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PALEOGEOGRAPHY RECONSTRUCTION OF PEMATANG GROUP IN NORTH AMAN TROUGH, CENTRAL SUMATRA BASIN

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Sari – Cekungan Sumatra Tengah terbukti sebagai cekungan yang produktif menghasilkan hidrokarbon. Akumulasi hidrokarbon yang paling besar saat ini ada pada interval *post-rift* Kelompok Sihapas, sedangkan interval *syn-rift* Kelompok Pematang belum dieksplorasi dengan baik. Dengan terbatasnya data, ada resiko dan ketidakpastian mengenai distribusi dan geometri reservoir batupasir pada interval ini. Penelitian terdahulu belum mengintegrasikan data sumur dengan seismik 3D untuk mengidentifikasi penyebaran reservoir batupasir pada skala sub-cekungan. Sehingga diharapkan dengan mengintegrasikan data sumur dan seismik 3D dalam penelitian ini, dapat mengurangi resiko dan meningkatkan peluang untuk menemukan cadangan hidrokarbon yang baru.

Interpretasi seismik semi-regional dilakukan pada seismik 3D termigrasi gabungan seluas 1.230 km^2, yang diikat dengan 45 sumur di area sub-cekungan Aman Utara. Secara umum struktur yang berkembang di daerah penelitian adalah struktur sesar-sesar normal berarah Baratlaut – Tenggara yang berkembang pada umur Eo-Oligosen. Sesar-sesar tersebut kemudian mengalami pembalikan menjadi sesar naik pada umur Miosen tengah. Rekonstruksi paleogeografi dilakukan dengan mengintegrasikan data batuan inti, elektrofasies dari data log talikawat, geomorfologi seismik, peta ketebalan sebagai cerminan paleotopografi dan model tektonostratigrafi *rift*.

Data biostratigrafi menunjukan perubahan paleoenvironment berumur Eosen-Oligosene secara gradual dari terestrial menjadi transisi marin. Fosil foraminifera baru ditemukan pada umur Miosen Awal yang menunjukan pengaruh laut terbuka. Data interpretasi batuan inti menunjukan litofasies batupasir *flaser* dan batulempung *lenticular* mencirikan perubahan kuat arus dalam periode singkat yang dikontrol oleh curah hujan dan iklim.

Paleogeografi pada Kelompok Pematang secara umum mengikuti 3 (tiga) tahapan tektonik *rift* yaitu: 1) fase awal dicirikan oleh lingkungan sungai berkelok, dataran aluvial, dan kipas aluvial; 2) fase puncak, dicirikan oleh lingkungan lakustrin dalam, lakustrin dangkal, pantai lakustrin, tepian lakustrin, dataran aluvial, sungai berkelok, kipas delta dan lakustrin deltaik dan; 3) fase menjelang *post-rift*, dicirikan oleh sungai teranyam dan dataran aluvial.

Kata kunci: paleogeografi, tektonostratigrafi, setengah lisu

Abstract - *Central Sumatra Basin is a proven prolific basin. Most of hydrocarbon accumulations are in post-rift interval of Sihapas Group, meanwhile the syn-rift interval of Pematang Group is still under-explored. Nevertheless, there are remaining risk and uncertainty of reservoir geometry and distribution in this interval. The previous studies on Pematang Group were not utilizing 3D seismic with integration with well data to identify sandstone reservoir distribution in North Aman Trough. Paleogeography reconstruction of Pematang Group with integration of well and seismic data as in this study will be useful to reduce risk and increase chance to find new resources.*

Approximately 1,230 sq. km of 3D merged post-migrated seismic cube which were tied to 45 wells in North Aman Trough have been interpreted with tectonostratigraphic approach. Main structure on this area is a series of Northwest – Southeast normal fault that were developed during Eo-Oligocene. Those faults were inverted to thrust fault during Middle Miocene – recent. Paleogeography reconstructions were inferred from conventional core data, wireline log electro-facies, seismic geomorphology, isopach map as proxy of paleo-topography and rift tectonostratigraphy model.

Biostratigraphy data suggests gradually changes of Eocene-Oligocene paleoenvironment from terrestrial to marine transition. However, foraminifera fossil has just started to appear in Early Miocene as indication of marine incursion. Core data indicates lithofacies of sand flaser and mud lenticular which is associated to rapid changes of sedimentation flow due to rainfall rate or climate.

Paleogeography of Pematang Group is influenced by three rift tectonic stages: 1) rift initiation, with environment of alluvial plain, alluvial fan and fluvial meander; 2) rift climax, with environment of deep lacustrine, shallow lacustrine, marginal lacustrine, nearshore lacustrine, deltaic, fluvial meander, alluvial plain and fan delta; 3) immediate post-rift, with environment of fluvial braided and alluvial plain.

Key words*: paleogeography, tectonostratigraphy, rift*

1. INTRODUCTION

Central Sumatra Basin is a proven prolific basin. Most of the hydrocarbon accumulations are in the post-rift interval or Sihapas Group. Meanwhile, the syn-rift interval or Pematang Group is well known as the kitchen for petroleum system in this area. Existing exploration work has found hydrocarbon indication in this interval and hydrocarbon accumulation in structure high.

Chevron Pacific Indonesia. At that time, the available dataset is only 2D seismic lines, regional gravity and well data.

Soon after, in 1997-1998 3D seismic acquisition commenced in this area and seismic based study conducted (Indrawardana, 2005; Suhirmanto, 2005). In relation to the petroleum system element, reservoir presence and stratigraphic trap definition are the main critical risks in this interval especially when dealing with stratigraphic or basin center play. Therefor paleogeography reconstruction study will be very beneficial to address this uncertainty. However, with limited number of well penetration in Pematang Group, 3D seismic utilization with validation to well data will be very useful to identify distribution and geometry of sandstone reservoir.

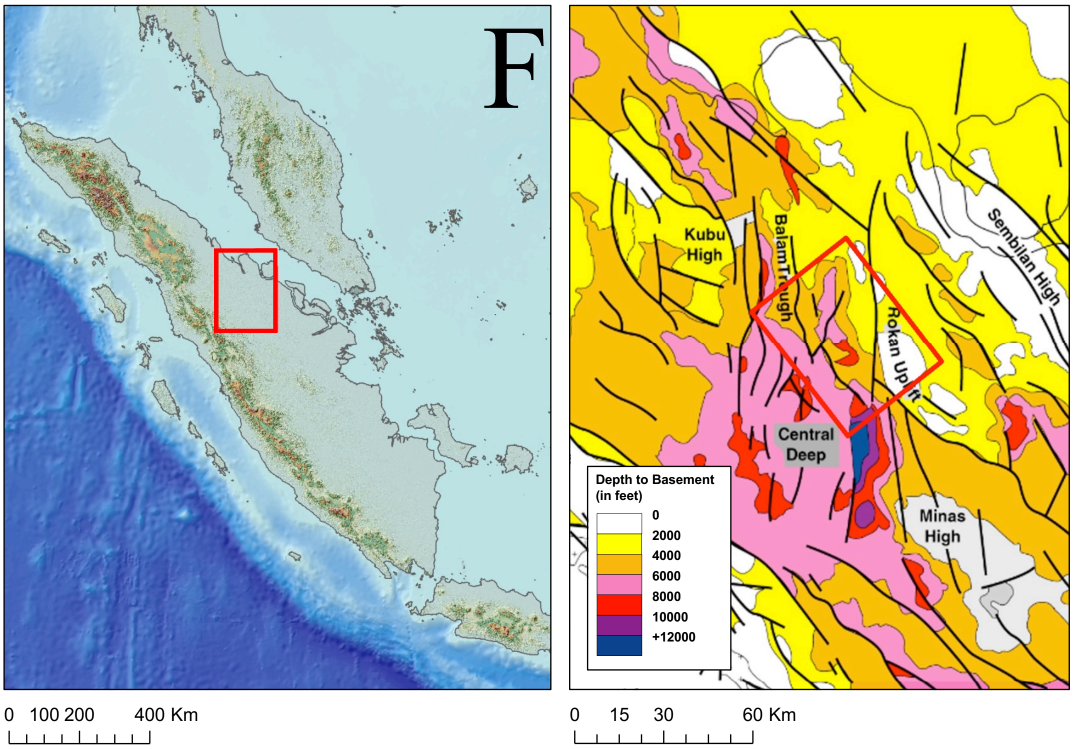

Figure 1 Figure on the right is showing distribution of Paleogene trough in Central Sumatra Basin (Heidrick et al., 1997), with area of study is bounded by red box. Meanwhile figure on the left is an index map.

Area of study located in Central Sumatra Basin, where PT. Chevron Pacific Indonesia has a concession for oil and gas production. Object for the study is Pematang Group deposited in North Aman Trough (**Figure 1**). This trough is bounded by Rantaubais high to the North, Central Deep to the South, Balam Trough hinge margin to the West and Rokan Uplift to the East.

Previous studies of North Aman Trough paleogeography could be referred to the Pematang Exploration Study (Cantwell et al., 1992) and Deep Gas Potential Study (Atallah et al., 1998) in the internal report of PT.

Sumatra is an active tectonic margin as a product of plate convergence between the Indo-Australia plate and the Australia plate (Hall, 2002). Indo-Australia plate has N6°E relative motion and collide with South of Eurasia plate with oblique direction (Heidrick et al., 1997). Subduction history in Sumatra has been commenced in the end of Paleozoic until recent (Hall, 2002).

