A Review of Regional Geology of the North Sumatra Basin and its Paleogene Petroleum System

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INTRODUCTION

The North Sumatra Basin (NSB) is located on the western part of Sundaland and covers approximately 60,000 km^2 of onshore and offshore regions (Figure 1). With over 100 years of production, North Sumatra Basin is one of Indonesia's most prolific sedimentary basins. As stated by Meckel (2012), 25 trillion cubic feet (TCF) of discovered gas reserves (equal to 4.5 billion barrels of oil equivalent, BBOE) and approximately 1.5 BBOE of oil and condensate reserves confirmed this basin as the third largest hydrocarbon-producing basin in Indonesia, after Central Sumatra and Kutei Basins, respectively.

The first hydrocarbon discovery was Telaga Said Field in 1885 (Figure 2). Since then, remarkable findings (e.g. Rantau, Arun, NSO A, Lhok Sukon A, etc) contributed to the considerable amount of oil and gas reserves. From 1985 onwards, drilling activity in the North Sumatra Basin was stagnant due to volatile geopolitical and geological condition in Aceh. A variety of underexplored plays still remain in the basin, especially from Paleogene and pre-Tertiary age.

TECTONIC EVOLUTION

Tectonic deformation in the North Sumatra Basin is subdivided into four periods (Davies, 1984), which is shown in Figure 3.

1. In Early Eocene to Early Oligocene, the northward movement of the Greater Indian Landmass along major Indian Ocean transform fault triggered rapid strike-slip motion along the west coast of Sumatra. This resulted as major right-lateral wrench faults along western boundary of Sunda Microplate. North – south weakness lines greatly influence subsequent deformation.
2. During Late Oligocene to Early Miocene, N-S trending major wrenches had rotated counter-clockwise due to Sunda Microplate movement, which also led to the separation of Sumatra from Malay Peninsula. Meanwhile, the formation of North Sumatra Basin was accommodated by a series of right and left stepping, right-lateral wrench faults.
3. Regional uplift in the Middle Miocene was observed by the reactivation of older horst and grabens in North Sumatra Basin and widespread erosion led to regional unconformities. This coincided with the incipient of sea floor spreading in Andaman Sea.
4. Two major compressive stresses occurred in the North Sumatra Basin during Late Miocene to Recent.

However, It is still debatable whether the basin was created by pull-apart or by rifting of an Eocene extensional force. The variety of depth and structural style in the sub-basins imply different styles and mechanisms of basin formation. At larger scale, among a series of back-arc basins in Sumatra, North Sumatra Basin has distinctive north-south trending grabens, which are not seen in Central Sumatra Basin (CSB) and South Sumatra Basin (SSB). This implies that these back-arc basins can't be interpreted to be formed from a same mechanism.

We suggest that the N-S oriented Paleogene faults were influenced by pre-existing weak zones in the basement before rifting because a series of strike-slip that had existed since Cretaceous (e.g Khlong Marui and Ranong Faults). These major strike-slip faults were suture zones in pre-Cenozoic, which were terrane boundaries (Hutchison , 2014). In the Eocene rollback of Indian Plate subduction, rifting trend followed the N-S weak zone. Consequently, it is seen in the North Sumatra Basin as N-S trending grabens. A speculative analysis upon the north-south trending grabens in North Sumatra Basin has been collected through above explanations and need further studies. Still, it is certain that Pre-Tertiary structural fabric had been an important control in basin formation and deformation.

STRATIGRAPHY

The stratigraphic chart of North Sumatra Basin is shown on Figure 4. The Pre-Tertiary basement of North Sumatra Basin includes sedimentary rocks, metasediments, and igneous rocks (Caughey and Wahyudi, 1993). Unconformably overlying the basement are the Paleogene (Late Eocene to Early Oligocene) Tampur and Meucampli Formations. Age dating issue of Tampur and Meucampli Formation had been reported by Barber et al. (2005), based on its stratigraphic position and regional correlation.

