A Comprehensive Geochemical Study Using Pyrolysis Analysis and Migration Pathway Map to Evaluate Source Rock Potential in Talang Akar Formation, Jambi Sub-Basin, South Sumatra, Indonesia*

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Abstract

The Talang Akar Formation dominated by shales interbeded with sands of the Jambi sub-basin has been a potential contributing source of hydrocarbon for the Gelam Field when drilled at the graben margins. The main structural elements of the Jambi sub-basin are horst and grabens formed during Paleogene. Their structural trend aligns from northeast to southwest, which was subjected to wrenching and further subsidence. During Plio-Pleistocene, the compression continued to form the northwest to southeast trending folds. Geochemical approach through pyrolysis analysis was conducted to determine the quantity, quality, and maturity of the source rock as well as the kerogen type and hydrocarbon that the organic materials produced as a potential source rock for the Gelam Field. Talang Akar Formation Shales from Jambi Sub-basin has good TOC values. It was also proven as Type III Kerogen, a gas producing kerogen, based on their hydrogen index values. Based on vitrinite reflectance and Tmax data, all shales of the Talang Akar formation has reached early mature phase, making it a potential source rock. Isopach and Shale Thickness Map were used to determine which location has higher value of total thickness of shale. Shale Thickness map was also used to determine the shale volume of the Talang Akar Formation. The shale volume was then used for volumetric calculations. To calculate the total mass of hydrocarbon generated (HCG), calculated values of mass of organic carbon and mass of hydrocarbons generated per unit mass of organic carbon were used. The value of HCG was then converted into TCF (considering its gas producing kerogen). Using depth structure map of the Talang Akar Formation and Basement, the pathway of the hydrocarbon can be determined to form a migration pathway map. It can be concluded that the Talang Akar Formation of the Jambi sub-basin is indeed a potential source rock and contributes to the Gelam field's gas production. Further geochemical analysis should be considered to conclude the full potential of hydrocarbon generation of the Talang Akar Formation shales of the Jambi sub-basin.

Introduction

Determining the amount of oil and/or gas in an active source rock is an important consideration in assessing the hydrocarbon potential of a petroleum system. Using pyrolysis analysis and volumetric calculation, organic materials are analyzed to determine their petroleum potential and maturity. Shown in Figure 1, the main structural elements of the Jambi sub-basin are horsts and grabens, formed in the Palaeogene, which aligns northeast to southwest. During the late syn-rift to early post-rift thermal sag phase of tectonic evolution of the South Sumatra Basin, widespread fluviatile and deltaic deposition occurred across the basin. The earliest sediments so far encountered form the Oligocene, Talang Akar Formation (Figure 2), which are fluvial channel sands in the deepest parts encountered. Figure 2 shows the position of the Talang Akar formation (Ginger, 2005). This paper will discuss the quality, quantity, and maturity of the source rock in the Talang Akar Formation from pyrolysis data. This paper will also discuss the volumetric calculation of Talang Akar Formation shales to determine its Hydrocarbon Generated (HCG).

Methodology

The Pyrolysis analysis uses secondary data. The data were acquired through pyrolysis analysis using samples from RAY-1 that represents all the wells. The subsurface mapping and migration pathway map also conducted through collected seismic data in research area followed by calculating the volume of Talang Akar Formation.

Pyrolysis Analysis

The Pyrolysis analysis uses secondary data. The data were acquired through pyrolysis using samples from RAY-1 that represents all the wells.

