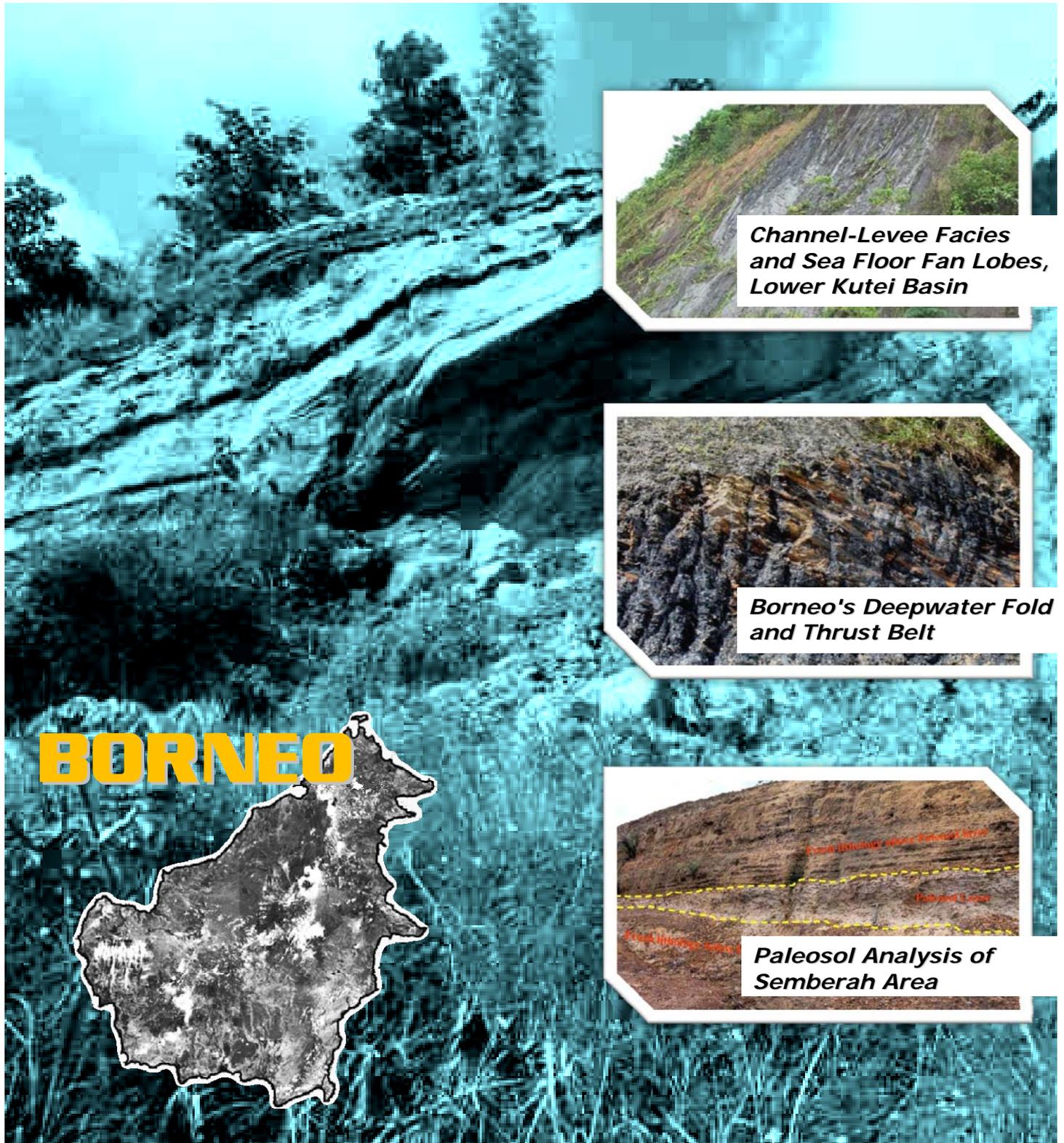


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- Cover topics related to sedimentary geology, includes their depositional processes, deformation, minerals, basin fill, etc.



Cover Photograph:

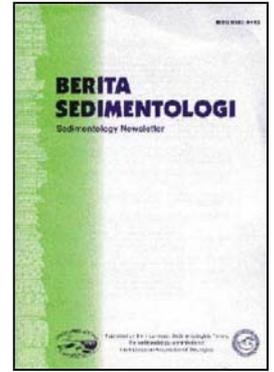
An Outcrop nearby Perjuangan Quarry, East Kalimantan.

Showing the Fluvio-Deltaic Channel Types of Sedimentation.

Photo Taken in May 2007

Berita Sedimentologi

A sedimentological Journal of the Indonesia Sedimentologists Forum (FOSI),
a commission of the Indonesian Association of Geologist (IAGI)



From The Editors

Moving eastward, **Berita Sedimentologi #21**, is focusing on Borneo. The island of Borneo is divided administratively by three countries: Indonesia, Malaysia and Brunei. Large sedimentary basins occur in the west part under Malaysian and-Bruneian territory and in Indonesian territory in the east. For the Northwest Borneo, a book was published to commemorate 100 years Miri field by Wannier et al., and an intensive regional paper is contributed by A. Cullen. A number of articles on Kutei / Mahakam and Tarakan provide us with recent research and geological understanding.

As FOSI aimed to go international in providing sedimentological understanding on Indonesia to international geoscience community, we invited 2 international reviewers on board. They are:

Prof. Dr. Harry Doust

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The Netherlands

J.T. (Han) van Gorsel

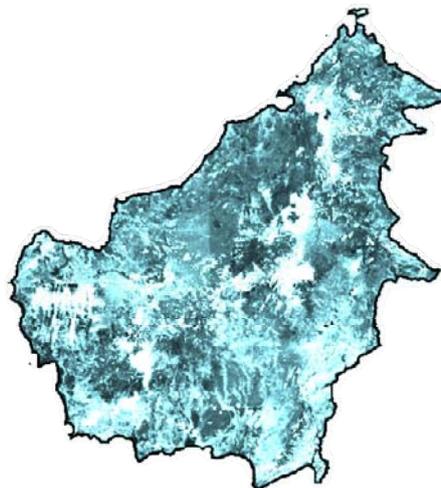
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Australia

Harry used to work for many years for Shell and wrote many articles about different basins in Southeast Asia and their classifications. Han was with ExxonMobil before and he compiled different literatures of Indonesia under and listed them in www.vangorselslist.com

We believe Harry and Han will give significant value to Berita Sedimentologi as a scientific journal. On behalf of the Indonesian Sedimentologists Forum we would like to thank them for their enthusiasm and welcome them to join us onboard.

Herman Darman

Editor in Chief



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About FOSI



The forum was founded in 1995 as the Indonesian Sedimentologists Forum (FOSI). This organization is a communication and discussion forum for geologists, especially for those deal with sedimentology and sedimentary geology in Indonesia.

The forum was accepted as the sedimentological commission of the Indonesian Association of Geologists (IAGI) in 1996. About 300 members were registered in 1999, including industrial and academic fellows, as well as students.

FOSI has close international relations with the Society of Sedimentary Geology (SEPM) and the International Association of Sedimentologists (IAS).

Fellowship is open to those holding a recognized degree in geology or a cognate subject and non-graduates who have at least two years relevant experience.

FOSI has organized 2 international conferences in 1999 and 2001, attended by more than 150 international participants.

Most of FOSI administrative work will be handled by the editorial team. IAGI office in Jakarta will help if necessary.

The official website of FOSI is:

<http://www.iagi.or.id/fosi/>

FOSI Membership

Any person who has a background in geoscience and/or is engaged in the practising or teaching of geoscience or its related business may apply for general membership.

As the organization has just been restarted, we use **LinkedIn** (www.linkedin.com) as the main data base platform.

We realize that it is not the ideal solution, and we may look for other alternative in the near future. Having said that, for the current situation, LinkedIn is fit for purpose.

International members and students are welcome to join the organization.



Total registered members:

189

May 2011



The Relic Fluvial-Dominated Morphology of Mahakam Delta

Salahuddin

Department of Geological Engineering, Gadjah Mada University, Indonesia

Introduction

The Mahakam Delta lies at the mouth of the Mahakam River on the east coast of Kalimantan, about 50 km south of the equator. Geologically, the delta is located in the Kutai Basin, one of the major hydrocarbon provinces of Indonesia since the end of the 19th century.

Several sedimentological studies have been carried out on the modern Mahakam delta since the early 1970's. Pioneer works of Allen *et al.* (1976) indicated that the deltaic channel morphology is mainly the product of the interplay of fluvial and tidal processes, and is reflected well by the sedimentary facies distribution. Straight channels that are directly connected to the Mahakam River are typically identified as distributaries and are presumed to be dominated by fluvial processes. They are clearly different from the sinuous and flaring channels which are not directly connected to the distributaries and are presumed to be dominated by tidal processes (Allen *et al.*, 1976).

Attributed to those channel morphology, it has been speculated that different areas of the Mahakam Delta are in different phases of abandonment (Allen and Chambers, 1998). The northern area is assumed to be in the process of abandonment as it comprises primarily straight channels having flared mouths. The eastern area is presumed to be totally abandoned as it is occupied by sinuous and flared channels. The southern area is interpreted as more fluvially active as the channels are straight and several sand bars appear in the distal reaches of the channels.

Another assumption that has been generally agreed is that the delta is prograding (Allen *et al.*, 1976). The overall morphology of the Mahakam Delta is regarded as an example of a

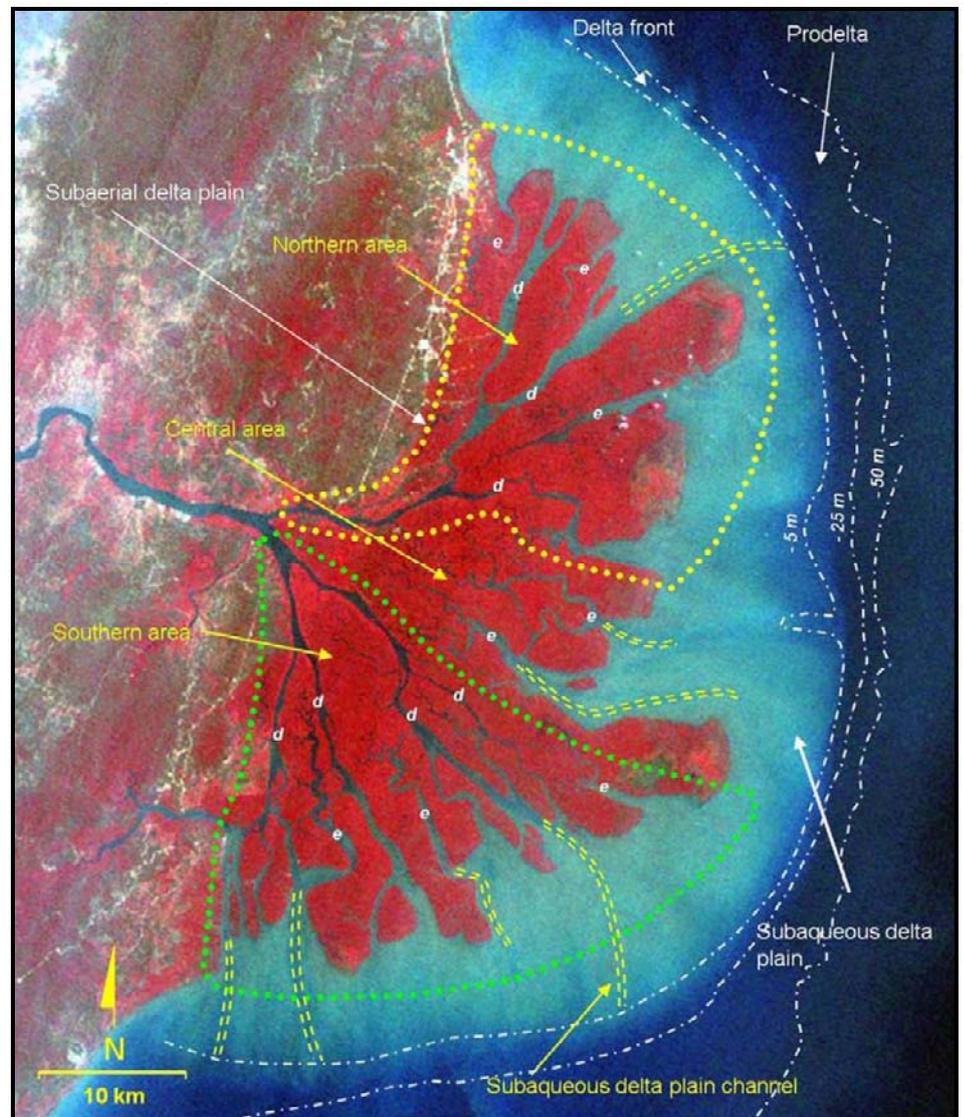


Figure 1. Morphological components of the Mahakam Delta. The subaqueous delta plain ranges from the shoreline to 5 m water depth. The delta front comprises the area from 5 to 25 m water depth and the prodelta is from 25 to 50 m. Letters d stand for distributary and e for estuary.

mixed fluvial-tidal delta in the classification of Galloway (1975).

However, it was speculated recently that the present-day riverine sediment discharge is much smaller than in the past (Storms *et al.*, 2005).

The above mentioned assumptions were built on qualitative analysis of morphology and sediment facies distribution; but they have not been systematically mapped in detail. Recent

studies on other deltas indicate that morphology, particularly coastline morphology does not reflect present-day depositional processes and that sediment facies distribution is not correlative to morphology (Dominguez *et al.*, 1992).

This short article attempts to present another sedimentologist's point of view on looking at the deltaic morphology, as supported by quantitative analysis of controlling

factors. Primary data on submerged morphology of the Mahakam Delta was detailed by 381 bathymetric echosounder (using a single frequency portable Raytheon DE719D MK2) survey lines that transversed all the channels as far as 10 kilometers to the offshore, with an accuracy of about 0.5% of the indicated depth, collected during two years from 2003 to 2004.

Morphologic Elements

The delta plain of the Mahakam Delta comprises an area of about 2800 km², which is about 60% subaerial and 40% subaqueous. It has a lobate, fan-shaped morphology, and is dissected by numerous channels (Figure 1).

Two types of channels can be distinguished on the basis of their morphology, the first being relatively straight channels that have a distributive (i.e. seaward branching) pattern and are commonly considered as distributaries; the other has sinuous and flaring channels that form a contributive (i.e. seaward converging) pattern and commonly are considered as estuaries.

The distributaries branch from the Mahakam River at the delta apex. The width of the distributary channels is relatively constant and ranges between 0.5 and 1 km, while the depth varies between 5 and 20 m. Generally, distributaries are relatively straight with low sinuosity; some have distinctly flaring mouths. The transverse profile of the channels is asymmetric and the thalweg meanders occasionally between banks, creating poorly defined lateral bars. At the lower reaches and the mouths of the distributaries, the channels are shallower and elongate bars are present.

The estuaries are not connected to the Mahakam River. They are widely flaring trumpet-shaped inlets that decrease in width rapidly upstream and connect to the distributaries through narrow and sinuous tidal channels at their upstream end. Estuaries are very sinuous in their upper reaches with symmetrical cross-sections. In their lower reaches, they become less sinuous and more asymmetric in cross-

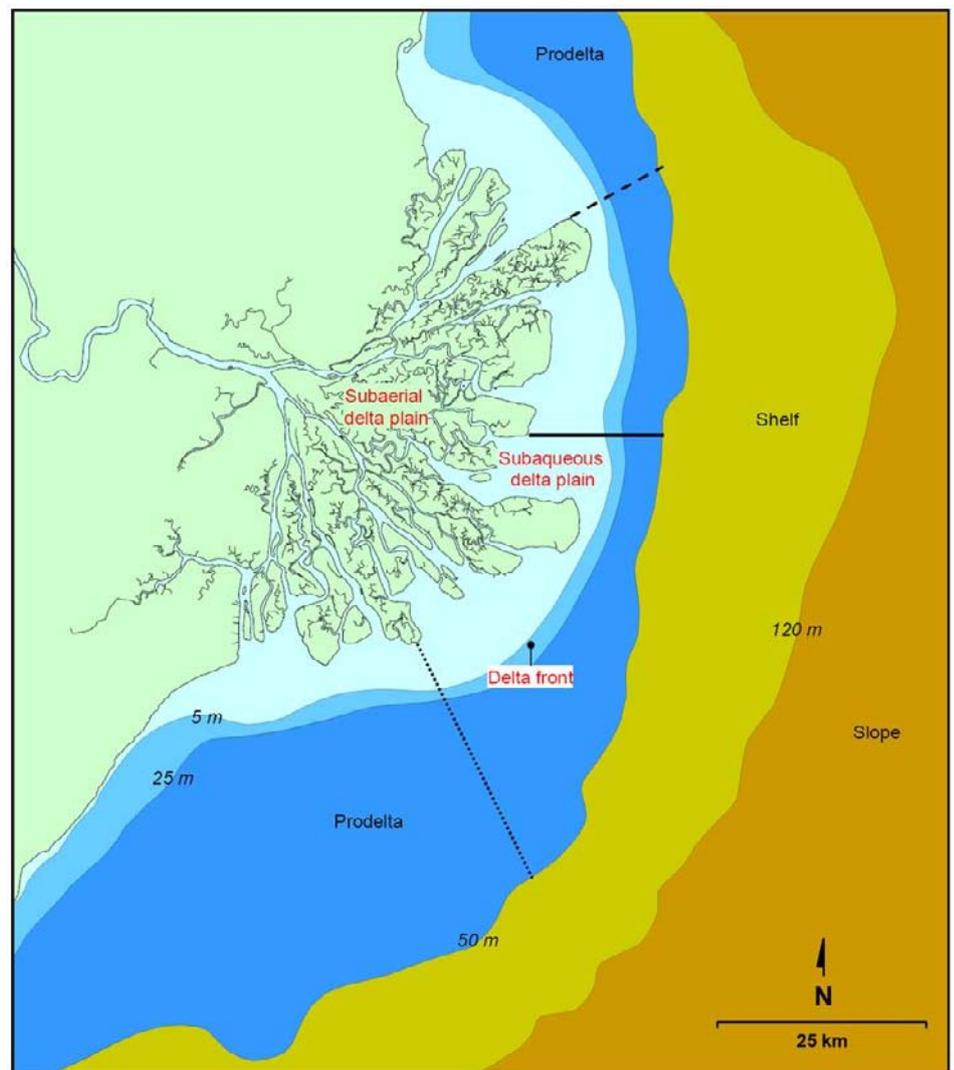


Figure 2. Symmetrical lobate geometry of the Mahakam Delta with a southward asymmetric bulge of the prodelta. The outer limit of the subaqueous delta plain forms a lobate deltaic geometry, suggesting that the location of the former coastline is now at 5 m water depth (Scruton, 1960; Coleman and Roberts, 1991). The coloured lines extending seaward from the coastline locate the bathymetric profiles in Figure 3.

section with flaring mouths. The depths of the estuaries are not much different from the distributaries, but they are narrower.

Distribution of these channels on the subaerial delta plain is uneven (Figure 1). The southern area has more distributaries than estuaries, the central area has no distributaries and is only occupied by estuaries, while in the northern area both types of channel are equal in number. Morphologically, distributaries in the northern area are more flared and shallower than the southern area, as indicated by higher width/depth ratios. In contrast to the distributaries, the width/depth ratios of the estuaries do not vary significantly and are quite constant in the northern, central and southern

areas. This evidence of channel distribution and morphology suggests that the three areas of the subaerial delta plain are different and can be distinguished.

Offshore, the three areas have similar features, i.e. extensive intertidal flats, numerous isolated bars and several submarine channels as extensions of distributaries and estuaries. The geometries of intertidal flats and isolated bars vary between areas. They are commonly perpendicular to the shoreline in the northern and central areas. In the southern area, their geometry is slightly more triangular. The submarine channels vary according to the type of extended channels rather than the area. The extensions from distributaries gradually

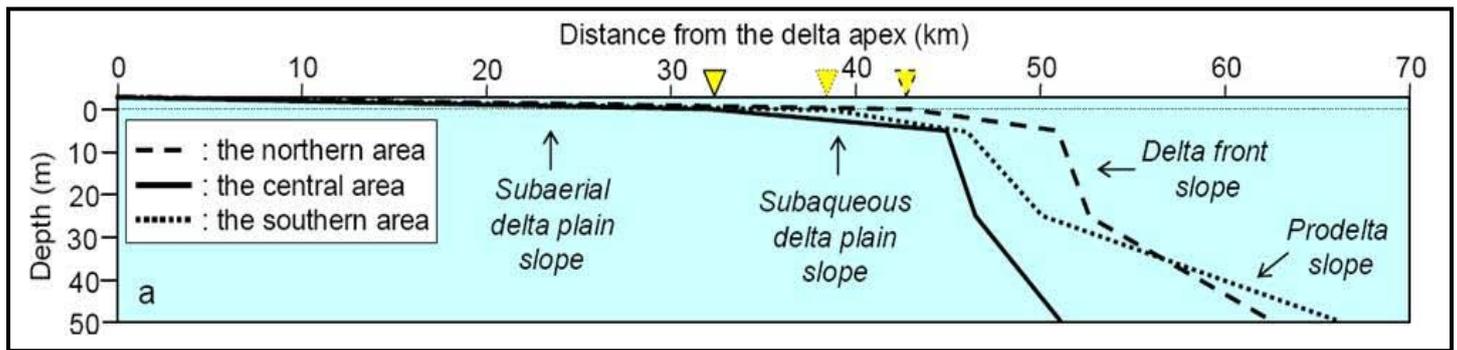


Figure 3. Bathymetric profiles from the delta apex to the prodelta; yellow triangles are shorelines with outline style keyed to area (see the legend box). Profile locations are shown in Figure 2.

shallow towards the slope break, while the extensions from estuaries rapidly shallow and die out before they reach the slope break.

The subaerial delta plain extends seaward about 42 km from the delta apex in the northern area, 30 km in the central area and 39 km in the southern area. It forms a nearly-flat swampy surface and has an extremely gentle slope of about 0.06 m/km. The proximal part of the subaerial delta plain is characterised by tropical lowland rain forest and a mixed hardwood and palm forest. These extend from the delta apex to the middle reaches of the distributaries, a distance of about 20–30 km in the north and south areas and about 10 km in the central area. The distal delta plain, which extends for about 20 km onshore from the shoreline, is characterised by Nipah palm (*Nyipa fruticans*) and mangrove swamps.

The gentle delta plain slope persists offshore across the subaqueous delta plain, which is about 7 km wide, to a water depth of 5 m where the slope abruptly increases on the delta front (Figure 2). There are several subtidal channels on the subaqueous delta plain that are extensions of distributaries; some of them extend as far offshore as the delta front (Figure 1). A thin prodelta sheet extends seaward from the base of the delta front (Roberts and Sydow, 2003). It is 20 km wide on the southern shelf, 15 km wide on the northern shelf, and is confined to a narrow 3 km belt along the central part.

Morphologic Responses to Hydrodynamics

Delta morphology, especially shoreline morphology, has long been accepted as an indicator of dominant hydrodynamic process (e.g. Galloway, 1975), but recent studies suggest that, in some deltas (e.g. the Sao Fransisco Delta; Dominguez, *et al.*, 1992), a significant component of the modern morphology is inherited from a pre-modern system so that present-day morphology is not necessarily a reliable indicator of hydrodynamic dominance.

The Mahakam Delta has a lobate geometry, which generally characterises fluvial-dominated deltas prograding into shallow water (Fisher *et al.*, 1969), although it has been described as a mixed fluvial and tidal morphology by several authors (e.g. Galloway, 1975; Allen *et al.*, 1976). The multiple distributaries that built the lobate morphology generally indicate a high fluvial discharge distributing the sediment load with a short recurrence interval of bifurcation and avulsion (Olariu and Bhattacharya, 2006). However, sediment transport data indicate that the present-day Mahakam Delta is tide-dominant and less fluvially-influenced than previously interpreted (Husein, 2008).

The volume of the Mahakam Delta is estimated to be 135 km³, which is calculated based on the area of the subaerial delta plain (~ 1700 km²) plus the subaqueous delta plain (~ 1100 km²) multiplied by the average delta thickness (50 m for the subaerial delta plain and 45 m for the subaqueous delta plain (after Roberts and Sydow, 2003). If the Mahakam Delta is assumed to have developed in the past

5000 years (Allen *et al.*, 1976), then the average fluvial sediment discharge has been 2.7x10⁷ m³/year. However, the present-day fluvial sediment discharge of the Mahakam River is estimated to be 634,685 m³/year (Husein, 2008) or 2.4 % of the discharge necessary to build the delta. This indicates that the present-day fluvial system delivers much less sediment than the pre-modern river, suggesting that there have been significant changes in the hydrodynamic environment. Although the Kutai Lakes system has been present throughout the Holocene, their influence on the downstream Mahakam River may have varied with time. At present, on-going subsidence in the Kutai Lakes region apparently traps most of the fluvial sediment and prevents its delivery to the Mahakam Delta.

The sediment transport patterns indicate that the southern area is more fluvially influenced than the northern area (Husein, 2008). However, the overall morphology of the two areas is virtually identical; the southern area has more outlets than the northern area, but both subaerial and subaqueous delta plains extend approximately the same distance from the delta apex. The only difference is that the delta front and prodelta slope more gently, and the prodelta extends farther seaward, in the southern area than in the northern area (Figures 2 & 3). This suggests that the present-day fluvial system has little influence on the delta plain morphology.

The wide southern prodelta is the result of greater suspended sediment discharge in the southern area relative to the northern area, as its distributaries have higher suspended

sediment concentrations (Husein, 2008). A small amount of suspended sediment drifts to the adjacent offshore water and is assumed to be influenced by the southward net current flow of the Makassar Strait (Eisma *et al.*, 1989) and carried hundreds of kilometres southeast of the delta.

The subaqueous morphology suggests that approximately 5 m of subsidence has shifted the shoreline landward from its former position near the offshore break in slope at the delta front and submerged part of the lower delta plain and the distal reaches of the distributaries, some of which remain as topographic features on the seafloor (Figure 1). The broad subaqueous delta plain causes waves to break, thereby reducing wave influence on the broad shallow platform.