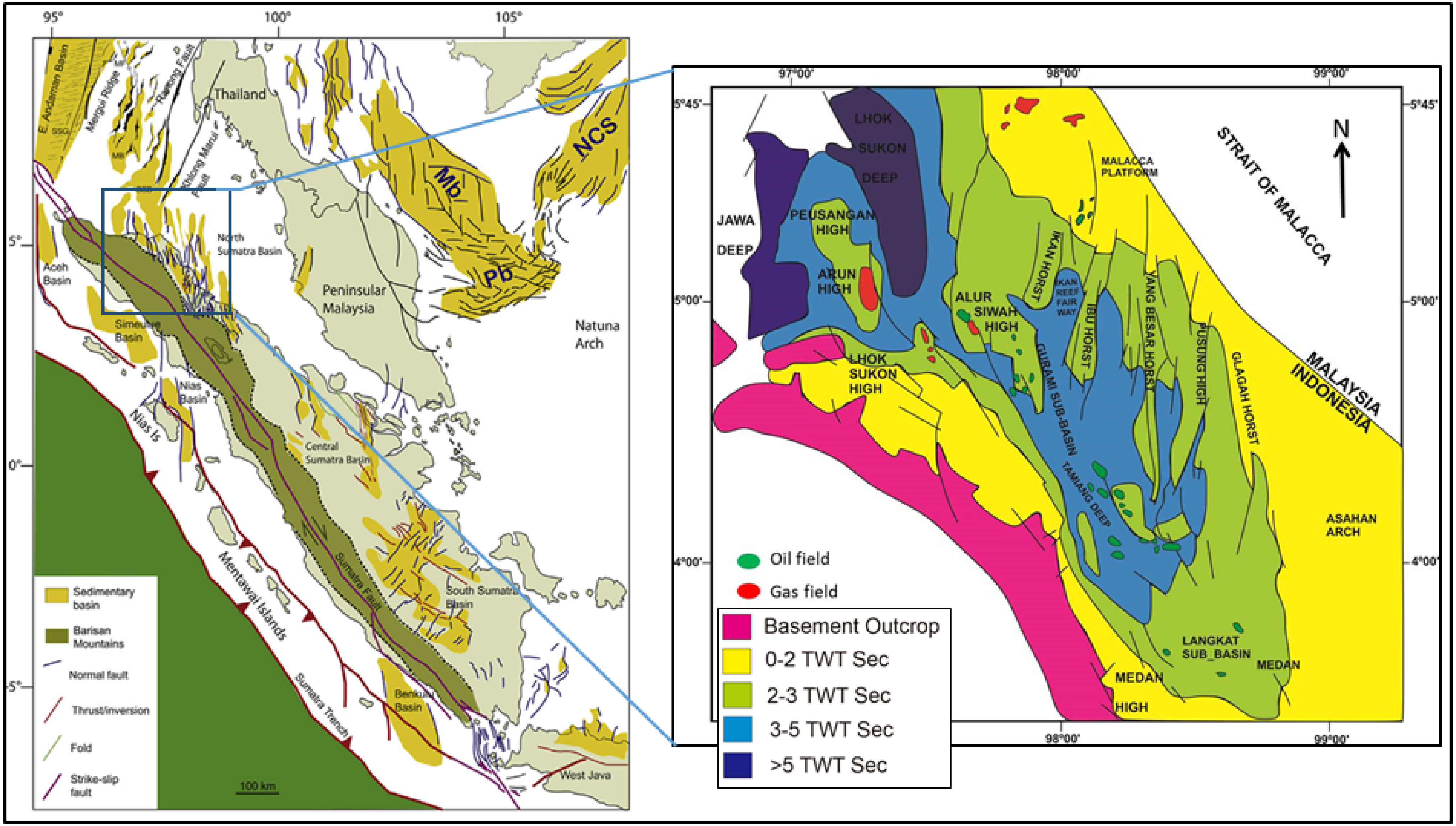

Figure 1. *Regional present day basement structure of Sumatra (Pubelier and Morley, 2013). Inset map is a zoom-in of North Sumatra depth-to-basement map showing structural features and their orientations (modified after Anderson et al., 1993).*