A. Quality

The data used to determine the quality of a source rock was Hydrogen Index, which is the ratio of S2 hydrogen (in mg HC/g Rock) to the Total Organic Carbon (TOC), and Tmax, the temperature at which the maximum rate of hydrocarbon generation occurs in a kerogen sample during pyrolysis. Based on the pyrolysis analysis that was conducted in depth of 5446.1 – 5987.5 of RAY-1 Well, the HI ranges from 130 – 319 mgHC/g TOC and Tmax value ranges from 445 – 453 °C. The Kerogen type could be determined by utilizing a modified cross plot from the Van Krevelen Diagram. As shown in Figure 3 it can be concluded that the kerogen is dominated by Type III kerogen, which produces mainly gas. The Tmax values that ranged from 445 – 453 °C are an indication that the organic materials have reached maturity surpassing the minimal temperature of the oil window. Figure 4 shows the ternary plot of macerals that could be used to determine the kerogen type of the samples. This ternary plot exhibits four different type of kerogen (Oil-Prone, Gas-Prone, Wet Gas-Prone, or Non-source) based on their petrographic characteristics. The samples mostly plotted in the Gas-Prone area, leading to a conclusion that the kerogen is mostly gas prone. Moreover, this plot (Figure 4) proved that the kerogen is indeed type III kerogen.

B. Quantity

The quantity or potential of the source rock was determined by using the Potential Yield (S1+S2) data, the ability to generate hydrocarbon, and Total Organic Carbon (TOC) (%wt). Figure 5 shows the cross-plot diagram of Potential Yield and TOC, and shows that, based on the pyrolysis analysis that is conducted in depth of 5446.1 – 5987.5 of well RAY-1, the TOC that ranges from 0.51 wt% - 8.28 wt% could be classified as Fair – Excellent. Moreover, the Potential Yield data that, ranges from 1.16 mgHC/g – 19.45 mgHC/g could exhibit the potential of the samples as Poor – Good. These results showed that the samples have a potential to be source rocks under a favorable temperature regime.

C. Maturity

A source rock achieves thermal maturity when it reaches a certain temperature showed in Tmax values from Rock Eval Pyrolysis ranging from 435 °C (early mature) to 470 °C (late mature) (Peters and Cassa, 1994). The maturity of a source rock can be identified by using the data Vitrinite Reflectance (Ro) (%), a measure of the percentage of incident light reflected from the surface of vitrinite in the source rock. According to Peters and Cassa (1994), a value of vitrinite reflectance of above 0.5% is considered to have reached early mature, and above 0.6% have reached peak maturity. From Figure 6, it can be shown that from depth 4478.3, the Gumai formation deposited above the Pendopo Formation, all of the source rock samples have reached the early mature phase. From the depth of 5200.1, the Pendopo Formation, have all reached peak maturity. All samples from the Talang Akar Formation have reached peak maturity, which indicate the ability of the Talang Akar source rock to generate hydrocarbon.

Subsurface Mapping

Subsurface mapping is the process to map a certain area below the surface using seismic lines and wells. This process used to determine the shape and thickness of the Talang Akar Formation as well as to calculate the volume of the Talang Akar Formation for the volumetric calculation.

A. Seismic Interpretation

Seismic interpretation is the main step of subsurface mapping. By identifying the horizon and faults of a formation, the shape of particular formation can be formed. Before conducting a seismic interpretation, well to seismic tie process is needed. Well to Seismic Tie is the process where well are correlated with the seismic lines to know where the horizon of a formation is located. This is done due to the difference in domain, in which seismic lines uses time domain and wells uses depth domain. Figure 7 shows the well to seismic tie of well RAY-1, using well tops of formation Air Benakat, Gumai, Pendopo, Talang Akar, and Basement to correlate the well tops and the seismic lines. Figure 8 shows one of the seismic lines which horizons and fault has been identified and shows the pre-rift and syn-rift of the basin. The blue line indicates the Talang Akar Formation, the red line indicates the basement, and the blue line with the dots indicates a fault.

B. Depth Structure Map

The interpreted seismic lines are used to generate the surface map. The domain of the seismic lines represents time; therefore, the surface map produced will be a time surface map. Velocity data was used to convert the time surface map into a depth surface map. Moreover, inputting the interpreted faults in the previous step to the depth surface map could turn this map into a depth structure map as shown in Figure 9. Figure 9 shows the depth structure map of the Talang Akar Formation.