The modern depositional processes and recent history of the Mahakam Delta indicate that its fluvial-dominated morphology is not a product of present-day processes, but reflects a phase of fluvially-dominant progradation that occurred prior to the present-day subsidence and transgression. The discrepancy between sedimentary facies and morphology developed because facies respond to changing hydrodynamic conditions much more rapidly than morphology, simply as a function of the much larger volume of sediment that must be transported to modify morphology (Husein, 2008). Essentially, the funnel-shaped estuaries and flared distributary mouths are ongoing tidal modifications to pre-existing distributary morphology.

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Influence of Hinterland Bedrock Lithologies on Aspect of Borneo's Deepwater Fold and Thrust Belt

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Abstract

Each of the catchment areas of Borneo's major river systems has distinct differences in their bedrock lithologies. As the provenance for the sediments delivered to the deepwater depositional systems, these lithological variations in the hinterland are an important consideration when predicting high quality turbidite reservoirs as they influence compaction and diagenesis. This paper examines these issues for the Baram, Sandakan, Tarakan, and Kutei Basins. Additionally, the role of hinterland bedrock composition of the Baram and Padas Rivers is considered in terms of influencing along strike changes in the structural style of the Northwest Borneo deepwater fold and thrust belts.

Introduction

Borneo's petroleum systems range in richness from prolific to non-commercial. The Kutei, Tarakan, and Baram Basins are the most prolific basins (Figure 1) with initial discoveries onshore dating back to 1897, 1905, and 1910, respectively. With the exception of the carbonate-dominated Luconia province of Sarawak, Malaysia, the bulk of this island's production has come from siliciclastic sandstone reservoirs deposited in coastal plain and shallow marine environments. Over the last decade, however, frontier exploration efforts focusing on Borneo's deepwater fold and thrust belts have extended the proven petroleum systems to include deepwater turbidites coeval with the up-dip producing shallow marine clastic reservoirs. Although the commercial success rate in Borneo's deepwater fold and thrust has been modest, large areas remain unexplored. Predicting the presence of high quality reservoirs (e.g., thick, well-

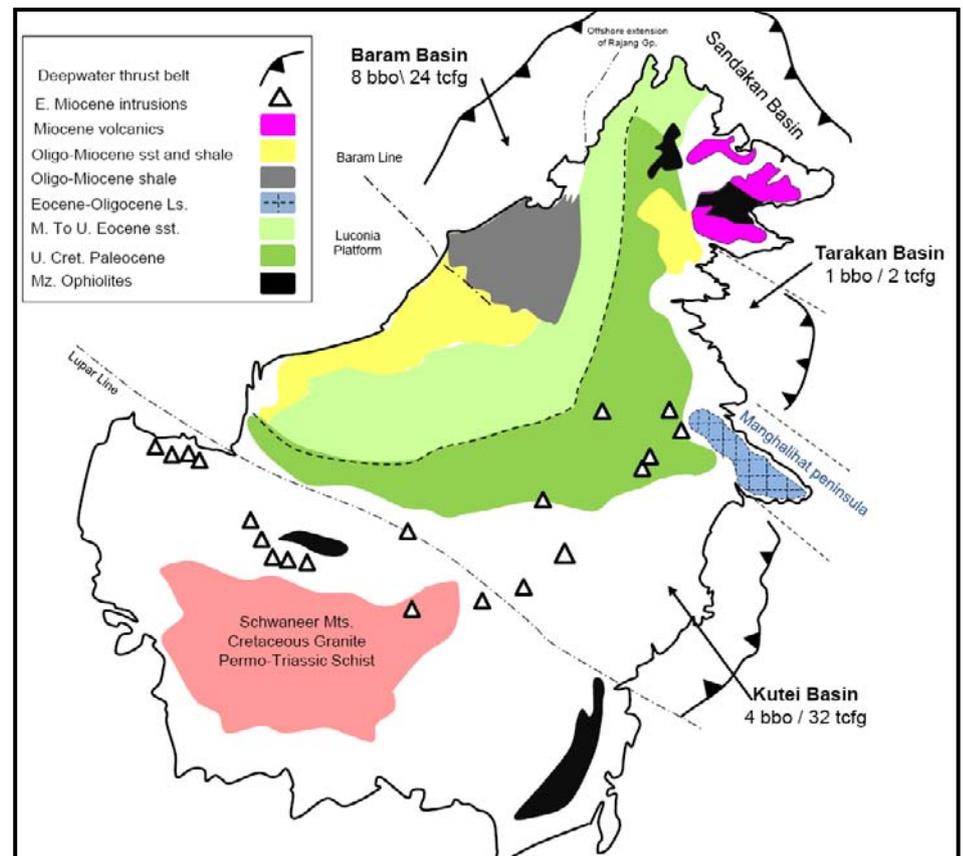


Figure 1. Simplified geological map of Borneo showing deepwater fold and thrust belts. Modified from Tate (2001). Oligo-Miocene units shown on the NW side of the island represent the approximate paleogeography at that time when the shoreline trend was approximately orthogonal to the present day shoreline.

connected, porous, and permeable sand bodies) is one of the critical success factors when exploring in deepwater fold and thrust belts. Methods for predicting the occurrence and distribution of turbidite reservoirs typically use 2D and/or 3D seismic to identify and map geometries indicative of canyons, shelf edge gorges, channel-levee and fan systems. This paper discusses the role that differences in the bedrock composition of the hinterland (onshore) can have with respect to not only the quality of Borneo's deepwater turbidite reservoirs, but also to control on the mechanical stratigraphy and structural style of the NW Borneo deepwater fold and thrust belts.

Regional Setting

Lying at the edge of the Asian Plate, Borneo records a complex tectonic history that is still not fully resolved. The rugged and deeply dissected interior highlands of the island are dominated the Rajang-Embaluh Group, a thick series of Upper Cretaceous to Paleogene deepwater clastic successions. The Rajang-Embaluh Group is the major important source of the sediment shed into the Kutei, Tarakan, and Baram Basins and there are important regional lithological changes within its various units (see reviews by Tate, 2001; Hutchison, 2005). The older parts of the Group, such as the Menturang,

Layar, Kapit, and Sapulut units), generally record phyllite to lower greenschist facies metamorphism, whereas younger units do not (e.g., Pelagus and Crocker Formations). The Rajang-Embaluh Group was strongly deformed and bevelled during the Sarawak Orogeny, *ca.* 40 Ma (Hutchison, 1996), an event that probably extended into Sabah and possibly affected Palawan (Cullen, 2010). The Luconia, Barito, Kutei, and Tarakan basins all contain Late Eocene rift sequences that may represent post-orogenic collapse that followed the Sarawak Orogeny. The Sabah region experienced a second, younger, orogenic pulse around 20 Ma (Hutchison et al., 2000; Balaguru et al., 2008). Plate tectonic models for the regional generally attribute the Sarawak and Sabah Orogenies to the progressive SE to NE collision of the Luconia, Dangerous Grounds, and Reed Bank continental block with a subduction zone dipping SE beneath Borneo (Hall, 1997; 2002). These two orogenic pulses ultimately resulted in a major shift in the distribution of Borneo's deepwater depositional systems whereby shallow marine Neogene successions unconformably overlie the former Paleogene deepwater basins. The Neogene basins that rim Borneo contain as much as 10 km of sedimentary fill derived from extensive denudation of the interior and reworking of shelf sediments (Hamilton, 1979; Hall and Nichols, 2002).

The circum-Borneo shallow water Neogene basins have a contemporaneous deepwater fold and thrust belts. Each of these deepwater fold and thrust belts, however, occupies slightly different settings that are worth noting (Figure 1). The Baram Basin faces the South China Sea and its fold belt overlies rifted continental crust of the Dangerous Grounds which collided with Borneo, ending a phase of SE-directed subduction. The foldbelt of the Sandakan Basin overlies, at least in part, Miocene oceanic crust of the Sulu Sea, as well as deformed Paleogene turbidites. The deepwater Tarakan Basin appears to have built onto Eocene age oceanic crust of the Celebes Sea. The deepwater Kutei Basin fold and thrust

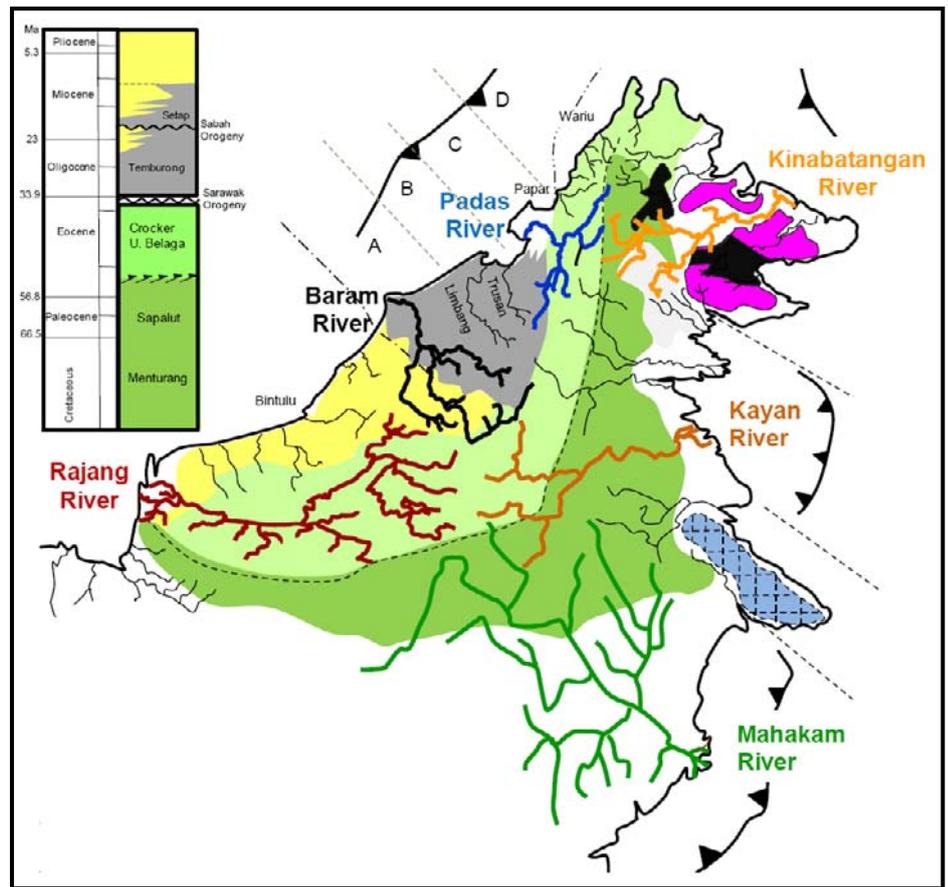


Figure 2. Enlarged area of the geological map of Figure 1 with drainages and major rivers shown. The inset stratigraphic column applies to areas within the catchments of the Baram and Padas Rivers.

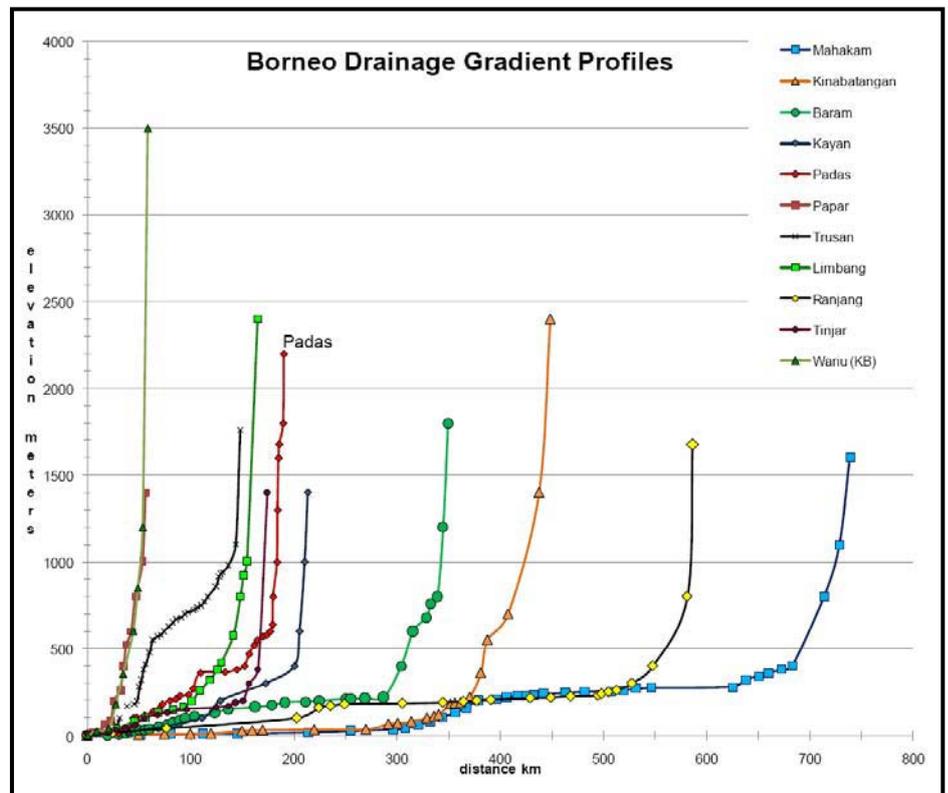


Figure 3. Gradient profiles of Borneo's major rivers and selected smaller rivers. Data have been digitized using Google Earth and Wikimapia.

belt overlies attenuated continental crust of the Makassar Straits and faces the Sulawesi deepwater fold-thrust belt which has an opposed sense of vergence. Although the present-day edge of the Asian plate lies on the eastern side of the Makassar Straits, Latest Miocene to Pliocene tectonic shortening (Hess et al., 2009), multiple tilted Early Miocene to Pliocene unconformities (Levell, 1987) in the Baram-Balabac Basin, as well as GPS motions and regional seismicity (Simmons et al., 2007) show that Borneo remains tectonically active even 1000 km from the plate edge. Balanced relationships between up-dip extension driven by sediment loading and concomitant down-dip contraction relative to tectonic shortening have yet to be determined at the island-wide scale.

Rivers, Catchment Areas and Provenance

The catchment areas of Borneo's rivers can be grouped into two main categories. Major river systems, such as the Mahakam, Rajang, Baram, Kinabatangan, Kayan and Padas Rivers, extend well into the interior of the island and have large catchment areas fed by numerous tributaries (Figure 2). Gradient profiles of the major rivers have long stretches with gentle gradients at relatively low elevations even far into the rugged interior (Figure 3). The major river systems are interpreted as long-established drainages that potentially represent major low-stand sediment delivery systems for the turbidites in the deepwater fold and thrust belts of Borneo. Minor rivers systems, such as the Bintulu, Limbang, Trusan, Papar, and Wariu, are relatively short and straight, have short high gradient profiles, and much smaller catchment areas (Figure 3). Because Borneo's coastlines are characterized as meso-tidal and have modestly strong wave action, the sediment that these smaller rivers deliver to the coast tends to be reworked along the shore, thus limiting the amount of deltaic progradation. The minor river systems with their smaller catchment areas tend to occur off the NW side of Borneo. The short and extremely steep gradient profiles

Table 1. Considerable range in bedrock compositions between the different catchments of Borneo's major river systems

River	Catchment Bedrock	Reservoir Considerations	Compositional Risk
Rajang	Eocene turbidites and shale	re-worked quartzose sands	Low
Baram	Oligo-Miocene marines shale	high percentage detrital clay	High
Padas	Eocene turbidites and shale	re-worked quartzose sands	Low
Kinabatangan	Mesozoic ophiolite, Paleogene phyllite & turbidites, Miocene volcanics	high percentage of unstable rock fragments	Medium
Kayan	Paleogene phyllite & turbidites	re-worked quartzose sands with mica	Low
Mahakam	Paleogene phyllite & turbidites, Reworked Neogene marine clastics	re-worked quartzose sands	Low

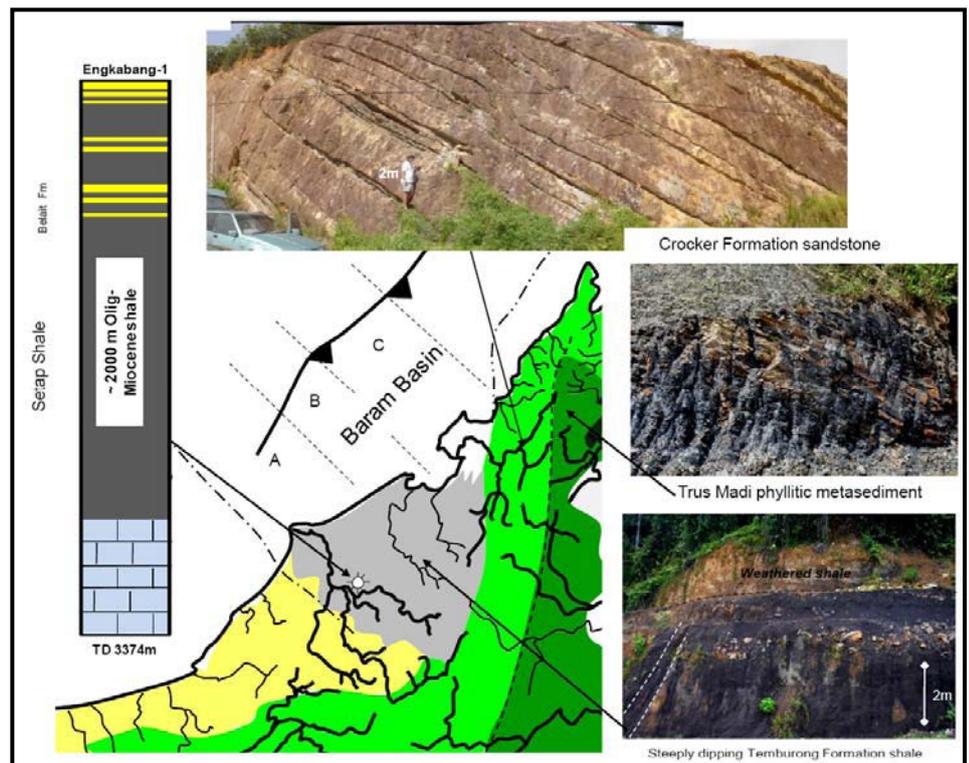


Figure 4. Photographs of representative outcrops of the lithostratigraphic units discussed in text and shown on the stratigraphic column of Figure 2. Engkabang-1 well data are modified from Hutchison (2005).

from Sabah attest to relatively youthful uplift. In this context the Padas River represents an important exception; it is the only river that has cut through the Crocker Range and has an expanded catchment area that includes intermontane valleys on the east side the range.

There is a considerable range in bedrock compositions between the different catchments of Borneo's major river systems (Figure 3 and Table 1). The range of hinterland bedrock lithologies has implications with respect to predicting reservoir quality at regional scale. Areas capable of delivering cleaner quartz-rich

turbidites to the deepwater basins are preferable to those areas that could supply a high percentage of unstable rock fragments, feldspars, and detrital clay (Table 1). The Holocene deltas of Rajang and Mahakam Rivers offer a good example of the influence of hinterland provenance on depositional systems. The catchment area of Rajang Rivers is dominated by Eocene sandstones and the Holocene delta has a higher percentage of mixed layer clays (60%) than the Mahakam delta (15% to 40%) which drains phyllitic bedrock (Kapit and Layar members of the Belaga Formation). The relatively high proportion mixed layer clays

minerals in the Rajang River results in the development of a regionally extensive aquiclude that promotes the development of thick (13m) peat domes in the Rajang delta, whereas the such domes are rare in the Mahakam delta (Gastaldo, 2010). It is interesting to consider what role the presence or absence of raised peat mires could have on the stability of lateral facies changes and the sequestration of organic carbon in terms of the development of potential coastal plain vs deepwater source rock intervals.

Hinterland Influence on Thrust Belt Structural Style

The hinterland of the Baram Basin consists of two contrasting types of bedrock. The hinterland of the southwest part of the basin is dominated by the shales of the Setap and Temburong Formations; whereas the hinterland of the northeast part of the basin is dominated by sandstones of the Crocker Formation (Figures 2 and 4). These relationships suggest that the large drainage systems of the Baram and Padas Rivers represent mud-dominated vs. sand-dominated delivery systems to the basin.

Along strike (SW to NE) differences in the structural style of both the shelf and deepwater areas of NW Borneo define four transverse structural domains in the Baram Basin (Figure 5). The B-C and C-D domain boundaries appear to be basement controlled, whereas the A-B boundary is interpreted to reflect differences between the Baram and the Padas-Champion depositional systems (Cullen, 2010). The deepwater structures in Domain A are characterized by high amplitude, symmetric, detached folds (Figure 6a). The deepwater parts of Domains B and C are dominated by asymmetric fault-propagation folds that ultimately root into a common detachment level (Figure 6b). The structural style of Domain A likely reflects the presence of low strength, possibly over-pressured, mud-rich rocks that deform by penetrative bed-parallel slip (Erslev and Hennings, 2003), which is consistent with a provenance of the shale-prone hinterland for the Baram Delta.

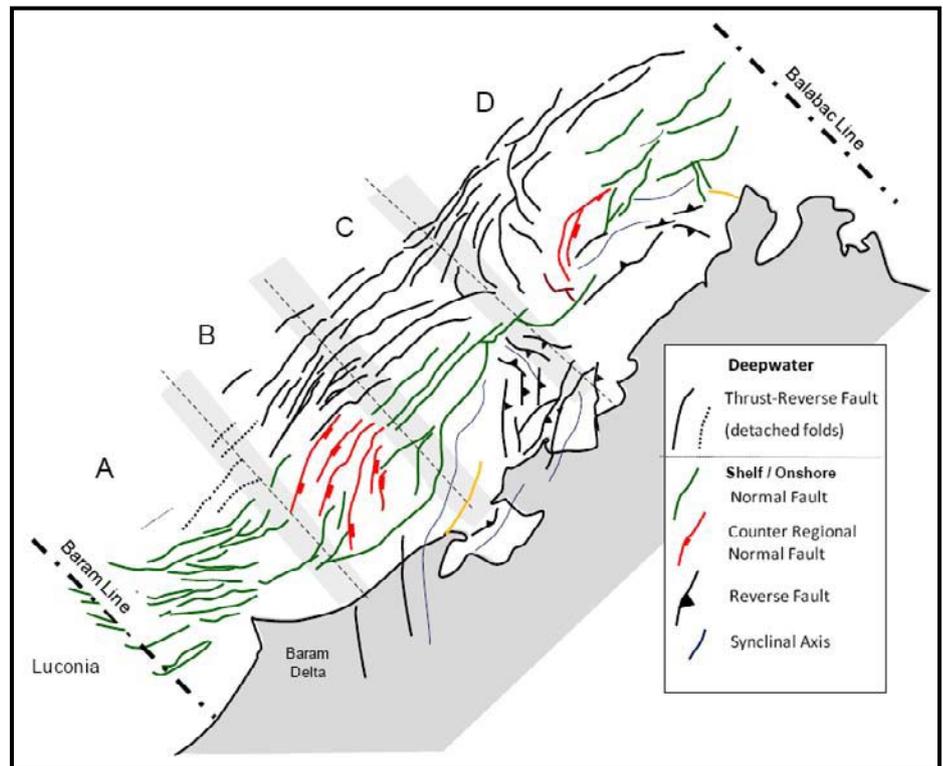


Figure 5. Linked shelf and deepwater structural domains of the Baram Basin (Cullen, 2010).

The deepwater sediments in Domains B and C are derived primarily from the Padas River catchment where the bedrock geology is dominated by sandy turbidites of the Crocker Formation. The fault propagation folds in the deepwater area of Domains B and C suggest a stronger mechanical stratigraphy than in the detached folds of Domain A, which is consistent with a higher percentage of sandstones in Domains B and C owing to a provenance in the Padas River catchment. Although differences in the total amount of strain in different domains of the NW Borneo fold and thrust belt may account for some of the differences in the structural styles between domains, lithology and layering represent more fundamental controls on such interrelated variables such as the strength of basal detachment, the coefficient of internal friction and the critical taper angle.

Thus, differences in the sand to shale ratios in the hinterland of the NW Borneo fold and thrust belt fold thrust belt potentially offers an example of hinterland control on the structural style of deepwater fold and thrust belts.

Conclusions

The different bedrock compositions of the catchments of Borneo's major river systems result in the erosion and transport of compositionally different sediment loads to respective receiving basins, which in turn influences lithostratigraphic aspects of those basins, such as the development of raised peat mires, the framework mineralogy of reservoir sands, and regional differences in ratio of sand to shale. In the Baram Basin, regional along-strike differences in the structural style of its deepwater fold and thrust belt appear to reflect contrasts in mechanical stratigraphy that can ultimately be related to differences in the dominant bedrock lithologies in the catchment areas from which the basin's sediments were derived; offering an example of hinterland influence on structural style.

