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Source rock quality and 1D maturity model in Pendalian Sub-basin, Central Sumatra Basin

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ABSTRACT. Pematang Formation is the main source rock in the Central Sumatra Basin. The formation which acts as source rock has been studied thoroughly in the central and eastern parts of the basin, but research regarding source rock in the western part of the basin, which is the study area, is very limited. This paper aims to define the quality of source rock from a geochemical view through the determination of organic content quantity based on the Total Organic Carbon (TOC) data, determining the type of kerogen, and thermal maturity of the source rock according to the values of Tmax and Vitrinite Reflectance (%Ro). Burial history and thermal maturity models (1D basin modeling) were also constructed to understand the timing of hydrocarbon generation. The results show that Pematang Formation among Sihapas and Telisa Formation has good organic content with TOC ranging from 0.2 to 42.48 wt%, and the maturity parameters indicate that the Pematang Formation has reached the mature stage. Both formations are dominated by Type II kerogen. 1D modeling of the SHT-1 Well indicates that the Pematang Formation is currently in the oil maturity window, starting from early oil to main oil at 20.61 Ma, but the model of the SMB-1 Well has not reached the oil maturity window. Tectonic activity is estimated to have had a significant effect on this difference when the uplift activity of Bukit Barisan in the Middle Miocene increased the maturity in the northwest. However, the inversion in the Late Miocene resulted in uplift and erosion of young sediments, thus lowering the temperature in some areas.

Keywords: 1D maturity model · Source rock.

1 INTRODUCTION

The Central Sumatra Basin is one of Indonesia's basins proven to produce hydrocarbon (Novianto & Irawan, 2013). Research about the source rock in the western part of the basin, which is in the study area, is still limited compared to the central and eastern parts of the basin and needs to be updated. This research will discuss the Pematang Formation, Sihapas Formation, and Telisa Formation as source rocks by determining the source rock's quality, quantity, and maturity based on geochemical data. Burial history and thermal maturity models (1D basin modeling) were also constructed to understand the timing of hydrocarbon generation as a result of data integration such as well data, biostratigraphy, paleowater depth, and heat flow to determine the ability of the source rock to produce hydrocarbon. However, understanding source rock quality and the 1D maturity model in the Pendalian Sub-basin can be additional information about Formations that act as source rock less explored in the western part of the Central Sumatra basin. Adminis-

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tratively, the research area is located at South Tapanuli Regency, North Sumatra (Figure 1.

2 GEOLOGICAL SETTING

The structure development of the Central Sumatra Basin is divided into four tectonic phases (Heidrick & Aulia, 1993) denoted as F0 (deformation), F1 (rift phase), F2 (sag and transitional), and F3 (compression) (Figure 2a). An important factor in the accumulation of hydrocarbons in the study area is the tectonic activity that occurred during the Middle Miocene period when the Bukit Barisan uplift began. The Stratigraphic Column of the Central Sumatra Basin is shown in Figure 2b (Eubank & Makki, 1981) unconformity above the bedrock, a succession of tertiary sedimentary rocks from oldest to youngest is Pematang Group, Sihapas Group, Telisa Formation, Petani Formation, and ends by Minas Formation.

3 METHODOLOGY

Geochemical analysis was conducted to determine the potential of the source rock. Geochemical data from the SHT-1 well and SMB-1 well were analyzed to determine the organic richness based on Total Organic Carbon (TOC) data using Peters & Cassa (1994) classification, quality of organic content (kerogen type), and measured maturity (Mukhopadhyay et al., 1995) using the Rock-Eval Pyrolysis parameters since the mature source rock has Tmax values above 435 oC. 1D modeling was built to simulate a reconstruction of the history and thermal maturity model of two research wells. Some information from the well report needs to be input such as the data of depth, thickness, lithological variations, and age of formation, boundary condition (heat-flow, paleo water depth). The model calibration stage is also carried out on the input data in building the burial and maturity model. If the calibration is inappropriate, re-modeling must be carried out until a close match between the vitrinite measured data and the vitrinite reflectance model. Vitrinite reflectance was modeled using the easy % Ro method (Sweeney & Burnham, 1990).

4 RESULTS AND DISCUSSION

4.1 Source rock quality

The ability of the source rock to produce hydrocarbons depends on several factors. There is the determination of organic content, the quality of the organic matter (kerogen type), and the thermal maturity of organic matter (McCarthy et al., 2011).