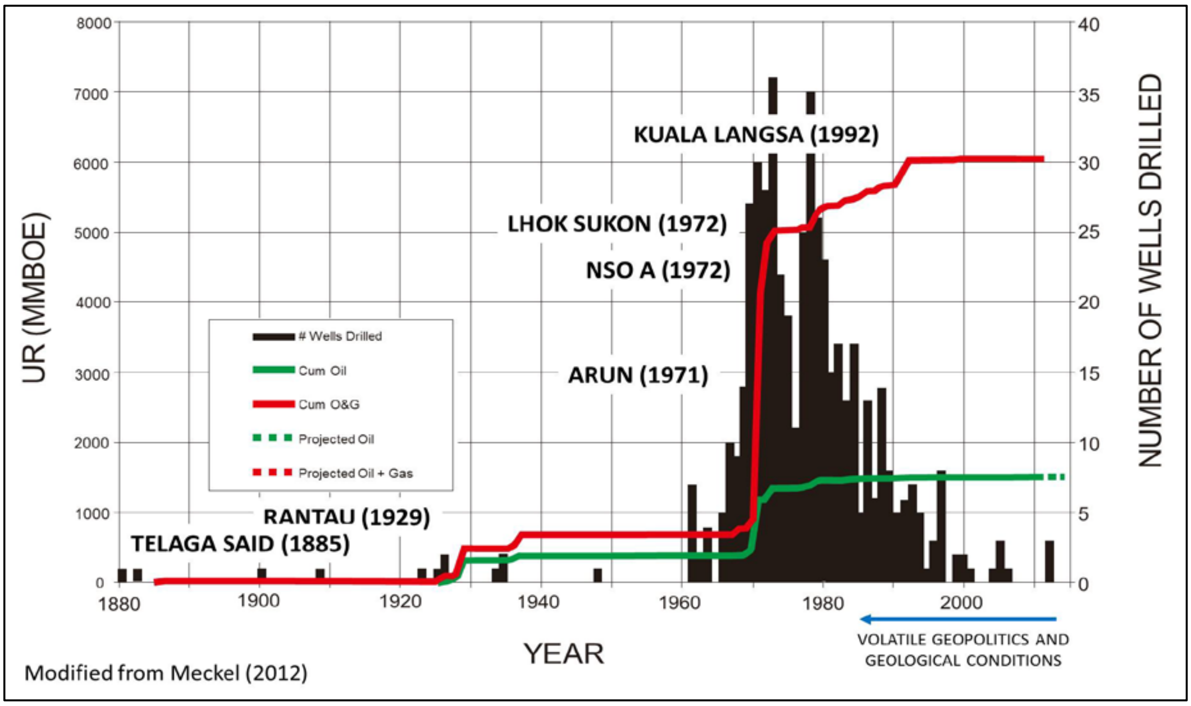

Figure 2. *North Sumatra Basin exploration history (after Meckel, 2012).*

