MIDDLE MIOCENE DEPOSITIONAL ENVIRONMENT SHIFT IN THE TARAKAN BASIN: SOME PERSPECTIVES FROM THE ONSHORE SIMENGGARIS AREA

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ABSTRACT

This paper aims to share ideas on the stratigraphic evolution of the Tarakan Basin based on data from the Simenggaris area, onshore NE Kalimantan. Various data sets were incorporated in order to get a robust and comprehensive interpretation, including well logs, cores, and paleontology and petrography analyses. Post-stack time migration 2D seismic data were utilized to generate isopach maps, which were then used as the framework for paleogeographic models.

We concluded that the stratigraphic succession in the onshore Tarakan Basin consists of two major depositional environments, with the shift occurring during Middle Miocene. The most significant marker of depositional system transition was observed in the paleontology and lithofacies association. In the Eocene-Early Miocene, the fossils were dominated by foraminifera and by low energy sediments such as shale and limestone with some tuff were also present, typical of a marine depositional system. Meanwhile, in the upper Middle Miocene to Pliocene, the fossils were dominated by pollen species and by siliciclastic sediments like sandstone, shale and coal, which were interpreted as a deltaic depositional environment.

Key words: *Simenggaris, Tarakan, Middle Miocene, depositional environment*

INTRODUCTION

There is limited literature discussing the Tarakan Basin to date. Achmad and Samuel (1984) initiated a stratigraphy study of the Tarakan Basin by using integrated data from fieldwork, well data (lithofacies and paleontology) and seismic stratigraphy. They subdivided the stratigraphy of the Tarakan Basin into 5 groups based on the depositional cycle which were primarily influenced by sea level changing.

After a long hiatus, Noon et al. (2003) published an updated Tarakan stratigraphy, which contained seven groups. The seven groups were classified based on sequence stratigraphy, in which they emphasized biostratigraphy and seismic stratigraphy. However, the two studies were mostly derived from offshore data (from Bunyu, Tarakan, etc.) and did not focus on the onshore area, such as Simenggaris.

In the offshore, most wells penetrated Plio-Pleistocene sediments only, which in the offshore can be up to 10,000ft thick. Hence, there is a limited number of wells that penetrated the entire Miocene interval and most of them only reached the upper part of the Miocene.

Data from the onshore Tarakan Basin need to be incorporated to get a complete perspective on the Tarakan Basin stratigraphic evolution. More data can be collected from wells located more landward than those already penetrated the Miocene and Paleogene. This paper intends to share our perspective on how the Tarakan Basin stratigraphy has evolved based on subsurface information that we have observed on the onshore Simenggaris area (Figure 1).

METHODOLOGY

Various subsurface data types were used in order to get a comprehensive and robust interpretation and analysis. The transition between major depositional environments was identified based on the integration of sequence stratigraphy and paleogeographic model. The sequence stratigraphy model was built by using lithofacies association and paleontological data (foraminifera and palynology), incorporated with seismic stratigraphy interpretation and well log facies interpretation. Isopach maps were also generated, and were used as framework for paleogeographic interpretation. In order to improve the confidence level of the paleogeographic model, lithofacies analysis from well log data, net to gross, petrography and core (conventional and SWC) were also incorporated into the isopach map.

