Paleozoic – Mesozoic and Eocene Outcrops in the North Sumatra Basin and their Implication to New Exploration Play Concept

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ABSTRACT

Paleozoic – Mesozoic and Eocene hydrocarbon plays in the North Sumatra Basin are still under-explored although they have been recognized for many years. The Paleozoic – Mesozoic play consists of Peusangan Group (Permian – Triassic) and Woyla Group (Jurassic – Cretaceous), which are overlain by Eocene – Early Oligocene Tampur carbonate/dolomite and onlapped by lacustrine Oligocene Bampo/Bruksah sediments. The Eocene play is represented by the Tampur Formation, which is a widespread carbonate/dolomite platform covering pre-rift sediments in the basin. A new mature source rock layer and highly permeable secondary porosity were observed in the Eocene Tampur carbonate outcrops. This finding suggests a possible new petroleum system involving the Eocene Tampur Formation as both source and reservoir.

Identifying a new play concept and petroleum system in the Paleozoic – Mesozoic and Eocene sediments of the North Sumatra Basin will have important implications for future exploration, because it may lead to discovering potentially large hydrocarbon accumulation within naturally-fractured and/or karst reservoirs. Paleozoic – Mesozoic and Eocene petroleum systems in the basin at the moment are a subject of an ongoing study incorporating outcrops, core and seismic data.

Keywords: *Tampur Formation, Peusangan Group, North Sumatra Basin, Paleogene*

INTRODUCTION

Following the discovery of giant Arun Gas Field in 1971, a significant effort has been made in exploration of Tertiary reservoirs, but this effort has not contributed significantly to increased reserves and production. Seismic acquisition and processing were conducted to help unlock the potential, but due to subsurface uncertainty, finding additional reserves in the Tertiary play is proving to be challenging.

Recently, a different strategy was employed by the North Sumatra Basin Exploration Team of PT Pertamina EP (PEP), namely to find new play in stratigraphically deeper targets, especially within the Eocene Tampur Formation and a potential Paleozoic – Mesozoic play beneath the Tampur Formation (see also Bahesti et al., 2015). This article will review the potential of both plays in the North Sumatra Basin, based on outcrop observations in an area called East Sumatra Block at the southeastern border of the basin (Figure 1). The focus of the field work was on the Tampur Formation (Eocene) and older sediments (Late Paleozoic – Mesozoic). The Tampur Formation comprises very dense limestone, mostly mudstone and wackestone, and has very low primary porosity but is highly fractured and contains abundant vugular porosity.

GEOLOGICAL SETTING

SE Asia was subdivided into a number of terranes that are bounded by major faults (e.g., Mitchell, 1981; Burnett et al., 1987; Metcalfe, 1992). These terranes have histories which are variably decoupled from that of their neighbours – meaning their contiguity today is no guarantee of proximity in the past. The Sibumasu terrane comprises much of the western part of the Malay Peninsula, extending southwards into Sumatra (Indonesia) and northward into West Thailand and Burma. It is bounded to the east by Bentong-Raub suture and to the west by Woyla Nappe terrane (Figure 2). Here we review evidence of Paleozoic – Mesozoic sediments assigned to the Sibumasu terrane as observed on outcrops and from subsurface data.