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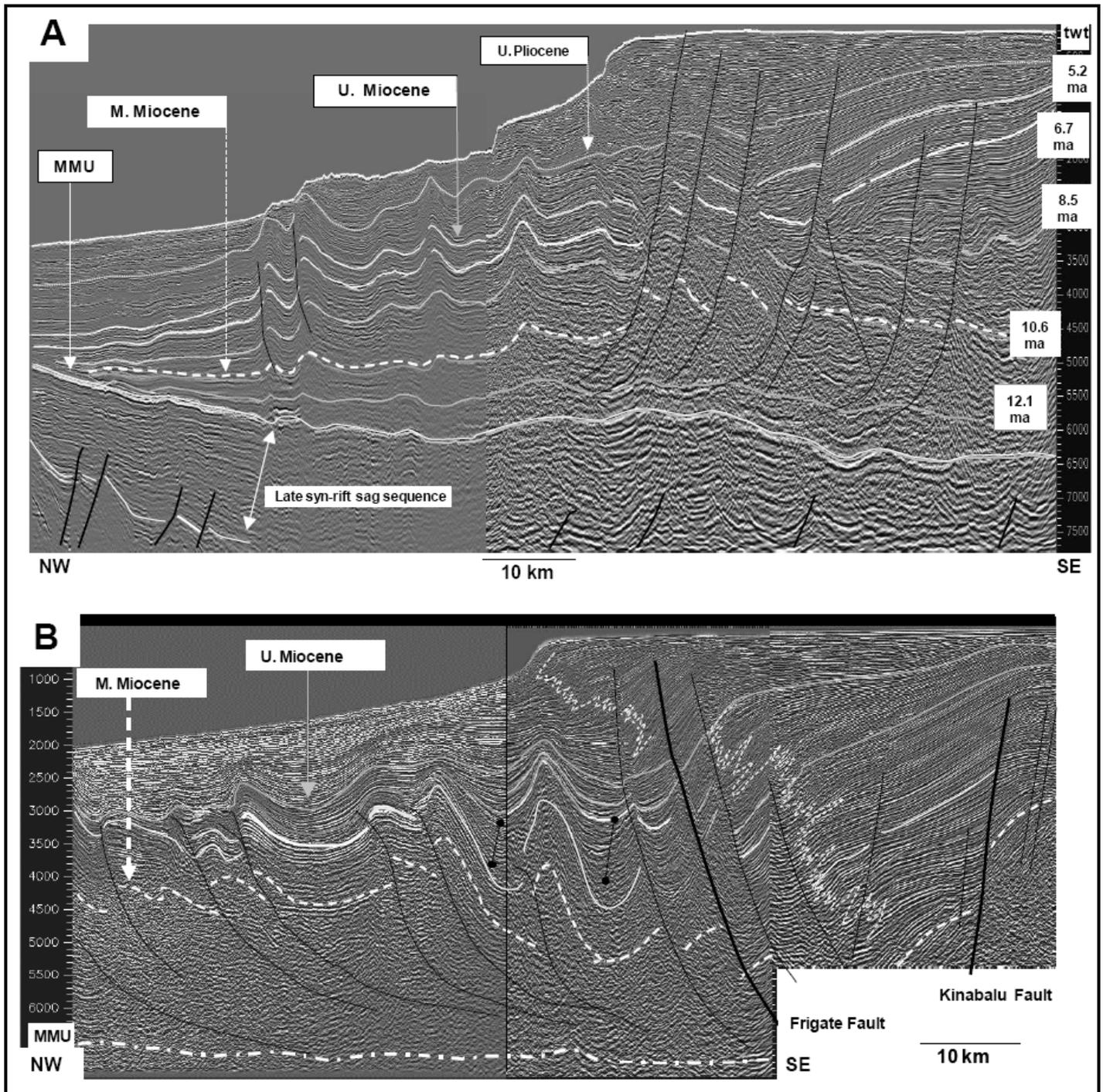


Figure 6. Seismic lines from structural Domains A (6a) and B (6b) illustrating the different structural styles in the deepwater fold and thrust belts of those domains. MMU is a Middle Miocene unconformity above which a regional detachment level appears to represent a mechanically weak decollement.

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Field Trip

Channel-Levee Facies and Sea Floor Fan Lobes in The Turbidites of Lower Kutei Basin, East Kalimantan

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Abstract

Recently open outcrops in the lower Kutei basin have been interpreted as slope turbidites. The new outcrops show channel-levee complexes. The sandstone bodies are mostly constituted by mass flows and debris flows which pinch out in short distance to thin bedded turbidites and silt shale alternations. This is interpreted as the transition from channel margin to levees. Channels are filled in general by thick mass flow deposits.

A detailed geometry of sandstone reservoirs in slope turbidite channel – levee complexes is described. Precise measurements of different architectural elements of the complexes are carried out in field outcrops. Two outcrops will be the object of this paper. One of them shows sea floor lobe and the other shows channel levee complexes in a slope.

Keyword: Lower Kutei basin, Samarinda, Lower to Middle Miocene, slope turbidites, channel – levee complexes, reservoir geometry, reservoir model.

Introduction And Geological Setting

Deltaic sedimentation has been continuous in the Kutei basin from late Oligocene to the present-day, represented by the modern Mahakan delta. A fluvial plain is associated to the delta upstream in the continent and carbonate buildups are observed in the shelf offshore to the delta. Turbidites are described beyond the shelf break further down slope (Sherwood et al., 2001, Saller et al., 2004, Saller et al.,

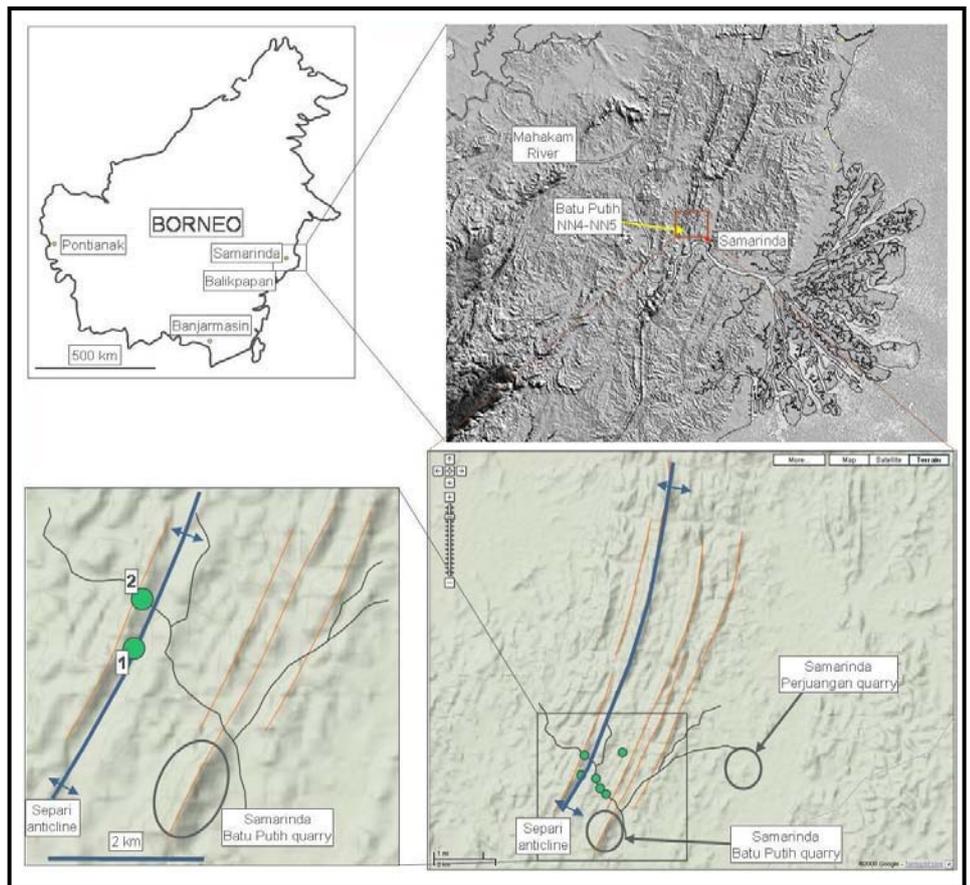


Figure 1. Outcrop location maps.

2008) as well as in Miocene oil and gas fields (Saller et al. 2006). These four environments shift continuously seaward and landward during the geological time constituting a complex geological history of the basin.

We are focusing in this paper on a section in North West of Samarinda city (Figure 1). The outcrops are currently easily accessible and are situated close to the main road from Samarinda to Tengarong. Three hill rows dominate the relief of this area. The first hill row is constituted by Batu Putih carbonate buildups (Figure 1), dated as Late of Early Miocene to

Early of Middle Miocene age (NN4 to NN5 nanoplancton zones, (Wilson, 2005). Shelf sand lobes and shelf break geometry can be observed above Batu Putih carbonate buildup (previously object of sedimentological and stratigraphic studies (Cibaj and Wiweko, 2007). The second hill row is occupied by Samarinda city rubbish dump. Hand phone web antennas are erected on the top of the third hill row. The section is Early to Middle Miocene in age. Our biostratigraphic studies show more precisely Late of Early Miocene to Early of Middle Miocene age (NN4 to NN5 nanoplancton zones).

Samarinda anticlinorium is constituted by a series of very wide synclines and very narrow anticlines. The studied outcrops are situated in Separi anticline, which constitutes the central part of Samarinda anticlinorium in almost its higher part (Allen & Chambers, 1998), representing, therefore, the oldest outcropping rocks. The vegetation cover makes it difficult to understand the exact detailed structure of the Separi anticline core. Nevertheless the selected outcrops show in their majority a strong structural dip (40 to 70 degrees) towards east (eastern flank of the anticline) with the exception of the outcrop No 2 dipping to the west (west flank of the anticline). We assume going stratigraphically upwards from the core of the anticline to the east (Batu Putih carbonate buildup).

The series is dominated by shale, interrupted from time to time (every 100 to 150 m) by sand pulses which form 5 to 30 m thick successions. These sand successions will form high relief hills in the landscape. A series of sand outcrops have been studied in the section. Dense vegetation covers the shale separating the sand intervals. The outcrops are numbered 1 to 7 from the stratigraphic bottom to the top (for more details see Cibaj, 2011). This is the only area in the Samarinda anticlinorium showing fairly well linked outcrops interpreted as slope turbidites. In this paper we are focusing in detail only in the outcrops 1 and 2. This succession is capped at the very top by Batu Putih carbonate which is interpreted as deposited in a shelf break environment.

The series cropping out at the core of Separi anticline has been previously described and interpreted as slope turbidites (Allen & Chambers, 1998, Cibaj & Wiweko, 2008). This study focuses on a detailed description of old and new outcrops of sand formations. Their interpretation shows the presence of channel-levee systems in the slope as well as the basin floor fan lobes.

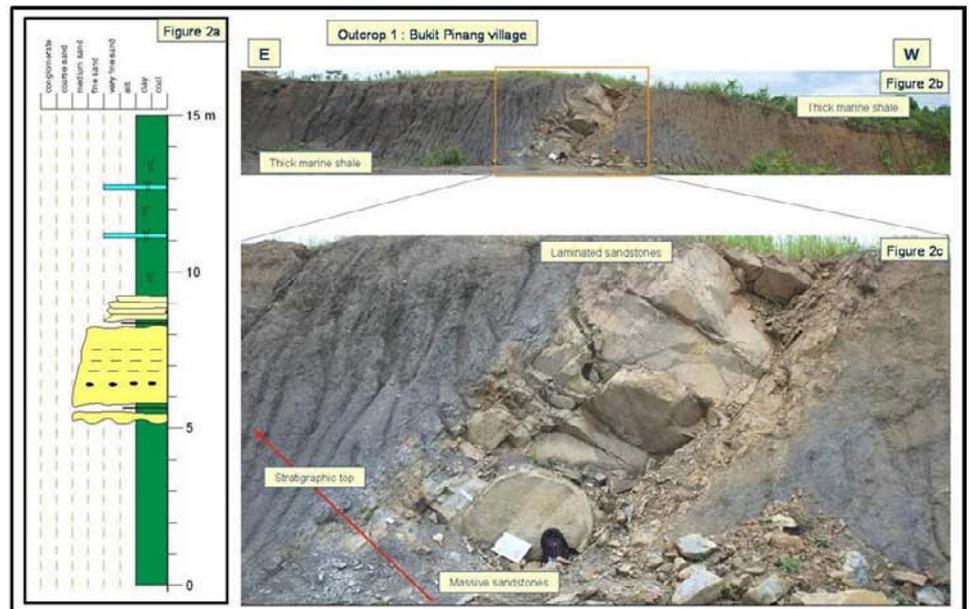


Figure 2. Log description and photos of the outcrop No 1.



Figure 3. Detailed photographs of the outcrop No 1.

Outcrop Detailed Description And Interpretation

Outcrop No. 1

Situation:

The outcrop is situated on a hill flank where new housing complex has been developed last few years (Bukit Pinang village) (Figure 1, 2).

Description:

The outcrop shows a structural dip towards the east (Figure 2). It is constituted by very thick shale (more than 100 m) with a 4 m thick sand bed

in the middle of the shale. This thickness is very constant laterally over a 300 m distance. The bottom surface of sands is very irregular and erosive (Figure 2c). The sand shows a massive texture at the bottom (Figure 3a) laminated at the top (Figure 3c). Clay clasts, 1-2 cm in diameter, are observed in 2 or 3 levels in the middle of the sand. They are oriented parallel with the stratification. Vegetal organic mater is dispersed all over the sand interval; print leaves can be observed in many cases (Figure 3b). Parallel laminations are observed towards the middle part of the sand. The top is constituted by

thin sand layers, 1-2 cm thick, with sharp base, massive at the bottom to parallel laminated structure at the top. Sometimes current ripples are observed. Thin shale separates sand layers (Figure 3c).

Shales are very dark and rich in vegetal organic matter. Dense vertical burrows are observed in the shale (fig 3d) visible only in oblique sun light. Their diameter can reach up to 0.5 cm and their length can be up to 2-5 cm. They have a slightly conical shape.

Interpretation:

Thin sand layers are interpreted as Bouma thin-bedded turbidites, Ta, Tb and Tc divisions. The massive sand is interpreted as gravity flow deposits. This sand is fairly extensive laterally and is interpreted as deposited in a basin floor, or in the transition between slope and the basin floor. Thick shales are interpreted as deposited in open marine conditions.

Outcrop No. 2

Situation:

The outcrop is situated in the road from Samarinda to Tengarong on the top of the third hill row near the portable telephone network antennas.

Description:

The outcrop is constituted by two main parts a lower part and an upper part. The formations show a structural dip towards the west (west flank of Separi anticline, Figure 4).

The **outcrop No 2 lower** is around 100m X 100m in dimensions (Figure 4). Two sand intervals are observed overall in this outcrop. The inferior sand interval is constituted by coarse-grained sand beds with floating clay clasts showing frequent lateral pinch out (Figure 5a, b, d, and e) to medium and fine-grained sands. The superior sand interval is around 15 m thick (Figure 4, 5a, and c). The bottom surface of this sand interval is very irregular and erosive showing some flute casts oriented overall to the east – north east. Sand beds are very massive, rich in clay pebbles and clasts.

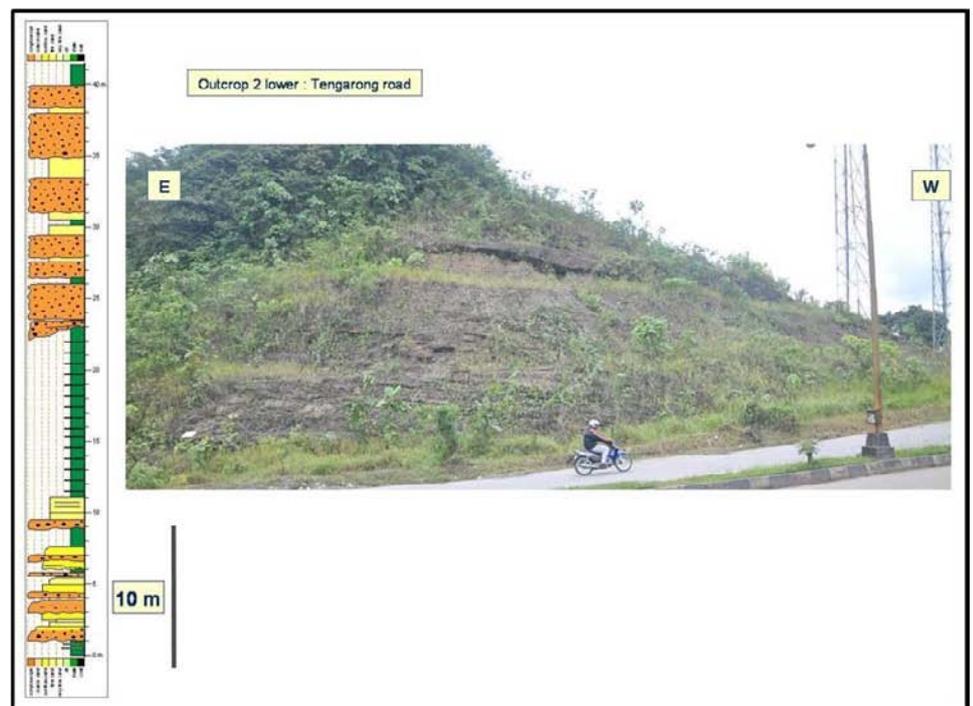


Figure 4. Log description and photo of the outcrop No 2 lower.

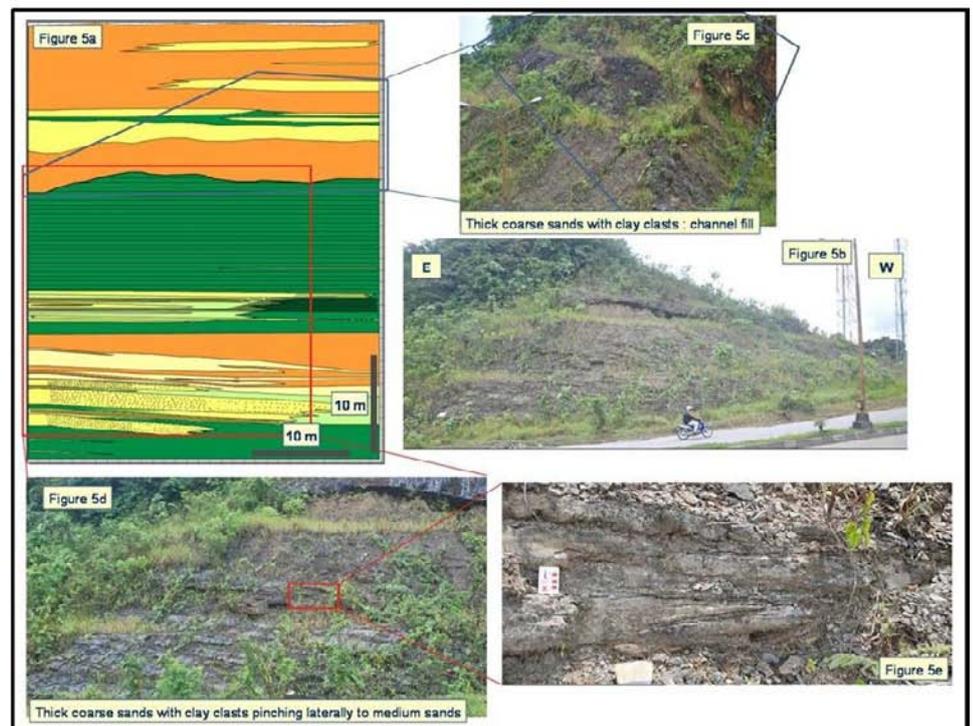


Figure 5. Detailed structure and photographs of the outcrop No 2 lower.

The **outcrop No 2 upper** is around 50m X 200m in dimensions and is constituted by three sand complexes (Figure 6). The inferior complex is around 7 m thick, the intermediate complex is around 11 m thick and the superior complex is around 15 m thick. They show important lateral variations.

- *Inferior sand complex* is constituted by medium-grained sands forming 0.1 - 2 m thick beds. Well cemented clay clasts float in the sand matrix. Their concentration decreases upwards in the complex. Rapid changes of the sand bed thickness are observed in the eastward direction. These changes are associated with the decrease of clay clasts in the formation as well.

- *Intermediate sand complex* exhibits a very rich internal structure. It is constituted by three sand beds 2 – 5 m thick (Figure 6). A detailed observation of the **section near the road** shows mostly mass flows constituted by well cemented clay clasts and pebbles floating in sand matrix (Figure 7b). Clay pebbles are around 2-5 cm and can reach until 10-20 cm in diameter. They show a high frequency presence in beds. Sand matrix is medium grained size, mostly constituted by Qz and coal clasts. Beds show a massive structure while clasts seem to be oriented slightly parallel with the bedding (imbrications). The top of sand beds shows very fine grained sands with parallel lamination. The top surface is not exactly parallel but shows mostly mounds or dunes with wavelength around $L = 5-10$ m. The clay pebbles show lower frequency in the upper part of sand beds. Consequently the sand beds show an overall fining upward trend of the grain size. The observation of the **section up cliff** shows lateral pinching out of many of the sand beds (Figure 7a). They are constituted by very fine grained sands with parallel lamination at their bottom, interpreted as traction carpets (Figure 7c). Clay pebbles floating in sand matrix are still observed but in much lower quantity. The pebbles are around 1-2 cm in diameter and show low frequency presence in thinner beds (around 10-20 cm thick). Concentrated vegetal organic matter is very frequent in the stratification planes.

- *Superior sand complex* is constituted by thinly laminated, fine to medium-grained sand beds 1 cm to 1 m thick separated by extremely rich in vegetal organic matter interbeds (Figure 8a & b). High content of vegetal organic matter is dispersed all over the sand beds. Parallel lamination is dominant in the sands at small scale but in big scale the whole series is constituted by mound or dunes with wavelength around $L = 5-10$ m constituting HCS like structures and sometimes cross bedding structures.

Interpretation:

The whole outcrop No 2 upper is interpreted as mass flow and debris flow. The wing shape of sand beds indicates deposition in levees. The

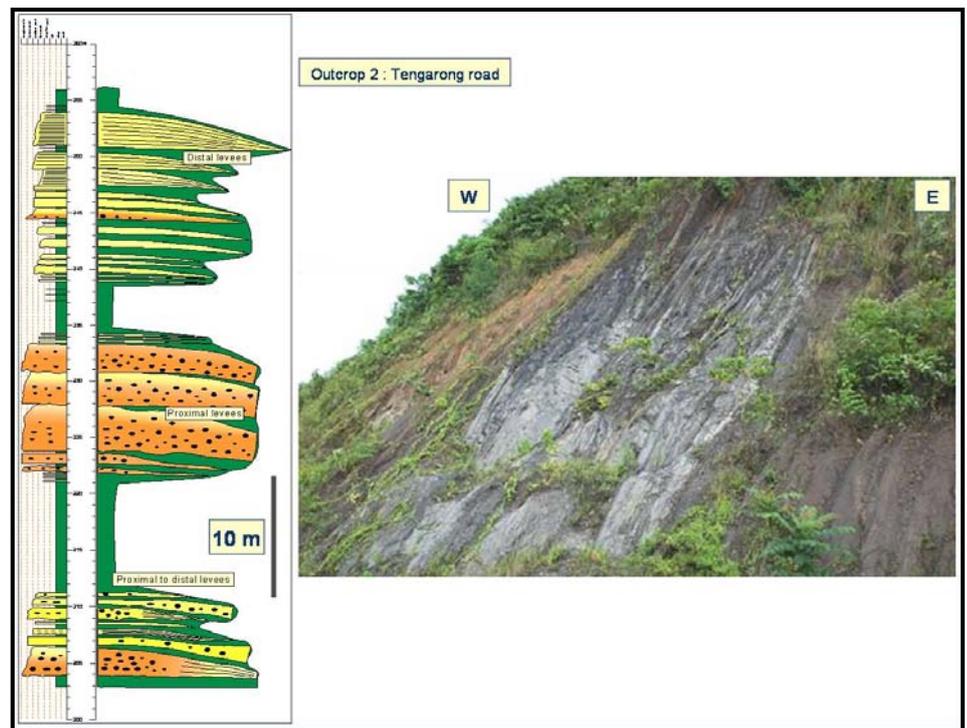


Figure 6. Log description and photo of the outcrop No 2 upper.



Figure 7. Detailed photographs of coarse-grained facies of the outcrop No 2 upper.

inferior complex, around 7 m thick, is interpreted as a proximal to distal (related to the channel proximity) levee complex. The intermediate complex, around 11 m thick, is interpreted as proximal levee complex and the superior complex, around 15 m thick, is interpreted as distal levee complex. The 15 m thick sand interval observed in the top of the outcrop No 2 lower is

interpreted as turbidity channel in a slope.

Although the dimensions of outcrops are small and do not give enough view of the sand development laterally we try to understand the geometry of channels and levees. A small sand layer at the bottom of the outcrop No 2 lower has been taken as miniature fractal model (Figure 9). Scouring at the

bottom of the sand are very often observed as well as the filling of scours with sand in the same way as the filling of the channels (Figure 10). Two different shapes can be distinguished. One is very thick and not very wide showing a massive structure (Figure 10). This can be interpreted as sand dominated channels described in McHargue et al, (2010). The other is wider and is interpreted as filled with sand and fine-grained sediments (Figure 11, Mchargue et al. 2010). Thin sands develop laterally to the scouring interpreted a overbank and levees (Figure 10, 11).

The whole section of the outcrop No 2 is interpreted as channel-levee complexes (Figure 12). Different parts of the section can be interpreted as being deposited in different parts of the channel or in overbank levees. This interpretation is based on the lithology and sedimentary structures present in different parts of the section.

Fowler et al., (2001) and Saller et al., (2004) have shown that sand can be deposited in sinuous turbidity channels in the Pleistocene and modern slope offshore Kutei basin. These channels are associated with levees as well. Slope channels filled with sands are formed in canyons related with delta front distributary channels. The whole outcrop No 2 is interpreted as channel – levee complex in a slope environment. The quantity of sand and the extreme variety of structures can be interpreted as an indication of the proximity of the basin floor. The lower slope environment is preferred as a best choice. Channel – levee complexes can be formed in intra slope small basins. The extreme rich vegetal organic matter deposited with the mineral material indicates that both mineral and organic matter have been transported and deposited together. Their source is related with fluvial input in the basin and probably the presence of a protoMahakam delta since these early times of Miocene in the Kutei basin.