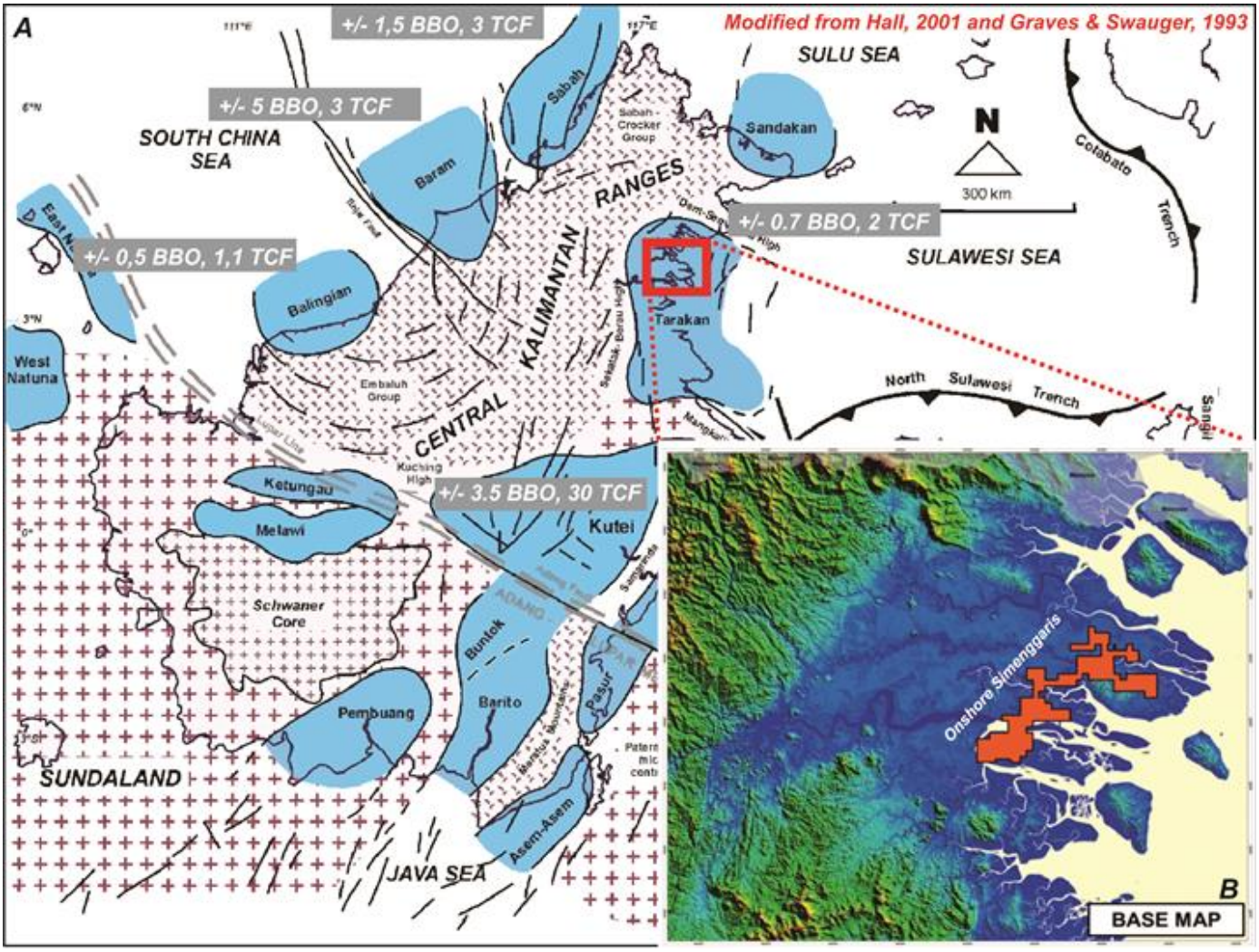


Figure 1: *Study location in onshore Simenggaris, Tarakan Basin. Neighboring basins (Baram and Kutai) are prolific hydrocarbon producers (after Balaguru and Hall, 2003a,b; Graves and Swauger, 1997).*

TECTONIC FRAMEWORK

The regional tectonic framework for the Simenggaris area was derived from the study on tectonic activities by Balaguru and Hall (2009). These tectonic activities influenced the stratigraphy and the structural geology in North Kalimantan, particularly in the Tarakan Basin (Figure 2).

The Tarakan Basin was initiated in 45-40 Ma (Middle Eocene), related to extension and spreading of the Celebes Sea. The spreading may have been caused by proto-South China Sea subduction under Northwest Kalimantan and provided the accommodation space for Paleogene sediments deposition. Active subduction between 38-22 Ma (Oligocene- earliest Miocene) resulted in the development of a volcanic arc along the NW Sabah margin, west of the Tarakan Basin. The volcanic arc isolated the Tarakan Basin from sediment influx; hence the dominant sediments were marine shale and limestone.

In the Neogene around 22-20.5 Ma (Early Miocene), the Dangerous Ground micro-continent commenced its collision with the accretionary complex of the NW Borneo subduction margin (Sabah Orogeny). The Tarakan Basin remained a starved basin with marine shale and limestone deposition. The deposition of clastic sediment was constrained to areas near the uplift in the Central Kalimantan Mountains. The Central Kalimantan Mountains were completely uplifted in the Middle Miocene, providing a significant increase of sediment influx into the Tarakan Basin. The deltaic sedimentation began its development following the uplift cessation. The progradation of deltaic sediment became more intensive in the Late Miocene and continues to shape current morphology in the study area.

STRATIGRAPHY

According to Achmad and Samuel (1984), stratigraphy of the Tarakan Basin can be subdivided into 5 depositional cycles. Depositional Cycle 1 occurred during Late Eocene to Late Oligocene in which extensive peneplanation and regional transgression took place. At the end of Late Oligocene, major uplift and volcanism occurred, which marked the end of Depositional Cycle 1. Later on, Depositional Cycle 2 was deposited during second peneplanation and regional transgression, which then was ended by a volcanism event in intra Early Middle Miocene. During Early Middle Miocene, subduction in the northwest of Kalimantan (Balaguru and Hall, 2009) caused major uplift in Central Kalimantan , which led to the huge sediment influx to the peri-basins of Kalimantan. The event also ceased regional transgression. Depositional Cycle 3 (Late Middle Miocene to Late Miocene) is dominated by prograding deltaic sediments. The deltaic sediments become typical stratigraphy fill for Depositional Cycles 4 and 5. The Depositional Cycle 4 began after new uplift in the western part of the basin during Pliocene and Depositional Cycle 5 began after marine onlap caused by Holocene global sea level rise.