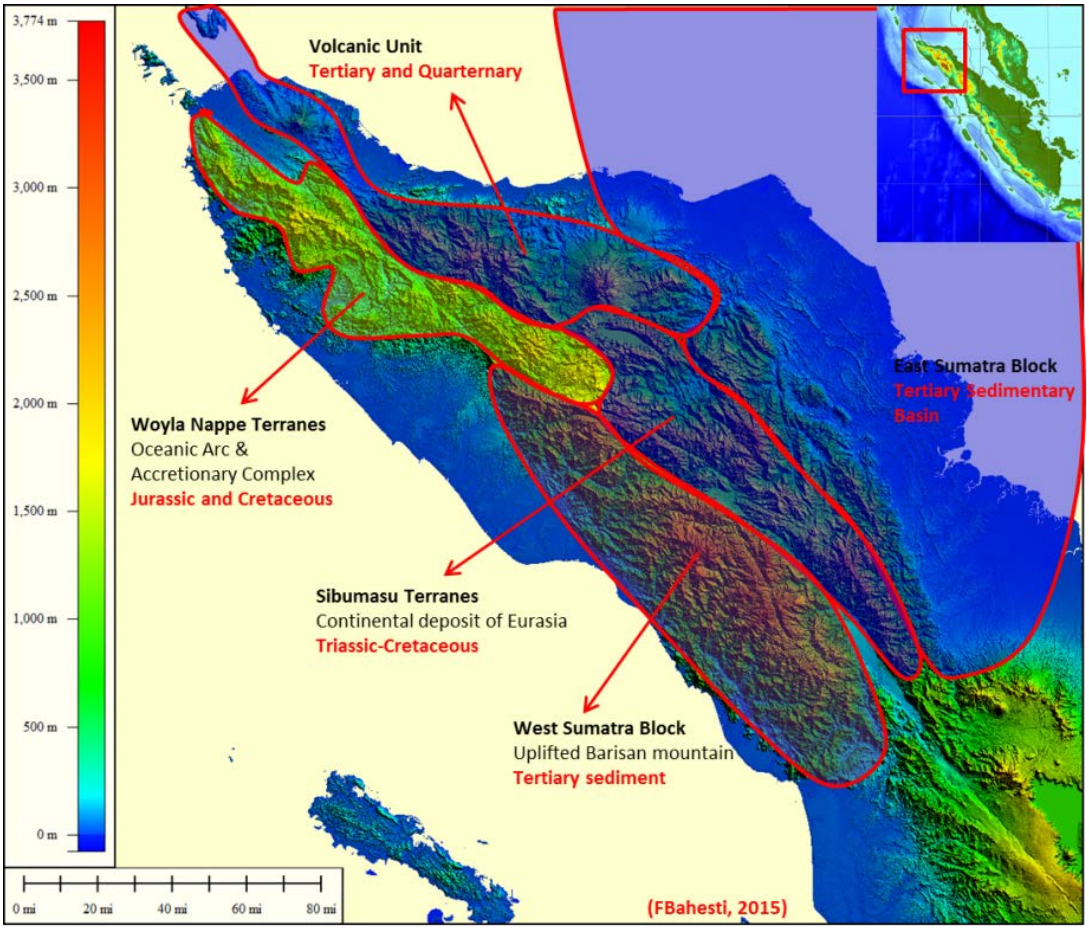


Figure 1.
Northern Sumatra topography, with Tertiary and pre-Tertiary Units. The study area is located within the East Sumatra Block.

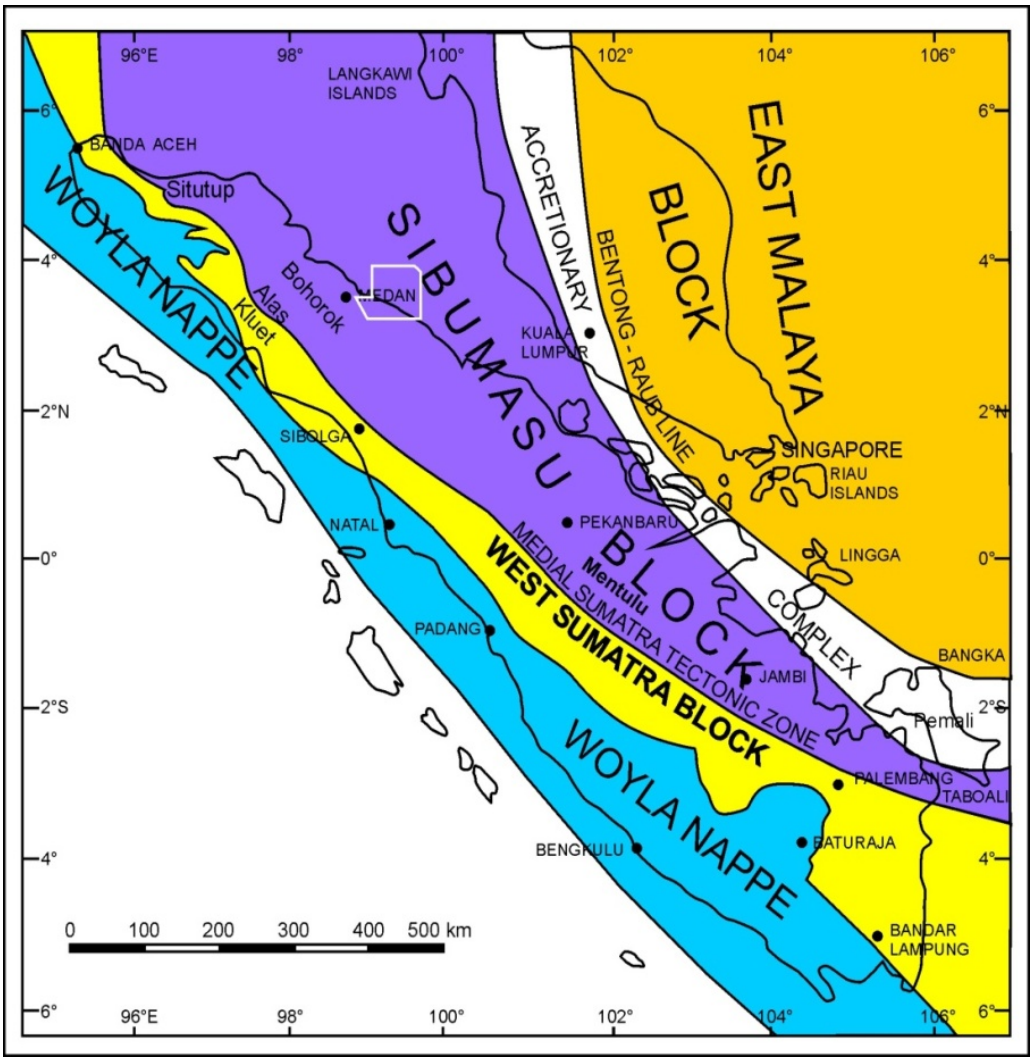


Figure 2.
Simplified pre-Tertiary terranes distribution map of Sumatra and Peninsular (East) Malaysia (Barber et al., 2005).