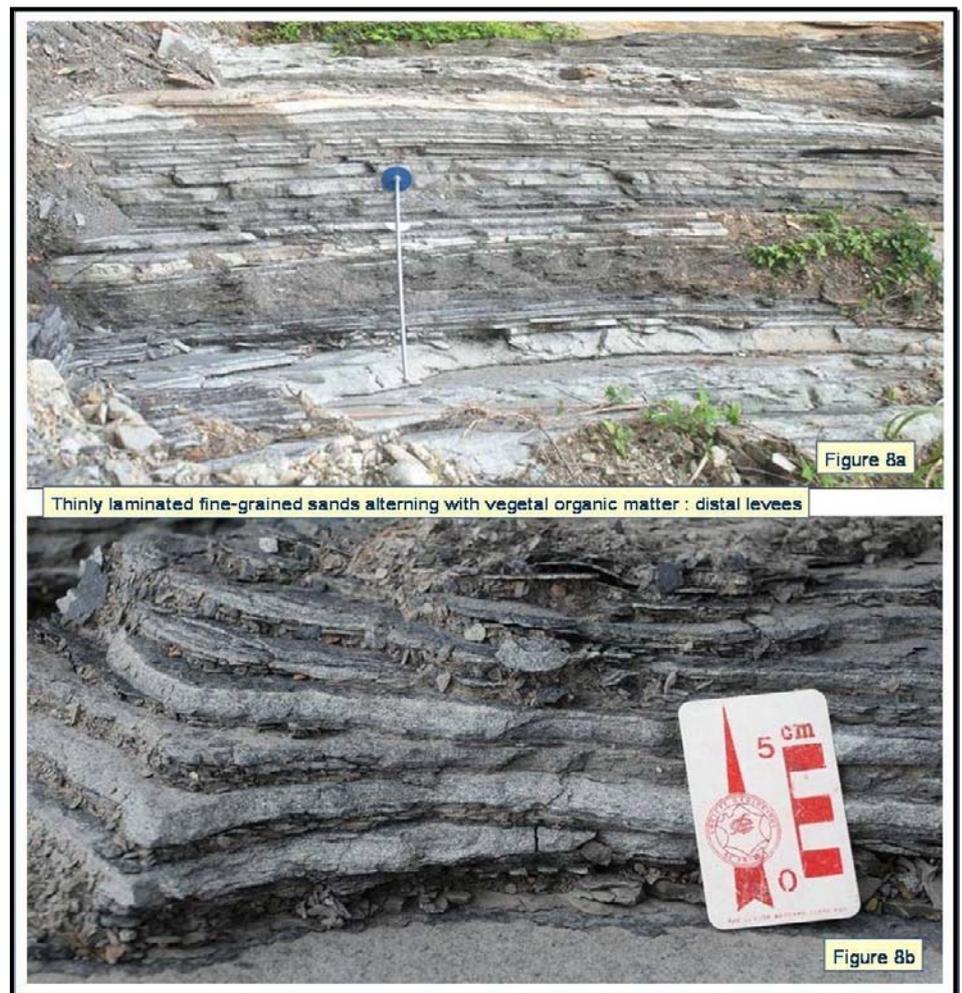


Figure 8. Outcrop No 2 upper, fine-grained facies photographs.

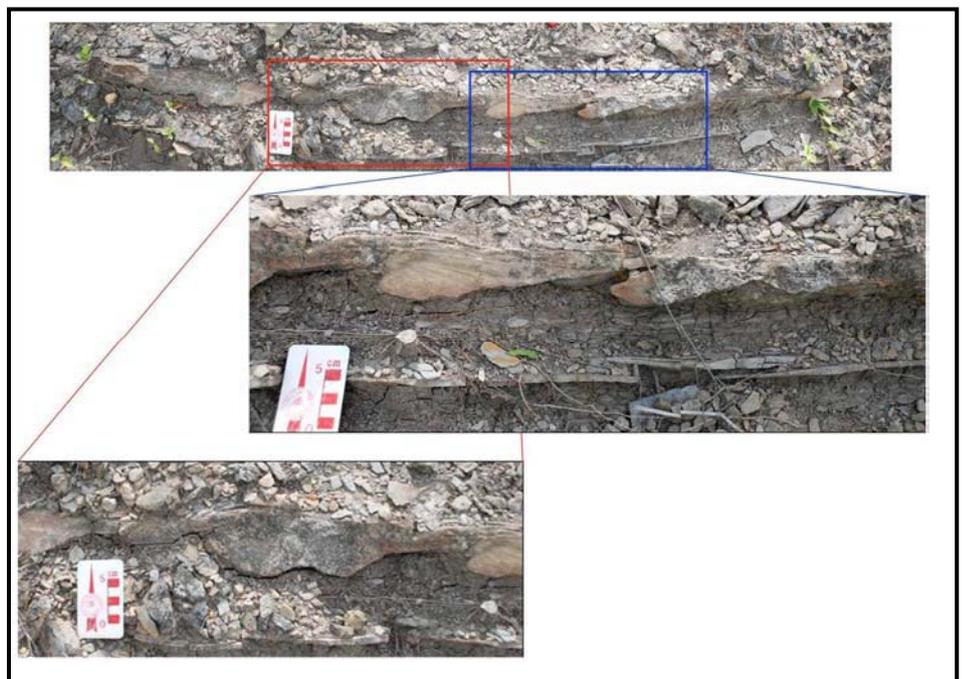


Figure 9. Miniature fractal model for channel – levee systems of the outcrop No 2, as observed at the bottom of the outcrop.

Discussion - Interpretation

Described outcrops show a wide variety of sedimentary features. There is a big difference between outcrop No 1 constituted by massive and parallel laminated sands (interpreted as lobe deposited at the end of the slope beginning of the basin floor) and the outcrop N2 constituted by mass and debris flows interpreted as turbidite channel-levee complex.

Channel-Levee Complexes are observed in the recent deposits of the deep water basin (Fowler et al., 2001). Individual levees are described as wedge shaped, thinning away from the channel, and show mudstone dominated lithology in wells. Large depocentres occur at points of gradient decrease, in slope mini-basins or on the basin floor. Deposition by the high-density part of turbidity currents is most likely, inferring a sand prone nature.

From outcrop No 2 to outcrops No 3 and 5 there is a variety of facies transition from mass and debris flow to thin-bedded turbidites, to highly bioturbated thin bedded turbidites. A detailed description of these outcrops is provided in Cibaj (2011). At the top of this trend is observed the Batu Putih carbonate which shows shallow marine conditions and interpreted as shelf break separating shelf from slope deposits (Cibaj & Wiweko, 2008).

Acknowledgments

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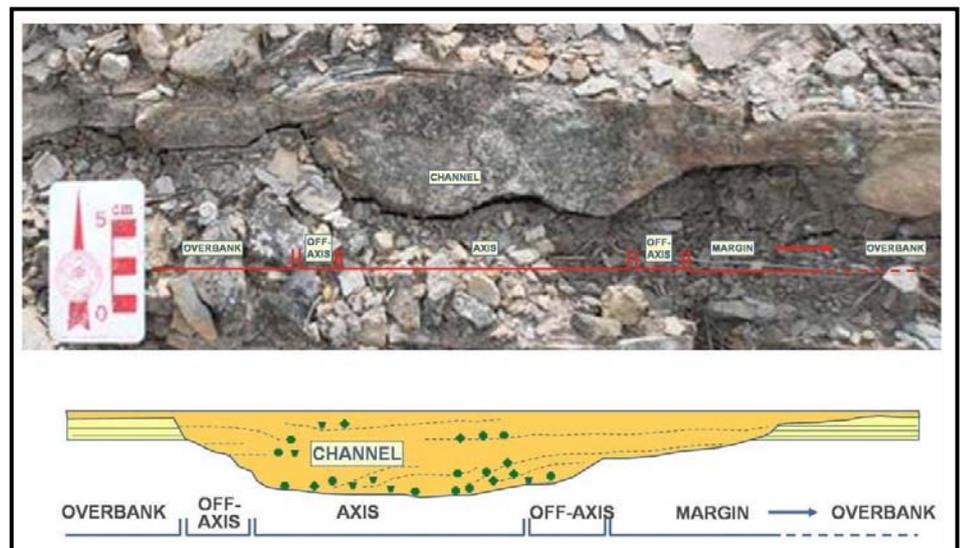


Figure 10. Miniature fractal model and detailed sedimentological model of a sand filled channel.

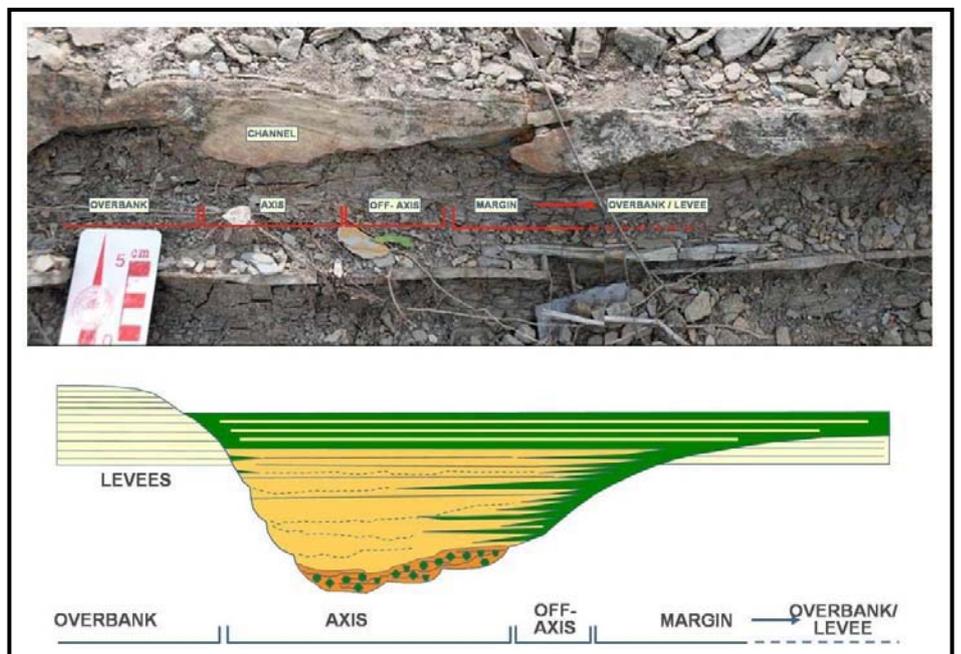


Figure 11. Miniature fractal model and detailed sedimentological model of a sand and shale filled channel.

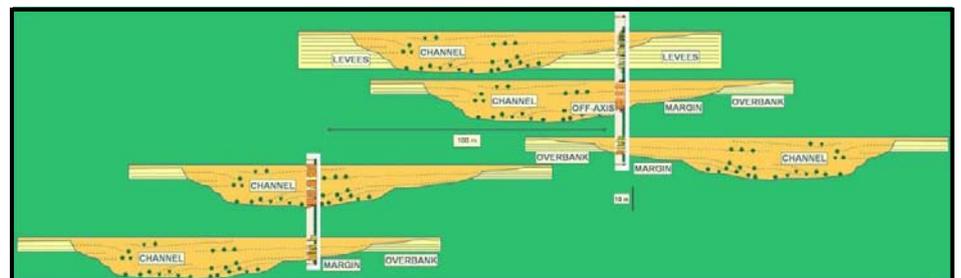


Figure 12. Sedimentological interpretation of the outcrop No 2.

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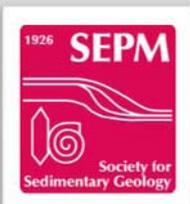
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A Simplistic Approach in Estimating Paleo-Bathymetry by Using Seismic Stratigraphic Features in Fluvial-Dominated Delta

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Abstract

The advance of high resolution 3D seismic technology has enabled much detailed imaging not only for structural features, but also for detailed stratigraphic features. If we squeeze a little bit more out of seismic data, it can provide us some important information. Seismic stratigraphy analysis in a prograding delta setting can deliver simple yet useful tool in understanding the geological and depositional aspects from seismic data. Recognizing unique seismic stratigraphic pattern of each part of delta and their chronostratigraphic correlative unit will allow us to understand the depositional relief of ancient delta sequence observable in seismic. This article discusses how to do simple estimation of paleo-bathymetry in a fluvial-dominated delta and its limitation. This is a little effort to make seismic interpretation more meaningful and much more fun.

Background

Seismic interpretation has been the back bone of oil and gas exploration since many years. The advance of high resolution 3D seismic technology has enabled much detailed imaging not only for structural features, but also for seeing some detailed stratigraphic features. For a geophysicist, seismic interpretation could be a routine job. Much of the time is spent interpreting seismic reflectors, seeking a continuity to build nice smooth maps. Sometime seismic interpreter are trapped in this routine, skipping an important step in interpreting seismic data, which is to relate the seismic features to their geological aspects beyond the structural information.

Seismic reflections are chronostratigraphic in nature, which

means we are following bedding or time plane while tracing the seismic reflector and not following lithology. Interaction of seismic reflections will reflect the timing of deposition and their relative position from one sequence to another, forming a geometry that will be unique for each depositional and geological setting. In other words, geometry of seismic reflections will be reflecting the geological processes that formed them. Therefore, it is important to think geologically while interpreting our seismic data. However, is there any way to get a geological or depositional setting sense while we are interpreting seismic data? When seismic data have enough details and areal coverage, we may have the chance to evaluate its geological aspect through seismic stratigraphy.

“Seismic Stratigraphy” is one of the branches of geological science. Seismic stratigraphy is the study of stratigraphy and depositional facies as interpreted from seismic data (Mitchum *et al.*, 1977a). A seismic sequence is a depositional sequence identified on a seismic section (Mitchum, 1977). A depositional sequence is a stratigraphic unit composed of a relatively conformable succession of genetically related strata and bounded at its top and base by unconformities or their correlative conformities (Mitchum *et al.*, 1977b).

The most studied depositional setting in seismic stratigraphy study is deltaic depositional setting, which provides a range of depositional setting changes that can be identified by good seismic data. Delta is a contiguous mass of sediments, partly sub-aerial, deposited around the point where a stream enters a standing body of water (Galloway, 1975). Galloway (1975) also subdivided deltas into three end members, based on the energy source which dominates

the seaward edge of the delta, which include: (1) fluvial-dominated, (2) wave-dominated and (3) tide-dominated deltas. The interaction of fluvial flow, wave action and tidal current are the main energy source in which one of them may be the dominant energy at the leading edge of the delta.

For the simplicity of this article, it will only discuss the quick interpretation technique of paleo-bathymetry using seismic stratigraphy approach without discussing extensively on the deltas typing and their detailed seismic characteristics. This article will also focus on fluvial-dominated deltas because this type of delta is the most ideal type to be evaluated by using this technique.

Some typical characteristic of fluvial dominated delta are summarized below:

Delta plain setting

Dominated by parallel reflection patterns with some channel scours indication, some bright amplitude of coal beds in upper delta plain, small scale carbonate build-up reflections, and small scale prograding clinoforms which may occur when the slope changes within the transition from upper to lower delta plain area.

Delta front setting

In a fluvial-dominated delta, the delta front is characterized by upper offlap or toplap, large prograding clinoform and downlap expression at the bottom of the packages which enter into prodelta setting. Sometimes, at the leading edge of a delta front there are onlap expressions of younger beds onto the delta front packages.

Pro delta setting and Basin floor setting

The prodelta setting is dominated by downlap seismic reflections and

parallel reflections at the leading edge of the delta front. This setting may also sometimes exhibit subsequent parallel reflectors on-lapping onto the prograding prodelta package slope, which may be an indication of turbiditic stratigraphic unit.

The illustration in Figure 1 describes that theoretically, each part of delta will have unique seismic stratigraphic signatures. By knowing specific seismic signature to its depositional setting and then tracing it outboard toward its genetically related unit down to the basin in the same chronostratigraphic interval, the geographic position of each location and relief difference between them at the time of deposition can be drawn. For ancient deformed delta, the reconstruction sometime will require structural restoration.

Modern Analog and Test Case

The key is to find areas that have delta plain seismic signature in shallow setting, which continues to the genetically related basin floor setting indicated by downlap surface that reflects deeper setting. In an ideal undeformed stratigraphic unit, the seismic time elevation difference between those two depositional settings will represent water depth difference in time. To get it in depth domain (meters), we have to multiply seismic interval velocity on the particular section with the time difference.

It has to be noted that the bathymetric difference will not be directly a real bathymetric depth but it will only be a minimum water depth difference between the shallow and deeper locations. We have to realize that the shallow package had minimum water depth when it was deposited. This depth will be added to the residual depth between the shallow and deeper stratigraphic packages. The paleobathymetry of shallow packages ideally can be inferred from biostratigraphy by using benthic foram fossil assemblage, but if we do not have it, seismic pattern association indicating unique depositional setting can be a hint to estimate water depth by comparing them to its modern analog. Another

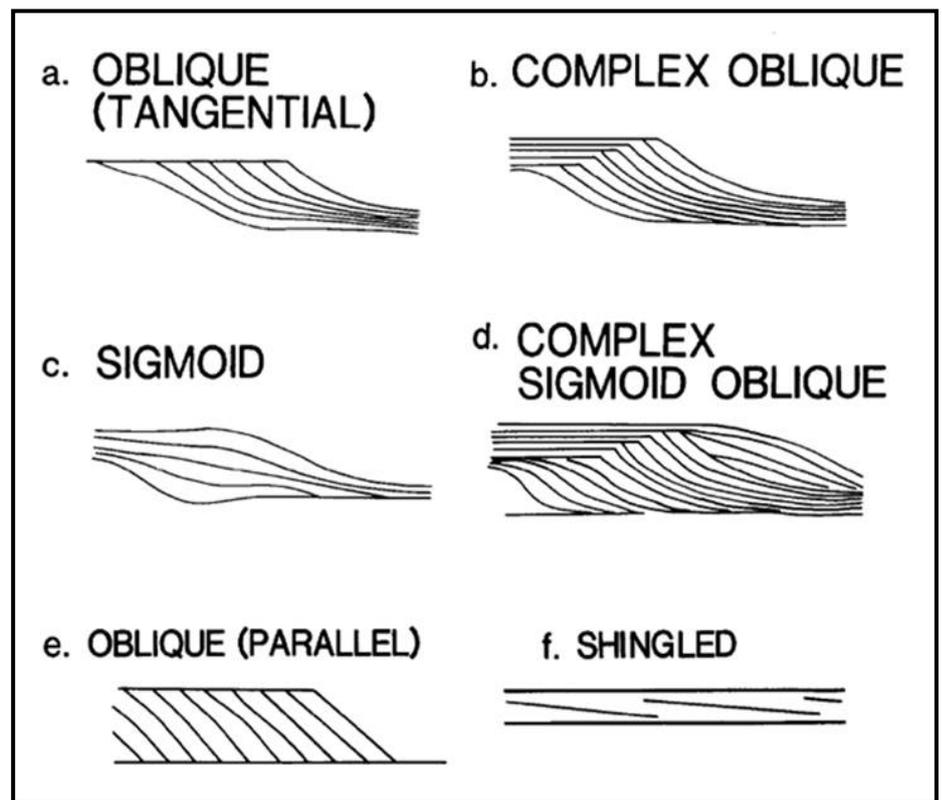


Figure 1. Model of seismic reflection pattern in fluvial-dominated delta and wave-dominated delta (modified from Mitchum *et al.*, 1977a)

thing to be considered is compaction factor that have to be corrected with decompaction calculation. The later correction will have to be applied in the academic world but in the practical fit for purpose use, it can be simplified

by using some factor or even disregard it for the sake of simplicity.

The seismic on Figure 2 is the modern analog in lower delta plain near self edge of the northern Mahakam delta.

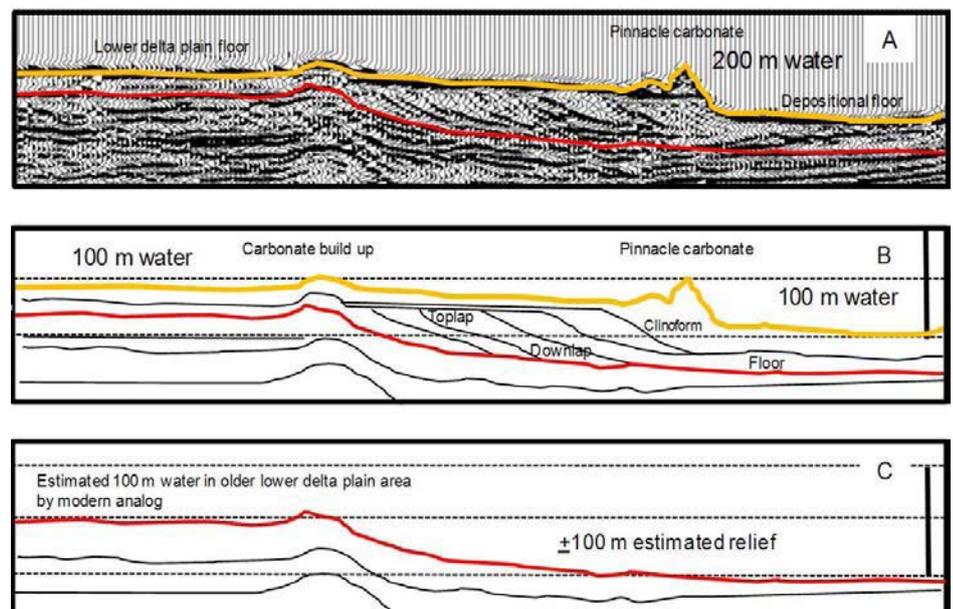


Figure 2. (A) Seismic image of modern sea bed on a lower delta plain near the shelf edge in northern Mahakam Delta shows flat delta plain on the left, carbonate build up and pinnacle reef, prograding clinoform complex, and near shelf edge depositional floor at about 200 meter water depth. (B) Schematic drawing of important seismic reflectors, the Yellow horizon is water bottom elevation at present-day. The Red horizon is the older water bottom. (C) Graphical estimation of older water bottom Red horizon.

At water bottom level (Orange horizon), it exhibits lower delta plain flat area, carbonate mound and pinnacles, break of slope and a basinal flat area with some bumps of what appear to be carbonate build up. Beneath the water bottom (Orange) horizon, it is observable parallel flat reflection patterns at the left side that continues to prograding clinoform complex stacking laterally to the right end. The top of the prograding complex exhibits toplap features as a sign of the top stratigraphic body. The deeper flat area consists of downlapping stratal pattern and parallel reflector which eventually conformably stacked at the far end of the section. The shallow and deeper delta plain settings at this location can be used as modern analog to do simple paleo-bathymetry estimation. On the Orange horizon in Figure 2, water depth estimation is simply done by measuring the depth of water bottom reflection on the seismic section then multiplied by seismic velocity of the water. To do similar estimation to the older strata is little bit tricky, since the paleo water bottom reflector might have been distorted or eroded. We will not be able to do an accurate estimation but we can do an educated guess of the paleo-bathymetry.

The steps are:

1. Identification of shallow part of delta setting which can be traced to its correlative deeper part of delta by observing key seismic stratigraphic reflection pattern.
2. Graphically estimate time difference between those shallow and deeper part of ancient water bottom reflector.
3. Estimating seismic interval velocity of the evaluated seismic stratigraphic unit.
4. Calculate the depth difference by multiplying time relief by seismic interval velocity.
5. Estimate the minimum possible paleo-bathymetry of the shallow part of delta by evaluating benthic foram biostratigraphic data when available, or by evaluating sedimentary structure of core when we have it in hand. If those benthic foram and core data are not available, we may develop and use seismic stratigraphic pattern

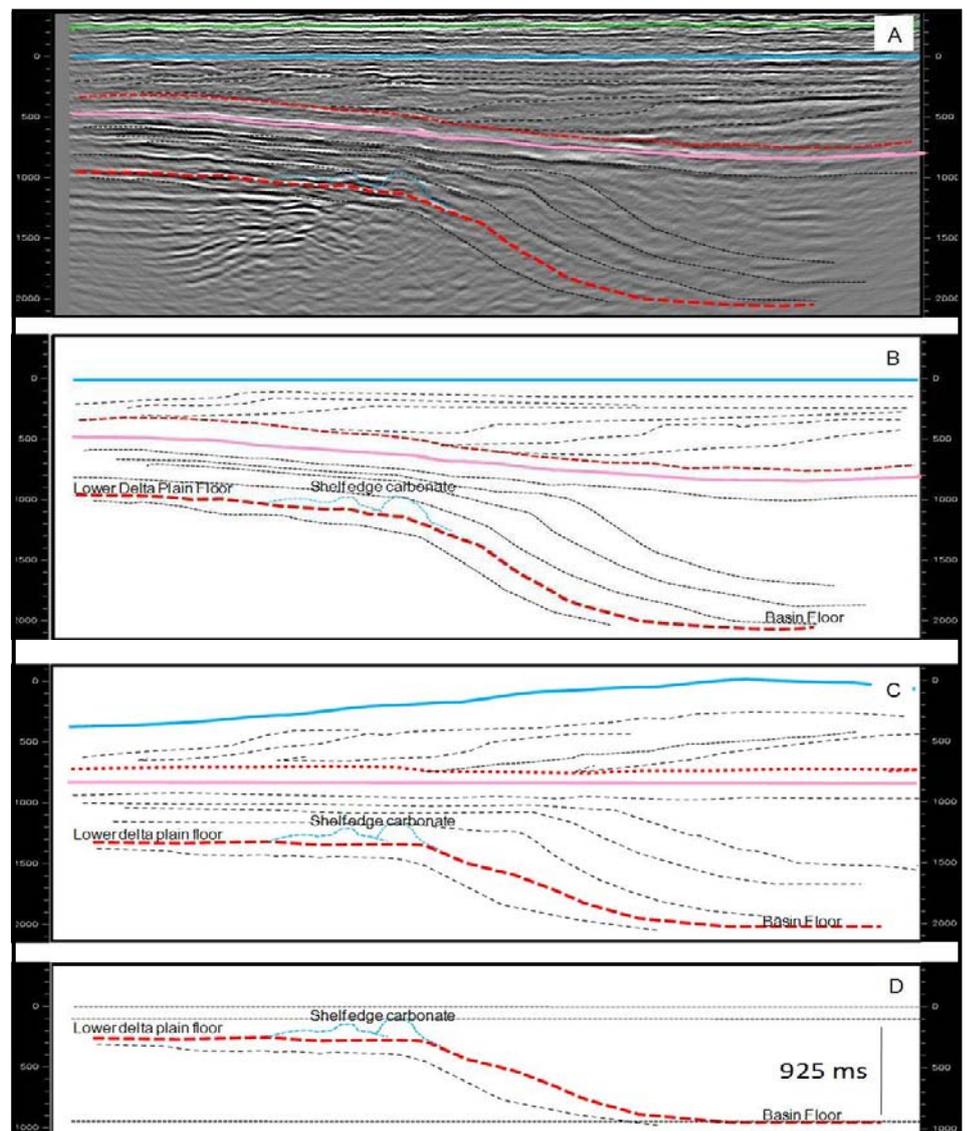


Figure 3. Simple application of seismic stratigraphy to estimate paleo-bathymetry in Late Oligocene stratigraphic unit. (A) Seismic interpretation flattened on Early Miocene Blue horizon. The Late Oligocene Pink and Oligocene lower dashed Red horizon in deformed state. (B) Schematic drawing based on seismic reflector tracing shows possible shelf edge setting with carbonate build up below Pink horizon. (C) Section flattened on Pink horizon shows a clearer flat reflector on delta plain above dashed Red horizon, clinoform complex and possible basin floor downlap surface. Lower dashed Red horizon is the chronostratigraphic surface. (D) Delta plain to basin floor relief graphical measurement indicates 925 ms time relief equivalent to +1,110 meters.

analog to its modern cousins as described in Figure 2.