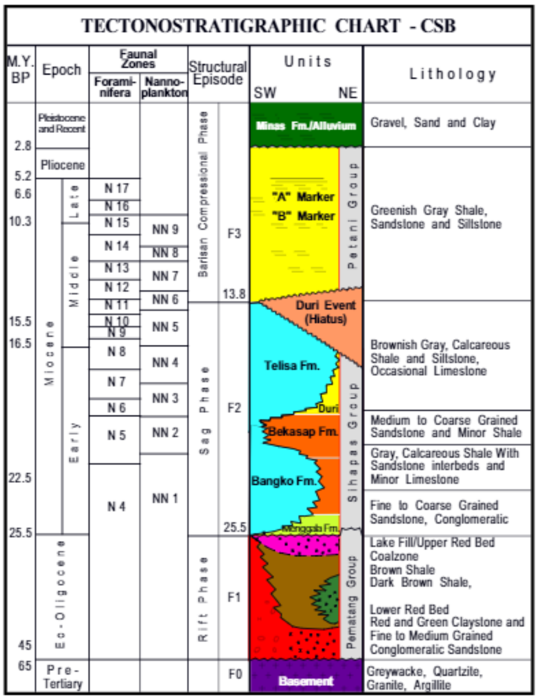

Figure 2 Generalized stratigraphic chart of Central Sumatra Basin (Heidrick et al., 1997)

Basement in Sumatra consist of accretionary of Permian - Carbon microplate (Hall, 2002). Collision between Sumatra-West of Java and Woyla block in Mesozoic has ended the magmatic activity in Mesozoic and as the result Cenozoic rock is deposited unconformably underlying Mesozoic rock (Barber, 2000).

Based on its position, Central Sumatra Basin is classified as a back arc basin in the Middle Miocene. The development of this basin is related to the Eocene-Oligocene rifting which is ended up with formation of horst and graben on a series of pull apart linked by a detachment (Heidrick et al., 1997). According to Heidrick et al. (1997), tectonic settings of the Central Sumatra Basin can be divided into three tectonic episodes (**Figure 2**) : F1 (50-26Ma), F2 (26-13 Ma) and F3 (13Ma-recent).

F1 occurred in Eo-Oligocene. This tectonic episode takes place as a product of a collision between India and Eurasia 45 Ma. Transtensional fault system formed in the South of China and continue to Thailand, Malaysia, Sumatra, and the South of Kalimantan. This fault system propagates development a series of half graben in Central Sumatra Basin. The development of this fault system is controlled by pre-existing basement suture (**Figure 3**).

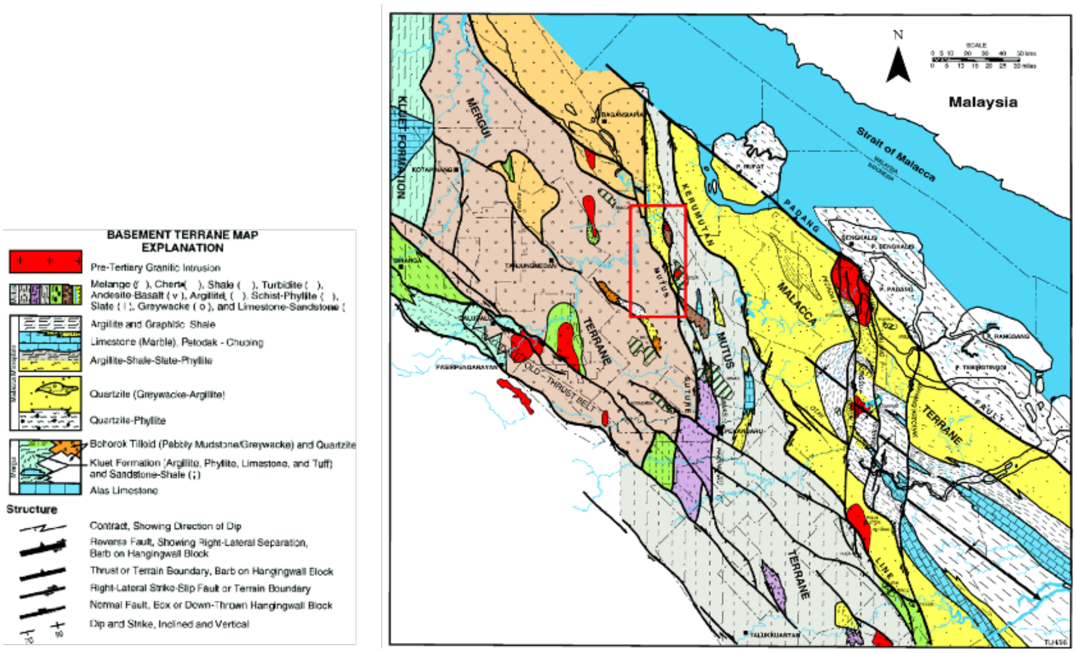

Figure 3 Structure map of basement in Central Sumatra Basin. Study area is marked by red rectangle within Mergui Terrane and Mutus Assemblages (Heidrick et al., 1997).

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In the end of F1 episode, there was transition from extension to regional sagging, which is marked by a weak structure inversion, denudation and peneplain formation. Pematang Group is deposited during period of F1.

F2 occurred in the early Miocene to middle Miocene. In this episode there was a re-activation of right left lateral fault with North-South direction and ended with a regional sagging. During this period, there were regional transgression and deposition of Sihapas Group.

F3 occurred since the late Miocene until recent, marked by structural inversion with main principal stress perpendicular to the axis of Sumatra. During this episode there were regional regression and deposition of Petani Formation and Minas Alluvium, unconformably underlying Sihapas Group.

2. DATA AND METHODOLOGY

Data used in this research are including primary and secondary data. Primary data (**Figure 4**) contains wireline log of 45 wells (well name is masked), 802 km of 2D seismic and 1,230 sqkm of 3D seismic. Secondary data is including 1,541 ft conventional core study from 20 wells (UGM, 2005) and biostratigraphy study from 9 wells (LEMIGAS, 2012).

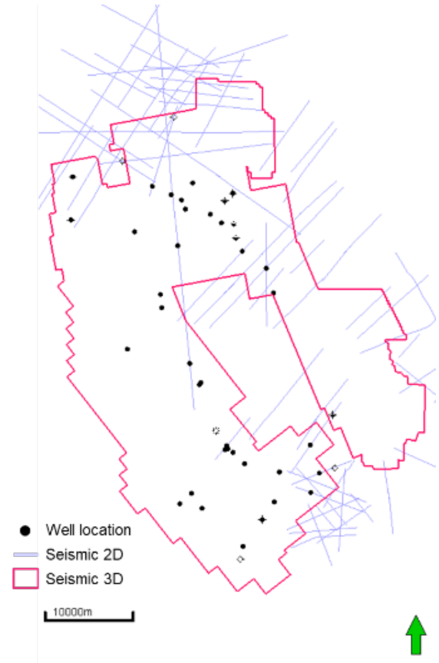

Figure 4 Data availability map in North Aman Trough.

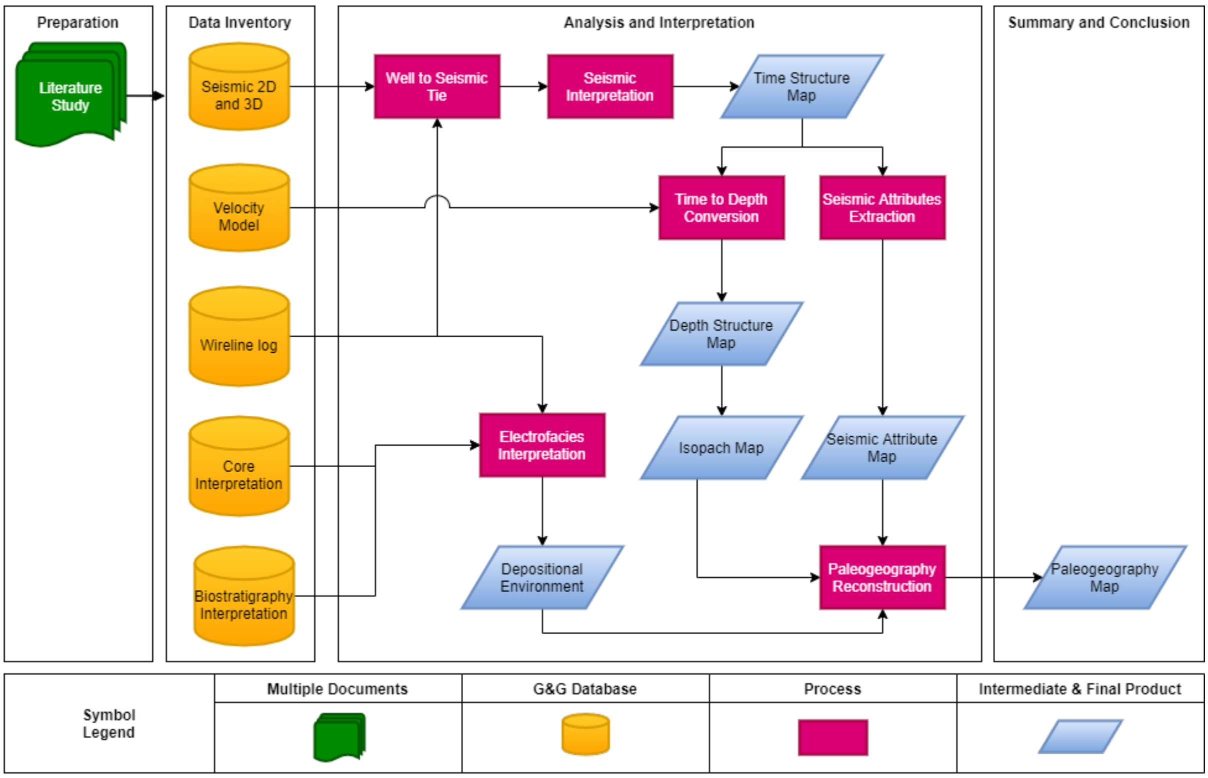

Figure 5 Research methodology consists of 4 general steps: preparation, data inventory, analysis - interpretation, and summary - conclusion.