4.1.1 Determination of organic content

The quantity of organic material could be identified using the Total Organic Carbon (TOC) value (Waples, 1985). In two available, the variation of TOC vs depth from three formations (Telisa, Sihapas, and Pematang formation) can be seen in Figure 3.

a. SHT-1 well
   The TOC content of SHT-1 in the Pematang formation interval ranging from 0.09 to 2.59 wt% is classified as poor to very good (Peters & Cassa, 1994). Sihapas formation has very limited TOC data ranging from 0.06 to 0.96 wt% (poor to fair) and has an average of 0.25 wt%. The Telisa Formation has an average of 0.67 wt%, and the classification of Peters & Cassa (1994) shows that the sample is fair.
b. SMB-1 well
   The TOC content of SMB-1 well shows the close result as SHT-1 well with the highest TOC value from Pematang Formation with an average TOC content of 2.18 wt%, classified as very good Peters & Cassa (1994). Sihapas formation has an average of 0.45 wt% classified as poor, and the TOC content of Telisa Interval ranges from 0.56-1.51 wt% classified as fair to good.

4.1.2 Types of organic matter

The quality of organic matter could be determined from several parameters, one of which is determining the type of kerogen using geochemical data plotting in the form of HI vs Tmax (Mukhopadhyay et al., 1995). The results of plotting HI vs Tmax values from the data of the SHT-1 wells (Figure 4a) show that the three formations are dominated by type II kerogen and classified as oil-prone (Peters & Cassa, 1994), and the plotting of SMB-1 well indicates as type II and III kerogen (Figure 4b).

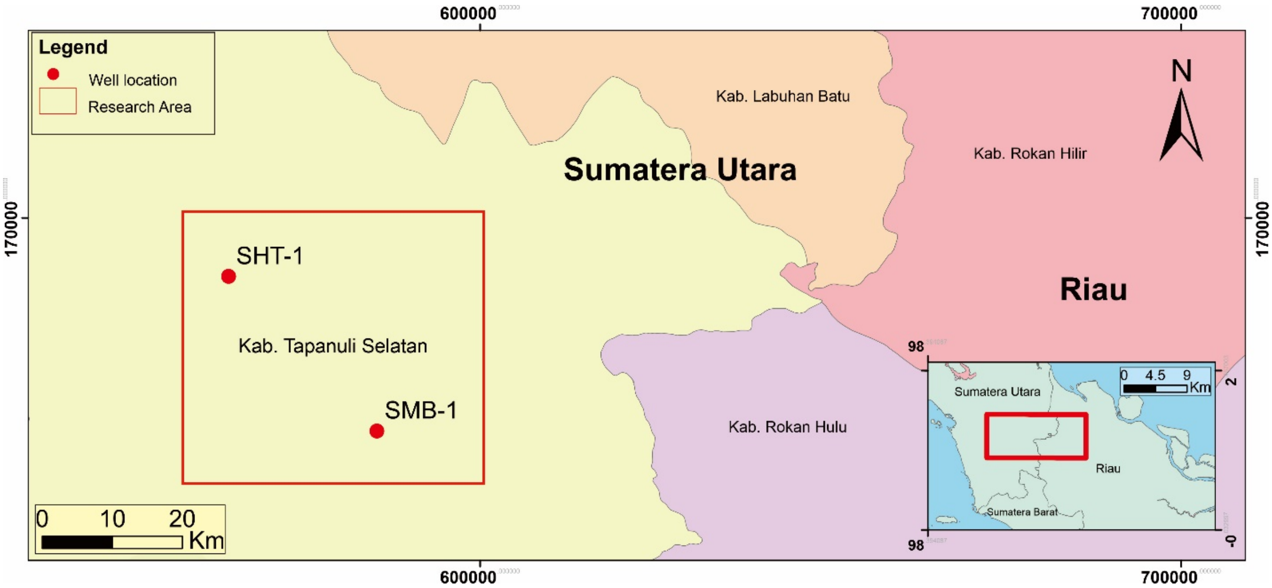

FIGURE 1. Research area with two available wells located in Tapanuli Selatan (Source: Peta Indonesia Geospasial, 2019).