Could this technique be applied to estimate paleo-bathymetry of much older and deformed strata? First, it will be ideal to have the seismic section in un-deformed state by restoring the section through balanced cross section, but in less faulted area simple horizon flattening in some cases will do the job. Simple horizon flattening may provide enough vertical restoration to have the correct impression of which end is the

shallow and the deeper depositional setting. The illustration in Figure 3 is the schematic section of sequentially restored seismic section example using simple horizon flattening technique from southern Mahakam delta area.

Seismic section displayed on Figure 3 originally deformed as an anticline, therefore to do seismic stratigraphic interpretation on the lower part is almost impossible. Sequential flattening technique started from Blue horizon to Pink horizon helps us to properly

observe some seismic stratigraphy features and determine which area is the shallow and the deeper deltaic setting. When the section was flattened on Pink horizon, we start to see some familiar pattern related to deltaic setting including parallel reflections on the left, offlap, clinoform complex in the middle and possible downlap pattern and basin floor parallel pattern on the right end.

With the same technique as previously discussed, we can estimate the minimum water depth at the time the dashed Red horizon stratigraphic unit was deposited. In this case we use top of carbonate build up growing on top of Red horizon as the shallow marker and break of slope as the shallow area indicator and while downlap and parallel pattern as the deeper basin location indicator. The structural difference between those two features is about 925ms (OWT). Having interval velocity at this package of about 1,200m/s, the relief between the two locations will be about 1,110m.

Mounded shape at the left end may be shelf edge carbonate build up in which normally carbonate forming organism live in photic zone in 50-100 meters water where sun light can penetrate into the water. Adding up carbonate water depth 50-100 meters to 1,110 meters relief, the paleo-bathymetry of sedimentary basin was at least 1,160-1,210 meters deep. When a more accurate estimation is needed, decompaction calculation must be taken into account, but even without it,

we already got a sense of how the depositional setting once looked like.

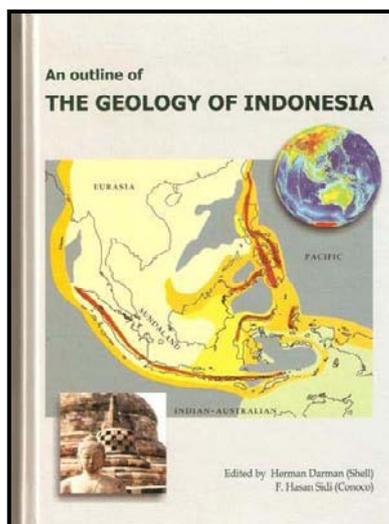
Conclusion

Seismic interpretation is not all about creating smooth structural maps. If we squeeze a little bit more out of seismic data, it can provide us some important information. By knowing the range of water depth of particular stratigraphic package we can think of what geological processes might have occurred within that particular interval during its deposition or estimating possible lithological facies variation within the stratigraphic unit. This simple step of paleo-bathymetry estimation technique will drive the interpreter to think in geological sense and have better understanding of scale aspect while interpreting seismic data. Other advantages of doing such approach are: Seismic Interpreter will have the sense of depositional scale and basin configuration. Correct sense of landward, seaward direction, basin slope angle and depositional relief can be achieved. We will also have a better sense of how deep the water was and how much the minimum accommodation space available. Seismic interpreters will have the ability to infer what type of transport system and associated reservoir geometry within each depositional setting. When it is combined with complete biostratigraphic analysis, the evaluation of lateral accretion or progradation rate of delta deposition evaluation will be possible to do. As a closing note, this simple paleo-bathymetry estimation

using seismic stratigraphic features alone will not be quantitatively accurate but it can make seismic interpretation work more geologically meaningful and much more fun.

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Paleosols as An Alternative Method to Define Sequence Boundary in Fluvial System: A Case Study in Semberah Field, Kutei Basin

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Abstract

Difficulties in reconstructing sequence stratigraphic framework of the Semberah Area, East Kalimantan, have brought up an idea to use paleosols to solve the problems. The Semberah Area has dominantly fluvial deposits, which are characterised by the presence of many erosional channel bases. In a vertical sequence, the erosional channel base cannot be easily distinguished from a sequence boundary, therefore, in order to help in sequence stratigraphic interpretation, a research on paleosols of the Semberah Field, Kutai Basin, has been undertaken.

The research mostly utilizes outcrop data above the Semberah Field, where the equivalent of the producing units is exposed. The outcrops are correlated to subsurface well data (logs and cores) and seismic lines to analyze their significance in the Sequence Stratigraphic Framework. A total of 21 outcrops have been described sedimentologically and subsequently investigated for their paleosol occurrences. The research documents 52 discrete occurrences of paleosols in the Semberah outcrops with individual paleosol thickness ranges from 25 to 225 cm. The results of the research show that paleosols are found ubiquitously in deltaic sediments in the Semberah Field. The common distributions of paleosols in the Semberah area consist of Argilisol 16%, Histosol 16%, Oxisol 8%, Protosol 6%, Spodosol 50% and Vertisol 4%. The Gleysol, Calcisol and Gypsisol are not found. The occurrence of paleosols within a Highstand Systems Tract (HST) is 70.6% well-developed with maturity varies from weak to moderate (stage 2

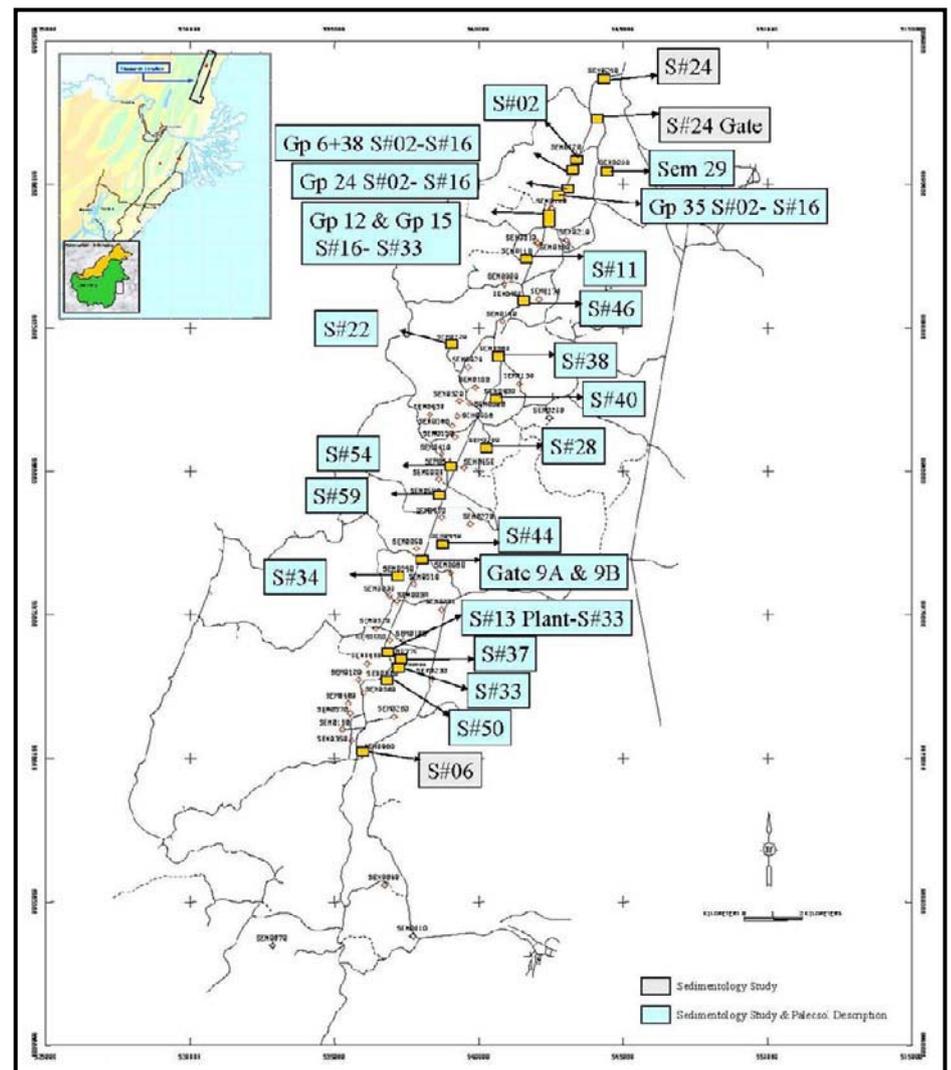


Figure 1. The research location of *Paleosols* study in Semberah Area, Kutei Basin.

to 4). The low accommodation space supports paleosols to develop well with its upper boundary most likely is associated with sequence boundary. The paleosol distribution within an Incised Valley Fill (IVF), Lowstand System Tract (LST) and Transgressive Surface of Erosion (TSE) are very well-developed with percentage of their occurrence as 3.9%, 1.9% and 1.96% with their maturity varies from moderate to strong (stage 4 to stage 5). In general, they will associate with an

erosional channel base known as sequence boundary at the bottom end border. Paleosols are not found in the beginning of Transgressive System Tract (TST) in Semberah area which is commonly characterized by the occurrence of Hydromorphic Paleosol. During the Transgressive System Tract (TST), the paleosols are not well-developed or even obstructed with percentage of their occurrence within the area as 21.5% and the maturity varies from stage 2 to stage 3.

Introduction

During the past decade, the research of Sequence Stratigraphy has progressed much, especially driven by practical need in oil & gas industry to reconstruct lateral continuity and reservoir character within time and space framework.

The application of Sequence Stratigraphy in fluvial deposits is still a topic of hot debate (Galeazzi and Vail, 1992; Wright and Marriott, 1993; Miall, 1996). The main problem is caused by the difficulties in recognising the indicator of sea level fluctuation, which is used as a basic indicator to divide the sequence stratigraphic components of fluvial or continental deposits. Many researchers (e.g.: Miall, 1996; Posamentier and Allen, 1993; and Posamentier and Allen, 1999) considered that in fluvial or land environment, local tectonic is the main and the most important factor that creates accommodation space and not sea level change.

Most of Indonesia's hydrocarbon reservoirs are of fluvial deposits, so understanding the model and character of reservoir within time and space is the most important and unconditional thing. One of the methods used as a tool in correlation and reconstruction to know the reservoir relationship in fluvial deposits is by relating paleosols to a sequence boundary.

The study of paleosols in fluvial deposits have not been done in Semberah Field or even in the Kutai Basin. The main difficulties in doing correlation with Sequence Stratigraphic method in fluvial deposits have been explained by Pangarso (2000), on his surface geological mapping of Lampake area. The explorationists of Kutai Basin also have the same difficulties when doing subsurface correlation of fluvial deposits in many oil & gas fields (Bachtiar, 2000, *personal communication*). Using and applying paleosols as a tool is necessary as an alternative method in solving such correlation problem.

As references, many publications that discuss about paleosols and fluvial sequence stratigraphy have been

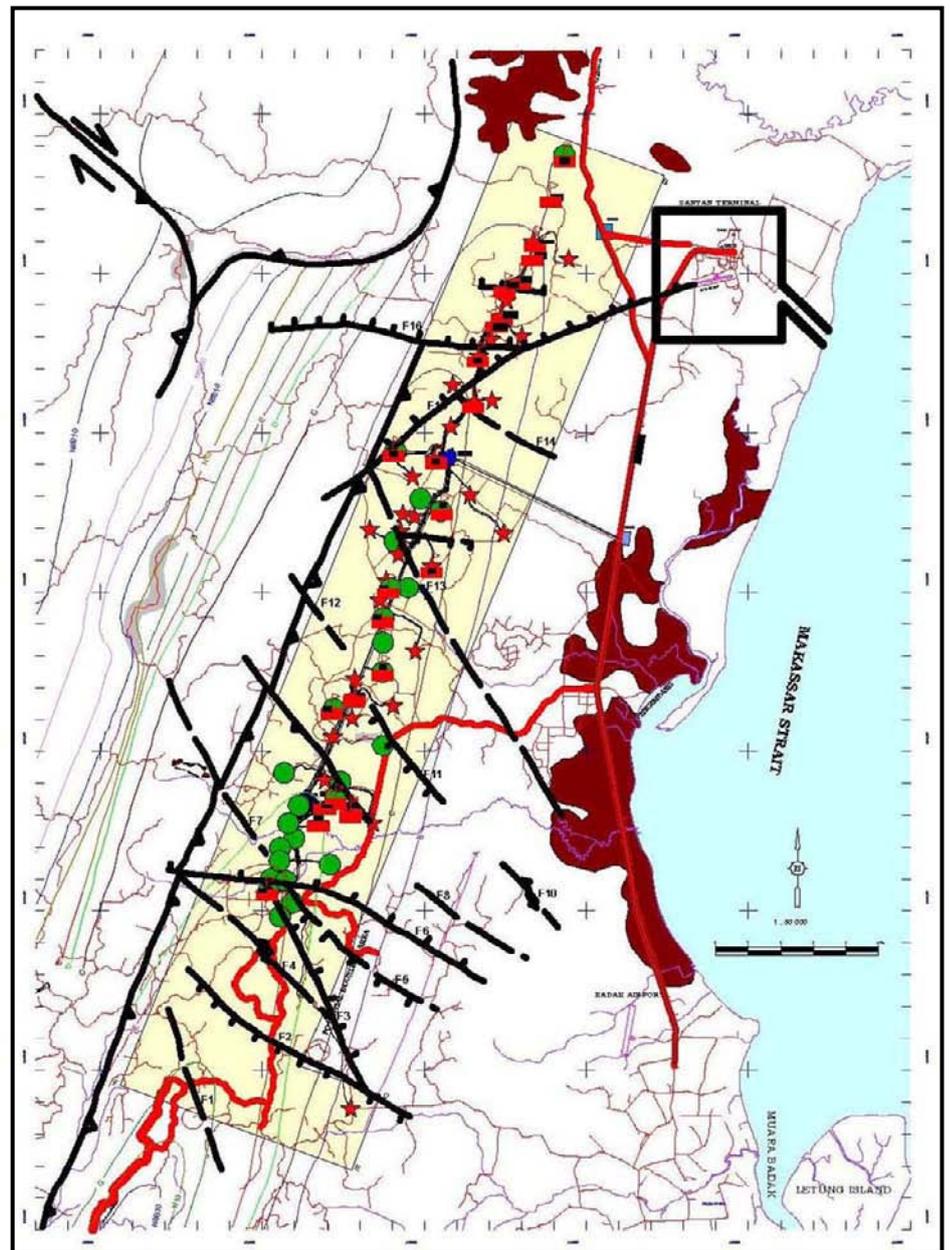


Figure 2. A Basemap showing well location (red star = gas & green circle = oil), outcrop & paleosols description location (red rectangle) and geological structure trends & pattern in Semberah Field - Kutai Basin. Interpreted from SAR data and Field mapping (modified from Bachtiar et.al., 1999).

published, such as Galeazzi and Vail (1992), which discussed the sequence stratigraphy of fluvial environment; Kraus (1999) who published a lot of paleosol's applications; Retallack (1997) that published the color guide to paleosols; Wright and Marriott (1993), which discussed sequence stratigraphy of fluvial depositional system; and Miall (1996) that published special books of characteristics of fluvial environment. The studies of paleosols have been also applied to many depositional environments such as explained by Kraus (1999), including eolian, palustrine, and deltaic depositional environments. Paleosols

can also be founded in marine environment if the sea level dropped until the marine deposit exposed and then followed by soil forming.

The initial survey that have been done by VICO Indonesia (*unpublished*) and the authors (Kurniawan *et al.*, 2001) shows that there are at least 26 outcrops along the Semberah anticline that show good indication and ideal to sedimentological study. Some of them have suitable characteristics to be used in paleosol study in fluvial deposits. About 61 wells have been drilled and more than 100 km seismic lines have been recorded along the Semberah

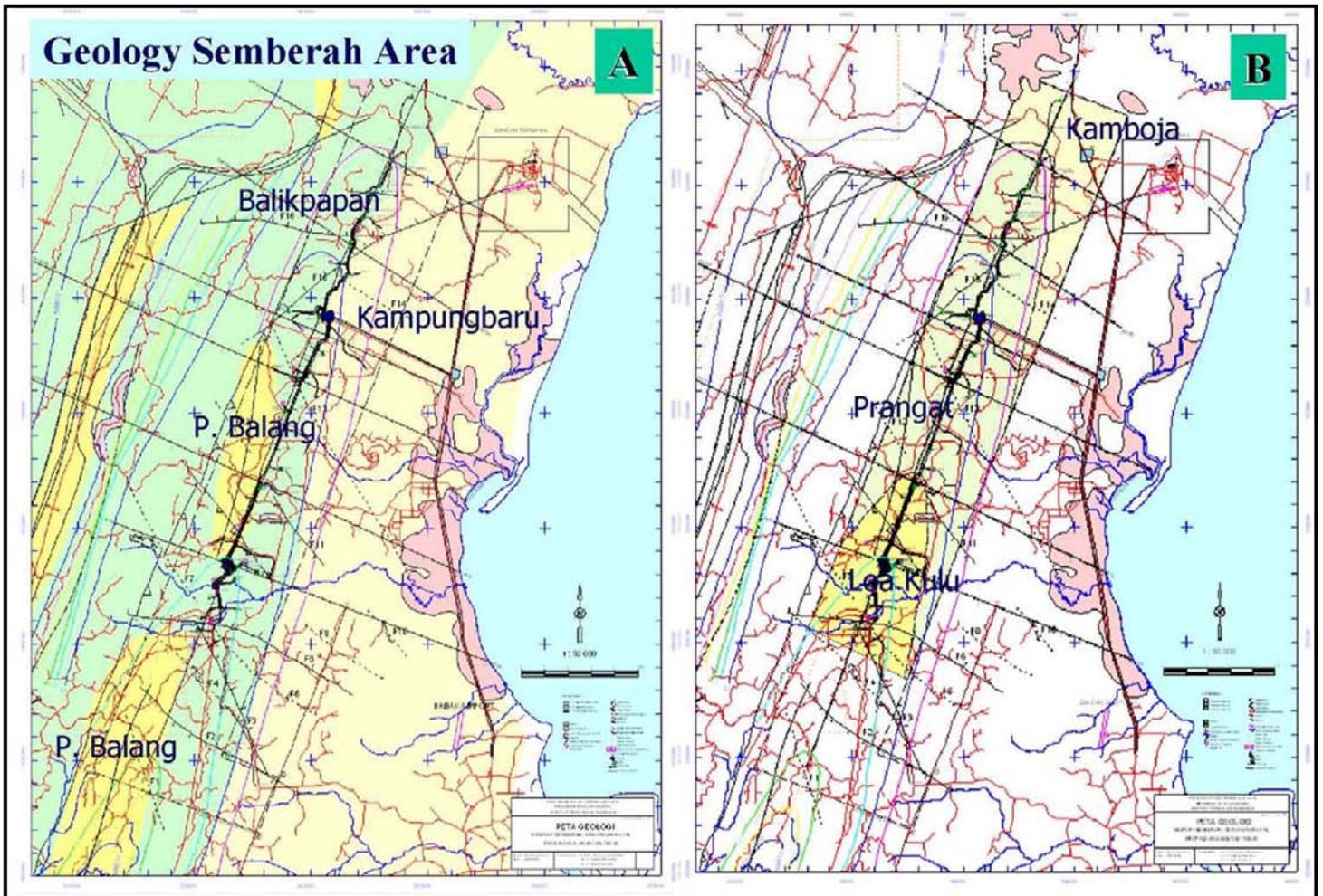


Figure 3. Geological map Semberah area; GRDC Bandung (A) and Chambers (B). The differences of both are in the formation name.

Anticlinal axis by VICO Indonesia, which permit the construction of outcrop correlation to subsurface data.

The purpose of the research are: 1) to document the occurrences of paleosols in the stratigraphic column, 2) to characterise the physical, chemical, and sedimentological features of the paleosols, and 3) to seek for their significance in Sequence Stratigraphic framework.

Geology of Semberah Field

The Semberah Field lies within Muara Badak sub district, Samarinda regency, East Kalimantan province, geographically spread out from 117° 15' 00" E – 117° 25' 00" E and 0° 10' 00" S to 0° 20' 00" S (Figures 1 & 2). The coverage of research area is about 150 km² (almost 86% of Semberah field acreage). The research area can be reached with land transportation using car or bus from Balikpapan to

GENERAL STRATIGRAPHY SAMARINDA AREA

From Chambers, et.al., 1992

Stratigraphy of leupold and van der Vlerk (1931)			Land and Jones, 1987			Chambers, et al, 1992		
	System	Blow Zone	Formation	Thickness (m)	Environment	Formation	Environment	
KAMPUNG BARU BEDS Tgh	Pliocene	N 19						
		N 18	(top not seen)					
UPPER BALIPAPAN BEDS Tf 3	Upper Miocene	N 17	KAMBOJA FORMATION	470	Alluvial floodplain	KAMBOJA FORMATION	Alluvial floodplain	
LOWER BALIPAPAN BEDS Tf 2		N 16						
	Middle Miocene	N 15	PRANGAT FORMATION	1375	Alluvial floodplain	PRANGAT FORMATION	Alluvial floodplain	
		N 9 to N 14	unconformity					
PULAU BALANG BEDS Tf	Lower Miocene	late	N 8	LOA KULU FORMATION	800	Deltaic to Marine Shelf	LOA KULU	
				LOA DURI FORMATION	450	Deep Marine	BATU PUTIH	Deltaic to Marine Shelf
		Early		Batuputih Limestone	2-50	Shallow Marine	LOA DURI	
BEBULU BEDS Te 4-5		N 7				?	?	
		N 6				(Mud Volcano)	Bathyal	
PAMALUAN BEDS Te 1-3	Upper Oligocene	N 5				?	?	
		N 4						

The age of the top and bottom of the Prangat Formation is uncertain

Figure 4. The Equivalent of Kutai Stratigraphic Column (modified from Chambers, 1992).

Samarinda then from Samarinda to Muara Badak, and finally from Muara Badak, we can use a motorcycle to the research location.

Physiographically, the Semberah Area is located in the northern part of Samarinda Anticlinorium in the lower Kutai basin. Referring to the morphology of modern Mahakam Delta, the Semberah Field is located in the northern part mainland from the center of active delta development.

Based on lithostratigraphic nomenclature arrangement and similarity of formation name of Land and Jones (1987), the lithology that outcrops in the research area consists of Loa Kulu, Prangat and Kamboja Formation, and consists of continues sedimentation series of paleo-Mahakam deltaic sediments of Middle Miocene to Pliocene age (Figures 3B & 4). Fluvio-deltaic to shallow marine deposits generally dominate the clastic sediments. Paleosols are proved to be well-developed in the fluvio-deltaic deposits within all formations that exist in the research area. The geological structure developed in the Semberah area is a plunging anticline toward northeast along +/- 50 km and the equivalent production zones of the Semberah Field are exposed in the upper-end of this anticline (Figure 3). The Semberah anticline is the northern part of Samarinda anticlinorium, which is bordered by NE-SW thrust fault in the west and dipping abruptly to the east in the shoreline area. Some cross-faults were also documented crossing the axial crest of the anticline (Bachtiar *et al.*, 1999). There is no 3D seismic data to clearly identify these cross faults continuing in the deep subsurface, but we still can trace them with the available 2D seismic data.

Problematic

The research was initiated from the difficulties of (1) applying sequence stratigraphy concept to correlate and reconstruct reservoir connectivity in fluvial depositional system. The main problem is caused by the difficulties in recognizing the indicator of sea level fluctuation, which is used as a basic

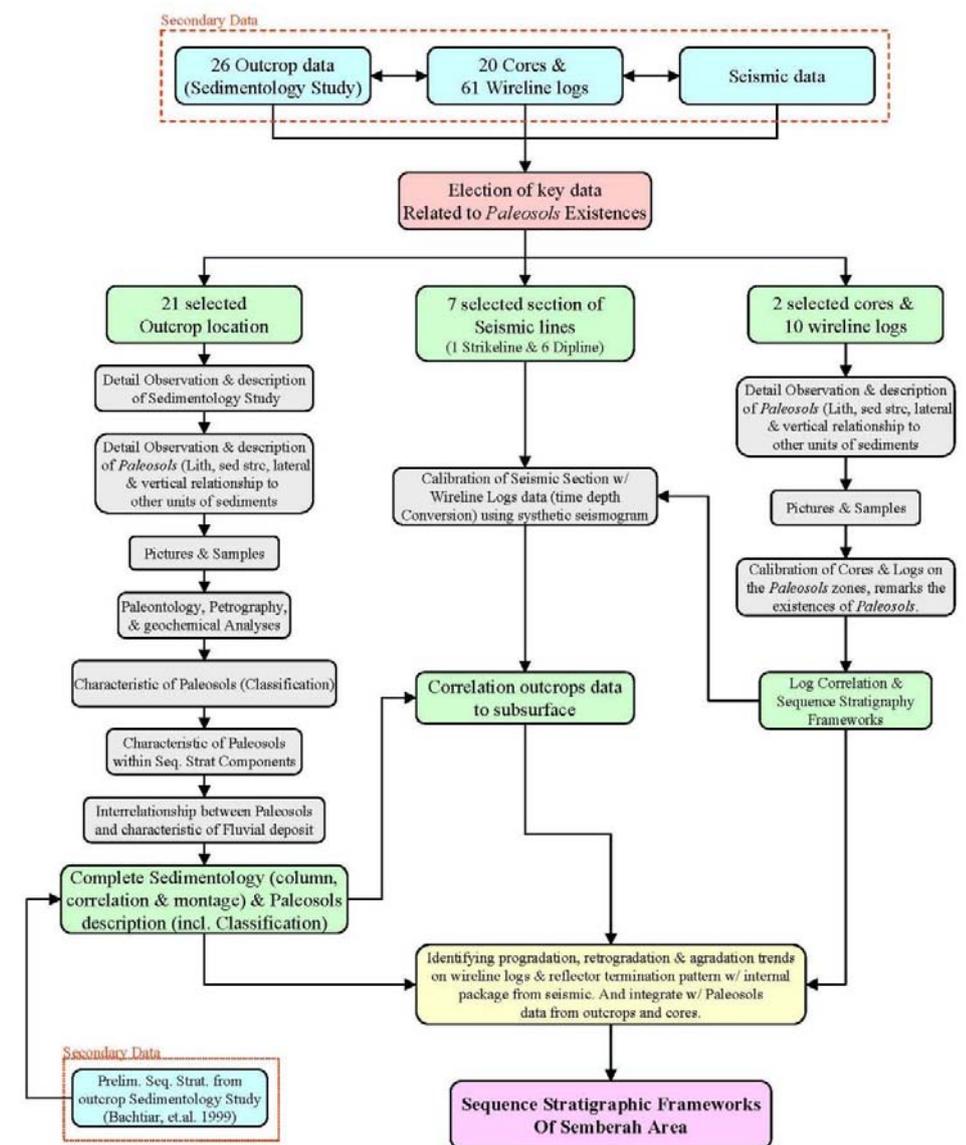


Figure 5. Research Flow Chart, use primary data (21 outcrops, 7 seismic line, 10 wells, 2 cores) and secondary data (26 outcrop sedimentology study, seismic line, 61 wells, 20 cores, sequence stratigraphy framework from previous study).

indicator to divide the sequence stratigraphic components of fluvial and continental deposits, (2) most of Indonesian's hydrocarbon reservoirs are of fluvial deposits, so understanding the model and character of reservoir within time and space is the most important and unconditional thing, (3) there is no detail correlation where sequence stratigraphic concept was applied in the Semberah area, and (4) the importance of paleosols study in Semberah area as one of alternatives correlation methods and reconstruction of reservoir connectivity within fluvial depositional environment.

