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A Fluvial Series in the Middle Miocene of Kutei Basin: A Major Shift from Proto-Mahakam Shallow Marine to the Continental Environment

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Kutai basin in Kalimantan, has been subject of geological studies for many years. It represents a very rich hydrocarbon province of Indonesia with many hydrocarbon fields located in and around the modern Mahakam delta in the eastern coast of Kalimantan. Most of their reservoirs are constituted by ancient deltaic deposits. The geological history of the basin shows that the Mahakam River (and probably other rivers) has been depositing deltas on the eastern coastline of Kalimantan for at least 12 last million years, since the Middle Miocene (Allen & Chambers, 1998).

There is a structural dipping of formations from the west to the east of the basin, showing younger formations to the East, to the still active depocenter of the basin. Rocks cropping out in the surface in the Samarinda anticlinorium (Fig. 1) are dipping to the east and constitute some of the oldest and deepest deltaic reservoirs in the subsurface of the hydrocarbon fields in the Mahakam area 50 km eastwards.

A succession of Middle Miocene rocks crops out in a section near and around Samarinda city (Fig. 1). In this paper we are focusing in the part of the section showing thick sandstone bodies constituting lenses surrounded laterally and vertically with shales. This succession is very well distinguished by its red shales dominating the landscape in a more than 30 km wide belt. The whole section has been interpreted as fluvial channels associated with flood plain deposits.

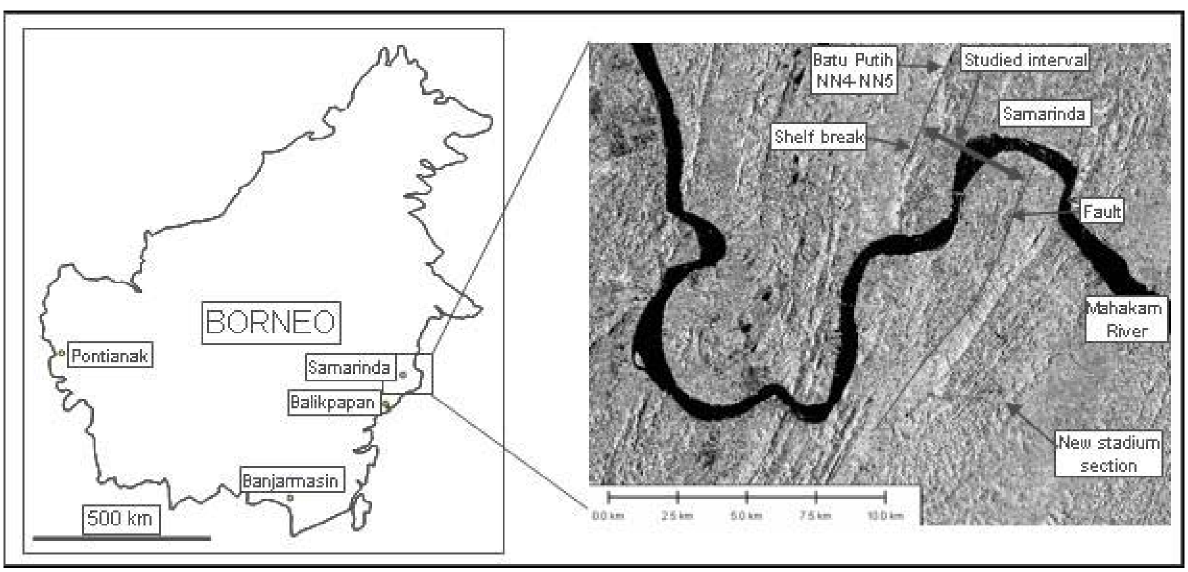

Figure 1 – Kutei basin and Samarinda city in the eastern part of Borneo highland. Batu Putih and its lateral extension is interpreted as a shelf break. The studied section is situated between Batu Putih and Palaran (new stadium).

Stratigraphy of Samarinda anticlinorium

Oldest rocks cropping out in the Separi anticline core are Middle Miocene in age and represented by slope shales and turbidite sandstones. They constitute a series with an observed thickness between 500 and 800 m. In the outcrop, the series shows 50 to 100 m thick dark shales, sometimes bioturbated, rich in dispersed vegetal organic matter alterning with 5 to 20 m thick sandstone lenses constituted by sharp base, fining upwards, fine to medium-grained sandstone layers 5 to 10 cm thick (sometimes less than 2 cm and sometimes more than 50 cm thick) (Cibaj & Wiweko, 2008).

This series is capped by carbonate buildups of Batu Putih limestone, representing a very good lithological, stratigraphic and depositional environment reference in the basin. The carbonate buildups were dated as NN4 to NN5 in age (Wilson, 2005). Slope shales and turbidites underneath Batu Putih carbonates are not younger than this age. From our own biostratigraphic studies we obtain the same age NN4-NN5.