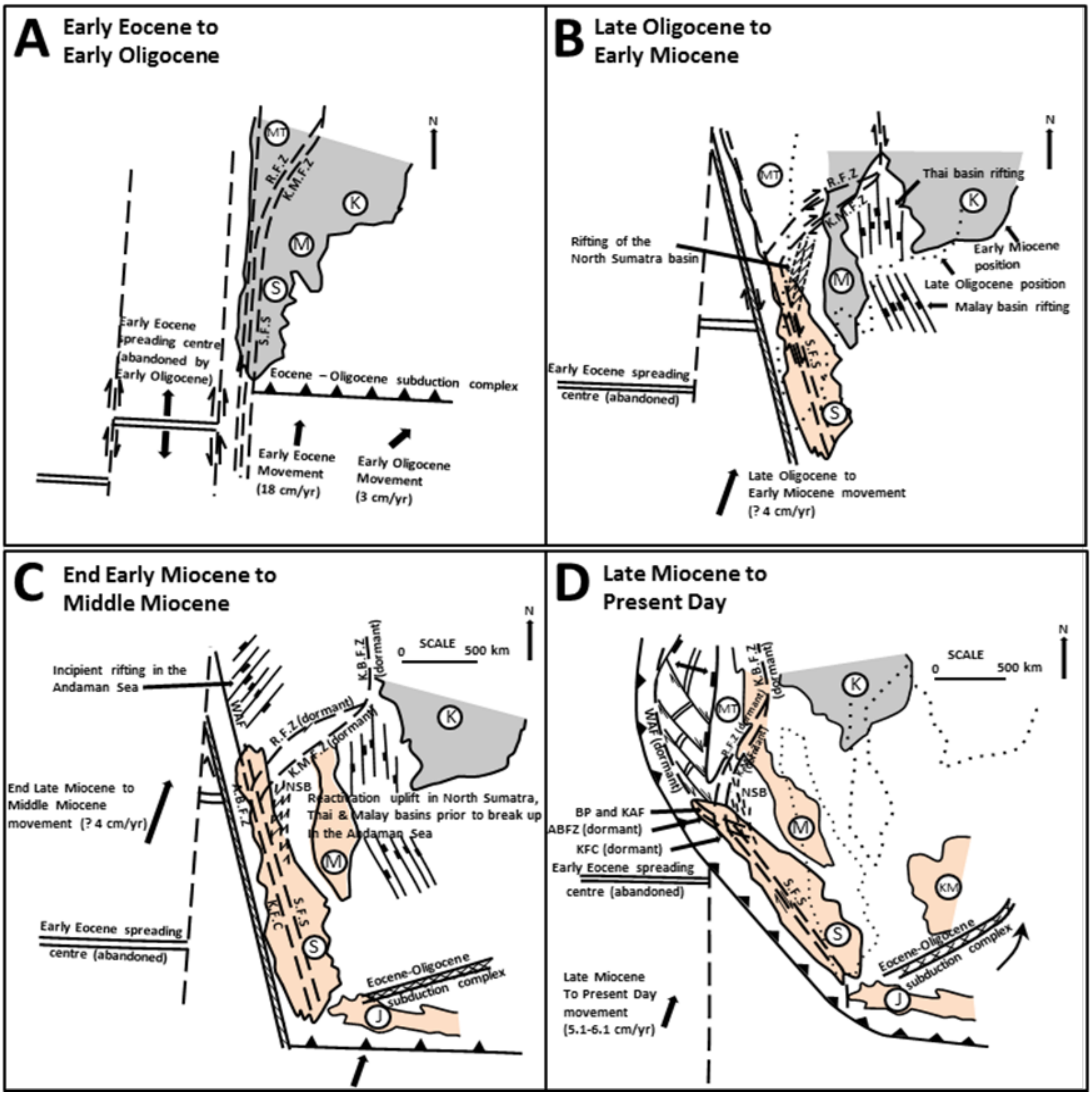

Figure 3. *Development along the trailing edge of Sunda Microplate (Davies, 1984).*