The utilisation of paleosols as a tool is necessary as an alternative method in solving the correlation problem

mentioned previously. In order to understand very well the solution to this problem, the work to be done include: (1) introduction to soil in the field with specific understanding of the relationship between paleosols and indication of sequence boundary, (2) explaining the development, maturity, model, classification and detailed description of paleosols as indication of sequence boundary, (3) correlation and reconstruction the reservoir relationship within fluvial depositional environment by understanding the relationship of paleosols, and (4) evaluating the available paleosol classification (Mack *et al.*, 1993; Soil Survey Staff, 1975; 1998) to be applied in the Semberah area.

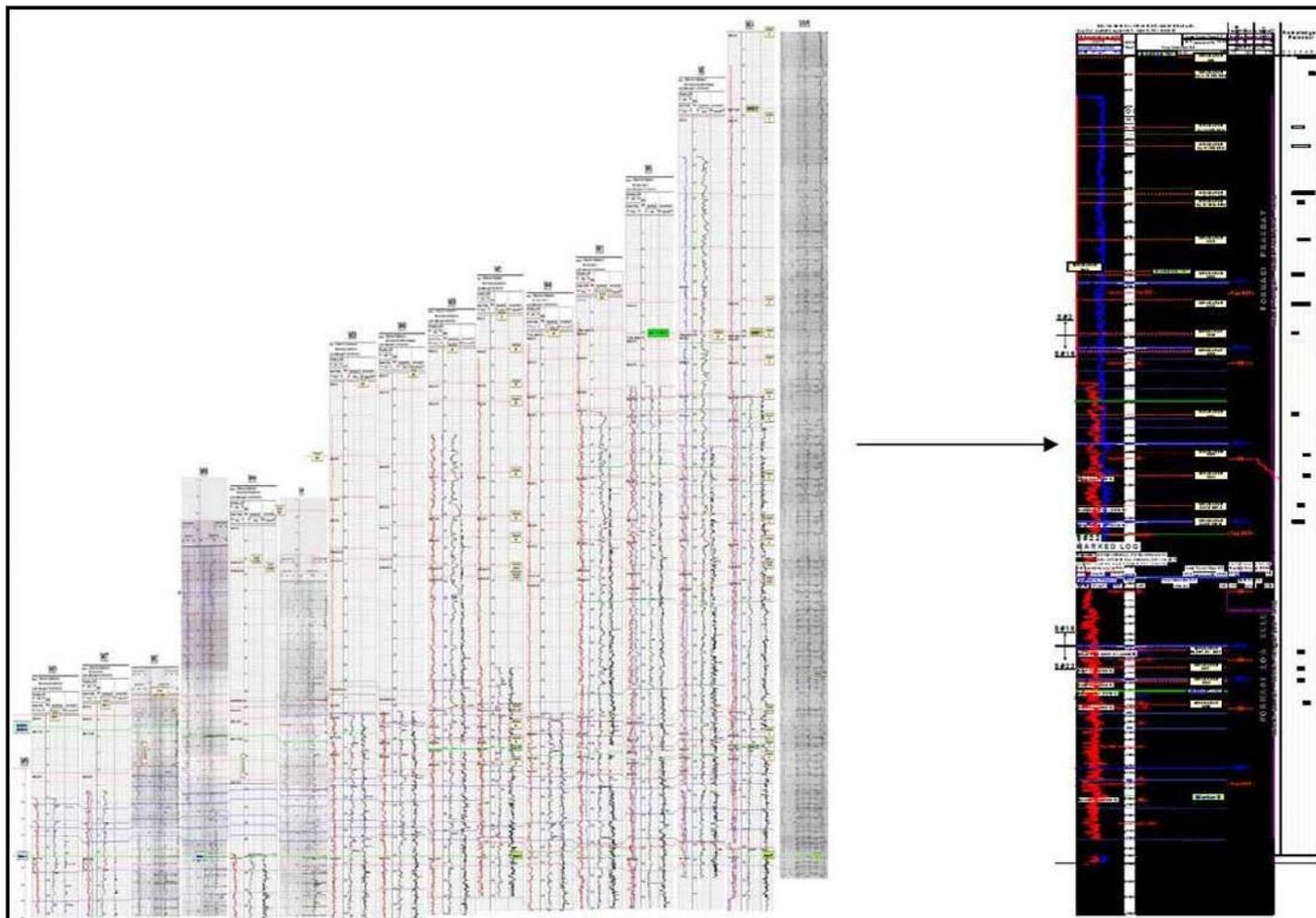


Figure 6. Wireline log correlation to place the 21 outcrops and 16 wells into sequence stratigraphic framework of Semberah area; resulted 8 sequences and then summarize into composite sequence stratigraphic log. All individual markers and outcrop then plotted to seismic correlation.

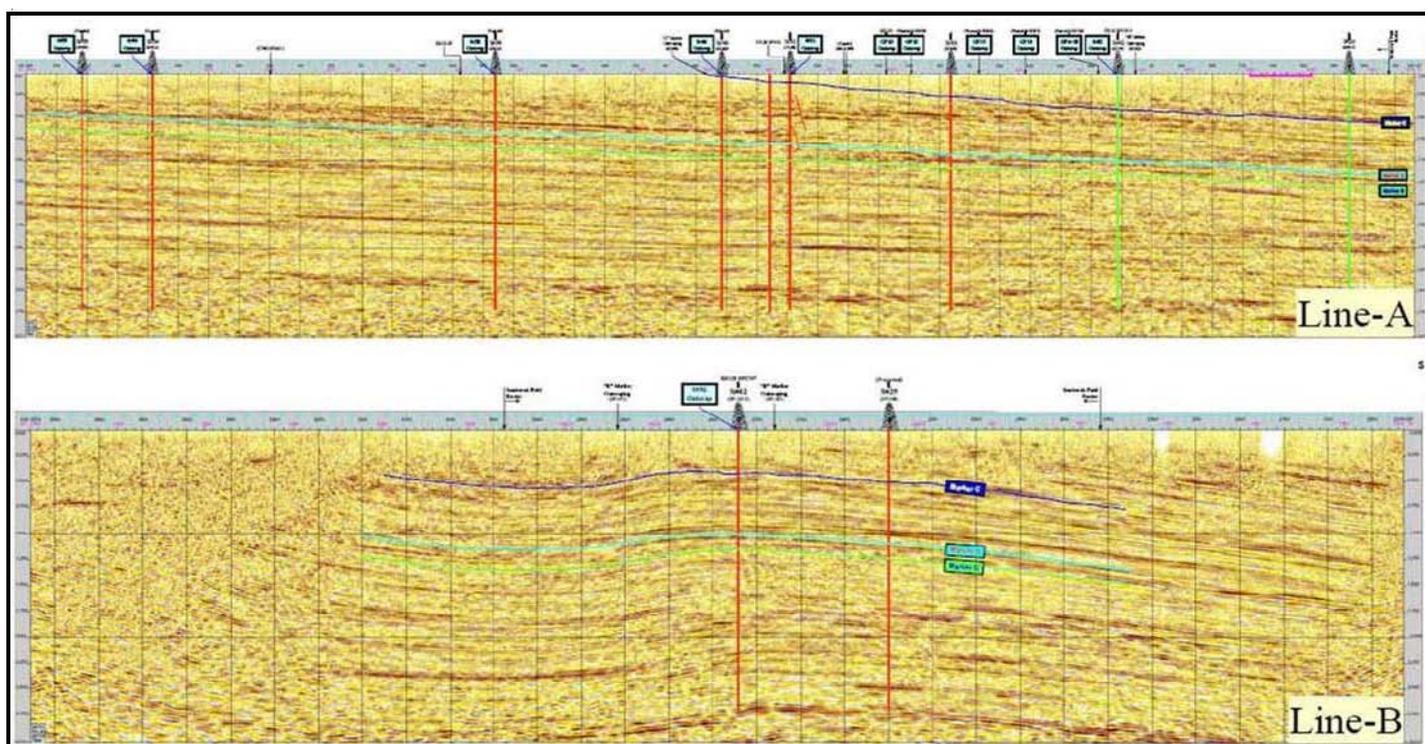


Figure 7. One of seven seismic correlation to place the 21 outcrops and 16 wells into sequence stratigraphic framework of Semberah area. This correlation was initiated by determining key seismic section line, which across drill hole points and chosen outcrops, calibration of seismic section with well logs data (Time depth conversion) using synthetic seismogram and correlation outcrops data to subsurface using chosen seismic section (final stacked / migrated hard copy) as guidance.

From previous studies and publications, it can be summarised that: (1) classification and type of paleosols represent the sedimentary process and rate of pedogenesis, (2) paleosols can develop well in HST due to low accommodation space, (3) paleosols can develop very well in LST and are associated with erosional channel base, (4) *hydromorphic paleosols* will develop only in the beginning of TST due to the increase of base level, accommodation space still low and overlap with channel sandstone, (5) as the accommodation space increases and sediment accumulation occurs faster in TST, paleosols will not develop or even will be obstructed.

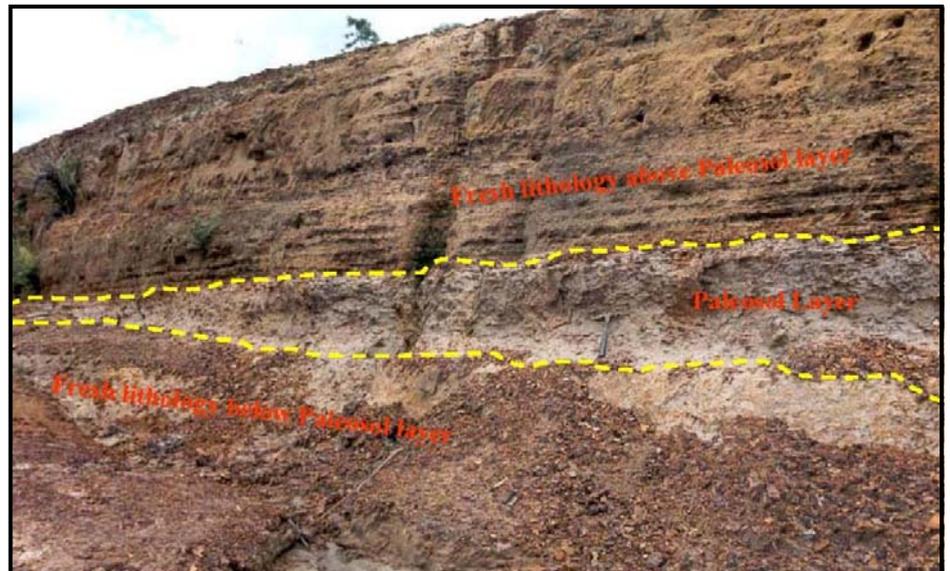


Figure 8. Step-1 in Paleosol description: describe Rock Type of paleosol; define fresh lithology within paleosols layer, fresh lithology above and below the paleosols layer (Mack, et.al., 1993).

Methods

The field study was undertaken in February 2001 for three weeks to document and describe many types of paleosols in the Semberah Field in order to find their similar characteristics, classify them and to apply this knowledge of paleosols within Sequence Stratigraphic framework in the Semberah Area.

The research uses outcrops, wireline logs, cores, seismic section and laboratory data (Figure 5).

1. Outcrop Data

- Determination of key outcrops by identifying the existences of paleosols from about 26 outcrops along the Semberah Anticline. About 21 outcrops are available to study paleosols (Table 1).
- Detailed observation and description of sedimentological study in the selected outcrops.
- Detailed observation and description of paleosols in the chosen outcrops including lithology description, sedimentary structures and the lateral & vertical relationship to the other units of sediments.
- Photo documentation and samples. Systematically, the samples are collected at three part of observation, i.e.: at the paleosol interval, upper part and lower part of the paleosol

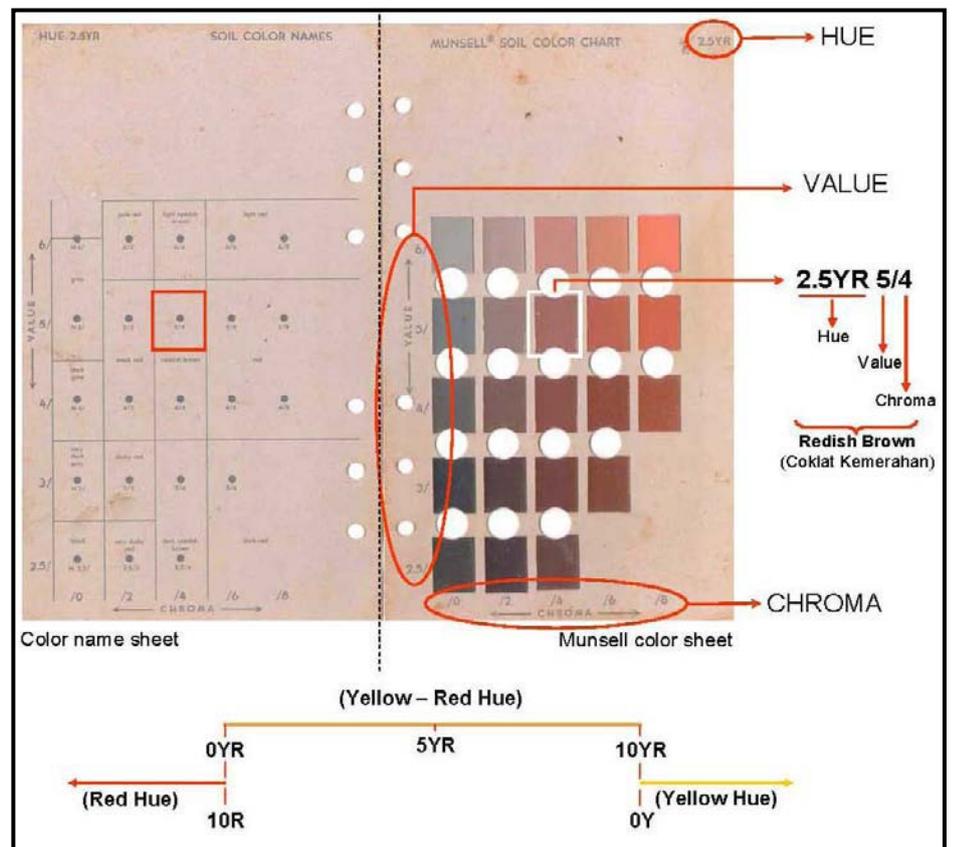


Figure 9. Step-2 in Paleosol description: define the Color, initiated with HUE then VALUE

interval, the amount of samples depend on the variation of existences of paleosols in the outcrops, usually indicated by a clay to very fine sand grained size and reddish brown or Fe-oxides colors. The next step is data processing in laboratory.

2. Core and wireline log

- Determination of key cores by identifying paleosols in about 20 cores along the Semberah Anticline. It is difficult to find paleosols in the Semberah cores due to less lithological variation in core preservation (most of them are sandstones), but some

of them do have paleosols (Figure 6).

- Observation and detailed description of paleosols on selected cores, including detailed description of lithology, sedimentary structures and lateral & vertical relationship with other units of sediment.
- Calibration of cores with wireline logs on the zones, which have paleosols and note the existences of the paleosols (Ye, 1995).

3. Seismic Section

- Determination of key seismic section lines that can be tied to borehole points and selected outcrops.
- Calibration of seismic section with well logs data (Time-Depth conversion) by using synthetic seismogram.
- Correlating outcrops data to subsurface by using selected seismic section (final stacked/migrated hard copy) as a guidance (Figure 7).

4. Laboratory Data

- Paleontological analysis of selected outcrop to complete secondary data, which have been done previously by GDA team (Bachtiar *et al.*, 1999). The objective is to know the depositional environment from sediment units of the outcrops and later on will be applied to sequence stratigraphic frameworks.
- Petrographic analysis of selected outcrop samples taken from paleosol intervals. The objective is to know the development degree, maturity, model and classification of paleosols.

Paleosols identification

Paleosols can be defined as soils that formed on a landscape in the past that were caused by a physical, biological and chemical modification from an exposed sedimentary rock (Kraus, 1999). According to Ailsa and Michael (1990), paleosols are soils that formed

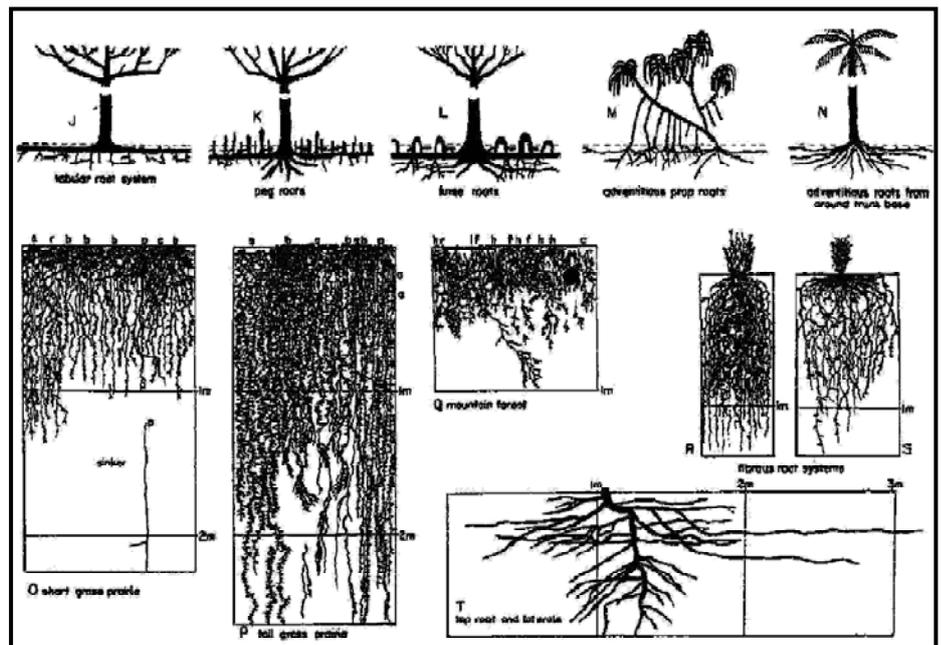
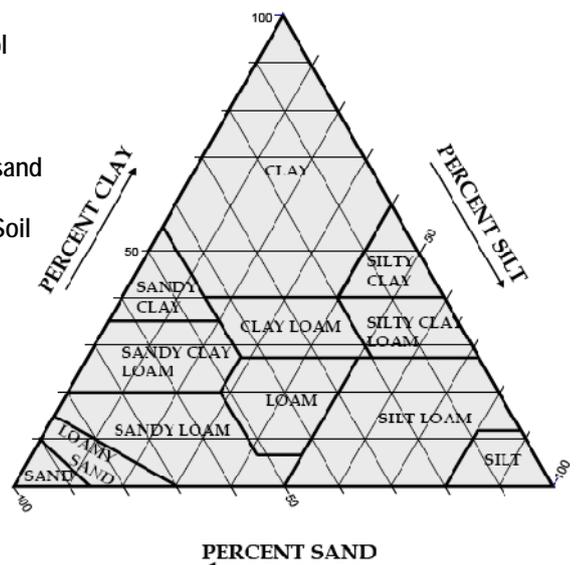


Figure 10. Step-3 in Paleosol description: describe Nature of Root Traces, with compare the appearance of root distribution in outcrop with model from Retallack, 1988.

TYPE	PLATY	PRISMATIC	COLUMNAR	ANGULAR BLOCKY	SUBANGULAR BLOCKY	GRANULAR	CRUMB
SKETCH							
DESCRIPTION	tabular and horizontal to land surface	elongate with flat top and vertical to land surface	elongate with domed top and vertical to surface	equant with sharp interlocking edges	equant with dull interlocking edges	spheroidal with slightly interlocking edges	rounded and spheroidal but not interlocking
USUAL HORIZON	E, Bs, K, C	Bt	Bn	Bt	Bt	A	A
MAIN LIKELY CAUSES	initial disruption of relict bedding; accretion of cementing material	swelling and shrinking on wetting and drying	as for prismatic, but with greater erosion by percolating water, and greater swelling of clay	cracking around roots and burrows; swelling and shrinking on wetting and drying	as for angular blocky, but with more erosion and deposition of material in cracks	active bioturbation and coating of soil with films of clay, sesquioxides and organic matter	as for granular, including fecal pellets and relict soil clasts
SIZE CLASS	very thin < 1 mm	very fine < 1 cm	very fine < 1 cm	very fine < 0.5 cm	very fine < 0.5 cm	very fine < 1 mm	very fine < 1 mm
	thin 1 to 2 mm	fine 1 to 2 cm	fine 1 to 2 cm	fine 0.5 to 1 cm	fine 0.5 to 1 cm	fine 1 to 2 mm	fine 1 to 2 mm
	medium 2 to 5 mm	medium 2 to 5 cm	medium 2 to 5 cm	medium 1 to 2 cm	medium 1 to 2 cm	medium 2 to 5 mm	medium 2 to 5 mm
	thick 5 to 10 mm	coarse 5 to 10 cm	coarse 5 to 10 cm	coarse 2 to 5 cm	coarse 2 to 5 cm	coarse 5 to 10 mm	not found
	very thick > 10 mm	very coarse > 10 cm	very coarse > 10 cm	very coarse > 5 cm	very coarse > 5 cm	very coarse > 10 mm	not found

Figure 11. Step-4 in Paleosol description: describe the Soil Structure based on classification of soil peds above. It is simplified from classification from Soil Survey Staff (1975) and Birkeland (1984).

Figure 12. Step-5 in Paleosol description: classify the Soil Texture. The Chart showing the percentage of clay (below 0,002 mm), silt (0,002-0,005 mm), and sand (0,05-2,0 mm) in the basic soil textural classes (modified from Soil Survey Staff, 1992).



on past *pedogenesis**) period, and have been buried, later on re-exposed, or continuously exposed on a landscape until present *pedogenesis* period.

Paleosols in outcrops can be recognized by identification of three main features of root traces, soil horizons, and soil structures (Retallack, 1988). Fenwick (1985) suggested some criteria in recognising paleosols in the field, i.e.: the presence of surface horizons enriched in organic matter, red-colored horizons that become more intense in color toward the top, marked decline in weather-able minerals toward the top of the soil profile, and disruption of original structures by organisms such as earthworms or by physical processes such as frost action and solifluction.

Paleosols can also be recognized in wireline logs by identifying the log responses of paleosol set and non paleosol set (Ye, 1995). Actually, it is not easy to recognize the individual of paleosols in wireline logs because the average thickness is only about 1–2 meters, which means it is not thick enough to see in the wireline log. However, the development of paleosol set is commonly within tens meters. Paleosol set means extensive development of paleosols, while non paleosol set means little or non development of paleosols.

The classification of paleosols used in this research is modified from the available classification and not all of the paleosols has been genetically applied as a regional sequence boundary, but only paleosols that are associated with the lower boundary of LST or the upper boundary of HST that can be used as alternative tool in sequence stratigraphic correlation within fluvial depositional environment. The profile, development and maturity of paleosols can help to identify the specific character of equivalent system tract and can be correlated.

**Pedogenesis* is the natural forming of soil processes by many processes such as humidity, weathering, leaching and weathering in limestone.

New Term	Description	Old Term	
O	Surface accumulation of organic materials (peat, lignite, coal), overlying clayey or sandy part of soil	O	MASTER HORIZON
A	Usually has roots and a mixture of organic and mineral matter; forms the surface of those paleosols lacking an O horizon	A	
E	Underlies an O or A horizon and appears bleached because it is lighter colored, less organic, less sesquioxidic, or less clayey than underlying material	A2	
B	Underlies an A or E horizon and appears enriched in some material compared to both underlying and overlying horizons (because it is darker colored, more organic, more sesquioxidic or more clayey) or more weathered than other horizons	B	
K	Subsurface horizon so impregnated with carbonate that it forms a massive layer (developed to stage III or more of Table 4)	K	
C	Subsurface horizon, slightly more weathered than fresh bedrock; lacks properties of other horizons, but shows mild mineral oxidation, limited accumulation of silica carbonates, soluble salts or moderate gleying	C	
R	Consolidated and unweathered bedrock	R	
AB BA E/B	Horizon with some characteristics of A and B, but with A characteristics dominant As above, but with B characteristics dominant Horizon predominantly (more than 50%) of material like B horizon, but with tongues or other inclusions of material like an E horizon	A3 B1 A&B	
a	Highly decomposed organic matter	—	SUBORDINATE DESCRIPTORS
b	Buried soil horizon (used only for pedorelict horizons with paleosols; otherwise redundant)	b	
c	Concretions or nodules	ch	
e	Intermediately decomposed organic matter	—	
f	Frozen soil, with evidence of ice wedges, dikes, or layers	f	
g	Evidence of strong gleying, such as pyrite or siderite nodules	g	
h	Illuvial accumulation of organic matter	h	
i	Slightly decomposed organic matter	—	
k	Accumulation of carbonates less than for K horizon	ca	
m	Evidence of strong original induration or cementation, such as avoidance by root traces in adjacent horizons	m	
n	Evidence of accumulated sodium, such as domed columnar peds or halite casts	sa	
o	Residual accumulation of sesquioxides	—	
p	Plowing or other comparable human disturbance	p	
q	Accumulation of silica	si	
r	Weathered or soft bedrock	ox	
s	Illuvial accumulation of sesquioxides	ir	
t	Accumulation of clay	t	
v	Plinthite (in place, pedogenic laterite)	—	
w	Colored or structural B horizon	—	
x	Fragipan (a layer originally cemented by silica or clay, and avoided by roots)	x	
y	Accumulation of gypsum crystals or crystal casts	cs	
z	Accumulation of other salts or salt crystal casts	sa	

Figure 13. Step-6 in Paleosol description: classify the Soil Horizon based on the appearance of organic material, root, clay / sand content and other material in Master Horizon and subdivided with their subordinate based on their composition, concretion/nodule, and other parameter mentioned in classification above. The classification referred to Retallack, 1988.