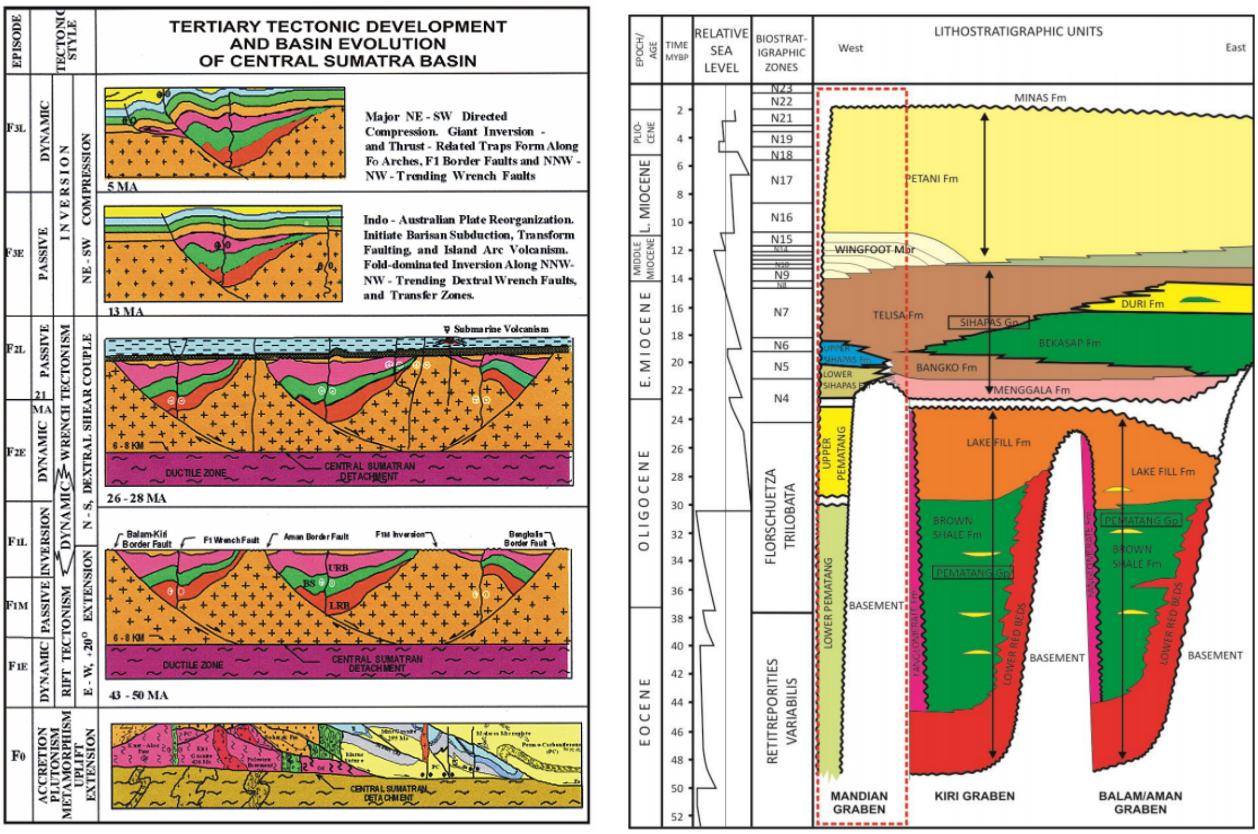

FIGURE 2. a) Tectonic development of Central Sumatra Basin (Heidrick & Aulia, 1993) b) Stratigraphic column in the study area (dashed red polygon) within the Central Sumatra Basin (Williams & Eubank, 1995).