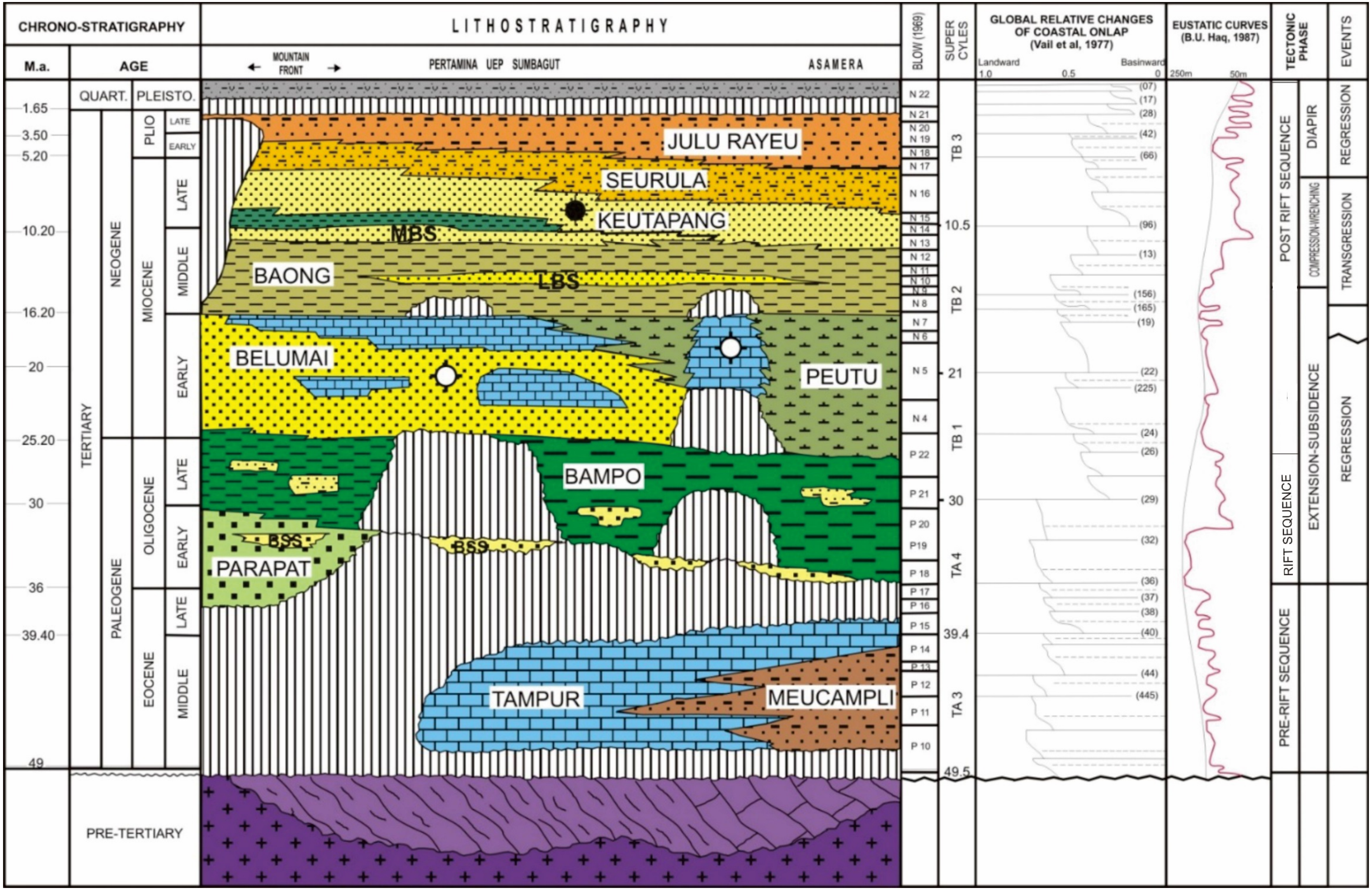

Figure 4. *Northern Sumatra Lithostratigraphy (modification after Ryacudu et al., 1992).*

Paleogeography model by Barber et al. (2005) illustrated that during in Eocene to Early Oligocene, North Sumatra Basin was a continental margin, rather than a rift basin. During that time, Sundaland was in a cratonic stage and the environment was more deeper to the northern part of North Sumatra Basin. This is the reason why the North Sumatra Basin is the only basin in Sumatra back arc basin that contains Eocene shallow marine limestone.

During Paleogene, in the North Sumatra Basin, marine influences persisted, but elsewhere the horst and graben stage is represented stratigraphically by alluvial fans and fluvial sediments that pass laterally into lake deposits. Alluvial fans and fluvial deposits are sedimentologically immature and characteristically contain clasts of granite and metamorphic rock derived from the nearby basement (Barber et al., 2005)

PALEOGENE PETROLEUM SYSTEM

The North Sumatra Basin is currently producing oil and gas, therefore the petroleum system is working and complete. Average geothermal gradient of the North Sumatra Basin is 45°C/km (Ryacudu and Sjahbuddin, 1994) in the synrift kitchens including Pase Deep, Lhok Sukon Deep, and Tamiang Deep.