Pre-Tertiary rocks were observed in the Tampur River, Bohorok River and the Bukit Lawang Area. Cameron et al. (1980) divided the pre-Tertiary stratigraphy in Sumatra into 3 major groups, the Tapanuli, Peusangan and Woyla Groups (Figure 3). The Pre-Tertiary sediments in the Tampur River were identified as interbedded breccia with polymict detrital rock consisting of fragments of quartz arenites and slates. They are part of the Peusangan Group that is exposed at the surface. The Peusangan Group also consists of Triassic Batumilmil limestone and sandstone, shale and chert of the Kuala Formation.

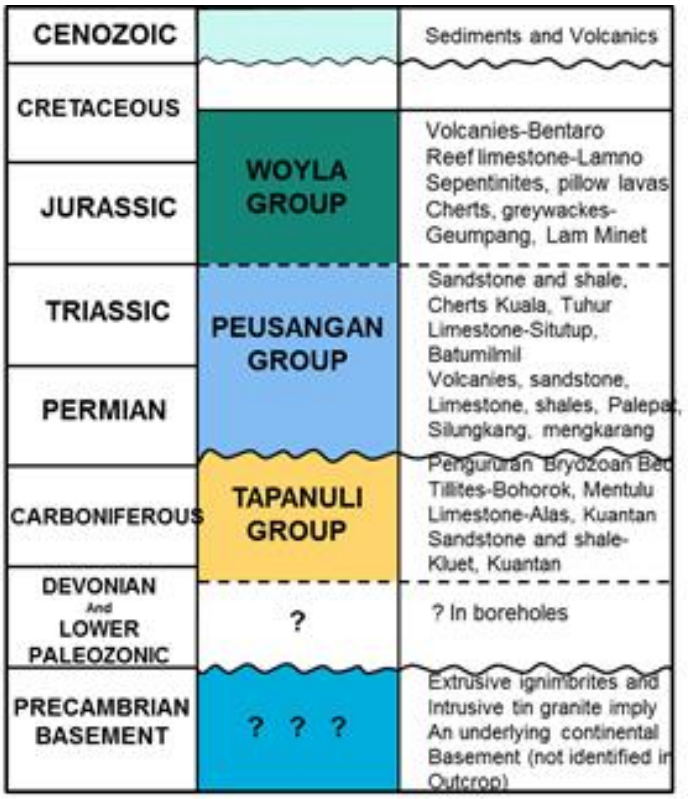


Figure 3. *Pre-Tertiary stratigraphic units in Sumatra (Cameron et al., 1980). The Peusangan Group consists of Triassic and Permian sedimentary and volcanic rocks.*

The oldest Tertiary rock in the basin is the Tampur Formation, which was originally called Tampur Limestone by van Bemmelen (1949) and was also discussed by Cameron et al. (1980) and Bennet et al. (1981). The formation consists of massive recrystallized limestones and dolomites with chert nodules. The unit also has basal limestone conglomerate and includes biocalcarenites and biocalcilutites. The Tampur Limestone was observed in the Tampur River, Tamiang area and Bukit Lawang area. Van Bemmelen (1949) reported corals and coaly plant remains, and algal laminations may be seen in outcrops within the gorges of the Tampur River.

*(**Editor's Note**: The name Tampur Formation has been used for carbonates at the base of the Oligocene rift-section clastics in the North Sumatra Basin (Collins et al., 1996). The formation is named after limestone outcrops along the Tampur River in Aceh and its age was initially viewed as Pre-Tertiary ('Tampoer Formation; 'T Hoen, 1922). Nowadays the age of the Tampur formation is commonly reported as Eocene (Caughey and Wahyudi 1994, Ryacudu and Sjahbuddin 1994, etc.) or Early Oligocene (Cameron et al. 1981). However, biostratigraphic evidence for these ages has never been documented. Although Eocene Nummulites limestone is present near the Ombilin Basin in West Sumatra, they look different from Tampur Limestone. An alternative explanation is that the basal carbonates in some North Sumatra wells are equivalent of the basal carbonate in the Singa Besar-1 well, just across the Malaysian border in Malacca Straits, which has a well-documented Middle-Late Permian age (with foraminifer Shanita and other Permian fauna; Fontaine et al., 1992). See also Primadi, 2013).*

DATA AND METHOD

Surface geological mapping was conducted in 2014, covering the study area from NW to the SE. The field mapping was done mostly along rivers such as the Tamiang River, Besitang River, Bukit Lawang and also Bohorok area (Figure 4). Outcrop samples were also taken during the geological mapping and the rock samples were subjected to laboratory analysis. In order to evaluate source rock potential, geochemical laboratory analysis was done on rock samples from the Tampur Formation.

