded, medium- to very coarse-grained sandstones, bell-blocky shape, overall fining-up succession, locally interbedded with thin coal seams and tuffaceous. At most upper this formation is characterized by funnel shape pattern of thin to thick bedded sandstones and mudstones, in several well represents calcareous and glaucony contents (Parum Pekan and Merbau Fields). From the well data and also outcrops analogue confirmed that Lakat Formation is transgressive succession from terrestrial fluvial settings in the lower part, then gradually into the paralic setting in the upper part of formation

GDE map of Lakat Formation is presented in Figure 8.

Tualang GDE Map

There are no abrupt changings of sedimentary setting during Early to Middle Miocene of Lakat Formation to Tualang Formation except deepening up.

Tualang Formation is consisting of marine mudstone locally interbedded with thin- to thick-bedded glauconitic sandstones. The sandstones are calcareous, thickening or coarsening-up succession of funnel shape.

In the study area, Tualang Formation is representing marine environment, where bars commonly developed following the shorelines (Fig. 9).

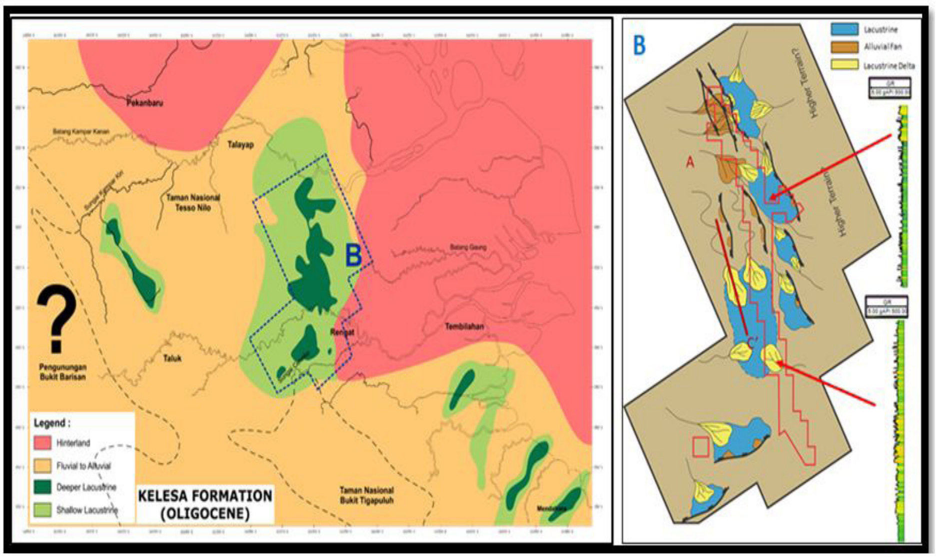

Figure 7. GDE map of Kelesa Formation, where studied area mostly the low area for synrift deposits

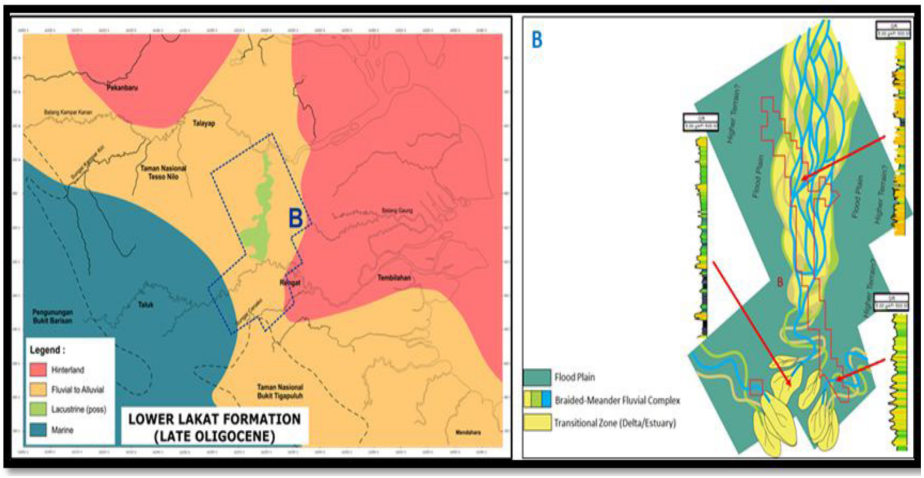

Figure 8. GDE map of Lakat Formation represents terrestrial of fluvial settings

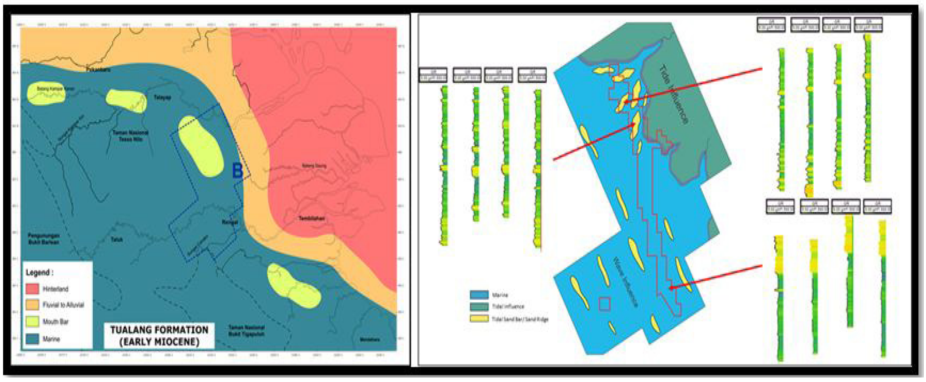

Figure 9. GDE map of Tualang Formation, where the studied area is transition to shallow marine.

DISCUSSION (PETROLEUM EXPLORATION IMPLICATIONS)

Bengkalis Trough is believed on of proven kitchen area in Central Sumatra Basin. Existing oil fields in this area are producing hydrocarbon from siliciclastic sandstones of postrift deposits (Lakat and Tualang Formations), there is not yet productive reservoir from synrift deposits (Kelasa Formation).

Kelesa Formation (De Coster, 1974)or Pematang Formation (Mertosono & Nayoan, 1974)is synrift deposits, which was commonly act as source rocks of petroleum system element in this basin is also containing coarse-grained sediments that possible developed in this setting. Outcrop analogue of this formation reveals both sandstone and conglomerate facies of fluvial and alluvial fan systems. But however, fan delta or deeper sandstone facies delivered by turbidity current are most likely able to be developed during this period.

Coarse-grained sandstone layers are most exploration target that where primary migration of expelled hydrocarbon from fine-grained sediment source rock move to coarse-grained sandstone layers. Both tectonic and stratigraphic traps would play the important rule.

Further detail study for identifying existence of sandstone reservoirs within synrift deposits of fluvial, alluvial or lacustrine would give important contribution for hydrocarbon exploration in this basin, and mature area of exploration, like Central Sumatra and South Sumatra Basins.

CONCLUSION

Kelesa Formation is representing synrift deposits in the Bengkalis Trough, which consisting of mudstone dominated facies in the deeper area, and coarse-grained sandstones and conglomerate facies that developed in fluvial and alluvial settings. There for Kelesa Formation, although it was known as hydrocarbon source rock, could play for the reservoirs and become further exploration target for synrift deposits by direct migration.

GDE map of Kelesa Formation indicate that sandstones facies developed in fluvial and alluvial fan setting near the basin boundary, and can provides consideration for exploration success ratio of Kelesa Formation reservoirs existence.

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