The Batu Putih limestone is overlain by a 650 m thick series constituted by shallow marine and deltaic parasequences (Cibaj & Wiweko, 2008). Each parasequence, around 20 to 40 m thick, shows at the lower part more than 10 m thick dark shales, followed towards the top of the by siltstone and fine-grained sandstone, showing a coarsening and thickening upwards trend.

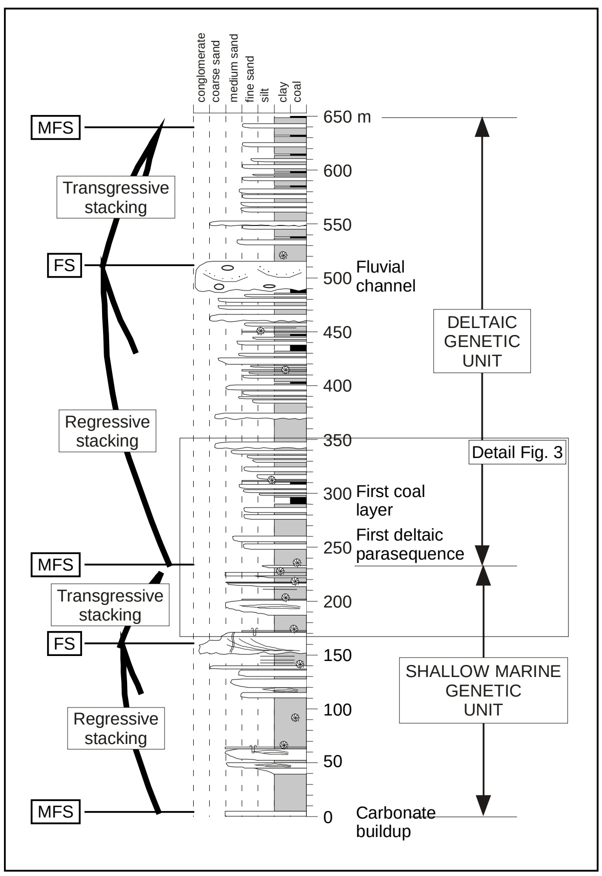

Figure 2 – Shallow marine and deltaic series observed on top of Batu Putih limestone, Sungai Kunjang section. Parasequences are vertically stacked following a regressive – transgressive pattern. A shallow marine Genetic Unit and a deltaic Genetic Unit have been interpreted in the section separated by a Maximum Flooding event.

A 850 m thick (at its most complete outcrop) succession of 30 to 50 m thick sandstone bodies surrounded laterally and vertically with red shales covers the shallow marine series.

A new series, around 250 m thick, of deltaic deposits follows upper in the section. It is constituted by deltaic parsequences (5th order) organized in regressive-transgresive parasequence sets (4th order) (Cibaj et al. 2007). Small carbonate buildups cap this series and have been interpreted as representing a 3rd order maximum flooding, (Cibaj et al. 2007).

Carbonate buildups are capped by a 200-250 m thick series dominated by thick sandstone bodies and thin shales. Sandstones, 20 to 30 m thick, are interpreted as fluvial channels (Cibaj et al. 2007) and represent a major shift in the depositional environment suggesting a relative sea level fall. The sequence boundary 10.2 Ma, very well known in the hydrocarbon fields of the Mahakam area, has been interpreted at the base of this series. This interpretation has been well supported by our own recent biostratigraphic studies.