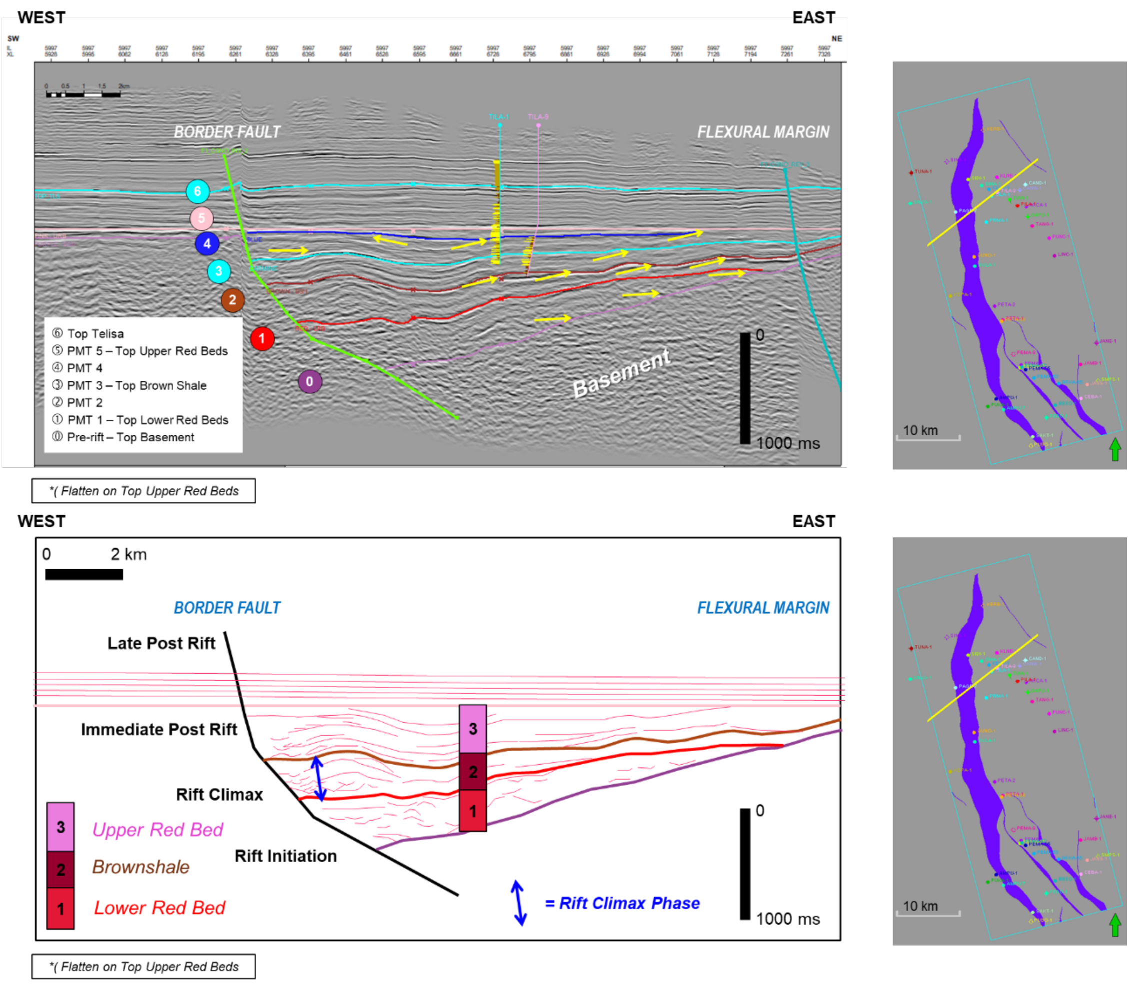

Figure 6 Seismic section perpendicular to border fault which is showing geometry of half-graben. Tectonostratigraphy boundary is clearly defines as reflector termination on yellow arrow. Purple polygon on right map is showing basement fault polygon.

Research workflow **(Figure 5)** started by literature study and data preparation. Then well to seismic tie is performed and continued by seismic interpretation of chronostratigraphic marker.

Time structure surfaces then gridded and multiple seismic attributes are extracted for each interval. This is including RMS amplitude, coherency, and frequency spectral decomposition.

Depth structure surfaces was converted from time to depth domain using velocity model and then thickness map were calculated for each interval. Depositional system is interpreted from wireline log electro-facies, which is calibrated to core and biostratigraphy data.

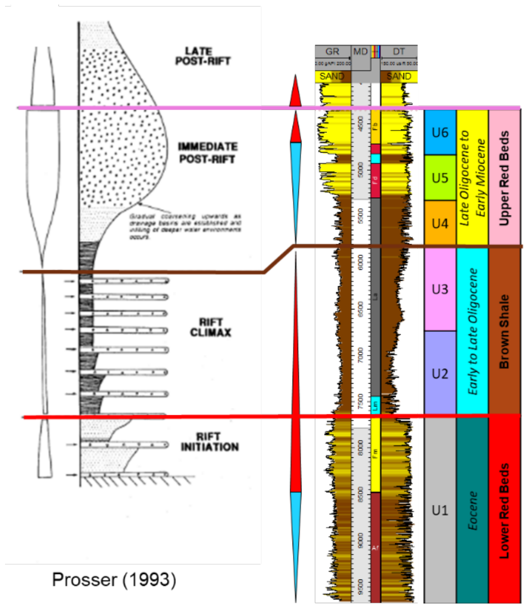

Figure 7 Stratigraphic profile of North Aman Trough is showing ideal rift tectonostratigraphic profile (Prosser, 1993).

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In the end, paleogeography map is reconstructed based seismic geomorphology, paleo-topography inferred from thickness map and validation to well data.

Analysis and interpretation methods in this study are referring to rift tectonostratigraphy model (Prosser, 1993), seismic geomorphology (Posamentier et al., 2007), spectral decomposition (Laughlin et al., 1995), electrofacies interpretation (Rider, 1996),

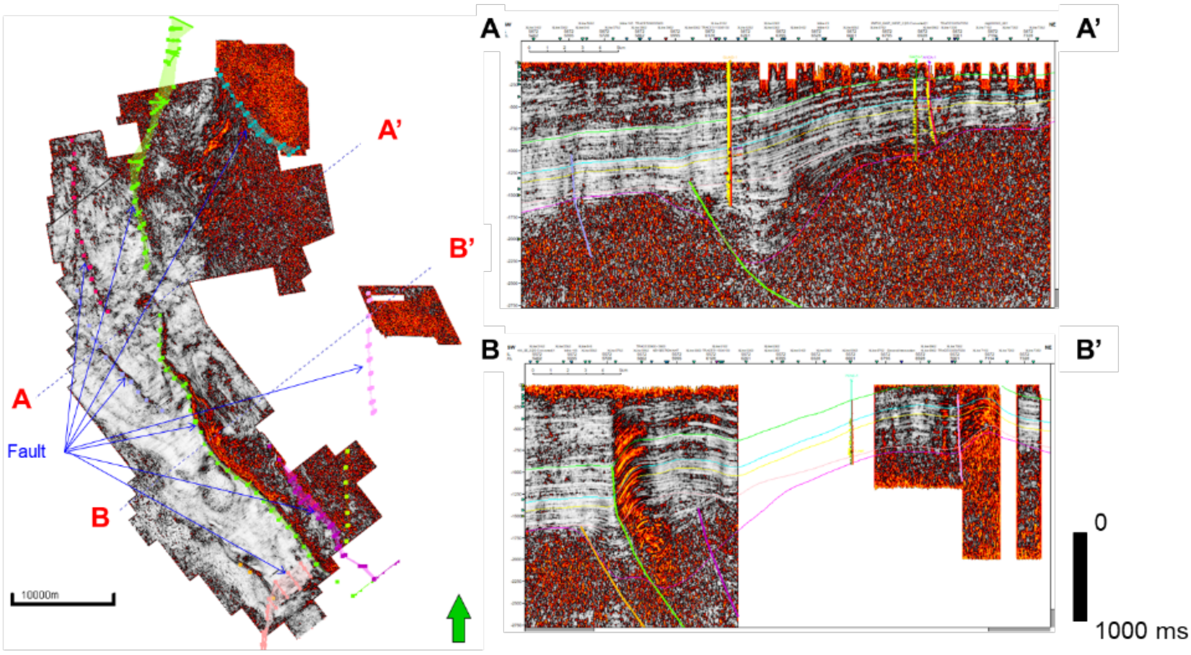

Figure 8 Coherency/variance seismic attribute extraction on time slice (left) and inline section (right). Each lineament is associated with discontinuity and interpreted as faults.