The resulted geological map and laboratory analysis have been used in re-evaluating structural-stratigraphic evolution and hydrocarbon prospectivity of the Eocene and Paleozoic – Mesozoic sediments in the North Sumatra Basin. A flattened geological section on top Eocene has revealed the paleogeography of carbonate platform development during the depositional period of Tampur Formation. The new outcrop data have re-defined both structural and stratigraphic trends of Paleogene to Pre-Tertiary rocks, which is useful for building a new geological model.

RESULT AND DISCUSSION

Tampur Formation (Eocene?) Play

Potential hydrocarbon exploration targets within the Tampur Formation include reefal buildups, fractured anticlines and karstic debris (Ryacudu and Sjahbuddin, 1994). The reefal buildup has been penetrated in existing deep wells such as Benggala-1. The outcrop of Tampur limestone at the Tamiang River is dominated by highly fractured, massive limestones (Figure 5).

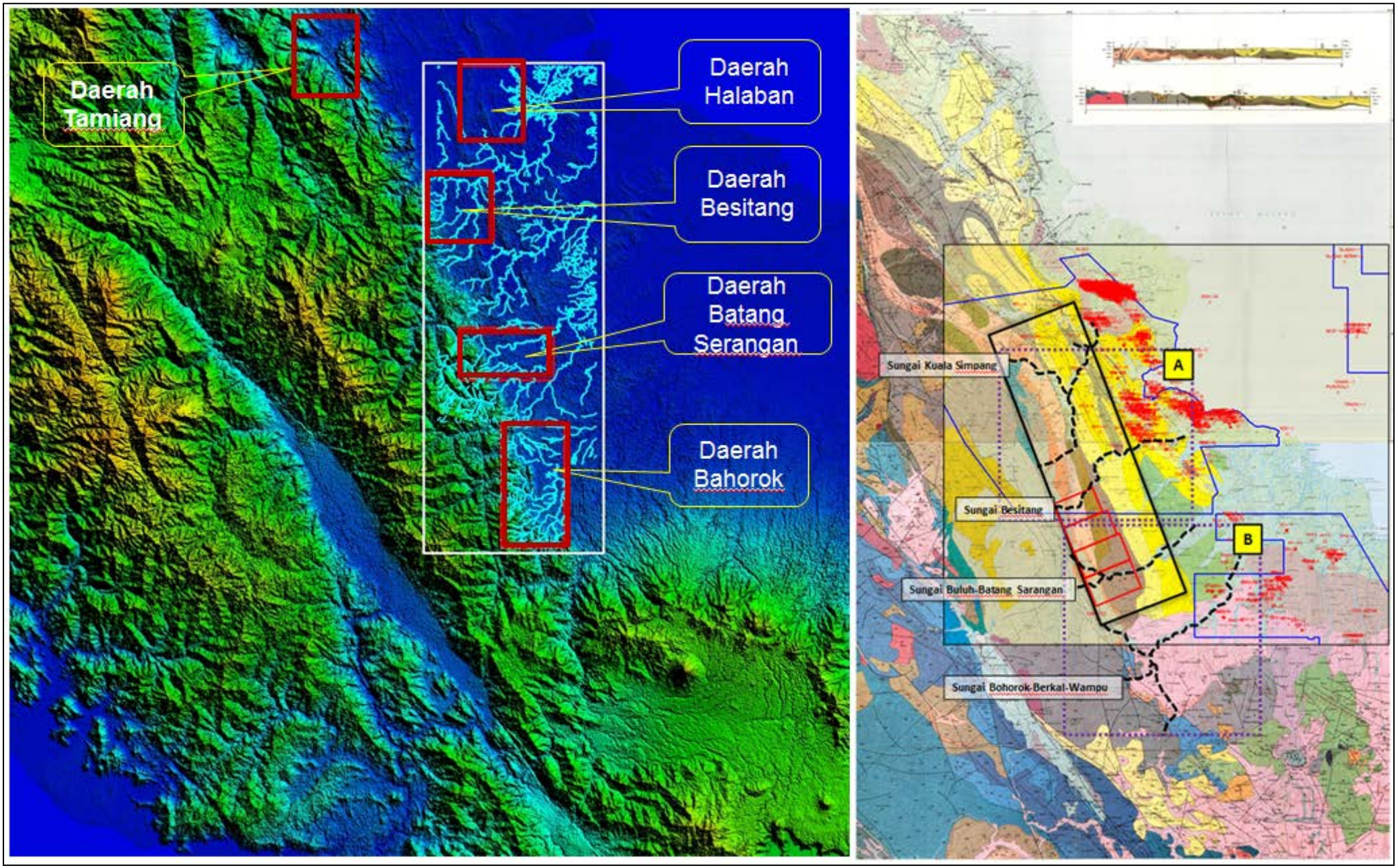


Figure 4. *Field geological obervation track map in North Sumatra and Aceh province.*