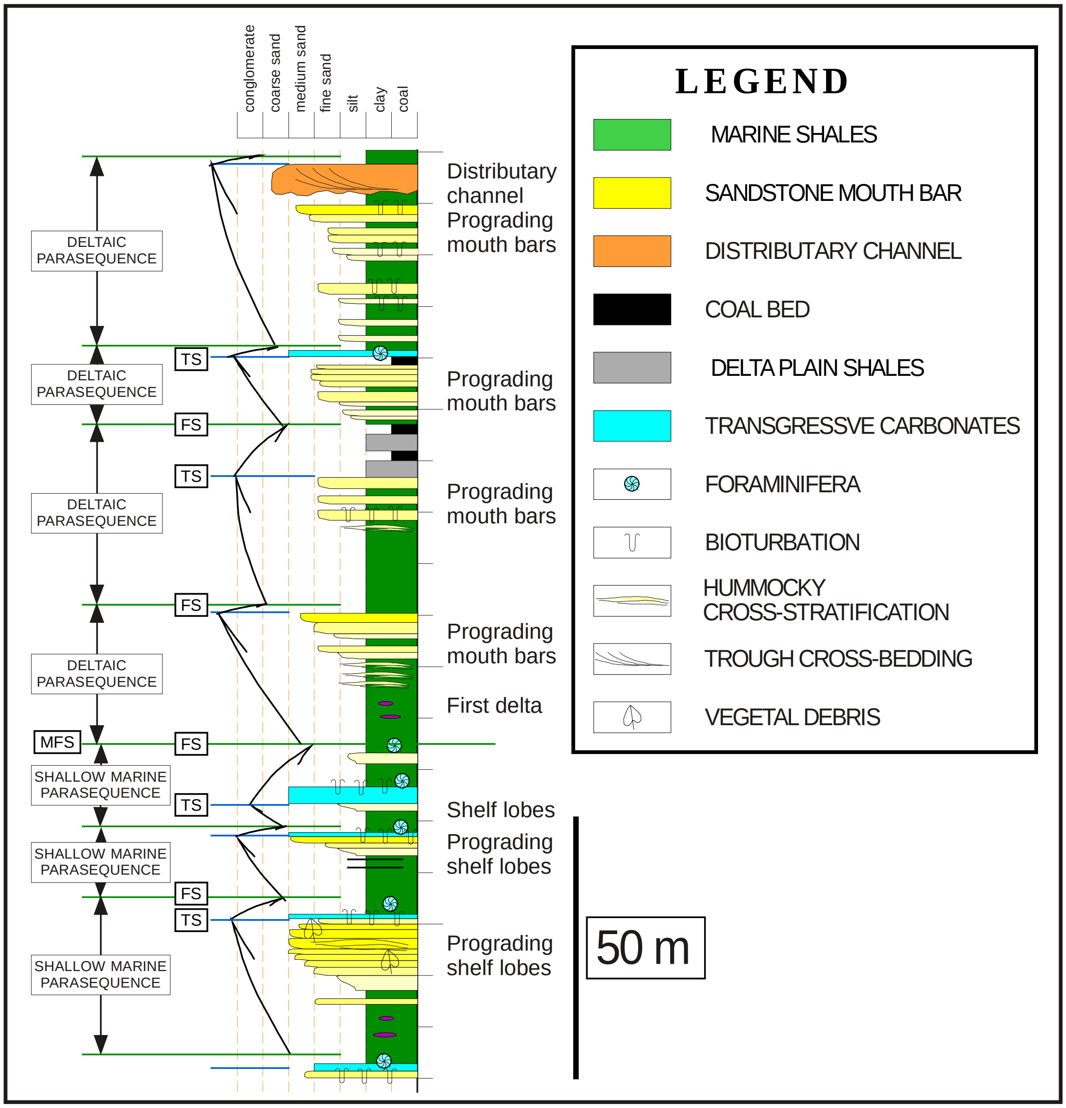

Figure 3 – Detailed log description of the Sungai Kunjang section showing the transition from shallow marine parasequences to deltaic parasequences.

Shallow marine succession

The Batu Putih limestone represents carbonate buildups on a shelf. Two clastic parasequences are observed on top of the Batu Putih carbonate in its location, showing on the bottom marine shales (10 m thick) overlain by coarsening upwards shoreface sandstones (10 to 15 m thick), capped on their turn by carbonate buildups (5 to 10 m thick) and organic black shales (5 to 10 m thick). Sandstones have been interpreted as prograding shelf lobes and carbonates as transgressive tract (Cibaj & Wiweko, 2008, their figure 10). Sandstone layers in this same outcrop show a wage-shape geometry which has been interpreted as shelf-break (Cibaj & Wiweko, 2008, their figure 11 & 12). This wage-shape geometry has been observed in the same sandstone parasequence correlated 4 km southward near the DPR house of representatives.