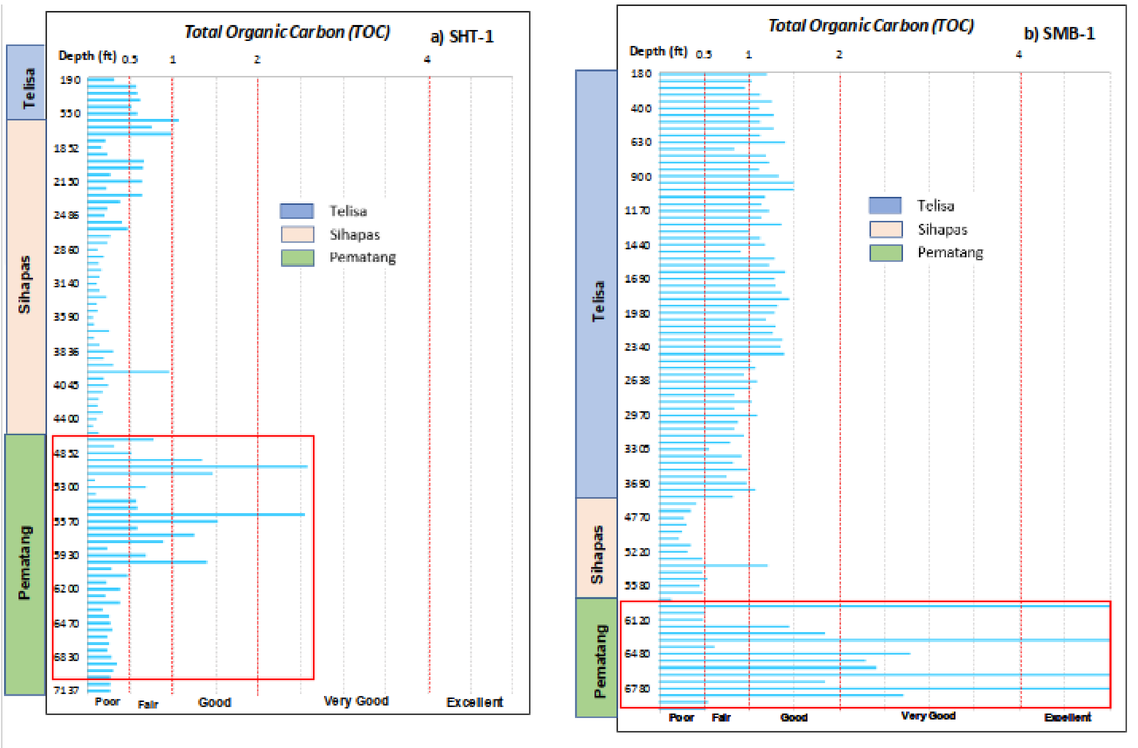

FIGURE 3. Quantity of organic matter by the amount of TOC in the a.) SHT-1 well, and SMB-1 well.

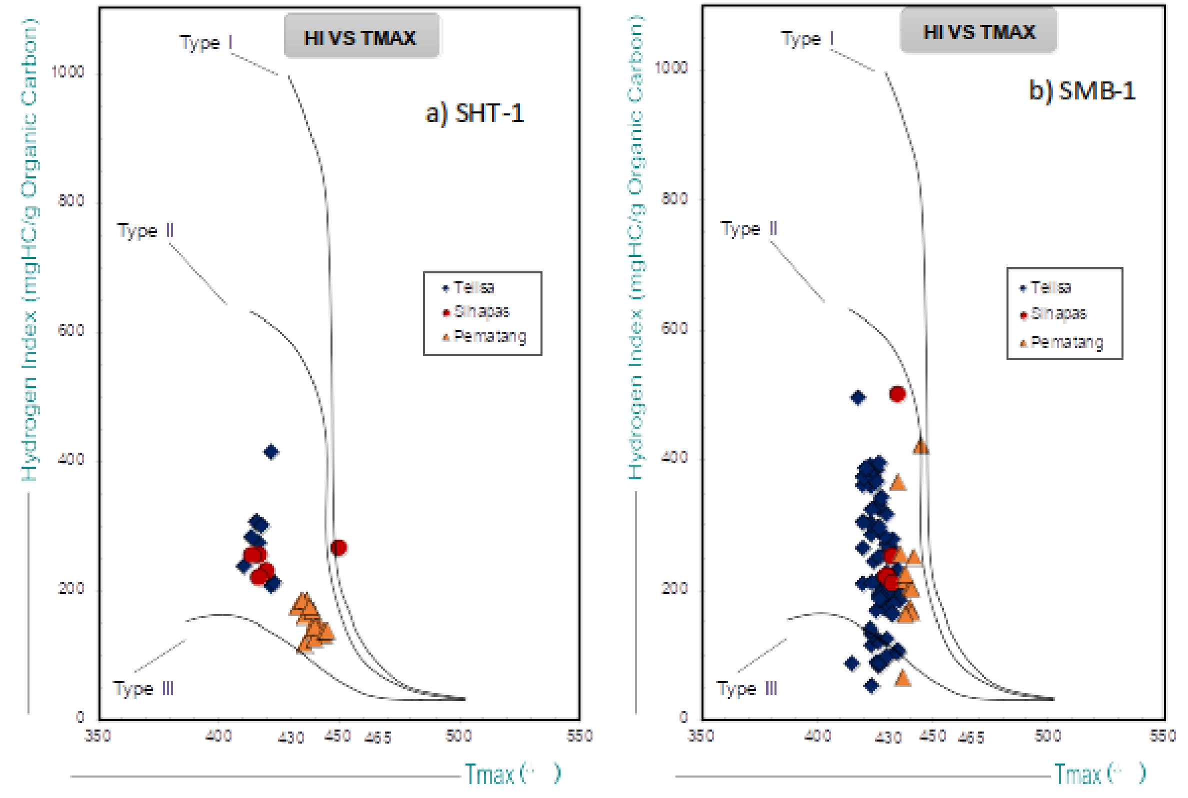

FIGURE 4. Hydrogen Index vs Tmax (Mukhopadhyay et al., 1995) showing the type of kerogen of a.) SHT-1 well, and b.) SMB-1 well.