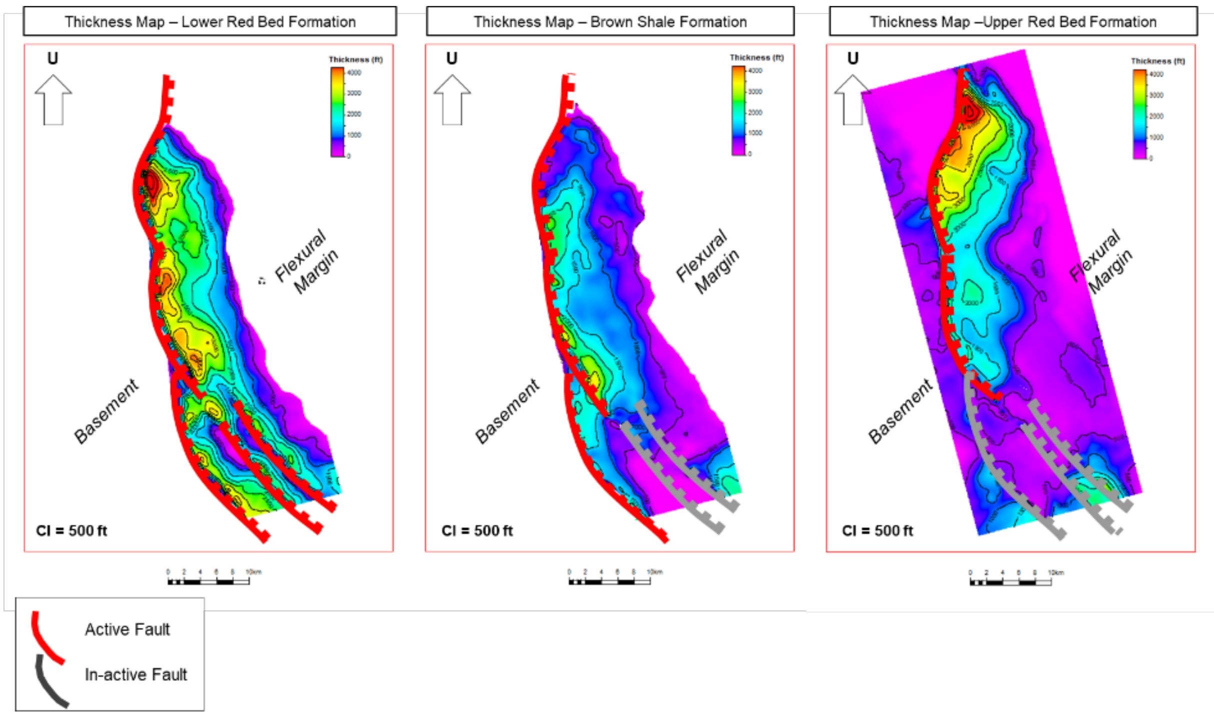

Figure 9 Thickness map of Lower Red Bed, Brown Shale and Upper Red Bed are showing variation of sediment thickness on hanging wall. Half graben unit could be inferred from number of depocenter (Rosendahl and Scott, 1989).

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depositional system in rift settings (Sladen, 1997), and analog study in West Natuna Basin (Burton and Wood, 2010).

3. RESULTS

Rift Tectonostratigraphy

Pematang Group can be divided into 3 major stages according to rift tectonostratigraphy (Prosser, 1993) as identified on seismic sections (**Figure 6**) and well profile (**Figure 7**): 1) Rift Initiation equivalent to Lower Red Bed, 2) Rift Climax equivalent to Brown Shale and 3) Immediate Post-rift equivalent to Upper Red Bed.

The geometry of Lower Red Bed in seismic section is showing a perfect wedge which is bounded by border fault to the West and

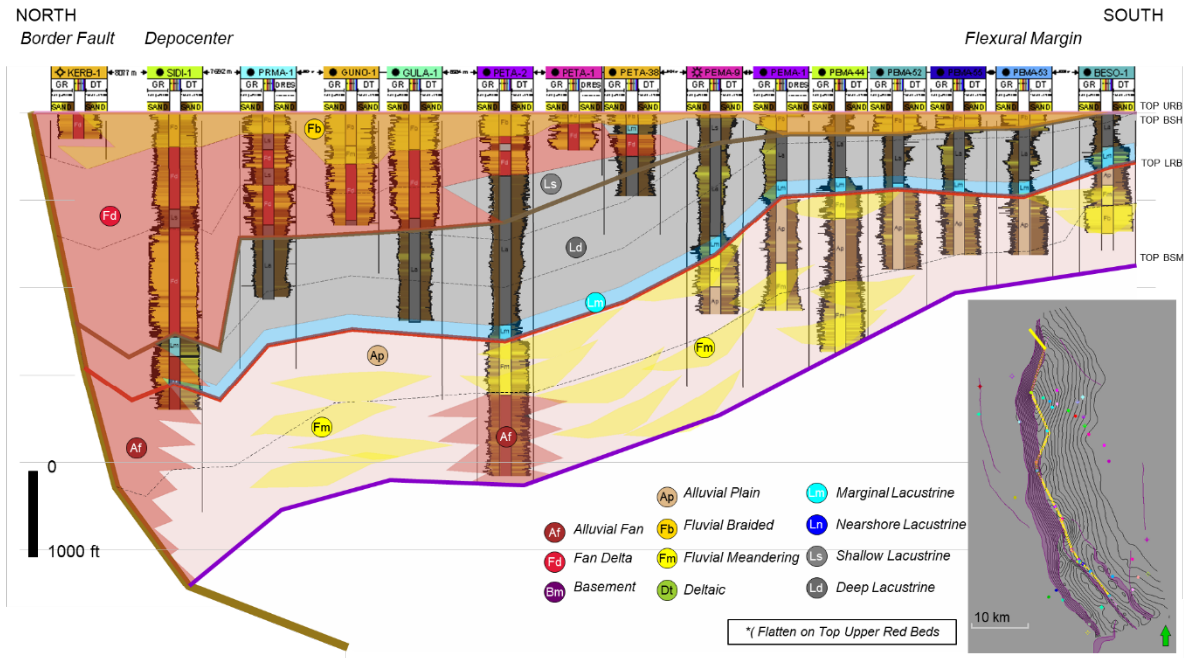

Figure 10 Well correlation of North Aman Trough from North to South along depocenter.

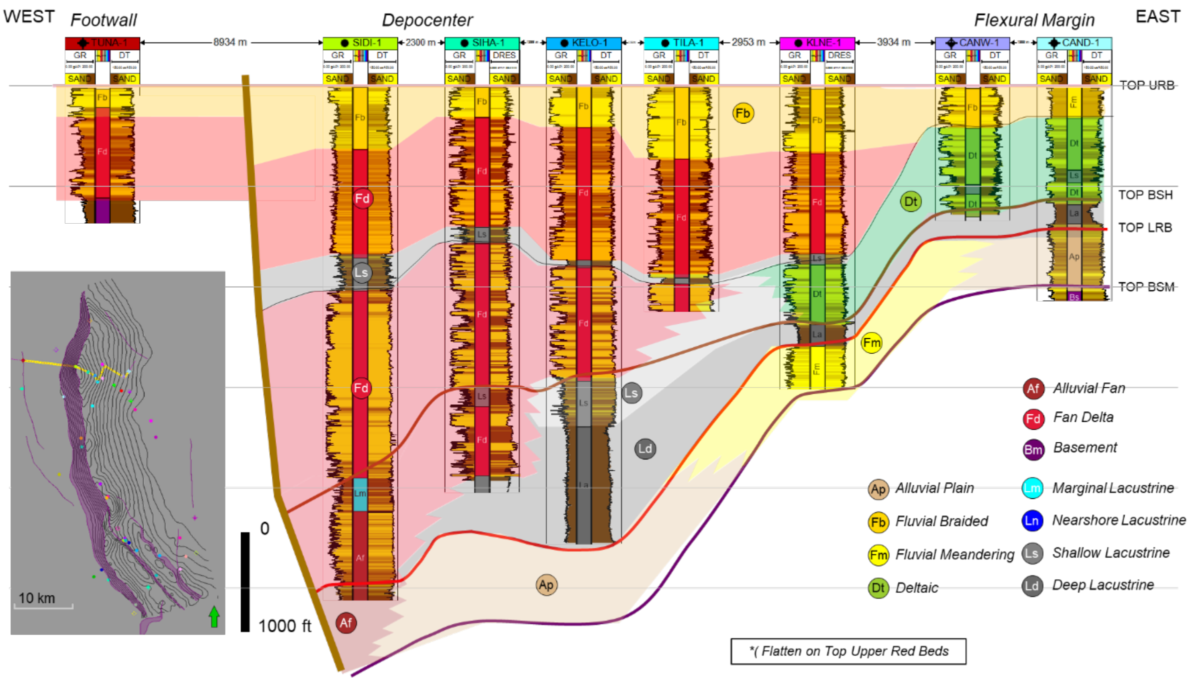

Figure 11 Well correlation of North Aman Trough from West border fault to flexural margin area in the East.

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onlapping to basement to the East (**Figure 6**). Seismic section shows a low amplitude, non-parallel and discontinuous reflector as indication of rift initiation stage. In this stage, rifting has just initiated, and depositional system has not established yet. Hence, the depositional system relied on rainfall rate, climate, or pre-existing drainage system.
Brown Shale interval is bounded by border fault to the West and onlapping to the basement or truncated by younger interval to the East (**Figure 6**). Seismic section indicates a low frequency, low amplitude, parallel reflector, and chaotic reflector close to border fault. Low amplitude reflector indicates shale rich lithology in this interval.

During this period, subsidence rate was exceeding the rate of sediment, hence the basin is starved. Chaotic reflector close to border fault indicates sedimentation from local high along rift shoulder.