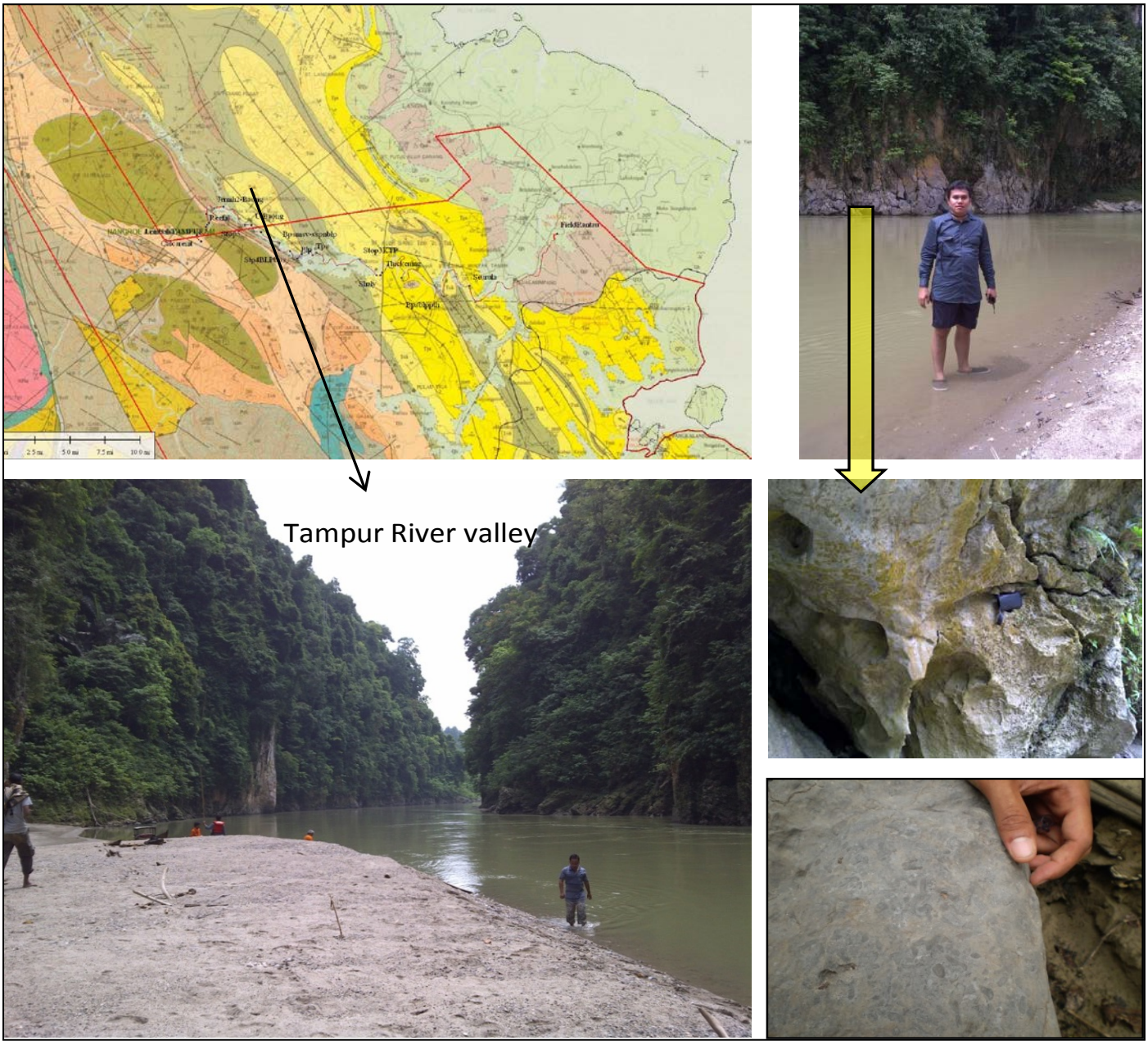


Figure 5. *Tampur Formation outcrops at the Tamiang River, Aceh.*

Paleo-depositional setting of the Tampur Formation was a widespread carbonate platform that developed during early Eocene "passive margin" phase, which was a period just before a major tectonic change in Sumatra. The onset of the tectonic change was interpreted from volcanic activities in the Barisan Mountains, which was recorded in the Late Mid-Late Eocene Breueh Volcanic Formation in the northern part of Sumatra (Cameron et al., 1980). The Tampur Formation was most likely deposited in a shallow water setting based on a reconstructed structural model. However, its precise bathymetry cannot be resolved from biostratigraphy analysis (it could be inner to middle sublitoral). Laboratory analysis indicates that calcareous nannofossils and pollen are present in the limestones.

Geochemistry analysis indicates that the lagoonal facies of Tampur Formation contains mature, organic-rich shales. The shales have potential to generate hydrocarbon, therefore they can be a source rock. At the moment, existing data is still limited to provide evidence for a working Eocene petroleum system, however this potentially new source rock must be taken into consideration in the future.