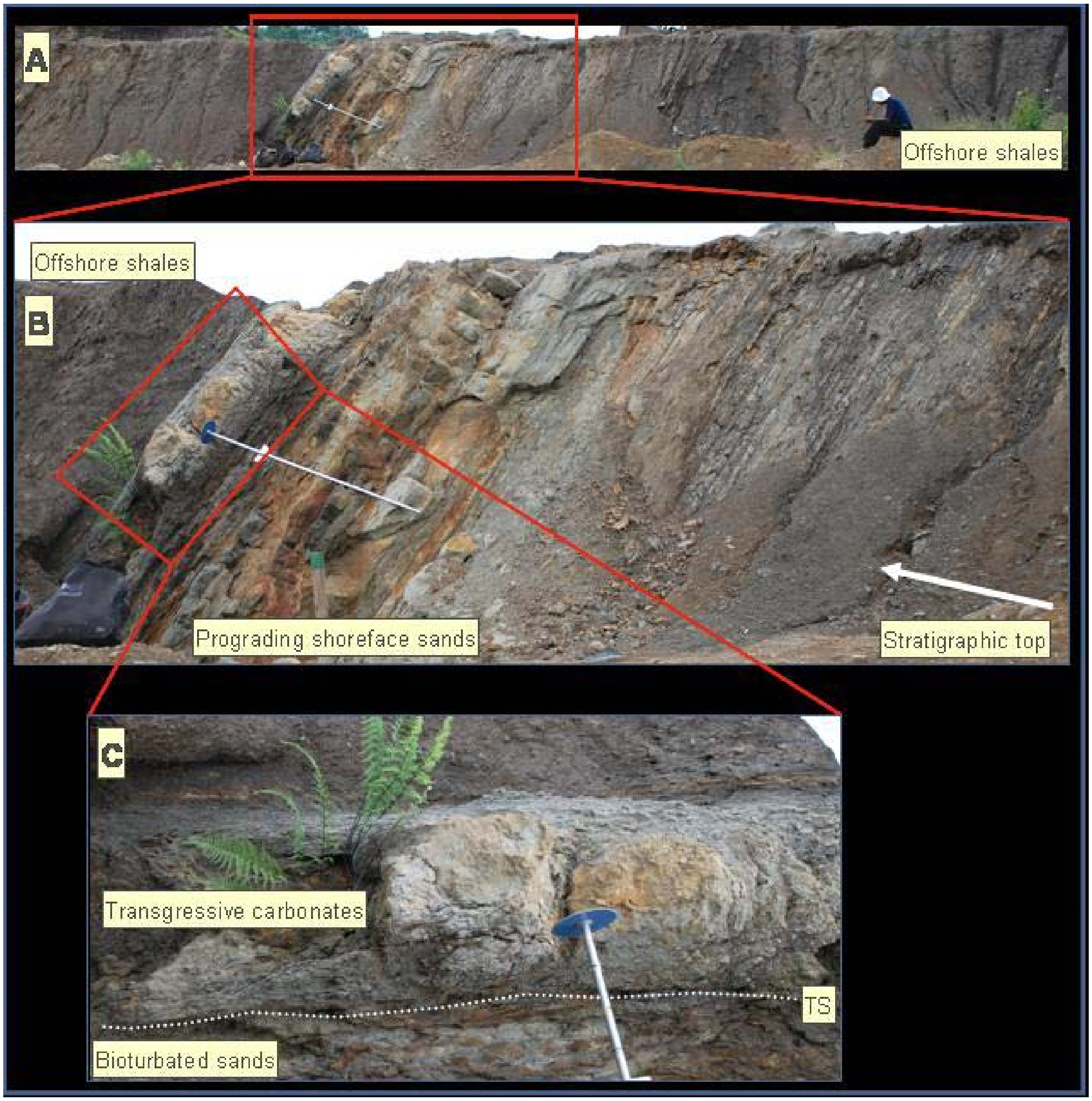

Figure 4 – Outcrop view of a prograding shelf parasequence. A – General view showing thick marine shales overlain by prograding sandstones. Stratigraohic top to the right, scale 1.5 m. B – Detailed view of coarsening and thickening upwards sandstones with carbonates on their top. C – Carbonate buildup rich in macroforaminifera representing the transgressive tract of the parasequence.

Stratigraphically the Batu Putih limestone is situated on top of sand and shale series interpreted as slope turbidites and on the bottom of shelf parasequences interpreted as showing shelf-break geometry (Cibaj & Wiweko, 2008). The Batu Putih limestone is therefore interpreted as being deposited on a shelf-break.
A new section has been opened recently on top of Batu Putih limestone in the Komplek Perumahan Mediterania as well as in the Sungai Kunjang showing shallow marine and deltaic parasequences (Fig. 2).

Seven parasequences are recorded in the first 240 m of the section (Fig. 3) with different characteristics from the parasequences observed upper in the section. They are around 20 to 40 m thick, showing at the lower part more than 10 m thick dark shales very rich in macroforaminifera (their paleontological study is completed) (Fig. 3, 4A). Siltstone and fine-grained sandstone lenses and layers are observed towards the top of the parasequence, exhibiting a coarsening and thickening upwards trend (Fig. 4B). Hummocky and swaley cross-stratification are the dominant sedimentary structures observed in sandstones, as well extensive bioturbation at the very top. The sandstone thickness varies from 2 to 10 m. Transgressive carbonates (0.2 to 1 m thick) very rich in macroforaminifera are capping the parasequence (Fig. 4C).

This stacking pattern of sediments in the parasequences is interpreted as being deposited in open marine shelf environment. The shales represent offshore sedimentation; sands represent prograding shoreface and the carbonate rich in macroforaminifera a transgressive tract.

Parasequences stack vertically in a regressive and then transgressive pattern. This pattern is interpreted as forming a Genetic Unit (Fig. 2).