Carbonate Content	Reaction with Dilute Acid
Noncalcareous	Acid unreactive; often forms an inert bead
Very weakly calcareous	Little movement within the acid drop, which could be flotation of dust particles as much as bubbles
Calcareous	Numerous bubbles, but not coalescing to form a froth
Strongly calcareous	Bubbles forming a white froth, but drop of acid not doming upward
Very strongly calcareous	Drop vigorously frothing and doming upward

Figure 14. Step-7 in Paleosol description: classify the Reaction with Dilute Acid. Classification above explain the scale of Acid reaction to approximate Carbonate content of paleosols (Retallack, 1988).

Paleosols description

The features that need to be described in detail during paleosol description of the outcrop and core are: rock type, color, nature of root traces, soil structures, soil texture, soil horizon, reaction with dilute acid, nature of contact (sharpness or lateral continuity), classification and maturity (Figures 8–17).

Paleosols in Semberah Area

The sedimentology study of Semberah area has described 26 outcrops and also subsequently investigated their paleosol occurrences. The outcrops represent age range of 10.5 Ma (Late Miocene) to 7 Ma (Late Miocene–Pliocene). Based on stratigraphic nomenclature of Land and Jones (1987), in the Kutai basin especially near to the locality type in Samarinda area, they all belong to the Balikpapan/Kampung Baru Formation. The lithology was dominated by sandstones, shales, siltstones, clays and coals, which spread out within various environments in deltaic system, e.g.: fluvial channel, distributary channels, floodplains, tidal channels, mudflats, and delta front bars.

In term of paleosol description, the research has documented 52 discreet occurrences of paleosols in 21 out of 26 outcrops in Semberah area. The individual paleosol thickness ranges from 25 cm to 225 cm. Based on the classification of Mack *et al.* (1993), the paleosols are classified as spodosol with typical character of having tabular root traces, heavily mottled A & C horizons, and granular peds structures with siderite nodules. Histosol and oxisol occurred in several places but not as ubiquitously as the spodosol. The spodosol occurrences are mostly associated with the swampy nature of the sedimentary depositional environments. The distributions of paleosols are found below the erosional surface at the bottom of channel sandstones, within channel

Category	Class	Features
Sharpness	Abrupt	Transition from one horizon to another completed within 1 in (2cm)
	Clear	Transition completed within 1-2.5 in (2-5 cm)
	Gradual	Transition spread over 2.5-5 in (5-15 cm)
	Diffuse	One horizon grading into another over more than 5 in (15 cm)
Lateral Continuity	Smooth	Horizon boundary forms an even plane
	Wavy	Horizon boundary undulates, with pockets wider than deep
	Irregular	Horizon boundary undulates, with pockets deeper than wide
	Broken	Parts of the adjacent horizon are disconnected, e.g., by deep and laterally persistent clastic dikes in Vertisols

Figure 15. Step-8 in Paleosol description: categorize the Nature of Contact with layer above and below, is it sharpness or lateral continuity contact. The classification above can be described based on the paleosol layer contact features in field (Retallack, 1988).

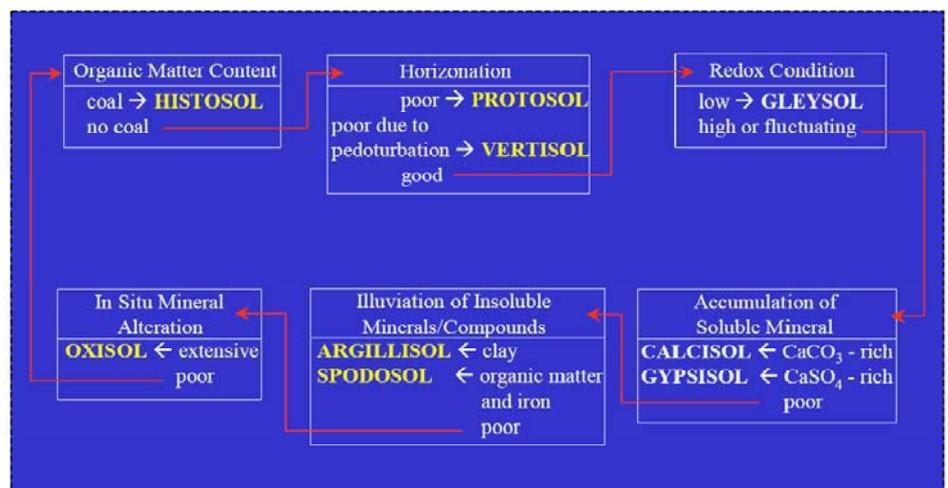


Figure 16. Step-9 in Paleosol description: Paleosols classification. The Classification above explain simple flowchart to determine Paleosols order based on pedogenic feature or process, adapted from Mack, et.al., 1993.

STAGE	0	1	2	3	4	5	6	7	8	9	10
Morphology Expression	No	not soil	weak ("band")	weak	moderate	strong	v. strong	v. strong	strong	moderate	weak
Morphology Description	geology	geology	weak solum	weak B	weak E or Bt	E and Bt normal	E and Bt thick	thick horizon	thick horizon	horizon can be disting.	horizon not clear
Horizon	D or R	C or Cr D R	A C D/R	A Bw C D/R	A E Bt C D R	A E Bt BCt C D/R	A E Bt Ct D/R	A Btt E Bt Ct D/R	A E Bto Bo Ct saprolit R	E A Bto Bo Ct saprolit R	E A Bo Ct saprolit R
Mineral Alteration	No	detected	v. weak	weak	weak	weak	moderate	moderate	strong	v. strong	complete
Key Development Character	No	Lab. evidence C	first evidence of horizon	first evidence of horizon B	first evidence E or Bt	E and Bt normal	E and Bt thick	Btt and strong weathering	Bto and strong weathering	Bo and strong weathering	v.strong weathering

Figure 17. Step-11 in Paleosol description: categorize the Paleosols Maturity. The maturity stage above explain the sequence of the development scale of paleosol maturity, started with stage-0 for normal or fresh lithology to stage-10 for very strong maturity (Follmer, 1995).

S#02; PS-01 (SPodosol – Stage 3/Weak)

Thick-ness (cm)	General Lithology	Grainsize	Munsell color	Horizon design	Descriptive (rock type)	Nature of root traces	Soil structure	Soil texture	Other Feature	Reaction with Dilute acid	Nature of contact		Remarks
											Sharpness	Lateral cont.	
0-5			10YR 5/4 (y/wsh brn)	R	Siltstone	-	-	-	-	Non calcareous	Abrupt	Smooth	Amber, coal frg., FeOx
5-10			2.5YR 4/4 (reddish brn)	O7	Sandstone (hard FeOx layer)	Tabular (infrequently)	Granular	Loamy Sand	Distinct, Common, Fine	Non calcareous	Abrupt	Irregular	Hard, FeOx
10-20			10YR 5/4 (y/wsh brn)	A	Sandstone (vf.fgr - muddy)	Tabular	Granular	Sandy Loam	Prominent, Many, Fine	Non calcareous	Clear	Wavy	FeOx, clay nodule
20-40			10YR 7/4 (v. pale brn)	B	Sandstone (vf.fgr - muddy)	Tabular (infrequently)	Sub angular blocky	Sandy Clay Loam	Prominent, Many, Fine	Non calcareous	Gradual	Wavy	FeOx, clay nodule, pH = 2
40-80			10YR 5/8 (y/wsh brn)	C	Sandstone (vf.fgr)	-	Platy	Sandy Loam	Prominent, Few, Fine	Non calcareous	Gradual	Irregular	FeOx, wavy lam, par lam, clay nodule
80-100			10YR 5/3 (brn)	R	Sandstone (fgr)	-	-	-	-	Non calcareous	Abrupt	Smooth	Wavy lam, par lam, clay drape, FeOx

S#02; PS-02 (SPodosol - Stage 4/Moderate)

Thick-ness (cm)	General Lithology	Grainsize	Munsell color	Horizon design	Descriptive (rock type)	Nature of root traces	Soil structure	Soil texture	Other Feature	Reaction with Dilute acid	Nature of contact		Remarks
											Sharpness	Lateral cont.	
0-5			10YR 5/4 (y/wsh brn)	R	Siltstone	-	-	-	-	Non calcareous	Abrupt	Smooth	Amber, coal frg., FeOx
5-10			10YR 6/4 (lg y/wsh brn)	A	Sandstone, muddy (hard FeOx layer)	Tabular	Granular	Sandy loam	Prominent, Many, Fine	Non calcareous	Abrupt	Irregular	FeOx
10-20			10YR 7/4 (very pale brn)	B	Tabular (jarang)	Tabular	Granular	Silty clay	Distinct, Few, Fine	Non calcareous	Gradual	Irregular	FeOx, pH = 4
20-40			10YR 6/3 (pale brn)	B	Tabular (jarang)	Tabular (infrequently)	Sub angular blocky	Clay	Prominent, Common, Fine	Non calcareous	Clear	Wavy	FeOx
40-100			10YR 6/4 (lg y/wsh brn)	C	Tabular (jarang)	-	Platy	Silty clay	Faint, Few, Fine	Non calcareous	Gradual	Irregular	FeOx
100-140			10YR 5/4 (y/wsh brn)	R	Sandstone (fr gr)	-	-	-	-	Non calcareous	Abrupt	Smooth	Wavy lam, par lam, clay drape, FeOx

Figure 18. An example of paleosol profile and description in Semberah Area. The paleosol unit PS-01 and PS-02 is located in Semberah-02 outcrop, a typical profile of Spodosol.

sandstones, in a series of crevasse splay deposits, and also below a transgressive surface. Sample of profile and description of paleosols in the Semberah area are shown in Figures 18 & 19.

Conclusions

1. Paleosols are found ubiquitously in deltaic sediments and can be well-documented on outcrops in the Semberah Field, Mahakam Delta,

Kutai Basin. The individual occurrence varies on each outcrop.

2. The cores in the Semberah area do not have representative paleosols because these cores were taken

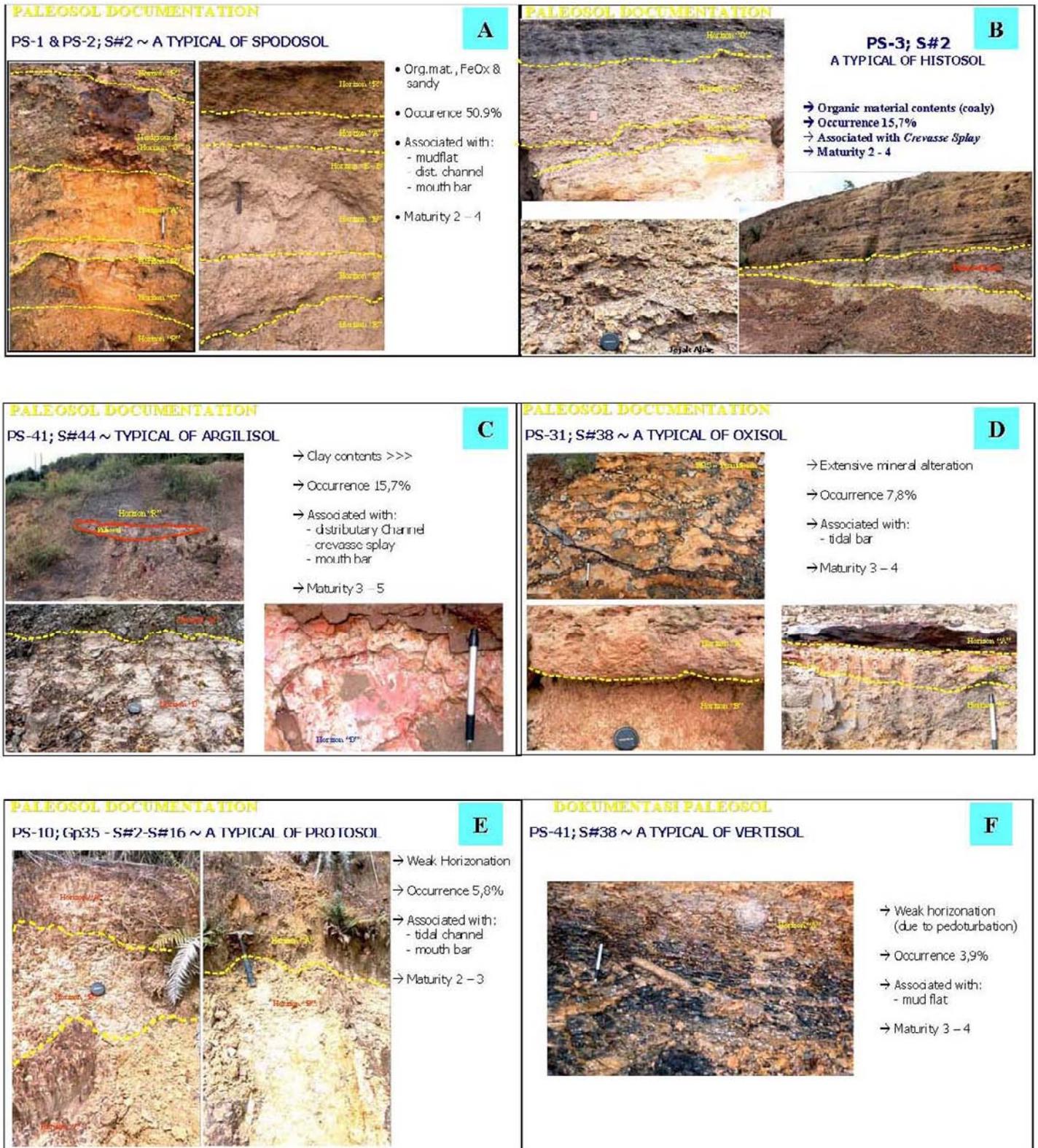


Figure 19. A typical paleosol profile in Semberah Area, (A) Spodosol, (B) Histosol, (C) Argillisol, (D) Oxisol, (E) Protosol, (F) Vertisol, using classification name from Mack et.al. (1993).

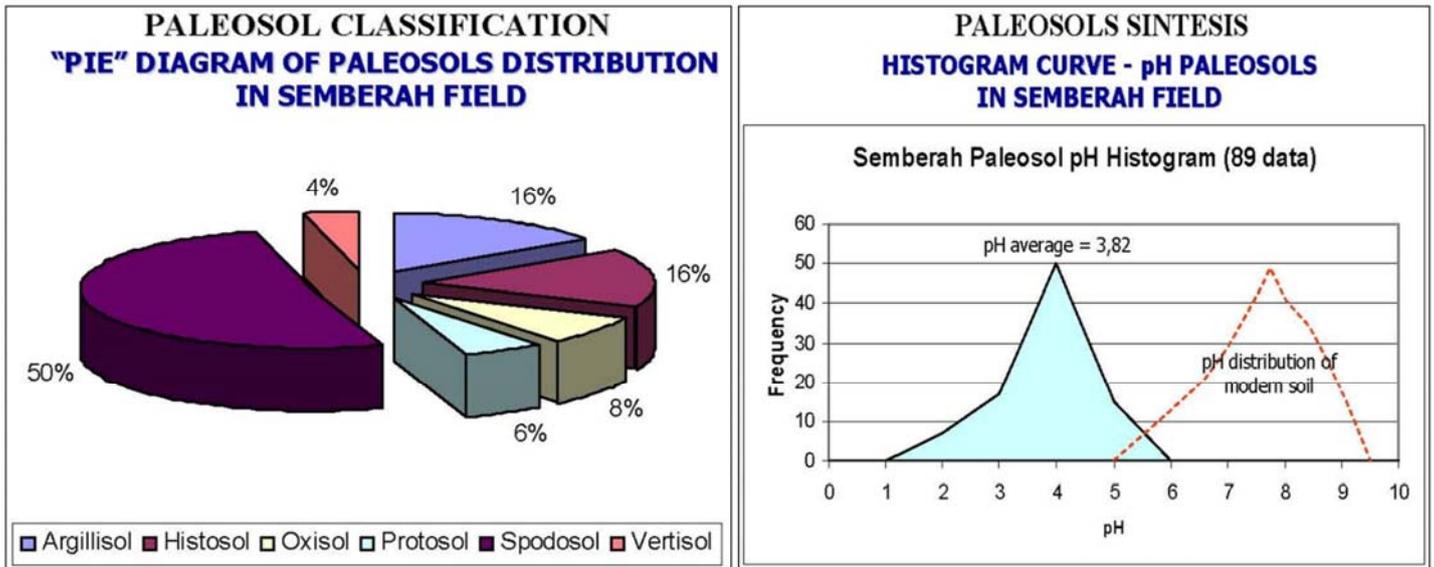


Figure 20. Pie diagram showing the percentage distribution of paleosols in Semberah area (left) and curve showing the pH average of paleosol and its related to pH of modern soil (right)

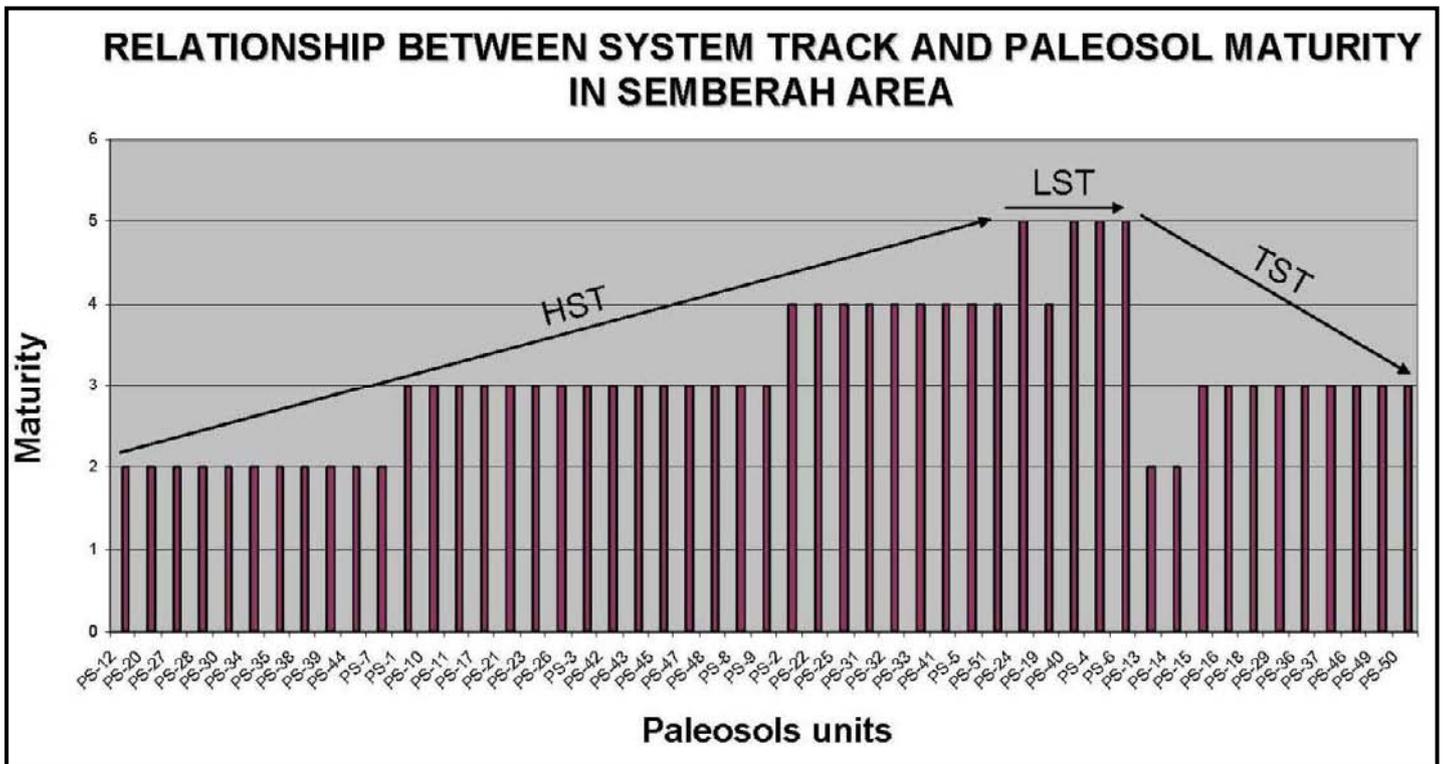


Figure 21. Paleosols Synthesis; A relationship between System Track and paleosols maturity in Semberah area. Their occurrence in HST represent to 70.6%, IVF : 3.9%, LST : 1.9%, TSE : 1.96% and TST : 21.5%

from a deep part and only within production reservoir only.

3. The paleosol description methodology refers to Retallack (1993) with small modification and efficiency, while the paleosol classification uses Mack *et al.* (1993). The paleosol maturity development is defined based on paleosol

development degree of maturity from Follmer (1998), where stage 0 to stage 6 scale use only morphological expression parameters while stage 7 to stage 10 need mineralogical parameter.

4. The composition of paleosols in the Semberah area consists of Argillisol 16%, Histosol 16%, Oxisol 8%,

Protosol 6%, Spodosol 50% and Vertisol 4%. The Gleysol, Calcisol and Gypsisol are not found. The average pH is 3.82 which is slightly lower than modern soil (Figure 20).

5. The occurrences of paleosols within sequence stratigraphic framework are (Figure 21):

a. **Highstand Systems Tract (HST)** is 70.6% well-developed with maturity varies from weak to moderate (stage 2 to 4). The low accommodation space supports paleosols to **develop well** with its upper boundary most likely associated to sequence boundary.

b. The paleosol distribution within Incised Valley Fill (IVF), Lowstand System Tract (LST) and Transgressive Surface of Erosion (TSE) are **very well-developed** with percentage of their occurrence as 3.9%, 1.9% and 1.96% with their maturity varies from moderate to strong

(stage 4 to stage 5). In general, they will associate with an erosional channel base known as sequence boundary in the bottom part border.

c. Paleosols are **not found** in the beginning of Transgressive System Tract (TST) in Semberah area which is commonly

Table O1. The result of paleosols research, documented 24 outcrops of sedimentology study and 51 units paleosols within 21 outcrops.

No.	Outcrop Name	Paleosol			Classification (Follmer '95)	Dep. Env Association	System Track	Maturity	None	Not Soil	Weak	Weak	Moderate	Strong
		Units	pH	Color					0	1	2	3	4	5
1	Semberah-24													
2	Gate S#24 to S#2													
3	Semberah-2	PS-1	2	10YR7/4	Spodosol	Upper Tidal DP	HST	3						
		PS-2	4	10YR7/4	Spodosol	Tidal Mouth Bar	HST	4						
		PS-3	3	10YR7/3	Histosol	Crev. Splay	HST	3						
		PS-4	4	5YR6/3	Argillisol	Crev. Splay	LST	5						
		PS-5	4	10YR7/3	Histosol	mudflat	HST	4						
4	Gp 6+38 - S#2 to S#16	PS-6	4	10YR6/3	Argillisol	Dist. Channel	TSE	5						
5	Gp 24 - S#2 to S#16	PS-7	4	10YR7/4	Spodosol	Dist. Mouth Bar	HST	2						
		PS-8	4	10YR7/6	Spodosol	mudflat	HST	3						
		PS-9	4	10YR7/4	Argillisol	Dist. Channel	HST	3						
6	Gp 35 - S#2 to S#16	PS-10	4	10YR7/2	Protosol	Mouth Bar	HST	3						
		PS-11	5	10YR7/6	Spodosol	Mouth Bar	HST	3						
		PS-12	4	7.5YR7/4	Spodosol	Tidal Flat	HST	2						
7	GP 12 - S#16 to S#33	PS-13	5	10YR7/6	Spodosol	Dist. Channel	TST	2						
		PS-14	4	10YR7/6	Spodosol	Dist. Channel	TST	2						
		PS-15	4	5YR7/3	Spodosol	mudflat	TST	3						
		PS-16	5	10YR7/6	Oxisol	mudflat	TST	3						
8	GP 15 - S#16 to S#33	PS-17	5	10YR7/4	Histosol	mudflat	HST	3						
9	Semberah-11	PS-18	3	10YR6/4	Histosol	Fluv. Channel	TST	3						
		PS-19	4	5YR5/8	Histosol	Fluv. Channel	IVF	4						
10	Semberah-46	PS-20	4	10YR6/4	Argillisol	Mouth Bar	HST	2						
		PS-21	4	10YR6/6	Spodosol	mudflat	HST	3						
		PS-22	5	7.5YR7/6	Argillisol	mudflat	HST	4						
		PS-23	3	5YR6/3 - 10YR7/4	Spodosol	Tidal Flat	HST	3						
		PS-24	4	10YR7/3	Argillisol	Dist. Channel	HST	5						
		PS-25	4	5YR5/3	Spodosol	Dist. Channel	HST	4						
11	Semberah-22	PS-26	2	5YR4/3	Spodosol	mudflat	HST	3						
		PS-27	3	10YR6/2	Spodosol	mudflat	HST	2						
		PS-28	5	5YR5/2	Spodosol	mudflat	HST	2						
		PS-29	3	10YR6/4	Spodosol	mudflat	TST	3						
12	Semberah-38	PS-30	4	10YR6/2	Histosol	Tidal Flat	HST	2						
		PS-31	3	10YR6/2	Oxisol	Tidal Bar	HST	4						
		PS-32	4	10YR6/1	Oxisol	Tidal Bar	HST	4						
		PS-33	4	10YR7/6	Oxisol	Tidal Bar	HST	4						
13	Semberah-40	PS-34	3	10YR6/4	Spodosol	mudflat	HST	2						
		PS-35	5	5YR5/3 - 10YR6/6	Spodosol	mudflat	HST	2						
14	Semberah-28	PS-36	4	10YR7/4	Spodosol	Mouth Bar	TST	3						
		PS-37	4	10YR6/3	Spodosol	Mouth Bar	TST	3						
15	Semberah-54	PS-38	4	10YR6/6	Protosol	Tidal Flat	HST	2						
		PS-39	3	10YR6/2	Protosol	Tidal Channel	HST	2						
16	Semberah-59	PS-40	5	10YR7/4	Argillisol	Tidal Flat	IVF	5						
17	Semberah-44	PS-41	4	10YR4/3	Argillisol	Crev. Splay	HST	4						
18	Gate 9A	PS-42	3	10YR7/4	Histosol	Dist. Channel	HST	3						
		PS-43	4	10YR7/4	Spodosol	Tidal Channel	HST	3						
19	Gate 9B	PS-44	4	10YR7/4	Spodosol	Tidal Channel	HST	2						
		PS-45	3	10YR6/2	Spodosol	Tidal Channel	HST	3						
20	S#13 to S#33	PS-46	4	5YR7/4	Histosol	Tidal Channel	TST	3						
21	Semberah-37	PS-47	5	10YR5/3	Vertisol	mudflat	HST	3						
		PS-48	3	10YR6/3	Spodosol	mudflat	HST	3						
22	Semberah-33	PS-49	4/5?	7.5YR7/6	Spodosol	Tidal Bar	TST	3						
		PS-50	2	10YR4/2	Spodosol	Tidal Bar	TST	3						
23	Semberah-50	PS-51	4	5YR5/2	Vertisol	Crev. Splay	HST	4						
24	Semberah-6													

- characterised by the occurrence of **Hydromorphic Paleosol**.
- d. During the Transgressive System Tract (TST), paleosols are **not well-developed** or even **obstructed** with percentage of their occurrence within the area as 21.5% and the maturity varies from stage 2 to stage 3
6. In oil and gas industries, paleosols are very useful to support the sequence stratigraphic interpretation, especially within the areas that are dominated by fluvial depositional environment that have many reservoir compartment.
7. Paleosols can be used to define the Sequence Boundary and also can avoid miss-leading interpretation based on their maturity.