Late Paleozoic-Early Mesozoic Play

Hamilton (1979) suggests that Sumatra was rifted from the northern edge of Australia (north of New Guinea) during the Triassic to Early Jurassic (*ca.* 200–250 Ma). Sumatra would have been part of a stable continental margin until subduction began in the Cretaceous (possibly *ca.* 100 Ma). Due to its tectonic development, it is possible to synthesize the pre-Tertiary basin of North Sumatra as part of the Sibumasu terrane that potentially was in passive margin phase during Permian to Triassic. The extent of this Pre-Tertiary basin is unknown because there is no way of recognizing it within relatively thick sediment strata.

Proven Pre-Tertiary petroleum systems with discoveries in Permian Ratburi Limestones of onshore Thailand and Triassic Plover Formation in NW Australia can be used as analogue plays to the Pre-Tertiary sequences in Sibumasu terranes of the North Sumatra Basin (Figure 6). The equivalent Permian and Triassic rocks in North Sumatra are found within the Peusangan Group, which is also exposed in ouctrops. The Peusangan Group includes the Batumilmil Formation, which is composed of at least four lithologies including (from bottom to top) red dolomitic limestone, light grey limestone with crinoid fossils and vein, dark gray limestone with veins, and black mudstone at the top. K-Ar dating of Batumilmil Limestone from Gua Batukatak shows an age of 240.9 ± 7.3 Ma (Early to Middle Triassic). Based on interpretation on Northern Sumatra geological map and paleontology analysis of crinoid fossil, the age of the formation is Early Permian to Early Triassic (Bachtiar, 2014).

The Pre-Tertiary sediments at Tampur River were identified as interbedded breccia with polymict detrital rock consisting of fragments of quartz arenites and slates. The outcrop is interpreted as part of the Kluet Formation, while the Pre-Tertiary sediments at Bohorok River (type locality of Bohorok Formation) comprise pebbly mudstone and polymict of igneous and sedimentary rock fragments (Figure 7). Cameron et al. (1980) suggested the Bohorok Formation was deposited in a glaciomarine environment during Early – Middle Carboniferous, while Barber et al. (2005) interpreted the age of the Kluet Fm. as also Carboniferous.

In Mesozoic time, Earth had a more widespread tropical climate where the plankton were abundant in the ocean. The ocean bottom was stagnant and anoxic, unlike it is today. The organic-rich muds were accumulated to form source rock layers in the basin (Figure 8). Our interpretation identified multiple Paleozoic – Mesozoic play types that are potentially oil bearing and sourced from the Jurassic to Eocene level (Figure 9). These include carbonate platform margin reefs sealed by transgressive Tampur limestone and Tertiary clastics; marl-sealed karstified structures and lowstand high energy fans in addition to deep water carbonates of Kluet Formation. The pebbly mudstone of Bohorok Formation could also be a potential source(?) & reservoir(?) when it was deformed by major tectonic between Tertiary and pre-Tertiary (K-T boundary).