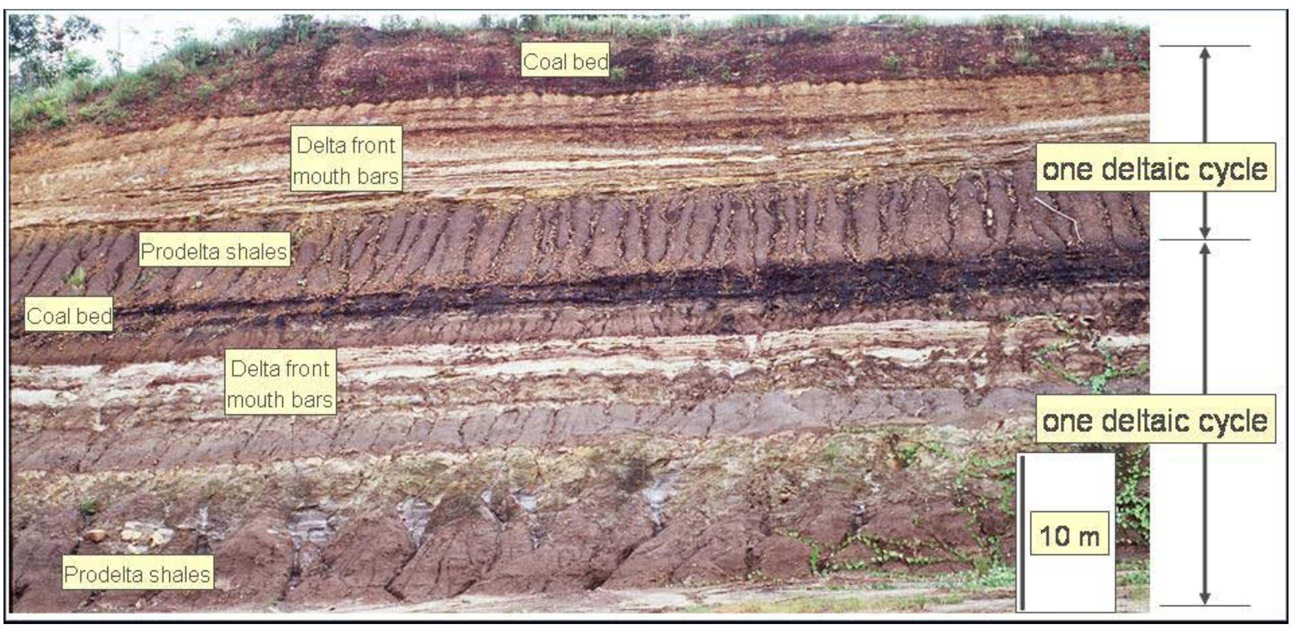

Figure 5 – Deltaic parasequences showing prodelta shales at the bottom, distal to proximal delta front mouth bars in the middle, delta plain shales and coal bed at their top. Complete deltaic cycles are common in outcrops.

Deltaic succession

A thick shale interval covers shallow marine parasequences and is interpreted as 3rd order Maximum Flooding event (Fig. 2 at 240 m, Fig. 3). First deltaic sedimentation appears in the section above the thick shale. The main sedimentological characteristic of deltaic cycles is the presence of well distinguished delta front mouth bars. Each mouth bar starts with shales at the bottom (prodelta or distal delta front) followed by lenses and thin silt layers (1-2 cm) alterning with shales. Fine-grained sands follow upper, organized in thicker, more continuous layers. The grain size becomes coarser, layers thicken and shale content decreases towards the top. The sand thickness varies between 20 cm and 2-3 m. Parallel lamination and hummocky cross-stratification are the dominant structures and the bioturbation is common, especially on the top of the sands. Two to three bars are commonly vertically stacked in one parasequence showing coarsening and thickening pattern. A thin shale interval (20 to 50 cm thick) is usually observed between two successive sand bars.

A sharp-based sand (10 m thick) showing trough cross-bedding is often observed on the top of the parasequence. This sand is interpreted as delta plain distributary channel side bars. Delta plain shales (2-3 m thick) cover the sand bars and a coal bed tops the whole parasequence (Fig. 3, 5).

Many deltaic parasequences are vertically stacked in the studied section and show a regressive pattern followed by a transgressive one (Fig. 2, 3 & 5). This pattern is interpreted as forming a Genetic Unit (Fig. 2).

Fluvial sandstones

The fluvial sandstone section constitutes a range of hills in the landscape covered by heavy vegetation. Recent developments in housing building and sandstone exploitation have opened many new outcrops. Thick red shales and thick white sandstones constituting the studied series, dominate this new landscape in Samarinda city.