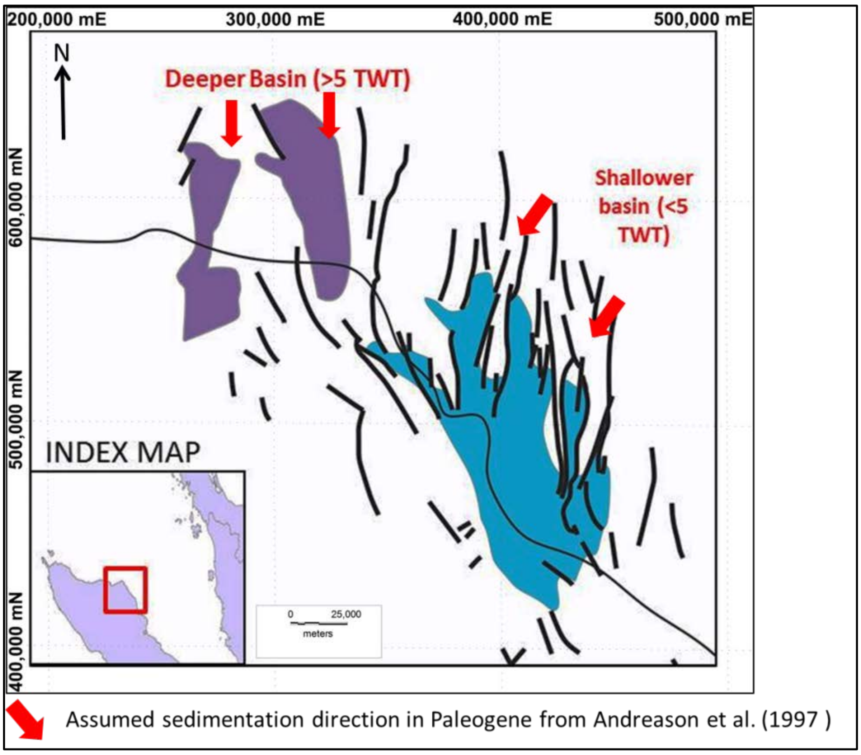

Figure 5. *Shaded area is the regional distribution of the Paleogene sediment in North Sumatra Basin which is controlled by Paleogene Faults. There are two sub-basins which are the depocenter of the sediment. In the northern part the sub-basin is deep whereas in the southern part, the sub-basins are generally shallower compared to the northern part (after Anderson et al., 1993).*

The Paleogene sediment within the syn-rift is very important because mainly they are prolific source rock which had reached oil and gas maturity window. The thickness of the Paleogene sediment is greatly influenced by basement paleotopography and its distribution is controlled by North-South-oriented graben (Figure 5). Most of the Paleogene source rocks have low Hydrogen Index (Type III) , hence expelled predominantly gas with minor oil (Figure 7).

The shallower depocenters in the south around Gurami sub-basin and Tamiang Deep still produce some oil onshore. The oil may be over cooked in the deeper depocenter in the north (e.g. Jawa and Lhok Sukon Deep), therefore gas accumulations dominate this area.

It is still interesting that the Paleogene sediment also have reservoir potential. The hydrocarbon sourced from the Pre-Tertiary section below or within the Paleogene sediment itself. The Tampur Formation, overlying the basement high can have potential reservoir within fractured dolomite. The seal capacity reported by Fuse et al. (1996) is showing that Bampo and Peutu mudstones (shale) deposited in Upper Oligocene to Lower Miocene, have high sealing capacities. These mudstone formations are excellent seals for Paleogene reservoirs, such as the Tampur Formation. Banukarso et al. (2013) reported that in the northern part of the basin, the Paleogene syn-rift sediment was significantly inverted, which potentially created trap for hydrocarbon. Consequently, the Paleogene sediment in the North Sumatra Basin have a complete petroleum system element. The summary of Paleogene petroleum system of can be seen in Figure 6.

Ryacudu and Sjahbuddin (1994) revealed that Tampur Formation can be reservoir and some wells penetrating these formation have yielded significant hydrocarbon. However there are problem with significant amount H_2S and CO_2. The CO_2 can reach 50%, but the origin of CO_2 is still unclear. The hydrocarbon oil and gas in Tampur is sourced from Lower Baong Shale. There are at least three play type within the Tampur Fm. as suggested by Ryacudu and Sjahbuddin (1994), which consist of: 1) Reefal buildups; 2)Fractured anticline, and 3) Karstic debris. The play cartoon of Tampur can be seen in Figure 8. In Alur Siwah-8, this formation tested 6.8 MMSCF per day (Barliana *et al.* 2000).