The latest stratigraphy study for the Tarakan basin by Noon et. al. (2003) classified the stratigraphy of the basin into 7 sequences. Sequence VII is the oldest, deposited during Middle Eocene. The sequence is comprised of coastal to deep marine sediments (Hidayat et. al., 1995; Situmorang and Burhan, 1995) and volcaniclastics. A Late Eocene unconformity (39.07 Ma) marked the end of Sequence VII. The overlying Sequence VI can be subdivided into two subsequences, VIB and VIA, each with its own lithology characteristics. Late Eocene Subsequence VIB is dominated by clastic sediments and coals as well as volcaniclastics, although with reduced intensity than it is in Sequence VII. Subsequence VIA was deposited during Early Oligocene, above a distinct angular unconformitydated as 33.3 Ma), andcontains dominantly shale and limestone.

Oligocene – Early Miocene Sequence V is subdivided into two subsequences as well, (VB and VA). The base of Subsequence VA coincides with a regional mid-Oligocene unconformity (dated as 29.4 Ma). The sequence is dominated by transgressive sediments, such as reefal limestone and calcareous shales. The end of Sequence VB is marked by the presence of a marine low-stand event of global significance at the Oligocene/Miocene boundary (dated as 23.8 Ma). The sediment is characterized by sag basin fill, consisting of shales, calcareous shales, limestone and occasionally volcaniclastics.

Sequence IV began its deposition during a regional event that was associated with plate reorganization (dated as 17.3 Ma). A “pivot point” of depositional environment shifts, between major transgressive sediments within Sequences VII –V to major regressive sediment, occurred within Sequence IV. Generally the sequence is comprised of progradation sediment of shale, sandstone, limestones and rare coals. Sequence IV ceased deposition by the presence of regional erosional event (dated as 11.3 Ma). Following the erosional event, sediment of Sequence III filled the basin with typical lithology such as claystone, sandstone, limestone and minor coals. Similar lithologies occur within Sequence II (Pliocene) and Sequence I (Pleistocene) in which each sequence is separated by a regional unconformity.