Upper Red Bed interval is bounded by border fault to the West, flexural margin to the East and truncated by parallel reflector on top (**Figure 6**). Seismic section indicates high frequency, parallel, discontinuous reflector which is suggesting lithology variation, high-rate sedimentation, and lower rate of subsidence. On top of it parallel and continuous seismic reflector with no definitive boundary suggesting a late post-rift stage.

Pematang Group is bounded by geometry of half graben and based on its depocenter (Rosendahl and Scott, 1989), it could be divided into North, Central and South. Fault interpretation is consistent with lineament in coherency/variance seismic attributes which can be displayed as time slices or sections as in **Figure 8**.

Thickness maps suggests a variation in fault activity along rifting period (**Figure 9**). During deposition of Lower Red Bed formation, all bounding faults were active, at period of Brown Shale only bounding fault in the West is active and at the period of Upper Red Bed, only North and Central bounding fault that were active.

Gamma ray log in Lower Red Bed is showing funnel and bell shape with serrated pattern (**Figure 10**). It indicates this interval is deposited in alluvial plain-fluvial meander system. Brown Shale interval consist of high gamma ray with some funnel shape along area of border fault (**Figure 11**) which is associated to lacustrine environment with fan delta and deltaic system. Meanwhile Upper Red Bed interval consist of funnel to blocky shape of gamma ray log. It is associated with progradation of fan delta-deltaic system below and fluvial braided system on top (**Figure 11**). Overall, the stacking patten is showing a transgressive-regressive pattern with Top Brown Shale as maximum rift surfaces. Depositional environment model is adopting syn-rift lacustrine basin settings from Sladen (1997) as in **Figure 12**.

Seismic Attributes

A basic RMS amplitude seismic attribute is utilized in this study. This attribute is extracted for each interval as proxy to identify gross geometry of sand body. Based on cross plot between RMS amplitude and net to gross ratio on well location (**Figure 13**), there is a positive correlation between these two parameters. Five clusters (rock types) can be identified with coefficient correlation within ranges of 0.38-1. Cluster 1-3 is sand rich meanwhile cluster 4-5 is shale dominated. Lower Red Beds is within cluster 3-4, Brown Shale is within cluster 4-5 and Upper Red Bed is within cluster 2-3.

On the RMS Amplitude map, warm color represents high value which is correlated to high net to gross or sandier interval. Identification of depositional system are based on seismic geomorphology (lobate, sinusoidal, anastomose, distributary or homogenous widespread) compared to syn-rift basin settings as in **Figure 12** and calibrated to well data.

Lower Red Bed

The RMS amplitude map of Lower Red Bed (**Figure 14**) indicates a relatively North-South trend of anomaly align with sediment thickness. This trend is interpreted as meandering belt of fluvial system with approximately 1 km width. This fluvial meandering system validated with bell shape on gamma ray log. Separated channel, isolated from the main fluvial system, is interpreted as ephemeral channel with non-continuous flow rely on rainfall or climate.

Transversal trend of seismic anomaly along border fault is interpreted as alluvial fan system, with depositional mechanism primary controlled by gravity. Isopach contour in North area indicates a lobe geometry which is interpreted as alluvial fan with possible active sediment source. Green background on the map is associated with high serrated gamma ray log interpreted as alluvial plain.

Frequency spectral decomposition map (**Figure 15**) is showing similar pattern as RMS amplitude map. Bright color associated with sand and dark color associated with shale.

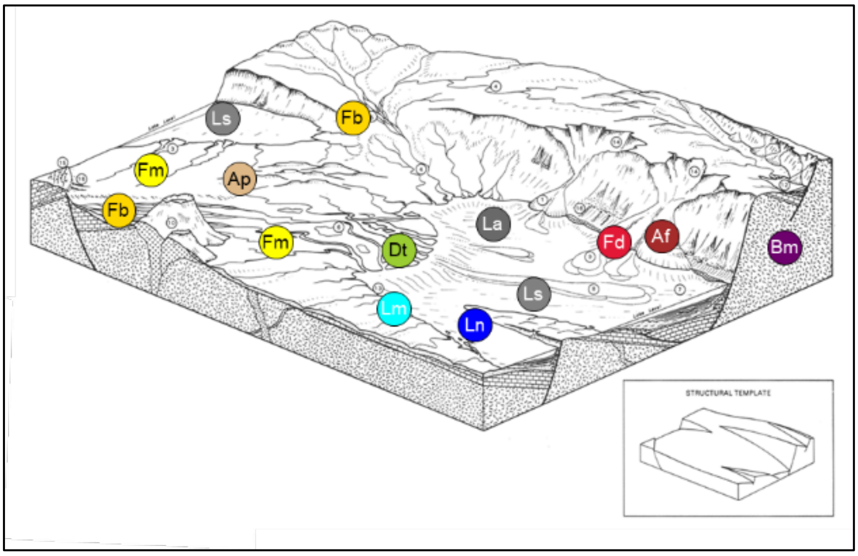

Figure 12 Depositional system model adopted from Sladen (1997). Symbol notation Ap=Alluvial Plain, Fb=Fluvial Braided, Fm=Fluvial Meander, Dt=Deltaic, Lm=Marginal Lacustrine, Lm-Nearshore Lacustrine. Ls=Shallow Lacustrine, Ld=Deep Lacustrine, Af=Alluvial Fan. Fd=Fan Delta and Bm=Basement.

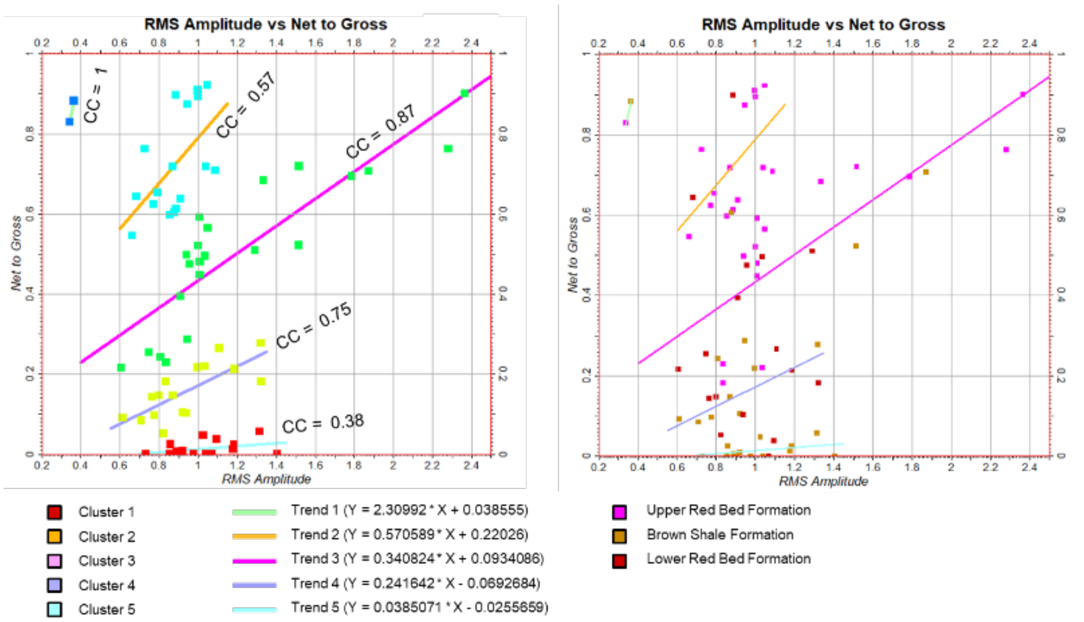

Figure 13 Cross-plot between seismic RMS amplitude and well net to gross. It indicates a linear correlation within 5 different clusters of rock type. Cluster 1-3 is sand rich meanwhile cluster 4-5 is shale dominated.

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Paleogeography reconstruction map (**Figure 16**) consist of 3 main depositional system: 1) fluvial meandering, 2) alluvial fan and 3) alluvial plain. Axial sediment transport direction is possibly from Rantaubais high in the North to South Aman Trough in the South.

Brown Shale

Well profile in Brown Shale interval (**Figure 17**) are showing high GR measurement, with

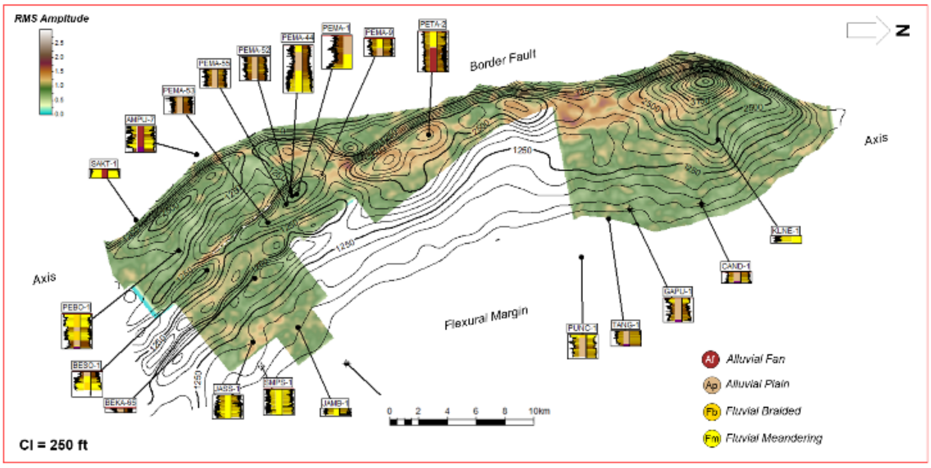

Figure 14 RMS amplitude map of Lower Red Bed overlaid by isopach contour. Well profile is showing GR-DT log with electrofacies interpretation.