4.1.3 *Thermal maturity*

The level of thermal maturity of organic materials can be determined by using geochemical data in Tmax and Ro. Classification of Peters & Cassa (1994) states that the sample is classified as immature if it has a value of <435, mature if it has above 435, and postmature if it has a value of >470. Figure 5 shows the results of plotting Tmax vs Depth in the three wells of the three formations, the Telisa Formation Figure 5a, Sihapas Formation (Figure 5b), and Pematang Formation (Figure 5c). These results show that the formations that enter the maturity window are the Pematang Formation.

4.2 Basin modelling

1D basin modeling can explain the burial history and the temperature that occurred and determine the source rock's thermal maturity time and type. The maturity model of the SHT-1 well (Figure 6a) shows that this well reaches the initial maturity window at an interval of 4167 ft (Pematang Formation) which reaches a %Easy Ro value of 0.55% at 20.5 Ma symbolized by dark green. Main oil occurs at intervals of 6868 feet at 11.02 Ma, symbolized by a light green color that reaches a %Easy Ro value of 0.70% (Table 1. Figure 6b shows the fit calibration of the SHT-1 model. The maturity model for the SMB-1 well (Figure 6c) indicates that this well has not yet reached the maturity window, and the fit calibration of this model is shown in Figure 6d.

5 DISCUSSION

Figure 7 shows that the Pematang Formation is currently in the oil maturity window, starting from early oil to main oil; meanwhile, the SMB-1 Well has not reached the oil maturity window. The location of the SHT-1 well and SMB-1 well in the Structural Pattern Map (figure 6, Pertamina BPPKA (1996)) is separated by several boundary faults, so tectonic activity during the Middle Miocene when the Bukit Barisan uplift was initiated (Eubank & Makki, 1981) is suggested to have a significant effect on the different maturity of these two wells and also on the petroleum system in this area, uplifting the Pematang interval in the western part of the area. The Inversion in the Late Miocene resulted in the uplift and erosion of young sediments, thus lowering the temperature in some areas. From the figure below, we know that the depth position of the SHT-1 well, which has touched the main oil stage, is at the deepest depth (8000 feet to the basement) compared to the SMB-1 well (6000 feet to the basement).

6 CONCLUSION

Based on the analysis that has been carried out on the geochemical data of the source rock from the two wells and interpretations with regional geological conditions, it can be concluded that the three formations analyzed, the Pematang Formation in the study area is believed to be able to produce hydrocarbons, especially in the SHT-1 well because it has high levels of the highest maturity compared to SMB-1 well. In addition to the Pematang Formation, the Telisa Formation has the potential to be classified as fair-good but is thermally immature, and Sihapas Formation has a low value of organic content and is thermally immature. 1D maturity model indicated the difference between SHT-1 well and SMB-1 well. SHT-1 well has reached main oil at middle Miocene, but SMB-1 well has not reached the maturity window. The Bukit Barisan uplift that began in the middle Miocene (Eubank & Makki, 1981) was interpreted to significantly impact the maturity of the western part of the research area. Tectonic activity is estimated to have had a significant effect on this difference when the uplift activity of Bukit Barisan in the Middle Miocene increased the maturity in the northwest. However, the inversion in the Late Miocene resulted in uplift and erosion of young sediments, thus lowering the temperature in some areas.

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REFERENCES

Badan Informasi Geospasial (2019). *Peta RBI: Peta Rupa Bumi Indonesia*. https://tanahair.indonesia.go.id/portal-web/download/perwilayah.