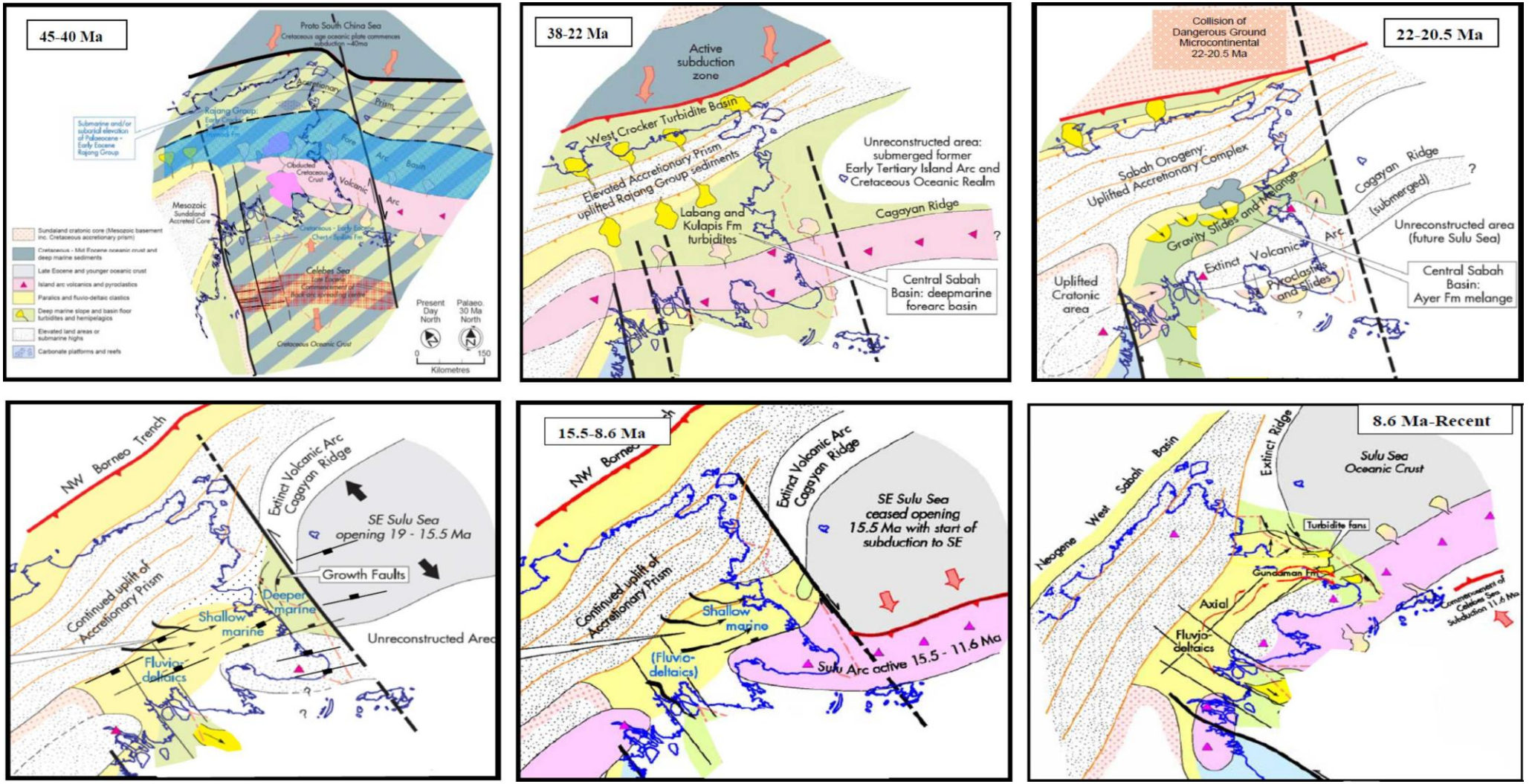


Figure 2: *Tectonic framework according to Balaguru and Hall (2009). Tectonic activity in North Kalimantan includes subduction and volcanism in Eocene-Early Miocene, collision and mountain build-up in Early Miocene-Middle Miocene, continued uplift that led to delta development in Middle Miocene-Late Miocene and finally, strike-slip reactivation in Late Miocene-Pliocene*

RESULT AND DISCUSSION

Transgressive pulse – Marine Depositional System

During the Eocene to Early Middle Miocene, the depositional system was interpreted as predominantly marine, as a result of the transgressive sea level (Figure 4). Eocene sediments consist of shale, tuff, and some streaks of carbonate. The lithofacies association indicates a low energy marine environment with some volcanic influences. In the Oligocene, the lithofacies analysis revealed dominantly shales and thick massive limestone in some areas, particularly in the southern part (Kapal-Fanny area, see Figure 4). In the southern part of Simenggaris, very thick limestone was encountered. The limestone can be easily identified from seismic by mounded and internally chaotic facies.

Paleontology in transgressive pulse sediments is dominated by marine foraminifera. In the Eocene, the presence of species such as *Discocyclina, Hantkenina primitiva, Globigerina ampliapertura, Globigerina pseudoampliapertura, Globigerina tripartita, Globorotalia centralis, Globorotalia cerroazulensis* are abundant. While the Oligocene is characterized primarily by the presence of *Nummulites f. intermedius*. The domination of Foraminifera fossils also support the interpretation that the area was in a marine depositional environment system.

In the Early Miocene, the lithofacies is dominated by shale and limestone with some tuff presence, but not as common as in the Eocene. The core data revealed a slump structure in siltstone at the Tanjung Kramat area (Figure 4), indicating a marine slope environment. It suggests a transgressive system, where the shoreline moved relatively landward compared to the Oligocene. The area that in the Oligocene was shallow marine became deeper as a slope, particularly in Tanjung Kramat where slump sedimentary structures were found. While in Kapal-Fanny, the area is dominated by thick limestones, which indicated a paleo-high. However, the growth of the limestones in the Early Miocene was not as extensive as in the Oligocene due to uplifting in the Central Kalimantan mountains. Minor presence of tuff is evidence of volcanic activity before it diminished in the Late Early Miocene, during the micro-continent collision in the northwest.

According to Achmad and Samuel (1984), the transgressive pulse, which was associated with the marine depositional environment system, coincides with the depositional cycles 1-2. The depositional cycle 1 is comprised of the Sujau and Mangkabua Formations, while the depositional cycle 2 comprises the Naintupo Formation.

The marine transgressive interval continued until the lower Middle Miocene. In the Middle Miocene, lithofacies and paleontological associations changed dramatically to a series dominated by siliciclastic sediments and pollen species.

Regressive Pulse - Deltaic Depositional System

Late Middle Miocene - Pliocene was marked as the regressive pulse, characterized by prograding siliciclastic sediments, dominated by sandstones with some coal interbeds. Conventional cores from the Middle Miocene interval show sandstones with flaser and lenticular sedimentary structures, indicating a strong influence of tidal currents. Moreover, the sandstones also show a mature texture, with rounded- sub rounded grains, good sorting, point grain contacts and quartz as the main mineral. The stacking patterns of the whole sequence also showed coarsening up patterns, interpreted as progradational series in a deltaic system.