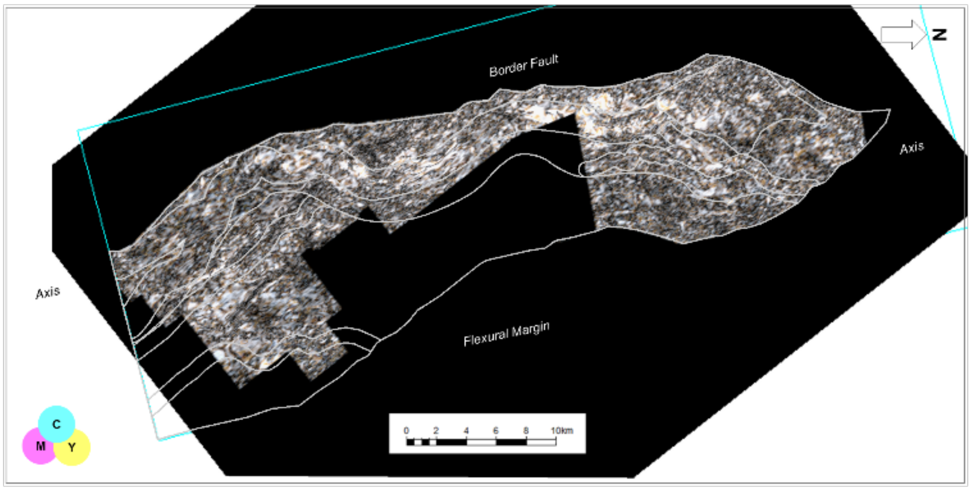

Figure 15 Frequency spectral decomposition map in CMY composition from near Top of Lower Red Bed.

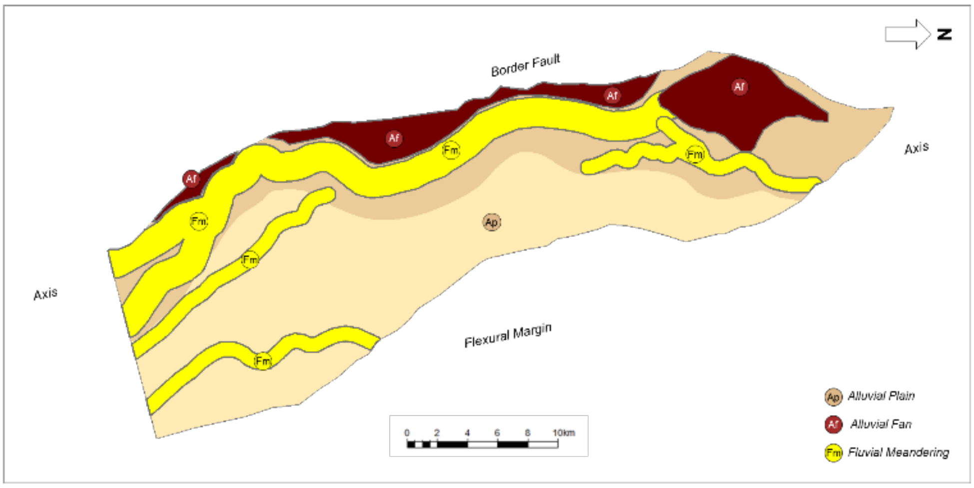

Figure 16 Paleogeography reconstruction map of Lower Red Bed.

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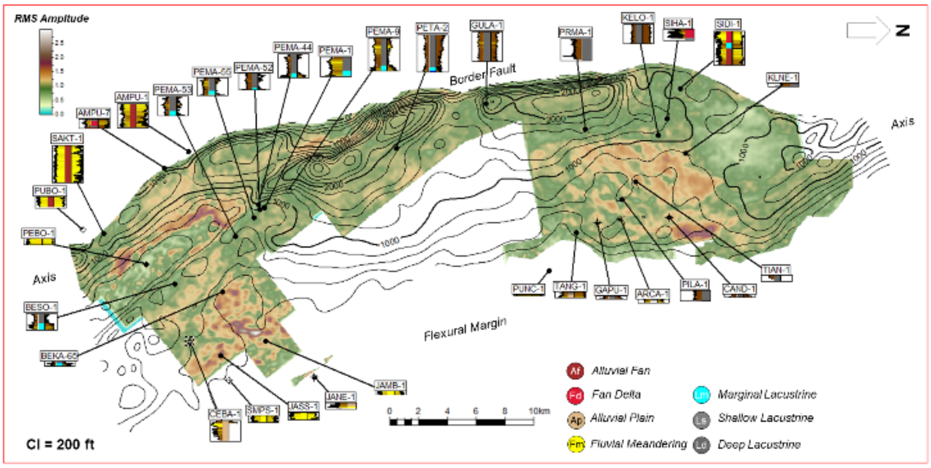

Figure 17 RMS amplitude map of Brown Shale overlaid by isopach contour. Well profile is showing GR-DT log with electrofacies interpretation.

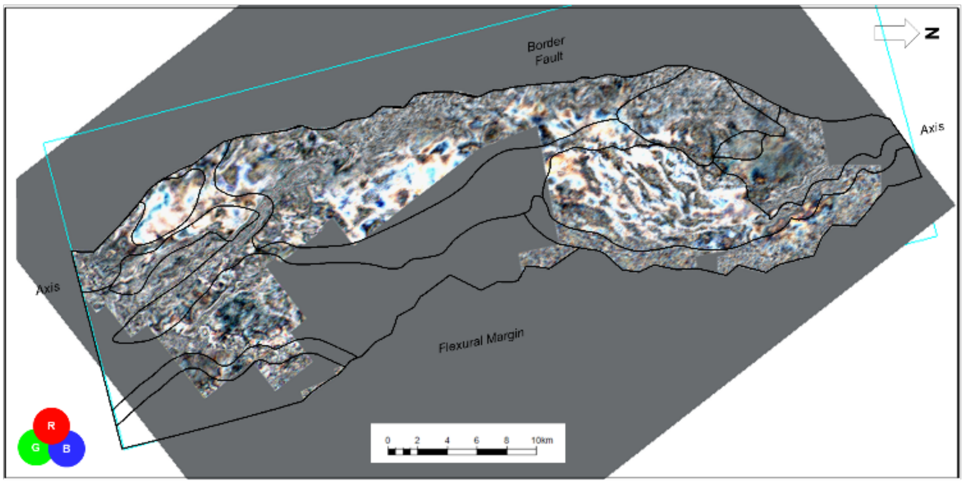

Figure 18 Frequency spectral decomposition map in RGB composition from near Top of Brown Shale.

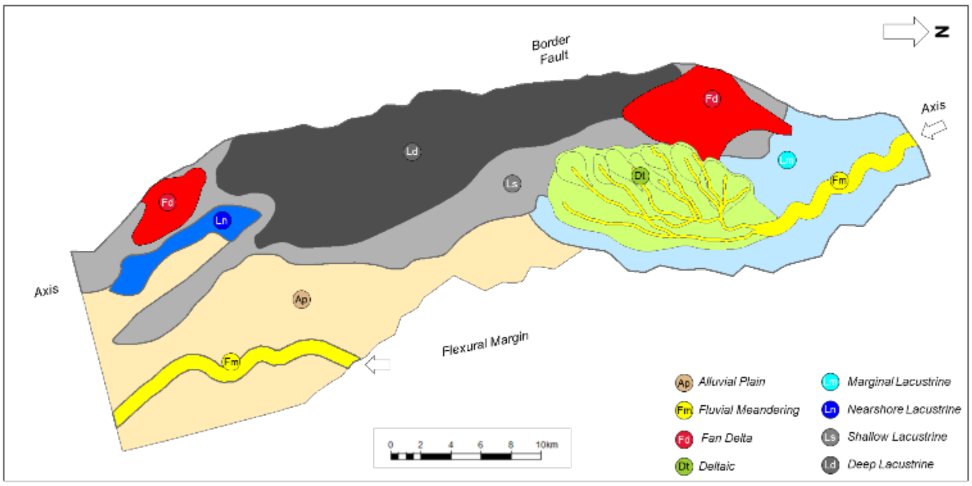

Figure 19 Paleogeography reconstruction map of Brown Shale.

exception at some area along border fault and the Southeast part of the basin. Variation on depositional environment is clearly observed as different patterns recognized on RMS amplitude map (**Figure 17**). Depocenter area is dominated by low value (green) which associated with high GR which is interpreted as deep lacustrine.

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In the Northeast part of the basin, a distributary channel pattern clearly identified and interpreted as deltaic system. Meanwhile in the front of it or border fault area, well data suggest progradation of fan delta system as in SIDI-1 and SIHA-1. In the south part, there are 3 anomaly patterns: 1) along hinge margin high which is interpreted as nearshore lacustrine, 2) lobate geometry develop perpendicular to bounding fault which interpreted as fan delta, and 3) channel meandering pattern at the Southeast of the basin.