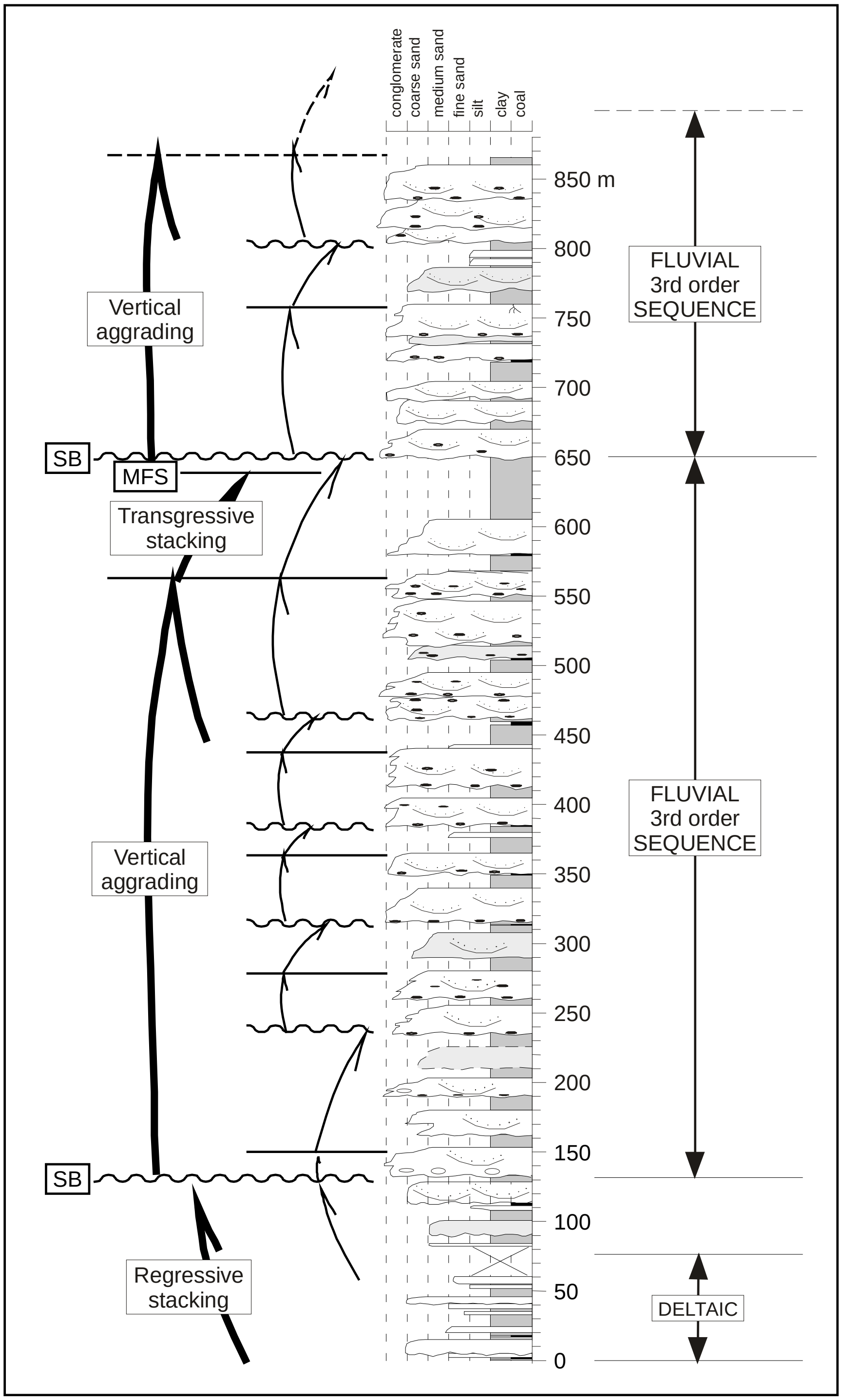

Figure 6 – Deltaic and fluvial sediments observed in the Harapan Baru section.

The studied section is situated in the most complete outcrop in the Harapan Baru village (Fig. 6). Three stratigraphic hierarchies are distinguished in the section: individual parasequences (Fig. 7), parasequence sets (Fig. 6, 7) and 3rd order sequences (Fig. 6, 7).

Coarse grained sandstones and conglomerates form lenticular bodies, surrounded by a mixture of shale and silts (Fig. 8, 9). They show sharp erosive base, and overall fining upwards grain size evolution. Trough cross bedding is the dominating sedimentary structure. Troughs are 2 to 5 meters wide and 20 to 80 cm in amplitude. Each set of trough cross stratification shows an erosive base, very coarse-grained sandstones or conglomerate at the base, fining upwards to medium –grained sandstones. An overall orientation of troughs towards south east is observed in outcrops.