In some intervals some carbonate streaks were found, as very thin layers in shale dominated sediments. Their presence marks short episodes of transgression in an overall regressive, prograding sequence. The carbonates also act as regional markers for sequence stratigraphy events in the Middle-Late Miocene, which is also useful to characterize sediment rock unit (formation).

In the Pliocene, most of the area was uplifted and eroded. Sediments from this interval can only be found in the eastern well (EM1), while in the west it is completely eroded. The Pliocene sediments in the EM1 well are massive blocky sandstones with high net-to-gross ratios. The Pliocene lithofacies association of sandstone, coal, and shale with high net-to-gross ratio of sandstone suggests an upper delta plain environment.

Based on net to gross ratios of sandstones four major sub-environments can be interpreted: upper delta plain, lower delta plain, delta front, and pro-delta (Figure 5). Upper delta plain has net to gross ratios over 50%. Stacking pattern in this interval also comprised predominantly blocky sandstone. Towards the lower delta plain, net to gross ratios gradually decrease to 40%-30%. Thin carbonate streaks also exist in this environment, indicating tidal current influence in lower delta plain sub-environment. The delta front, the sub-environment has net to gross values of 30%-20%, with mainly funnel shape electric log patterns. The pro-delta sub-environment has the lowest net to gross values of 20%-10%, and is associated with shale and isolated limestone.

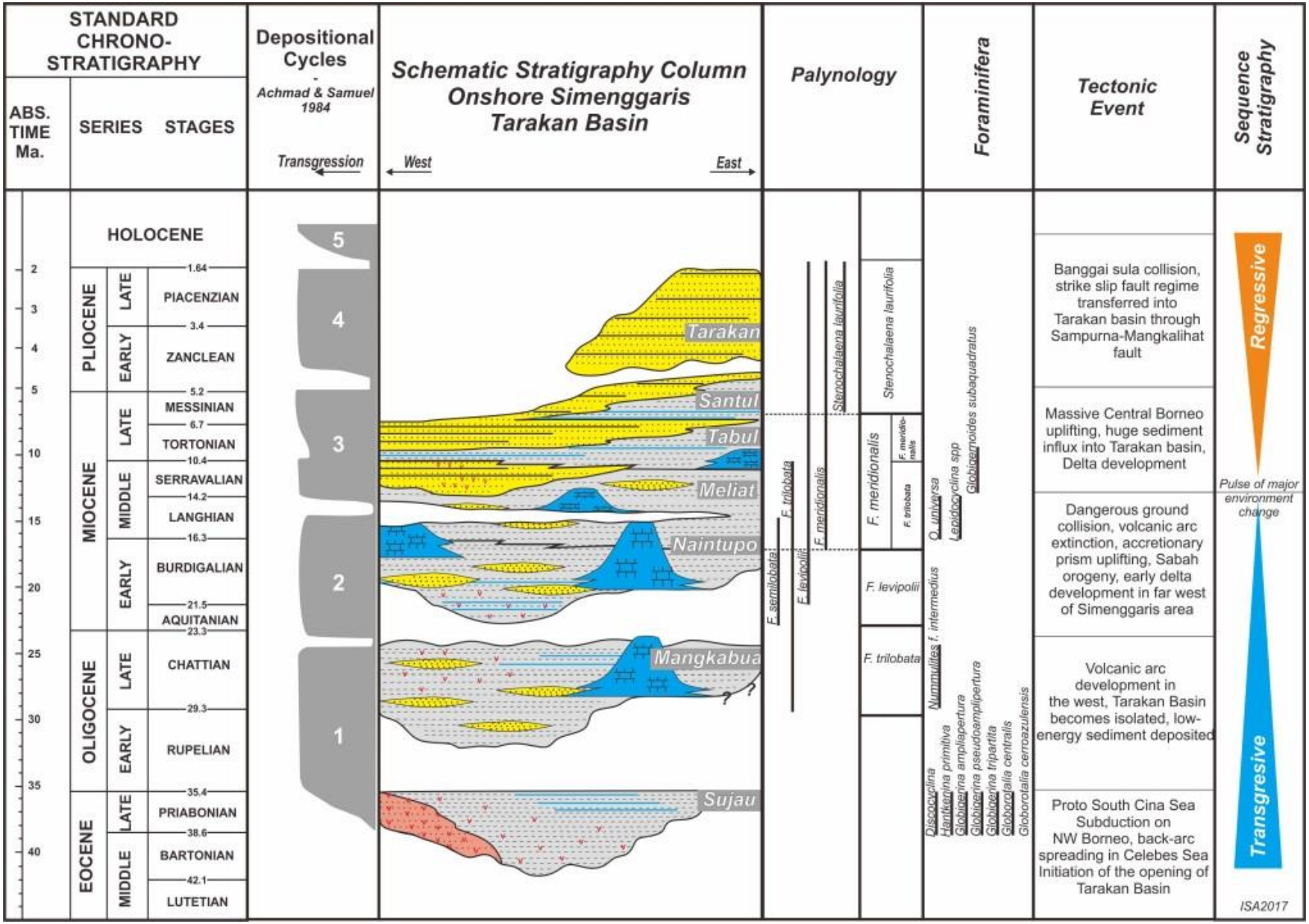


***Figure 3**: Schematic stratigraphic column based on well data in Simenggaris area. Major stratigraphic depositional environment change occurred in Middle Miocene.*