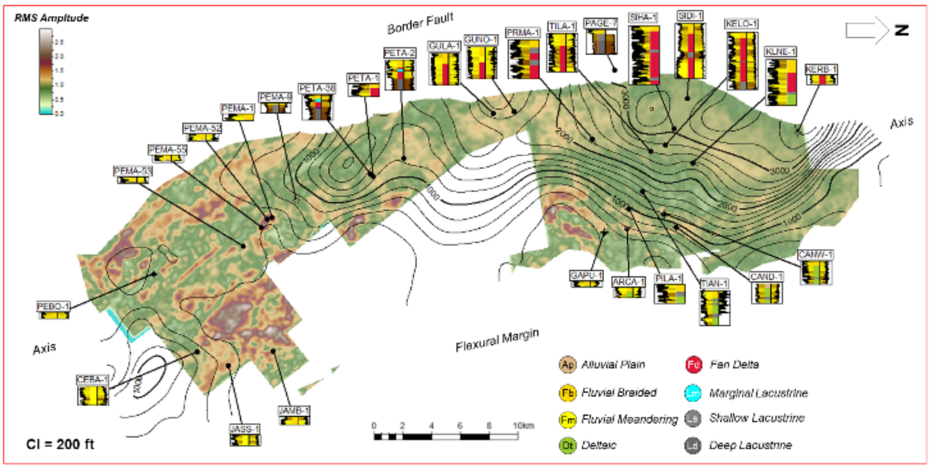

Figure 20 RMS amplitude map of Upper Red Bed overlaid by isopach contour. Well profile is showing GR-DT log with electrofacies interpretation.

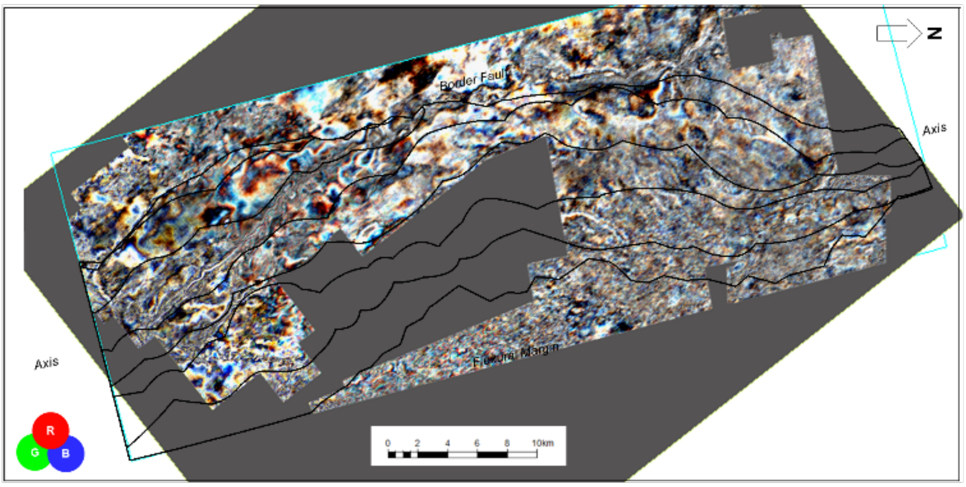

Figure 21 Frequency spectral decomposition map in RGB composition from near Top of Upper Red Bed.

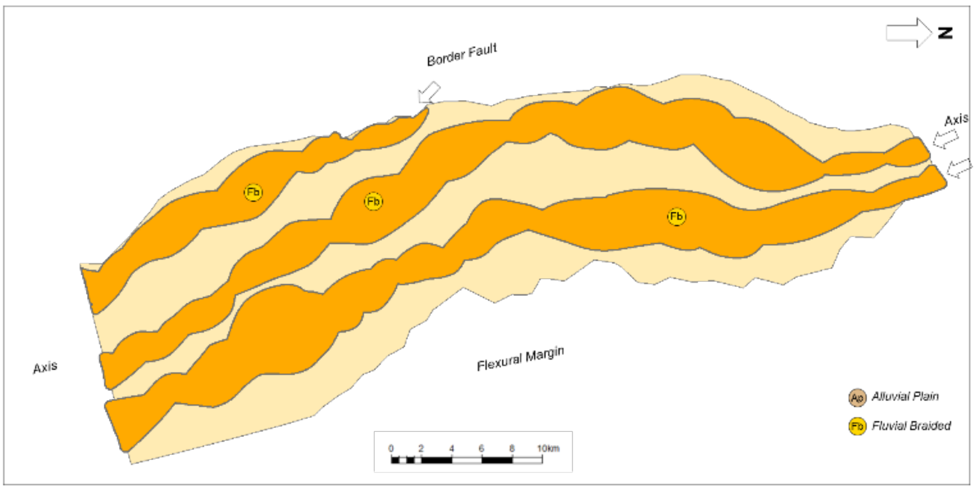

Figure 22 Paleogeography reconstruction map of Upper Red Bed.

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Frequency spectral decomposition map (**Figure 18**) is showing similar pattern as RMS amplitude map. Bright color is associated with sand, dark color is associated with shale and NW-SE lineament is associated with fault.

Paleogeography reconstruction map (Figure 19) consist of 8 main depositional system: 1) deep lacustrine, 2) shallow lacustrine, 3) marginal lacustrine, 4) nearshore lacustrine, 5) deltaic, 6) fluvial meandering, 7) alluvial plain and 8) fan delta.

Upper Red Bed

In general, Upper Red Bed could be classified into 1) progradation system as continuation of previous interval marked by funnel shape of GR log at the bottom, and 2) blocky-bell shape GR log on top.

RMS attribute map (**Figure 20**) suggest three relatively North-South trend which is associated with fluvial braided system located in: 1) most western part along Central to South bounding fault, 2) along depocenter and 3) along flexural margin.

Frequency spectral decomposition map (**Figure 21**) is showing a similar North-South trend, but not clear enough to image architectural element of fluvial braided system. Bright color with undefined pattern is associated with sand and dark color with fine texture is associated with shale and NW-SE lineament associated with fault.

Paleogeography reconstruction map (**Figure 22**) consist of 2 main depositional system: 1) fluvial braided system and 2) alluvial plain. North-South seismic section suggest that south part of the basin was tilting with the evident of angular unconformity.

5. DISCUSSION

Main structure on this area is a series of Northwest – Southeast normal fault that were developed during Eo-Oligocene **(Figure 23**).

Those faults were inverted to thrust fault during Late Oligocene (F2) and Middle Miocene – recent (F3). F3 deformation is responsible for generation of fold thrust belt in North Aman Trough.

Biostratigraphy data (**Figure 24**) suggests that the Pematang Group deposited during period of Eocene to Oligocene (LEMIGAS, 2012). Pollen analysis indicates seven unit (U1-U7) stratigraphic framework and conclusion that paleoenvironment is gradually changing from terrestrial to marine transition (lower deltaic plain). However, foraminifera fossil occurrence is identified starting the early Miocene as indication of marine incursion. Thus, marine influence in Pematang Group is unlikely.

Conventional core from 9 wells (**Tabel 1**) has been interpreted following modified lithofacies classification of fluvial system (Miall, 1982). In general, there are 5 facies association interpreted on the existing study (UGM, 2005): 1) channel of braided stream, 2) flood plain of braided stream, 3) channel of meandering stream, 4) flood plain of meandering stream, 5) lacustrine and 6) channel in lacustrine. Additional combination of facies association is when Paleosol presence.

The presence of lithofacies SFL (flaser bedded sandstone) and MFL (lenticular bedded mudstone) are not associated with tidal (Davis and Dalrymple, 2010) but rapid change of sediment flow due to rainfall rate or climate as explained by Bhattacharya (1997), Martin (2000) and Maciaszek et al. (2019).

Summary of facies association (plotted on well location as in **Figure 25**) are consistent with paleogeography reconstruction.

6. CONCLUSION

North Aman Trough could be divided by its depocenter into North, Central and South. Basin formation and basin filling is progressing due to activity of bounding fault. Variations on bounding fault activity is clearly identified by variations of sediment thickness on hanging wall of bounding fault.

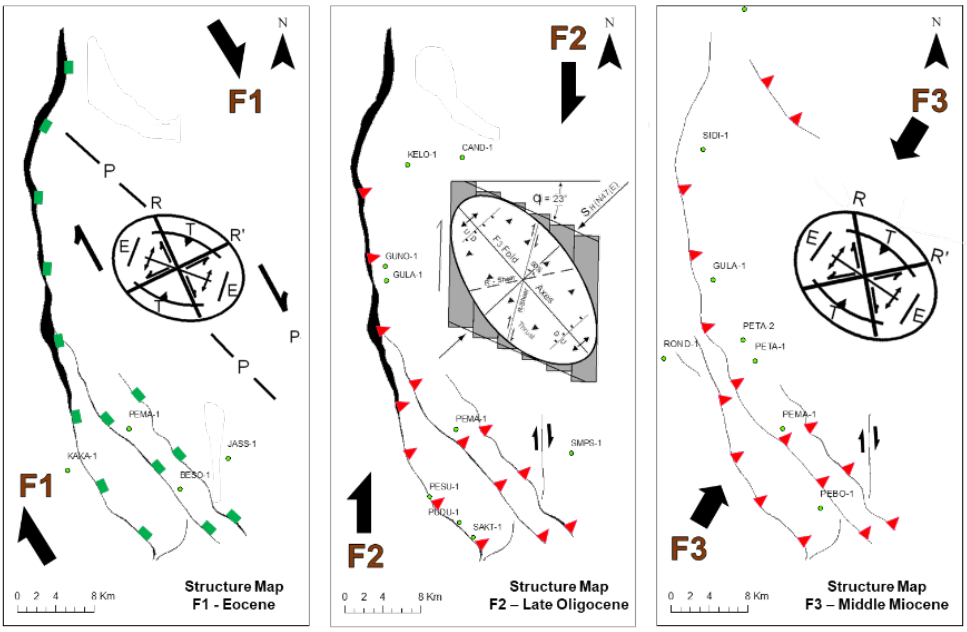

Figure 23 Structures in North Aman Trough were associated with pre-existing structure on basement and reactivated according to its orientation to main principal stress during F1, F2 and F3 (Heidrick et al., 1997).