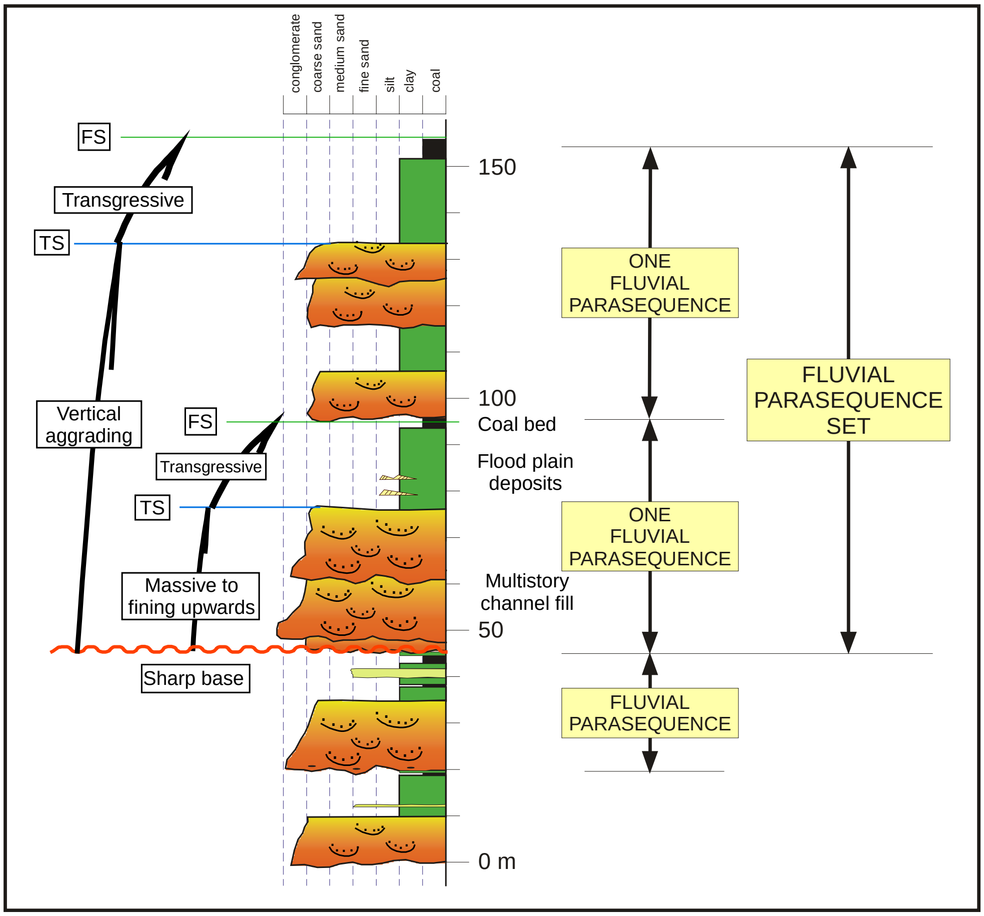

Figure 7 – Fluvial deposits stacking pattern in parasequences and parasequence sets.

Figure 8 – A complete fluvial parasequence with massive sands at the bottom (A), fining upwards to flood plain shales and coal bed. Stratigraphic top to the right.

White quartz grains and pebbles as well as red and green chert pebles constitute the sandstone and conglomerate. They are well rounded, probably because of a long transport before deposition. Their source should be related with Kuching High in the upper Kalimantan (Bahtiar, 2002). Silicified or coalified wood trunks as well as root traces are very often observed in the sandstones. Shale blocks and limonite nodules are observed especially in the lower part of sandstone bodies.

The sandstone bodies are 30 to 50 m thick and show a lateral extension of many hundred meters (Fig. 7, 8, 9). They are interpreted as fluvial channels. Multistory channels constitute the thickest sandstone bodies. Lateral migration of point bars eroding previous channels are usually observed in outcrops (Fig. 10). In some cases the transition to the flood plain deposits, associated clay plugs or even over bank deposits can be observed (Fig. 11).

The Perjuangan quarry, which has been the object of many publications (Bachtiar, 2002, Hook et al. 2001) shows multistory channels. This quarry is situated in the very top of the described series.

Structureless, red and gray-white shales surround horizontally and vertically the sand bodies. Root traces and soil formation features are observed in the shales. Sometimes silt layers and lenses, 10 to 20 cm thick, can alternate with shales. Limonite nodules are often aligned according to stratigraphic plans of shales. Shales are 10 to 40 m thick and are interpreted as flood plain deposits.