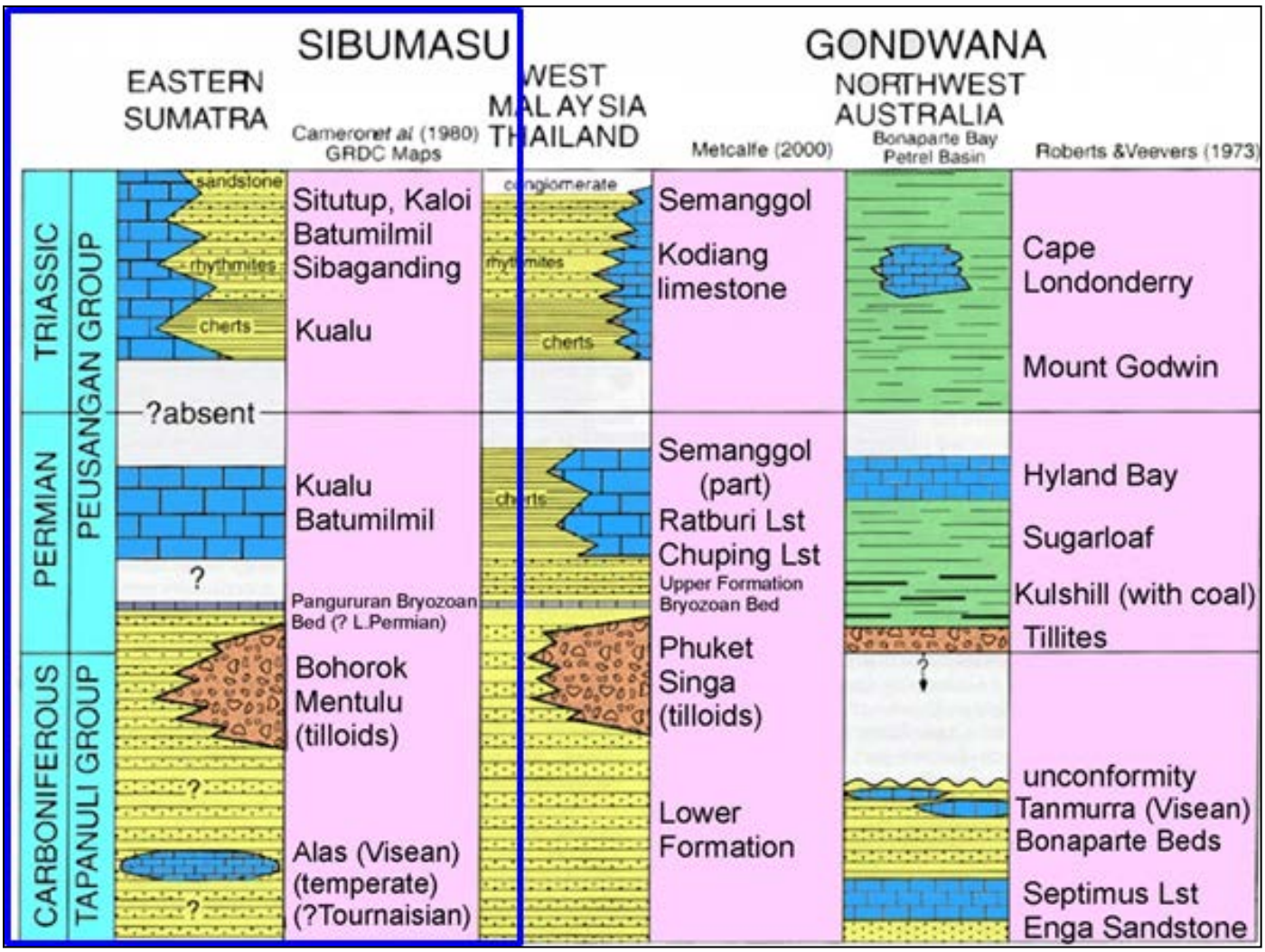


Figure 6. *Comparison of the Carboniferous, Permian, and Triassic sequences in the Sibumasu terranes (Barber et al., 2005). The Permian Ratburi Limestones are proven gas reservoirs in onshore Thailand, while Triassic rocks are also proven gas reservoirs in NW Australia.*





Figure 7. *Pre-Tertiary outcrops of Kluet Formation (A) at the Tamiang River and Bahorok Formation (B) in Bohorok area.*