Eubank, R. T., & Makki, C. A. (1981). Structural geology of the Central Sumatra back-arc basin. *Proceedings Indonesian*

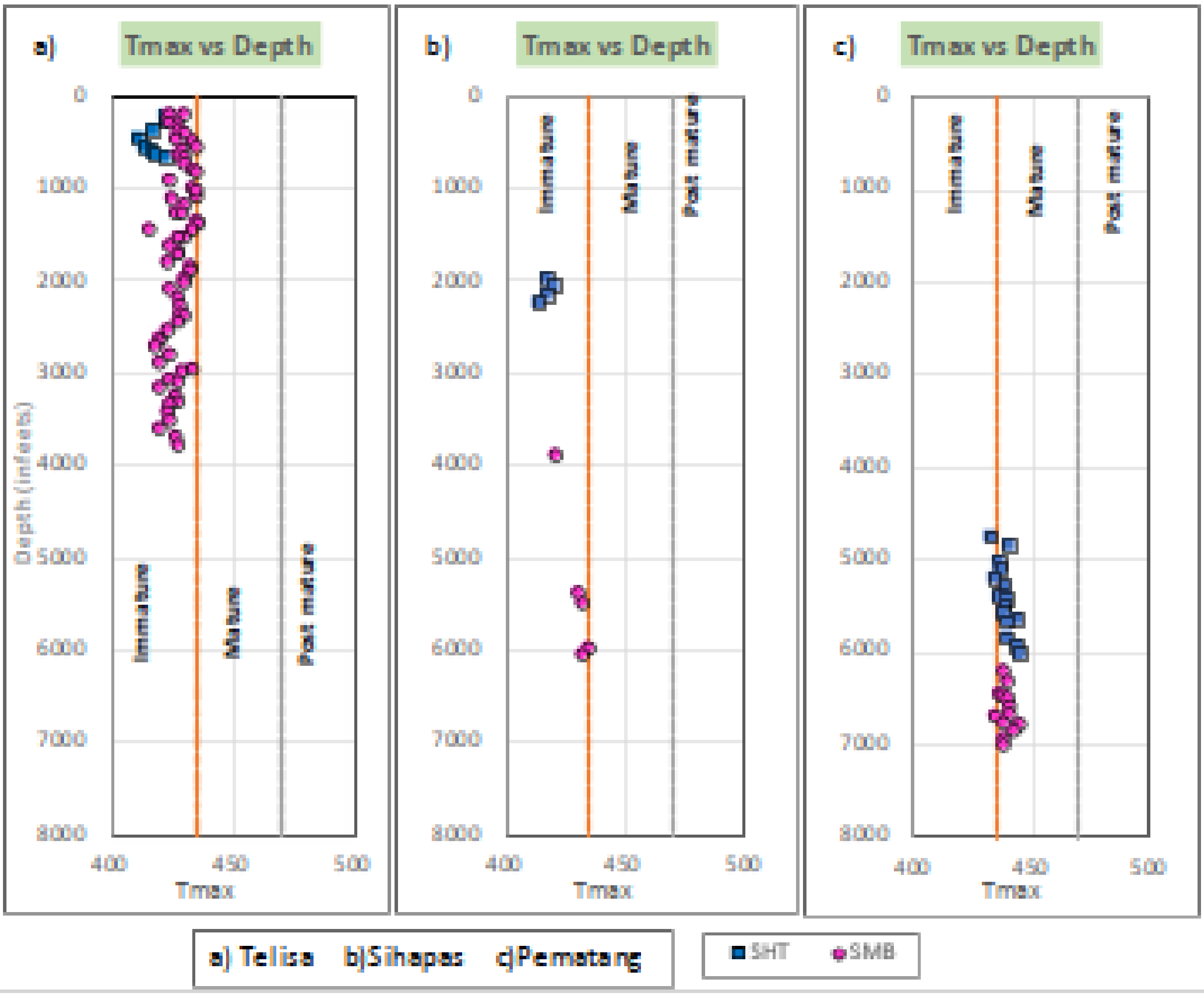

FIGURE 5. Plotting of Tmax vs depth in three available wells a.) Telisa Formation, b.) Sihapas Formation, c.) Pematang Formation.

TABLE 1. Summary of maturity time and recent maturity depth of Pematang Formation in research wells.