A recent study by Sijabat et al. (2016) shows that the hydrocarbon in Tampur Fm. can be sourced from Pre-Tertiary rocks, including Jurassic-

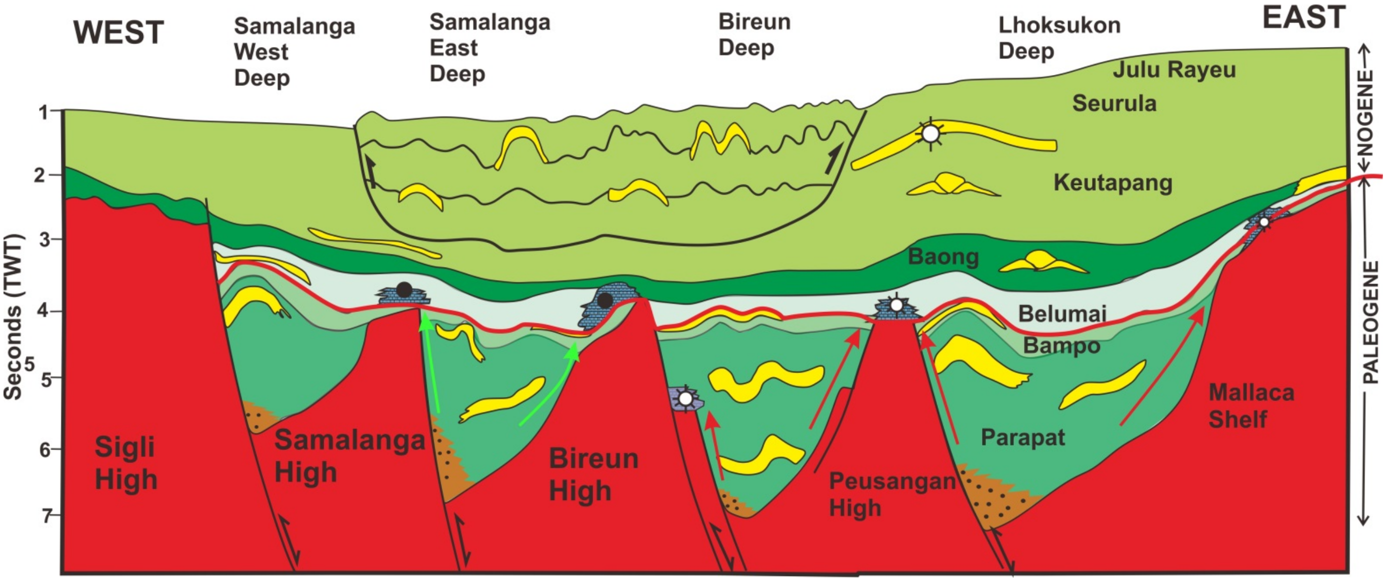

Figure 6. *Petroleum play cartoon in the North Sumatra Basin (after Meckel, 2012).*

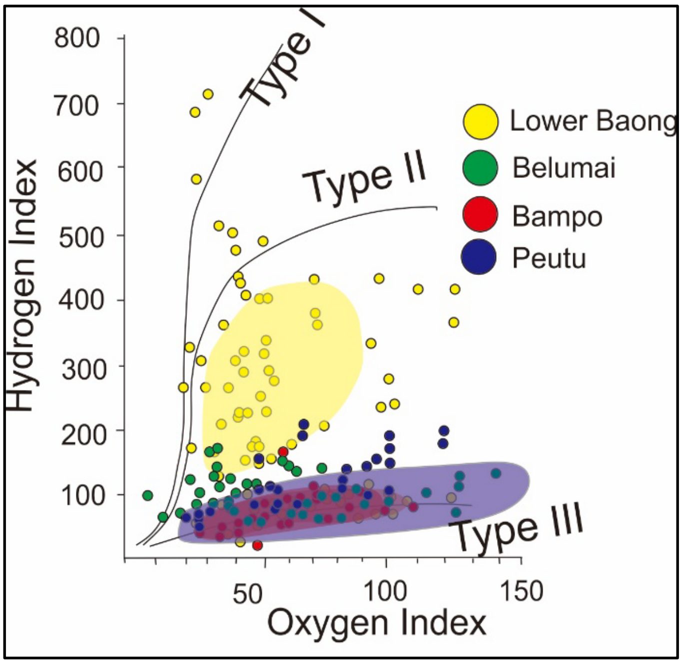

Figure 7. *Hydrogen Index vs. Oxygen Index of Lower Baong, Belumai, Bampo and Peutu shales (after Sjahbuddin & Djaffar, 1993 and Buck & McCulloh, 1994).*