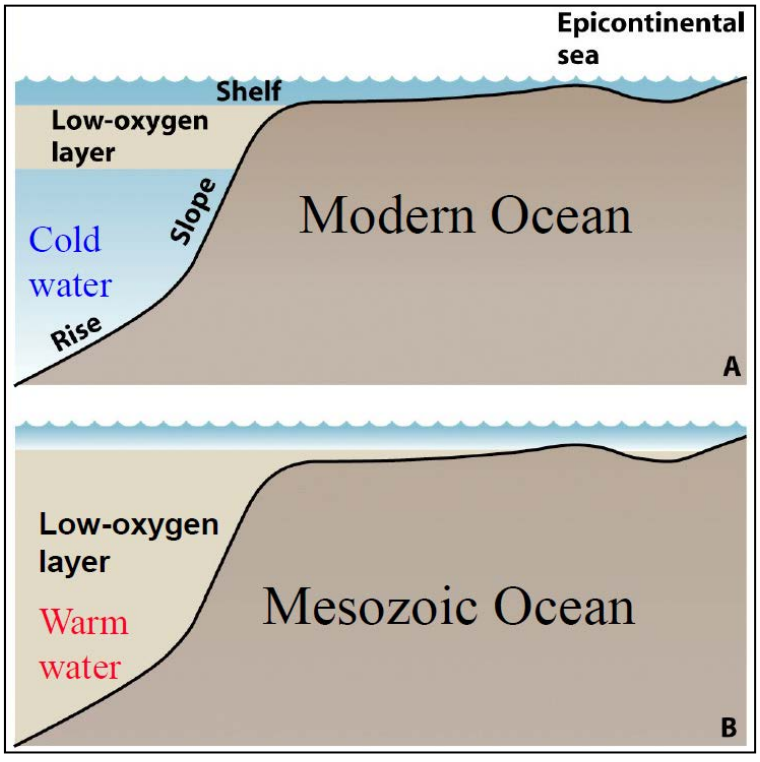


Figure 8. *Earth climate system during Mesozoic age (Stanley, 2005).*

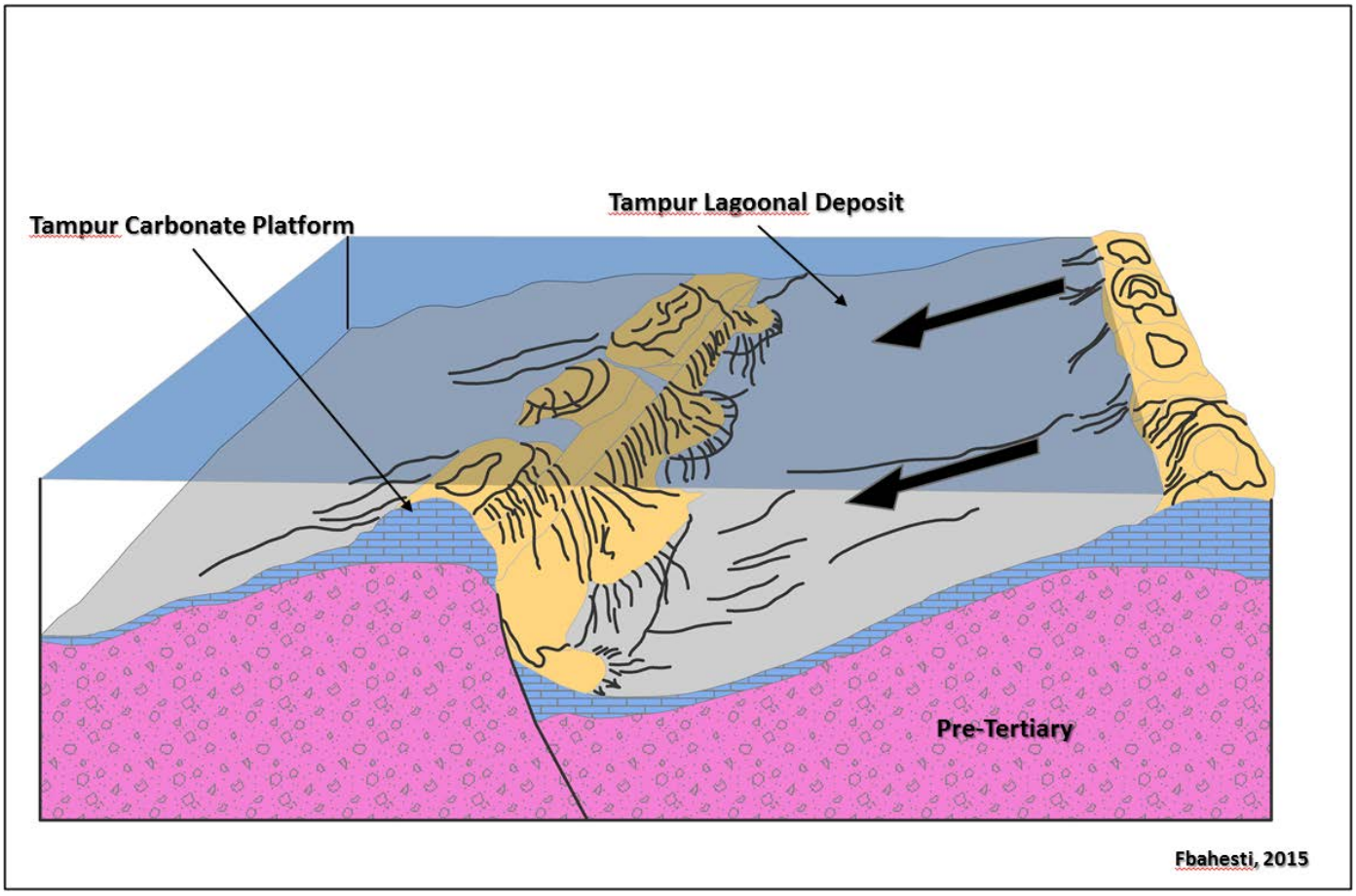


Figure 9. *3D geological model during Tampur platform carbonate and its lagoonal facies deposition.*

CONCLUSIONS

Hydrocarbon potential has been proven in the Eocene? Tampur Formation based on gas tests in highly fractured carbonates (e.g. Glagah-1 & Salem-1 wells). The geological model suggests a concept of carbonate platform deposition that was conformable with younger, local lagoonal facies, which could be good source rock in generating and expelling hydrocarbon to migrate into Tampur fractured carbonate. Although Paleozoic – Mesozoic sediment may consist of highly tectonized metasediments and are generally tight and have low probability of hydrocarbon accumulation and preservation, the Carboniferous, Permian, and Triassic sequences in the Sibumasu terranes in North Sumatra could be analogues of Thailand and NW Australia proven hydrocarbon plays. Outcrop observation and its ties to seismic have supported the concept of a passive margin pre-Tertiary basin in North Sumatra's Sibumasu terrane.

Paleogene synrift lacustrine fan/delta deposits in western Indonesia basins have been recognized as having high reservoir potential (e.g. Noeradi et al., 2005; Eubank and Makki, 1981). In the Central Sumatra Basin for instance, lacustrine fan/delta reservoirs have been explored and produced sporadically even though its reservoir characteristics, both geometry and quality, is still inadequately understood (Waren et al., 2015). Similarly, this lack of understanding also occurs in the Ombilin Basin, which has promising exploration targets in the synrift deposit (Noeradi et al., 2005). It is believed that synrift lacustrine fan/delta reservoirs in both basins will play an important role in the future.

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