Well	Formation	Maturity Time (Ma)		Recent Maturity depth (ft)		Description
		Early Oil	Main Oil	Early Oil	Main Oil	
SHT-1	Pematang	20.61	11.02	4583	6004	Early oil and Main oil
SMB-1	Pematang	-	-	-	-	Immature

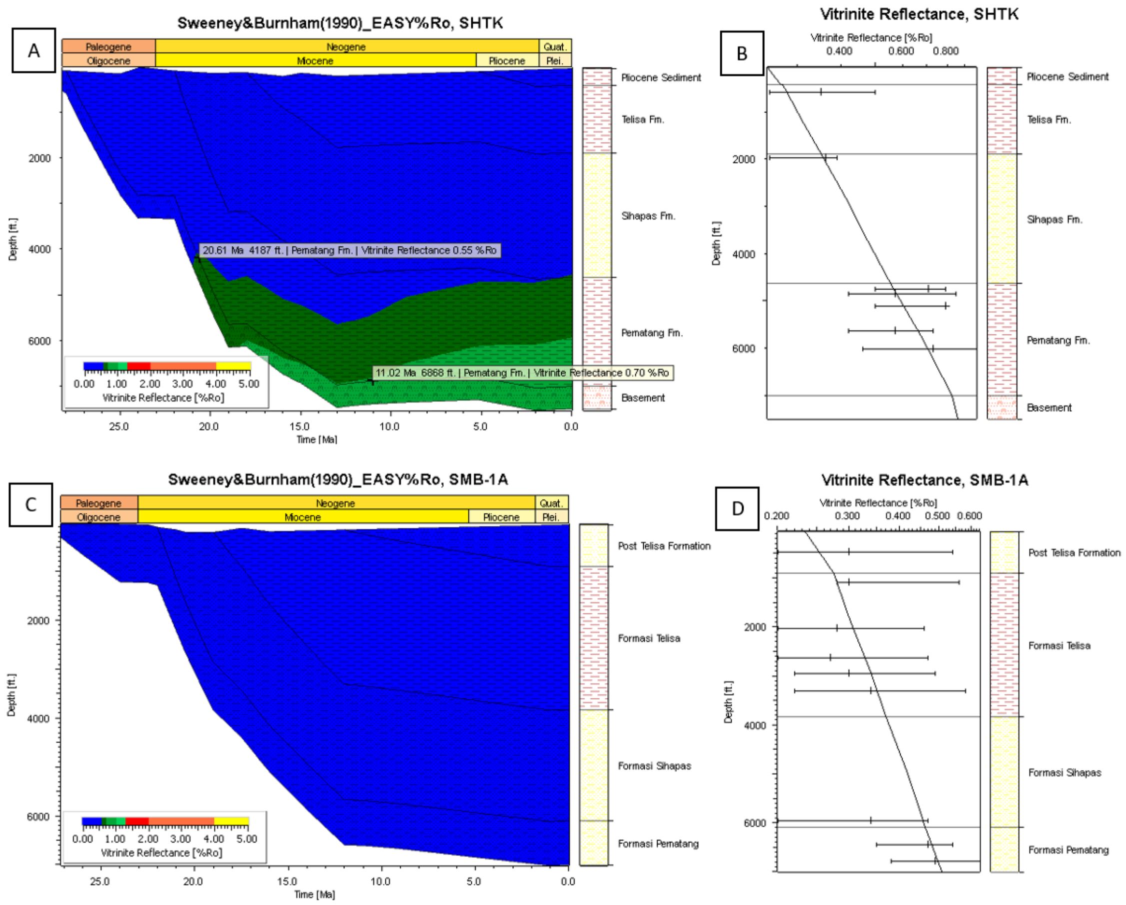

FIGURE 6. The simulated vitrinite reflectance value and the associated geohistory of all formations in research well (SHT-1) (a and b). (c) 1D maturity model of the SMB-1 well indicates that this well has not reached the maturity window. (d) The Ro Model and Ro calibration were measured to build the SMB-1 model.