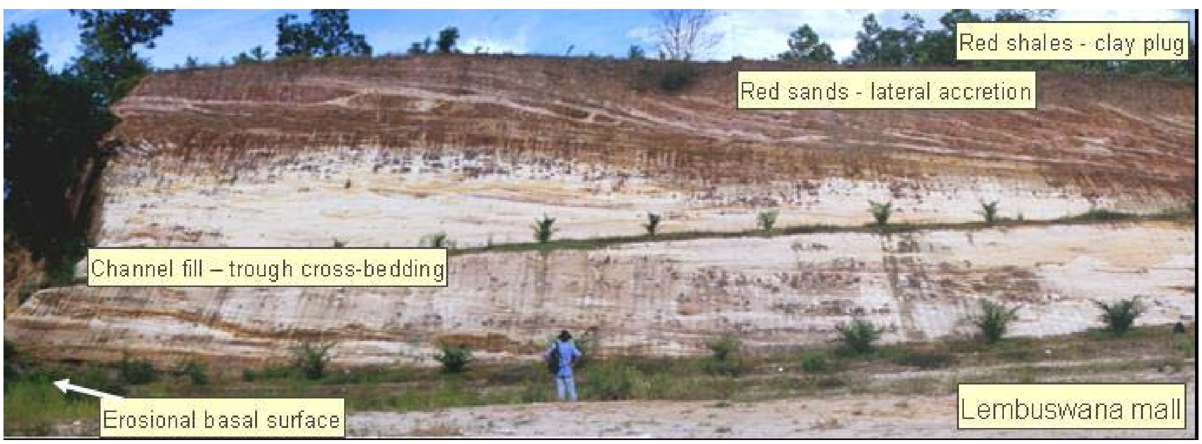

Figure 9 – Fluvial channel showing sharp base, trough cross-bedding and the clay plug red shales.

Figure 10 – Point bar migrating to the left eroding previously deposited point bars in the same channel belt.

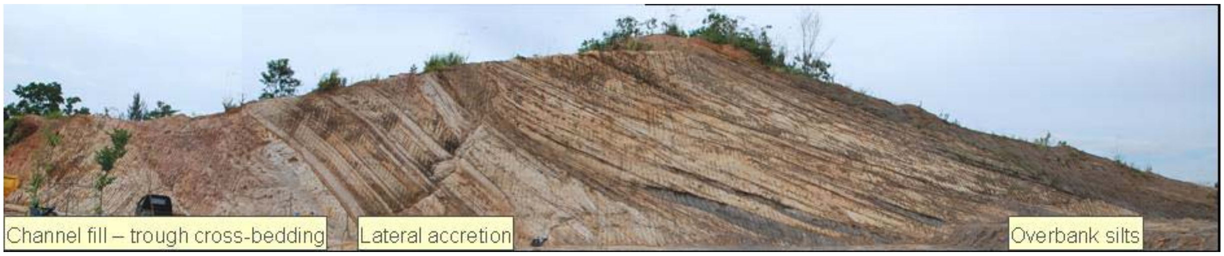

Figure 11 – Over bank deposits constituted by silts and shales cover the channel and its lateral accretion. Stratigraphic top to the right.

This vertical stacking pattern of the parasequence is related with the evolution of the accommodation potential with time. The sharp erosive surface at the base of the parasequence is interpreted as base level fall. The sand accumulation in the channel shows a relative rise of the base level and increase in the accommodation potential. Flood plain shales are interpreted as representing a still stand and the coal bed at the top showing the maximum of the accommodation potential.

Many parasequences are vertically stacked in parasequence sets showing the same stacking pattern: massive at the bottom, fining upwards (Fig. 6, 7)

The transition from deltaic sedimentation underneath to the fluvial deposits of studied series is not well exposed in the outcrops. A major shift in the depositional environment from shallow marine to continental is interpreted from the sedimentary structures and the stacking pattern of the sediments. Deltas at the bottom of the section (Fig. 6) show a regressive vertical stacking. This same trend is observed in the first fluvial channels (interval 80 to 120 m in Fig. 6). The first conglomerate associated with a very erosive channel base is interpreted as a sequence boundary (fig. 6). This sequence boundary is the result of the overall normal regression observed from the shift in the environment from deltaic to fluvial.

It is difficult to consider the environment shift as a forced regression (in the sense of Posamentier et al. 1992) as suggested by Hook et al. (2001) for the Perjuangan quarry outcrop. Their suggestion is based in an important facies shift interpretation showing a Forced Regression. The facies shift seems to be more important at the base of the fluvial series showing a change from shallow marine to continental environment. The Perjuangan quarry is situated towards the top of this 600 m thick fluvial series, which makes the happening of a forced regression more improbable.

The 3rd order sequence shows vertically stacked fluvial parasequences and parsequences sets. The transgressive tract and maximum flooding event is represented by 50 m thick shales and coal (Fig. 6, interval 600-650 m). Two 3rd order sequences are recorded in the studied section. The upper one is not complete in the outcrop. Its maximum flooding event should have prepared the conditions of the returning deltas in the basin (new stadium, Palaran section, Cibaj et al. 2007).

Paleontological studies in the continental series are very difficult. Bachtiar (2002) dated this series as N9 in age, which has been contradicted by Hook et al. (2001). Wilson (2005) gave the age NN4-NN5 for the Batu Putih limestone (more or less the same as N9) which is at least 650 m underneath our series. Our detailed foraminifera and nanoplancton biostratigraphic studies show that NN4-NN5 nanoplancton zone continuous still 50 m above the fluvial section in the new stadium section (Palaran).

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