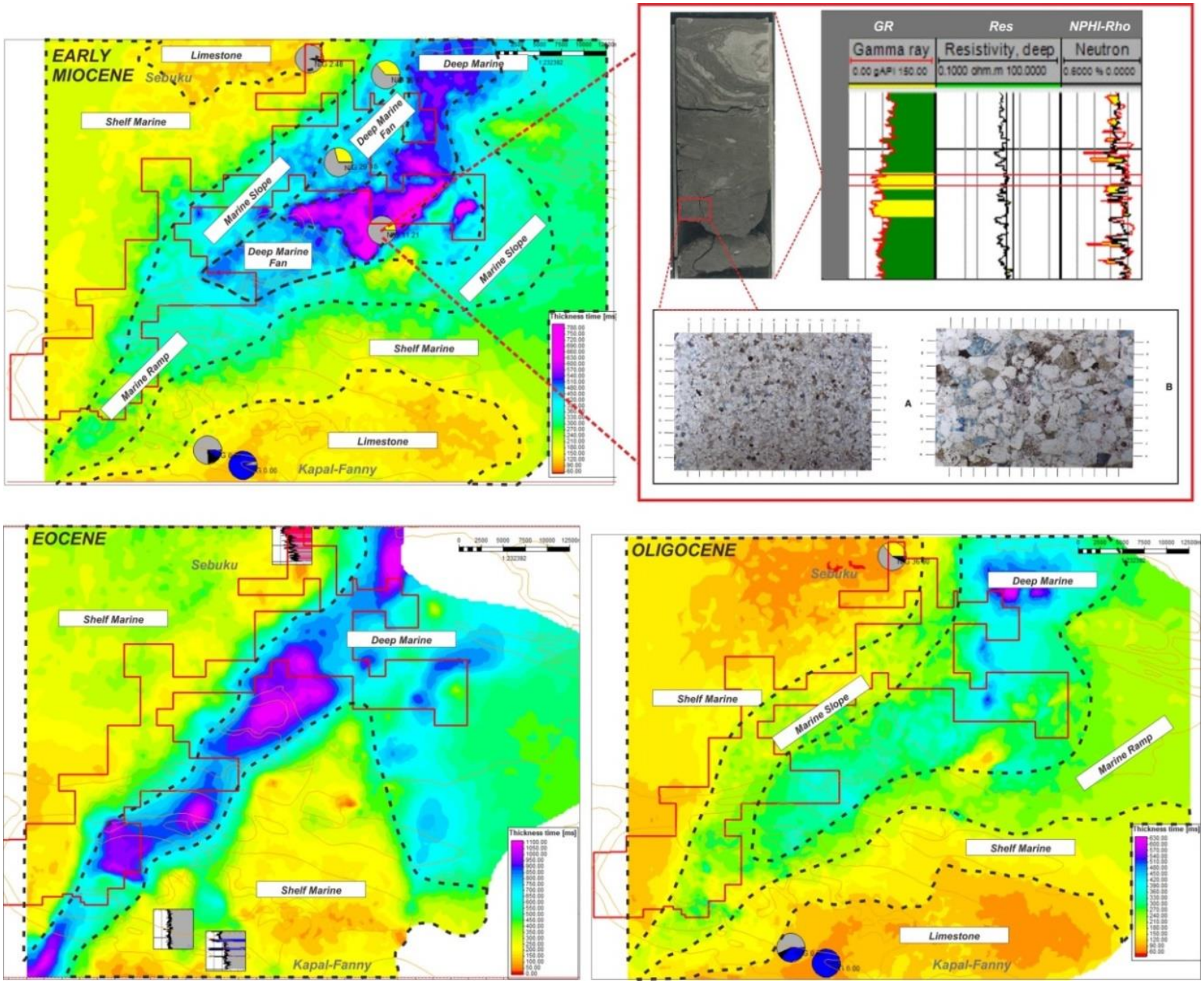


Figure 4: *Gross Depositional Environment maps based on isopach and net-to-gross ratio of sandstone in transgressive pulse, which was deposited in the marine depositional environment. This interpretation is supported by the presence of thick limestone and from slump structures in cores, indicative of a marine slope environment.*