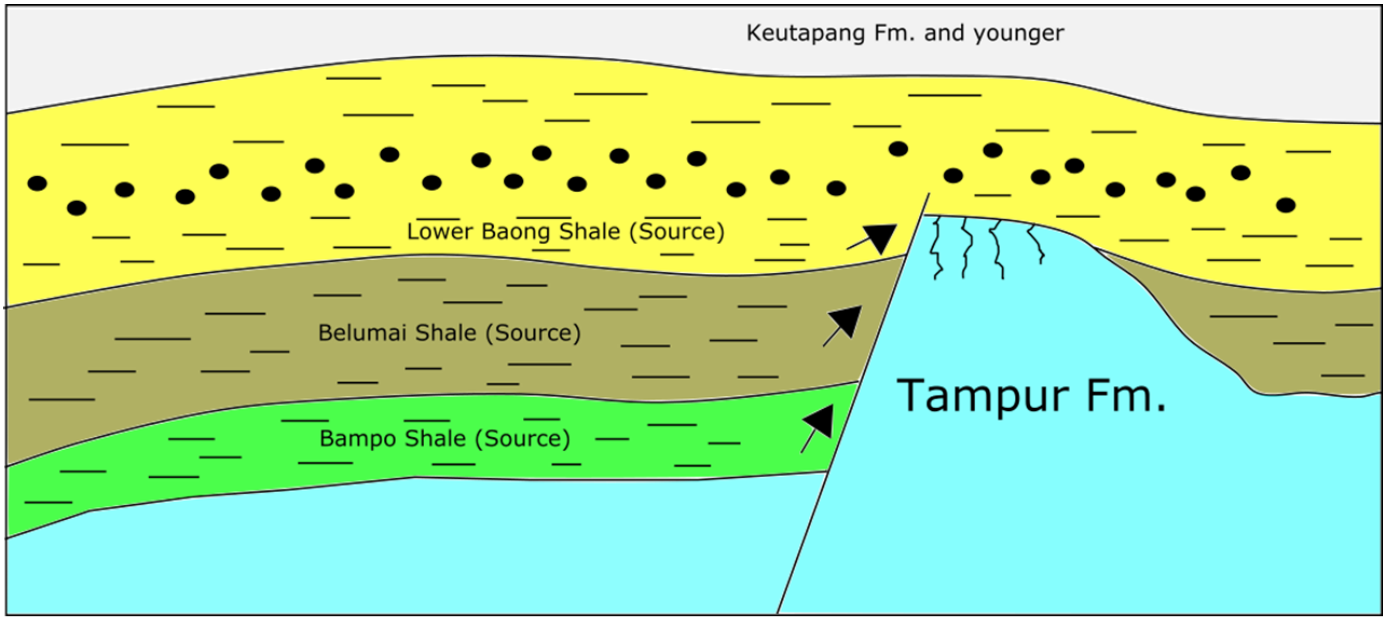

Figure 8. *Play cartoon showing hydrocarbon accumulation in Tampur Formation (after Ryacudu and Sjahbuddin 1994).*

Cretaceous shales. The Pre-Tertiary source rock shows good organic richness, with TOC ranging from 1.3-2.1 wt% and is classified as Type III kerogen.

CONCLUSION

Despite being a mature basin, significant hydrocarbon play may still remain in the Paleogene interval of the North Sumatra Basin. Unfortunately, better understanding of this petroleum system will require more data and studies. It is necessary to have more sampling control to measure quality and quantity of source rock in the Paleogene sediment. Seismic imaging for deeper section will also help to understand the reservoir distribution. It is necessary to conduct more precise dating in the syn-rift sediment for holistic understanding of hydrocarbon habitat and tectonic evolution in North Sumatra Basin.

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