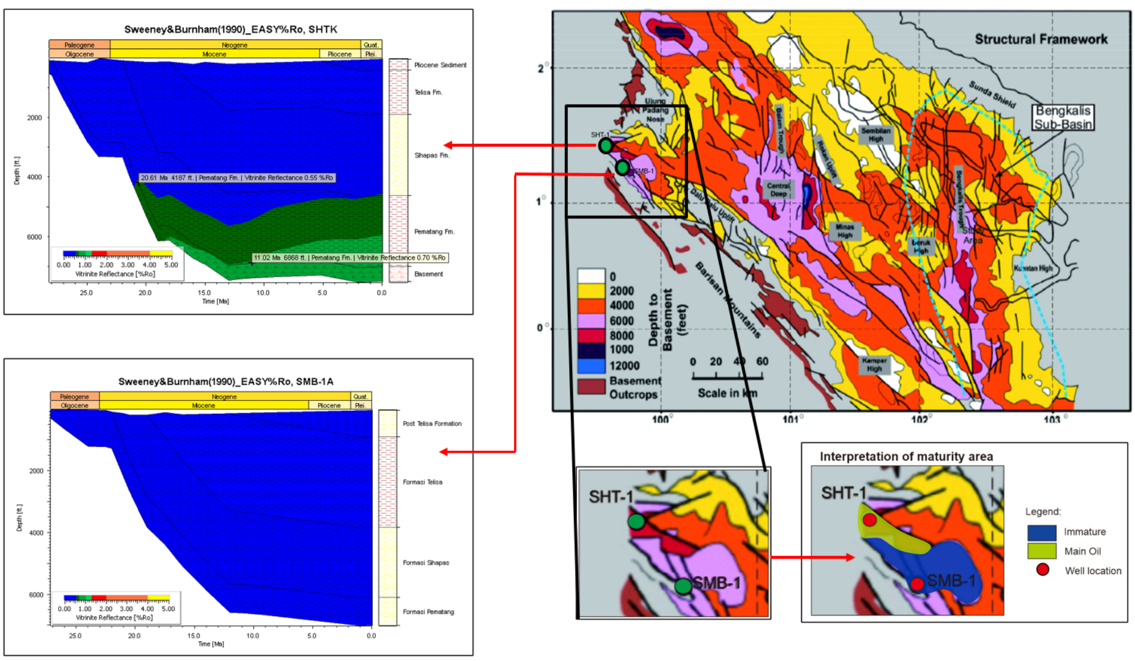

FIGURE 7. Interpretation of maturity area in Structural Pattern Map (modified after Pertamina BPPKA, 1996).

Petroleum Association. Jakarta. p. 153–196. https://doi.org/10.29118/IPA.203.153.196.

Heidrick, T. L., & Aulia, K. (1993). A structural and tectonic model of the Coastal Plains Block, Central Sumatra Basin, Indonesia. *Proceedings of the 22nd Annual Convention Indonesia Petroleum Association*. Volume 1. Jakarta. p. 285-318. https://doi.org/10.29118/IPA.572.285.317.

Mazied, M., Amin, S., & Irawan, C. (2008). Source investigation of oils discovered in the West Kampar Block, Central Sumatra Basin. *Proceedings of the 32nd Annual Convention Indonesian Petroleum Association*, Volume 1, p.119–131. https://doi.org/10.29118/IPA.2184.08.G.119.

McCarthy, K., Rojas, K., Niemann, M., Palmowski, D., Peters, P., & Stankiewicz, A. (2011). *Basic Petroleum Geochemistry for Source Rock Evaluation* (No. 2; Oil Field Review, pp. 32–43). Schlumberger.

Mukhopadhyay, P. K., Wade, J. A., & Kruge, M. A. (1995). Organic facies and maturation of Jurassic/Cretaceous rocks, and possible oil-source rock correlation based on pyrolysis of asphaltenes, Scotian Basin, Canada. *Organic Geochemistry*, 22(01), p. 85–104.

Novianto, A., & Irawan, E. W. (2013). Pemetaan Daerah Reservoir Formasi Pematang Menggunakan Seismic Atribut Lapangan Fengfu Cekungan Sumatra Tengah. *The 6th Malaysia-Indonesia Geological Heritage Conference*. p.11–20.

Pertamina and BPPKA. (1996). *Petroleum System of Indonesia Basin: Central Sumatra Basin*.

Peters, K. E., & Cassa, M. R. (1994). *Applied Source Rock Geochemistry*. In: Magoon, L.B., Dow, W.G. (editor), The Petroleum System - From Source to Trap AAPG Memoir 60, p. 93–120.

Sweeney, J. J., & Burnham, A. K. (1990). Evaluation of a Simple Model of Vitrinite Reflectance Based on Chemical Kinetics. *The American Association of Petroleum Geologist Bulletin*, 74 No.10, 1559–1570. https://doi.org/10.1306/0C9B251F-1710-11D7-8645000102C1865D.

Waples, D. W. (1985). *Geochemistry in Petroleum Exploration*. Springer Netherlands. Boston, 235 p. https://doi.org/10.1007/978-94-009-5436-6.

Williams, H. H., & Eubank, R. T. (1995). *Hydrocarbon habitat in the rift graben of the Central Sumatra Basin, Indonesia*. In: Lambiase, J.J. (editor), Hydrocarbon Habitat in Rift Basin. Geological Society, London, Special Publications, 80(1), 331–371. https://doi.org/10.1144/GSL.SP.1995.080.01.16.