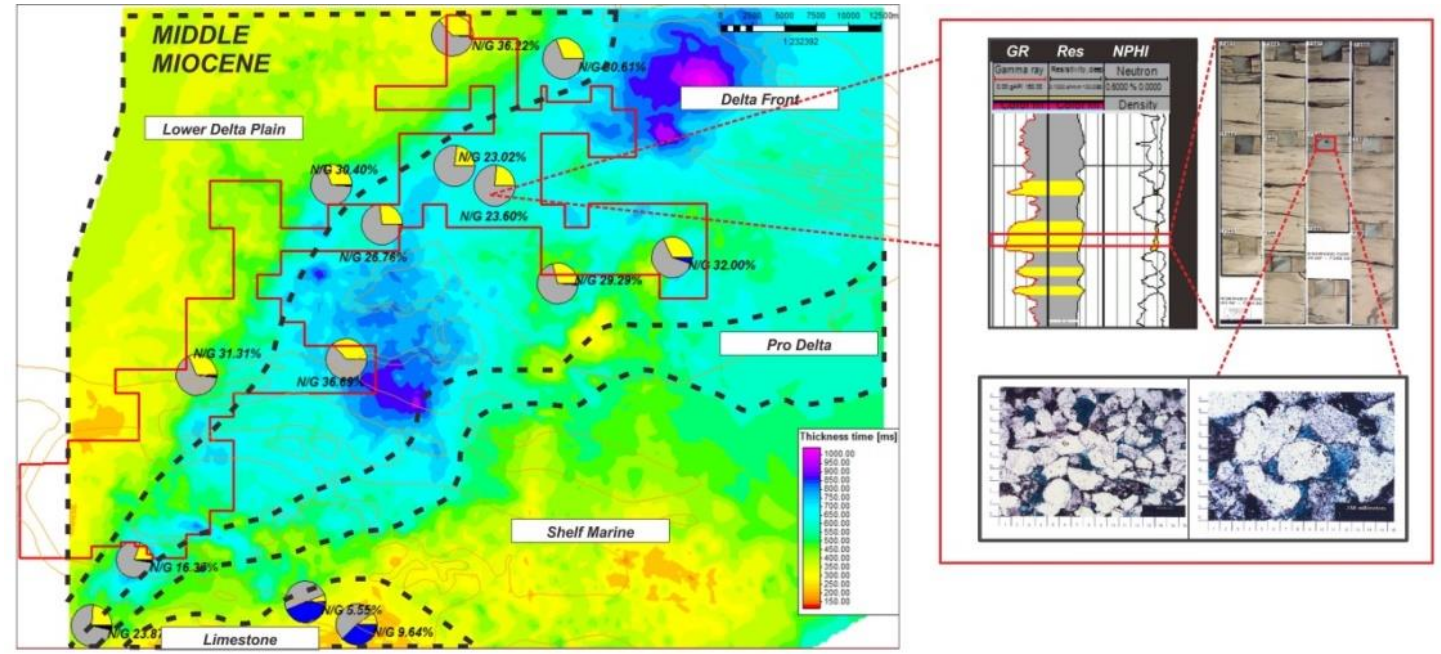
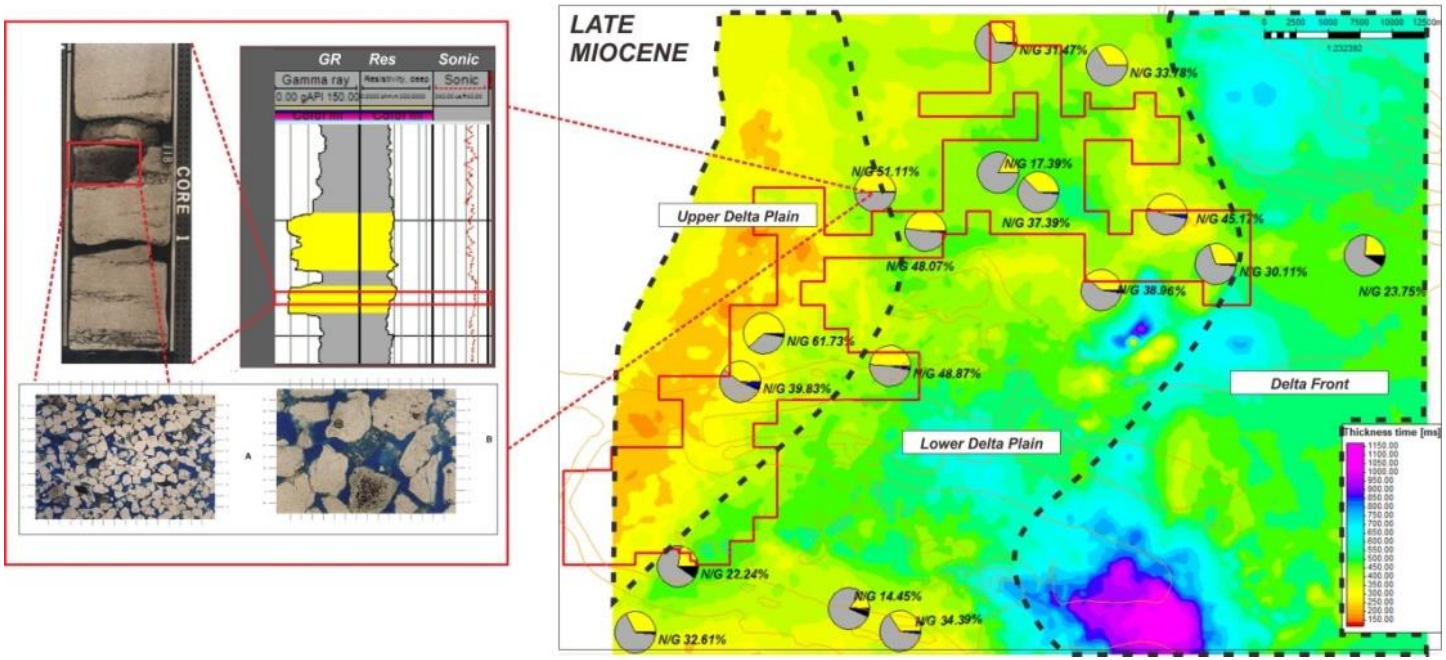