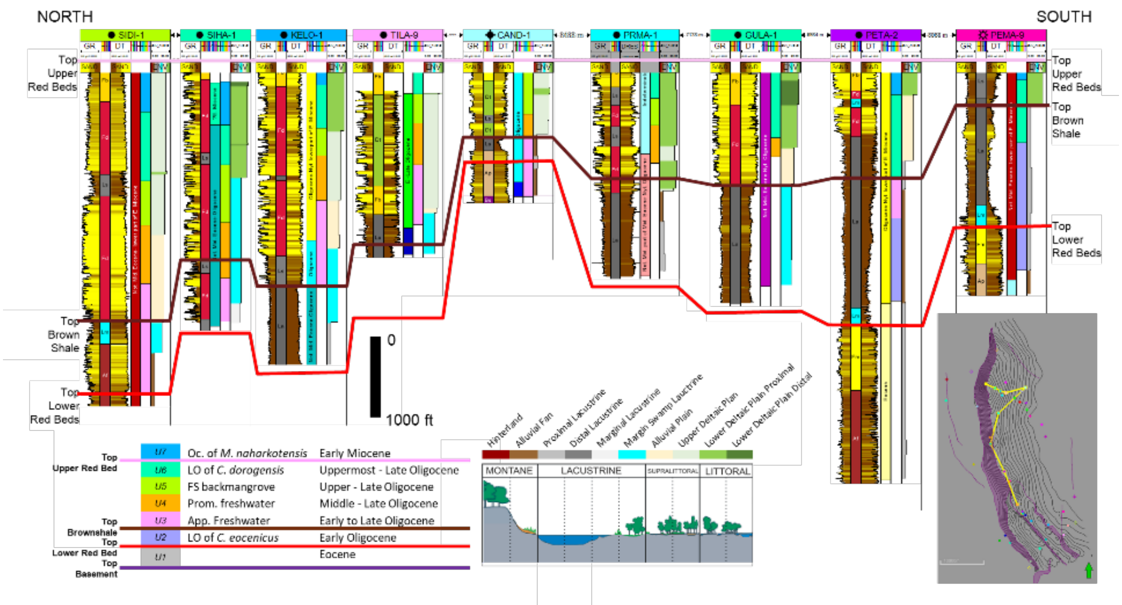

Figure 24 Well section of North Aman Trough with biostratigraphy data (LEMIGAS, 2012). Seven brackets of age (U1-U7) derived from pollen analysis ranging from Eocene to Oligocene. Paleoenvironment suggest evolution of terrestrial (montane-lacustrine) to marine transition (Lower Deltaic Plain).

During deposition of Lower Red Bed, all bounding faults were considered active, on period of Brown Shale only bounding fault in the West is considered active and on the period of Upper Red Bed, only North and Central bounding fault that were considered active. However, palinspastic reconstruction might be required to restore the missing interval during early Miocene deformation (F2) and to understand fault kinematic.

Biostratigraphy data indicates that Pematang Group is deposited during period of Eocene-Oligocene with the abundance of pollen and the absence of foraminifera. Occurrence of

Tabel 1 Summary of facies association from conventional core interpreted lithofacies (UGM, 2005). Lithofacies definition is a modified fluvial system facies (Miall, 1982).

Architectural Facies	Σ	Gravelly Fluvial				Sandy Fluvial																		Lacustrine			
		Gm	Gp	Gt	Imb	Sp	St	Sm	Sh	Sr	SFL	Sb	Sbr	Ss	Se	C	P	DF	SDF	MFL	Ml	Mm	Mb	Ml	Mm	Mb	COQ
Upper Red Beds Formation																											
Braided Channel (Ch br)	28	x	x		x	x	x	x	x	x	x	x	x		x		x	x		x		x	x		x	x	
Braided Channel with Paleosol (Ch br, P)	2	x															x			x	x		x	x		x	
Flood Plain in Braided Fluvial (Fp br)	5		x		x	x	x		x	x							x			x	x	x		x	x		
Flood Plain in Braided Fluvial with Paleosol (Fp br, P)	7	x			x	x		x									x			x		x	x		x	x	
Brown Shale Formation																											
Channel in Lacustrine (Ch La)	17	x	x		x	x		x	x					x				x		x	x	x	x	x	x	x	
Lacustrine (La)	10							x						x						x	x	x	x	x	x	x	x
Lower Red Beds Formation																											
Braided Channel (Ch br)	1	x				x	x						x														
Meandering Channel (Ch me)	7	x			x	x		x	x		x							x		x		x	x		x	x	
Floodplain in Meandering Fluvial (Fp me)	3	x			x	x		x	x		x		x				x			x		x	x		x	x	
La	1							x														x	x		x	x	

Gravelly Fluvial Sequences
Gm : Massive conglomerate
Gp : Planar cross stratified conglomerate
Gt : Through cross stratified conglomerate
Imb : Imbrication

Sandy Fluvial Sequences
Sp : Planar cross stratified sandstone
St : Through cross stratified sandstone
Sm : Massive sandstone
Sh : Flat laminated sandstone
Sr : Ripple laminated sandstone
SFL : Flaser bedded sandstone
Sb : Bioturbated sandstone
Sbr : Mudflake breccia sandstone
Ss : Slump sandstone
Se : Scoring
Ml : Laminated mudstone
Mm : Massive mudstone
Mb : Bioturbated mudstone
MFL : Lenticular bedded mudstone, siltstone
C : Coaly parting
P : Paleosol
DF : Debris flow
SDF : Sandy debris flow

Lacustrine Sequences
COQ : Coquina
Ml : Laminated mudstone
Mm : Massive mudstone
Mb : Bioturbated mudstone

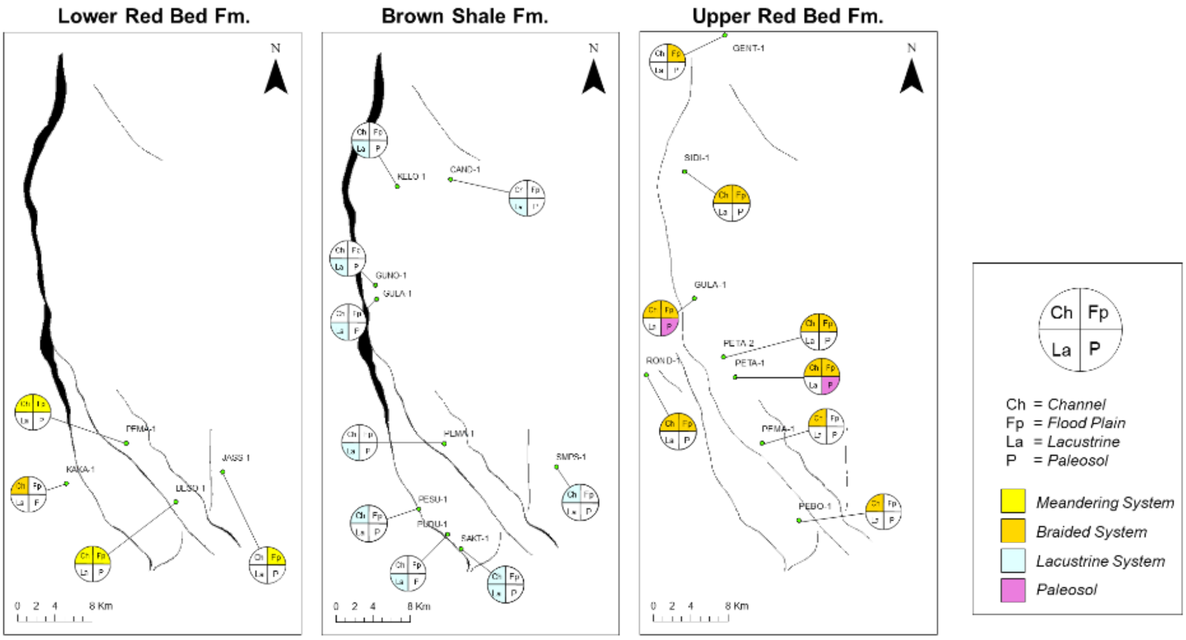

Figure 25 Summary of core study (UGM, 2005) which is plotted on well location for each interval. Four quadrat circle is representing architectural facies of channel, floodplain and lacustrine with additional information of paleosol occurrence. Depositional system is expressed by color.

foraminifera fossil since Early Miocene is a strong indication of marine incursion. The presence of paleosol in Upper Red Bed is evidence of sub-aerial exposure with a long period of time. Heterolithic structure of flaser and lenticular are associated with rapid flow changes due to rainfall rate or climate. Hence, it could be inferred that Pematang Group is deposited within terrestrial environment.

Paleogeography of Pematang Group is controlled by three rift tectonic stages: 1) rift initiation, with environment of alluvial plain, alluvial fan and fluvial meander; 2) rift climax, with environment of deep lacustrine, shallow lacustrine, marginal lacustrine, nearshore lacustrine, deltaic, fluvial meander, alluvial

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plain and fan delta; 3) immediate post-rift, with environment of fluvial braided and alluvial plain.

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