Acknowledgement

We would like to thank VICO Indonesia, in particular Mr. Safarudin, for permission to undertake our research and publish this paper. I also would like to thank my supervisors Prof. Soejono Martodjojo, Dr. Andang Bachtiar and Dr. Budi Mulyanto for their cooperation, support, ideas, and advices during my research.

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East Kalimantan Program

Extracted from <http://www.eastkalimantan.org/> by Herman Darman

The East Kalimantan Programme (EKP) aims to enhance and support long-term scientific cooperation in coastal zone research between research groups from Indonesia and the Netherlands.

The Research Cluster: "*Upsetting the balance in the Mahakam Delta: past, present and future impacts of sea-level rise, climate change, upstream controls and human intervention on sediment and mangrove dynamics*" is one of the clusters that is funded within the EKP programme.



Figure 1. Sampling activities in Mahakam Delta: shallow coring (left), and sediment sampling (right)

Objective

The objective of the cluster is to study the impact of external forcing factors such as sea-level rise, climate change, upstream sediment, as well as human interference on past, present and future development of the Mahakam delta at different time scales. We will pay special attention to determining the resilience and restoration potentials of mangrove ecosystems and develop models forecasting catastrophic changes in coastal ecosystems. We will aim to understand issues of governance across scales, and how ecosystem appreciation and governance can be linked. The cluster will use the Delft3D model (Delft Hydraulics) as a tool to integrate data into scenarios and will extend it from its present limited decadal time scale to millennial time scales, enabling better prediction of future changes in the Mahakam delta.

Scientific relevance

We expect that this integrated multidisciplinary research effort will lead to a deeper understanding of the delicate abiotic and biotic checks and balances in delta systems in general. To our knowledge the Mahakam delta will be the first tropical delta for which short-term morpho-dynamic models and long-term sedimentary-stratigraphic models will be integrated into a single

comprehensive model. This will enable study of the impact of long-term processes such as sea-level rise as well as short term sudden anthropogenic ecological disturbances simultaneously. This model can play an important role in coastal management. Governance systems, from national government to local land and marine tenure systems, focusing on sustaining and enhancing sources of resilience in societies and life-supporting ecosystems, will reap the benefits from a versatile delta model that is able to produce scenarios at different spatial and time scales. Our research will thus lead to socially robust knowledge with recommendations for improved management of land and water, following the Ecosystem Approach of the CBD, the development of tools for matching ecosystem processes to societal levels of organization, and, through our cooperation with the Queensland study, we will provide a test of the costs and benefits of (good) governance.

Projects

The cluster research programme is subdivided into 8 work packages (WP) also named *projects*, of which WP1, WP2 and WP3 focus on sediment dynamics in different time scales (5000, 200 and 50 years), WP4, WP5 and WP7 on hydrological aspects, WP6 on

mangrove ecosystems and WP8 on stakeholder issues. Details on approaches and methods are given in each of the project pages that can be reached through the links below.

WP1: Simulating the Holocene development of the mixed tidal-fluvial Mahakam delta (Salomon Kroonenberg, Jajang Sukarna)

WP2: Quantifying sediment fluxes in the Mahakam Delta using remote sensing (Zoltan Vekerdy, Orbita Roswintarti)

WP3: Impact of decadal climatic cycles on sedimentation in the modern Mahakam Delta, Indonesia (Salomon Kroonenberg, Jajang Sukarna)

WP4: Water and sediment distribution at lowland river junctions: the Mahakam Lakes region (Ton J.F. Hoitink, Safwan Hadi)

WP5: Discharge regimes, morphometry and tides in the Mahakam delta channel network (Ton J.F. Hoitink, Gadis Sri Haryani)

WP6: Searching the brink: assessing indicators for system change through hyper-spectral analyses of mangrove systems (A. Skidmore, Wawan Kustiawan)

WP7: Hydraulic interaction between channels, lakes and aquifers in the middle Mahakam region (Ton J.F. Hoitink)

WP8: Stakeholder interests and potential for sustainable coastal management through rights regulation practices in the context of decentralisation in the Mahakam Delta, East Kalimantan (G.A. Persoon, J.M. Otto)

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EXAMPLE OF REMOTE SENSING ANALYSIS ON MAHAKAM DELTA BY BUDHIMAN (2004)

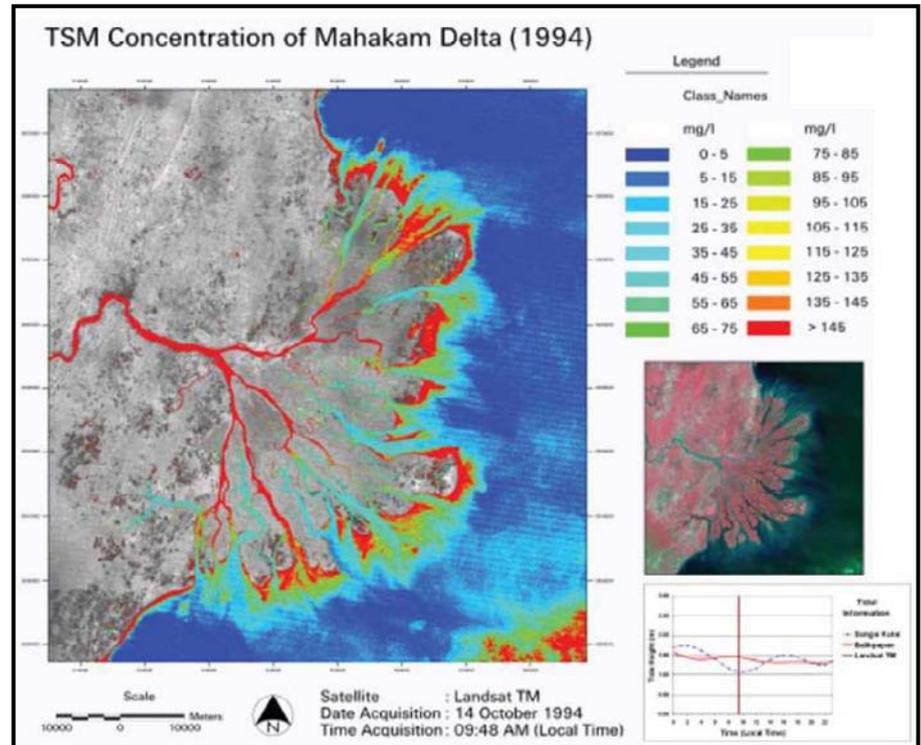


Figure 2.a. Modeled Total Suspended Matter concentration at high river discharge and low tidal amplitude: mainly fluvial distributaries are active (Landsat TM), Budhiman, 2004

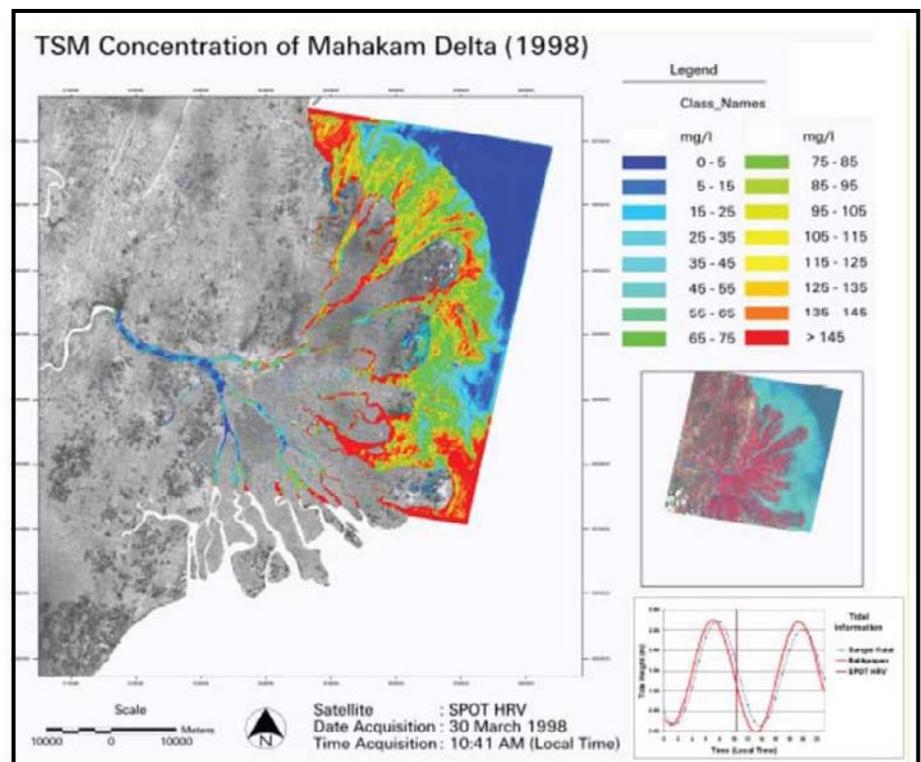


Figure 2.b. Modeled Total Suspended matter concentration at low river discharge and high tidal amplitude: mainly tidal channels are active (SPOT HRV), Budhiman, 2004

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Results

Results for the Mahakam Cluster research will be posted as the project progresses. Some early results and data gathered from the completed field seasons are available below.

- Simulating the Holocene development of the mixed tidal-fluvial

Mahakam delta (Data Report WP1). All data gathering for this project has ceased and there are no further plans for extra data gathering in the near future. The first phase of the fieldwork consisted of a combined subsurface echosounder survey and a coring campaign. The ten mechanical corings (up to 25.5 m deep) were carried out in combination with WP 3. A second field campaign in the Mahakam delta was performed using a higher resolution echosounder; the detailed very high-resolution seismic/bathymetric survey resulted in a survey of unprecedented detail in the subsurface characterization of the Holocene Mahakam deposits.

- Rainfall-runoff modelling in large tropical poorly gauged basin - The Mahakam River, Kalimantan (Data Report WP4). Surface water level, groundwater level and rainfall were measured along the Mahakam River. The data has been collected over an interval of more than one year.
- Discharge regimes, morphometry and tides in the Mahakam delta channel network (Data Report WP5). Data analysis has been focused on water level variation along the river from the outer delta up to the lakes area. Water level sensors were located at selected locations along the river and in the delta, salinity sensors in

Example of high-resolution seismic/bathymetric survey of the delta platform in the tidal zone up into the fluvial and tidal channels using the Innomar Parametric Echosounder (www.innomar.com) in Dalman et al., 2009

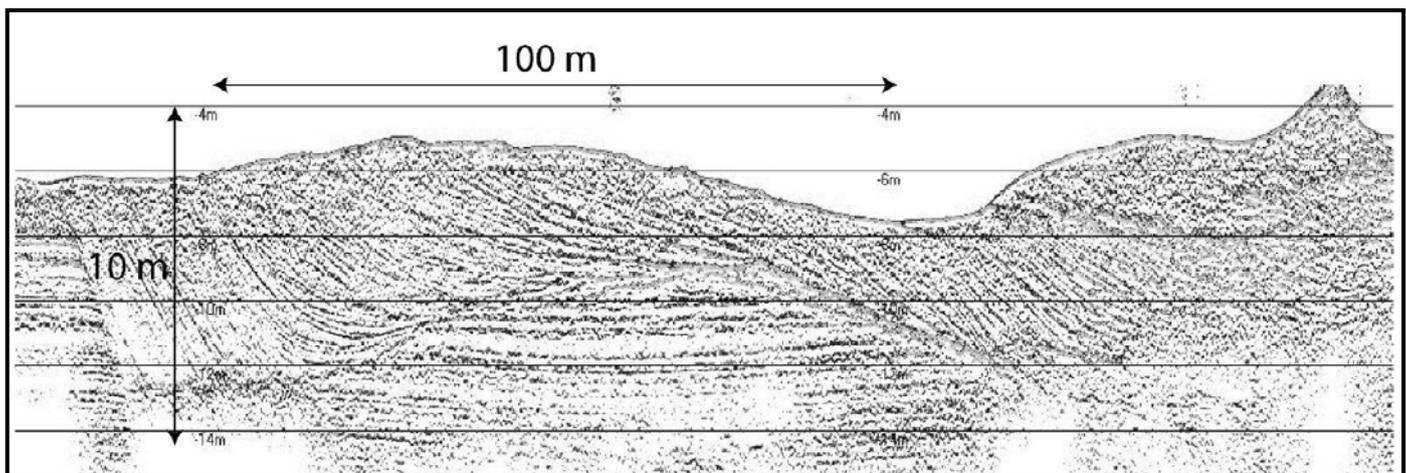


Figure 3.a. Cross-section profile of a channel fill in a meander bend of a tidal channel. Note the change in elevation of the paleo-channel floor. The channel is filled by lateral accretion; changes in angle are most likely caused by change in direction of accretion.

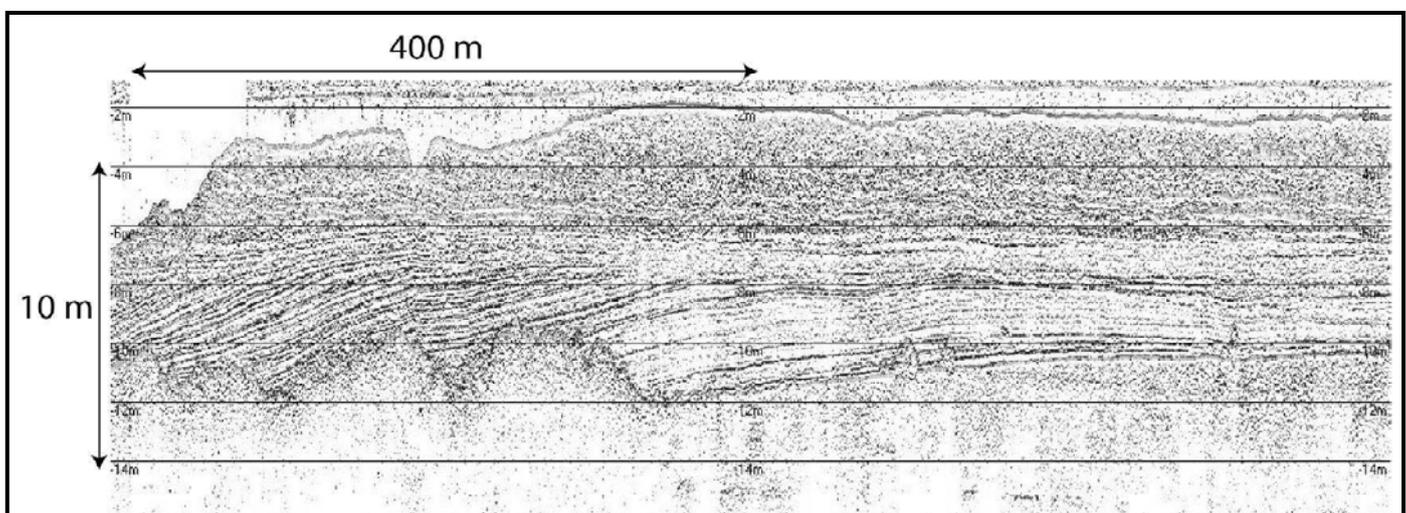


Figure 3.b. Prograding clinofolds overlain by aggrading parallel beds in a tidal channel. Note the irregular surface at 10-12 m bsf, most likely caused by the upward migration of shallow gas.

the delta, a horizontal ADCP discharge station and a turbidity sensor near Samarinda city. After installing the permanent stations for long-term measurements, several surveys were conducted to collect bed samples, bathymetry and hydrography along the study area (from Samarinda until the delta apex). In total, eight hydrographic surveys were completed during spring and neap tides.

- Stakeholder interests and the potential for sustainable coastal management through regulation practices in the context of decentralization in the Mahakam Delta (Data Report WP8). This research aims to examine and detail the evolution of formal and informal arrangements for the use of natural resources in the Mahakam Delta. On the basis of socio-legal research at the level of the state and the people, the researchers will propose improvements of the laws and regulations of the use rights, in particular with respect to shrimp aquaculture and fishery. Literature

research and fieldwork has been done.

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PT. GEOSERVICES

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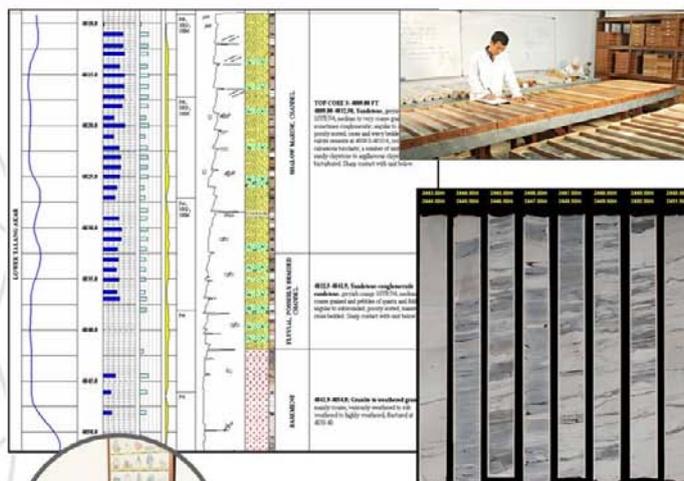
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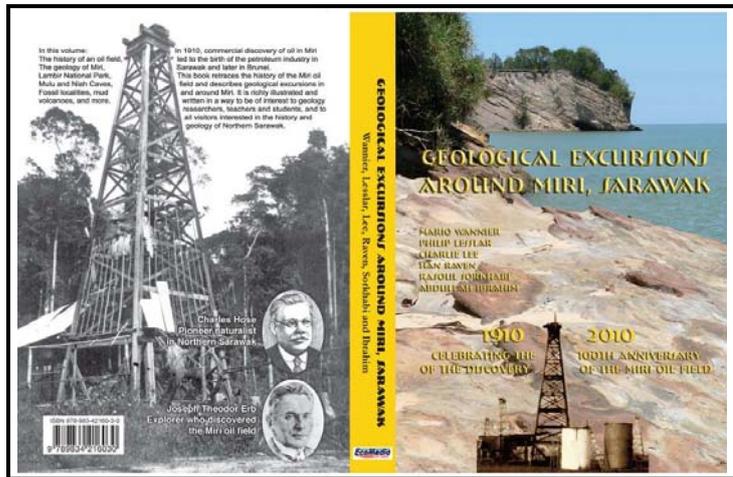
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Book Review

Geological Excursions Around Miri, Sarawak

1910-2010 Celebrating The 100th Anniversary of the Discovery of The Miri Oil Field



Authors

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Charlie Lee
Han Raven
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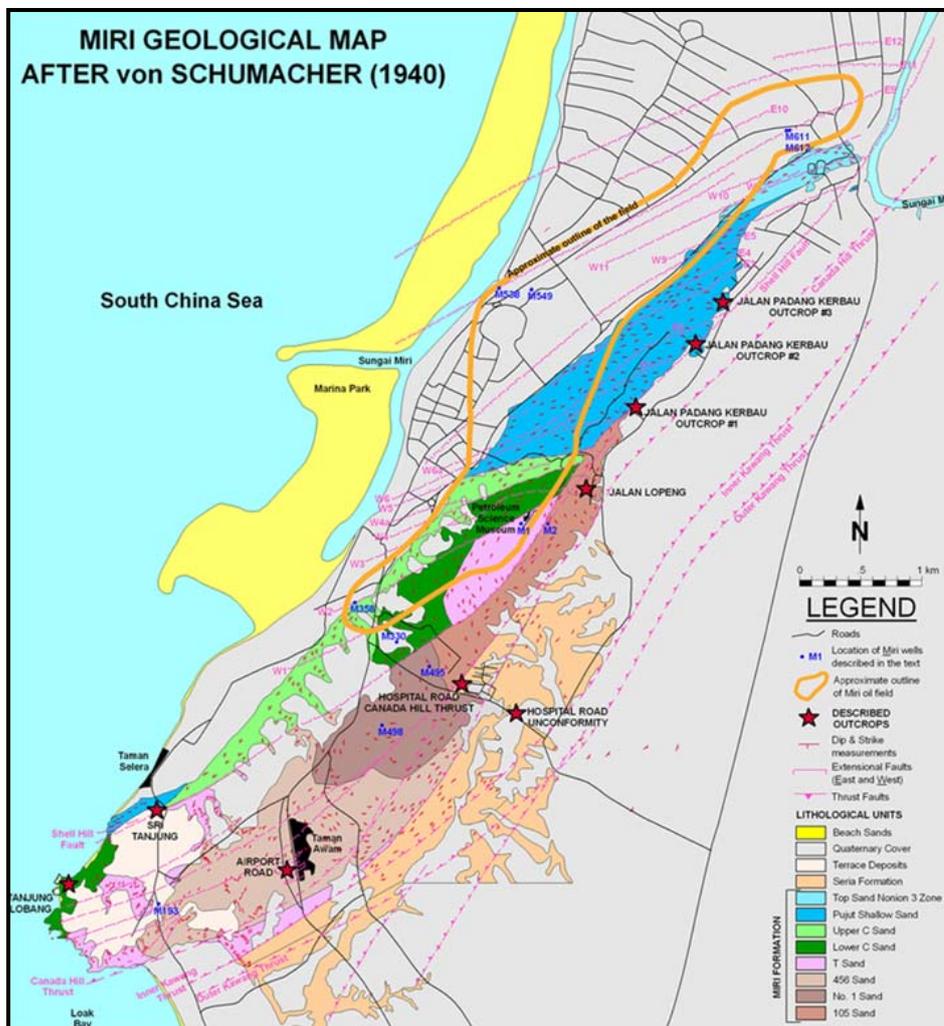
Published in **2011**

To commemorate the 100th anniversary of the Miri Oil field discovery in Sarawak, Malaysia (NW Borneo), a book titled “Geological Excursions Around Miri, Sarawak” has been published this year. Wannier et al has prepared an A5 size book with ± 280

pages, divided into 5 main chapters.

The first chapter titled "Miri and the birth of the Oil Industry in Malaysia" provides a historical and industry overview. In this chapter the authors also explain the contribution of the

pioneers on the discovery of Miri Field such as Charles Hose (1863–1929), Joseph Theodor Erb (1874–1934) and others. The history of Miri Field production is discussed and the authors also explain the impact of the 2nd World War on the production and the final years of the field.



The geology of the area is discussed in the following chapter, starting with the rock records, continuing with tectonics, geological history and ending with petroleum geology. This chapter is a very simple introduction to petroleum geology, and very useful for non-geoscientists.

Fifteen outcrops or excursion stops are described in great detail in Chapter 3, which includes Mulu National Park, Mud Volcanoes and some outcrops in Brunei. The outcrop descriptions include detailed maps, stratigraphic sections and color photos of outcrops.

Chapter 4 is dedicated to fossil collectors and those who are interested in fossils. This chapter starts with an introduction to fossils. The rest of the chapter discusses the types of fossils found in different places in the area. Fossils described in this book include microfossils such as foraminifera, nannoplankton, pollen, trace fossils, crabs and mollusks, and tektites in Brunei.

Wannier *et al.* explain their efforts and ideas in preserving the geological

heritage in this area in Chapter 5, and describe the collaboration with local government in setting up open air museums of outcrops and preparing brochures related to outcrops for non geologists.

The book is completed with a Glossary of Geological Terms (Chapter 6) and References and Bibliography (Chapter 7). This book on the geological excursions around Miri will be available in June 2011 and can be purchased from:

Belle's Bookshop

Lot 605-610, Taman Pelita Commercial Centre Jalan Miri-Pujut
P.O.Box 1740, 98008 Miri, Sarawak, Malaysia
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Book price Softcover : RM 65.00;

Hardcover : RM 85.00

As this is the only published excursion guide book for Miri, it is a 'must have' for geological field trip participants. With the content and quality of pictures, the price of the book is very reasonable. Unfortunately the coordinate of the locations are not stated in the book. However the roads in this area are easy to be recognized.

Herman Darman

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