Figure 5: *Gross Depositional Environment maps based on isopach and net to gross ratio of sandstone in the regressive pulse, which is dominated by delta depositional environment sediment. The interpretation is supported by high ratio of sandstone. The core data shows mature texture sediment usually associated with transitional environment.*



Paleontological data show the regressive phase sedimentss are dominated by the pollen fossil species. Some marine foraminifera were found only in the lower interval of the late Middle Miocene section, such as *Orbulina universa*, *Lepidocyclina spp.* and *Globigerinoides subquadratus*. However, foraminifera were not encountered in the younger sections. Pollen-bearing facies began to be present since the Late Oligocene, marked by the appearance of *Florschuetzia trilobata*. In the Early Miocene *Florschuetzia semilobata* is common, together with the *Florschuetzia levipolii* and *Florschuetzia trilobata*. Furthermore, *Florschuetzia meridionalis* marked the beginning of sediment deposition in the Middle Miocene. In the Middle Miocene, *Florschuetzia semilobata* appeared in the lower part interval while *Florschuetzia trilobata* appeared in the upper part of the interval. In the Late Miocene, pollen fossil comprised the association of *Florschuetzia meridionalis* and *Florschuetzia levipoli*. The Pliocene interval is marked by the first appearance of *Stenochlaena laurifolia*.

According to Achmad and Samuel (1984), the regressive pulse is associated with the sediment Cycles 3-5. The Middle Miocene sediment is associated with the sediment Cycle 3, which is tied to the Meliat Formation. The Late Miocene sediment is also associated with Depositional Cycle 3, but with more prominent deltaic influence. Cycles 4 – 5 correspond to the Tarakan and Bunyu Formations, which are mostly eroded in the study area.

CONCLUSIONS

Based on our evaluation, we identified two major depositional environment systems in the Tarakan Basin. The two depositional environment systems have strong relationship with relative sea level change and the regional tectonic activities around the basin. The first pulse occurred during Eocene-Early Miocene when the environment was dominated by transgressive pulse sediment. Tectonically, the Tarakan basin is a back-arc basin due to the subduction in Northwest Kalimantan. A volcanic arc formed in the west, isolating the basin and gave way to the influence by low energy sediment. Thus, the basin was dominated by shale and limestone. Volcanic activities were also recorded in the sediment, with significant tuff deposits in the Sebuku area within the Sujau formation (Eocene). The Sesayap area also shows the influence of volcanic activities within the Early Miocene sandstones. Petrography analysis revealed abundant opaque minerals, which are associated with hydrothermal processes.

The second pulse occurred during the Middle Miocene – Pliocene, when the environment was dominated by the regressive pulse, with siliciclastic-rich prograding sediments which comprised sandstone, coal and shale. The sediments were deposited in a deltaic system. The sandstone texture indicates a distal depositional environment, with rounded – sub-rounded, well sorted, fine to medium sandstones with and point contact grains. From the regional tectonic perspective, in the Middle Miocene major Central Kalimantan uplift occurred, providing a huge amount of siliciclastic sediment input for the Tarakan Basin.

The paleontology analysis revealed specific characteristic of each pulse. The transgressive pulse sediment is dominated by foraminifera, which support the interpretation of marine influence. In the Eocene larger foraminifera (Discocyclina) and planktonic foraminifera (*Hantkenina primitiva*, *Globigerina ampliapertura, Globigerina pseudoampliapertura, Globigerina tripartita, Globorotalia centralis*, *Globorotalia cerroazulensis*) are present. The Oligocene, is marked by the presence of Nummulites intermedius. In regressive pulse foraminifera are very scarce and disappeared going upward.

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