C. Shale Ratio

The Shale Ratio was required to calculate the volume of the shale. The shale ratio is obtained by calculating the total depths of Talang Akar shale in the wells, divided by their total well depth. The shale ratio was calculated from four wells, which were averaged. The shale ratio obtained is approximately 0.59.

D. Shale Volume

The shale volume value is obtained by multiplying the total volume of the formation and the shale ratio. This value is used to calculate the Hydrocarbons Generated for the volumetric calculation. The volume used for the volumetric calculations was the shale volume of the Talang Akar Formation below 4478.3 ft depth. The particular depth was chosen as it was the minimum depth to reach thermal maturity. The volume of mature shale is found to be approximately 2.10 x 1012 cm^3.

Volumetric Calculation

Volumetric calculation was used to calculate the total mass of hydrocarbons generated based on the equations formulated by Schmoker (1994). The first calculation was aimed to obtain the value of Organic Carbon Mass. To determine the Organic Carbon Mass, *M* (g TOC), the data of average TOC (wt%), average formation density, ρ (g/ cm^3), and Volume of source rock, *V* (cm^3) were needed.

$$M \text{ (g TOC)} = [\text{TOC (wt\%)}/100] \times \rho \text{ (g/ cm}^3) \times V \text{ (cm}^3) \quad (1)$$

The values TOC are divided by 100 to convert from percent abundance to fractional abundance. By using the data obtained from previous calculation, *M* could be calculated and has a value of 4.97 x 10^{15} g TOC.

Further calculations were conducted to obtain the value of mass of hydrocarbons generated per unit organic carbon Mass, *R* (mg HC/g TOC). The data needed to calculate *R* are the present day hydrogen index, Hi_p (mg HC/g TOC), and the original hydrogen index, Hi_o (mg HC/g TOC). The difference between these hydrogen indexes used to calculate the mass of hydrocarbons generated per gram of TOC. The value of Hi_p is 207 mg HC/g TOC while the value of Hi_o is 319 mg HC/g TOC. The equation is as follow:

$$R \text{ (mg HC/g TOC)} = Hi_o \text{ (mg HC/g TOC)} - Hi_p \text{ (mg HC/g TOC)} \quad (2)$$

From the equation, the value of mass of hydrocarbons per unit mass of TOC can be calculated, which is 112 mg HC/g TOC.

Finally, the mass of hydrocarbons generated per unit mass of organic carbon, *R* (mg HC/g TOC), and mass of organic carbon, *M* (g TOC) data were used to calculate the total mass of hydrocarbons generated, HCG (kg HC).

$$HCG \text{ (kg HC)} = R \text{ (mg HC/g TOC)} \times M \text{ (g TOC)} \times 10^{-6} \text{ (kg/mg)} \quad (3)$$

The HCG value obtained from the previous calculations data, which are approximately 5.56 x 10^{15} g TOC. To convert HCG into equivalent value of barrels of oil or cubic feet of methane, the graph by Schmoker (1994) was used as shown in Figure 10. The green line shows the value of hydrocarbons mass correlated with the equivalent value of gas (ft^3). Gas equivalent was used because pyrolysis analysis indicating type III kerogen as a dominant kerogen. In addition, the kerogen has gas prone macerals dominance, which reveals that the main product of the Talang Akar formation shale was gas. It can be concluded from the graph in Figure 10 that the gas equivalent is approximately 29 TCF.

Migration Pathway

The primary migration pathway map for Talang Akar Formation in research area was taken from the depth structure map according to the main depocenter of the basin followed by the pathway from lower into the highest contour (Figure 11). The normal fault was also used as the pathway map for the oil from source to migrate. The migration starts at 4478.3 ft at the thickest shale from isopach map in which after the pyrolisis analysis shown the vitrinite reflectance of source rock in Talang Akar formation has reached early mature state.

Conclusions

The study of Talang Akar formation's shale source rock evaluation was done by utilising pyrolysis data. The study has shown that the shale composed of type III kerogen and has gas prone macerals. The pyrolysis data, moreover, exhibit that the shale has a very good potential and has reached thermal maturity indicated by its average Tmax. The maturity of the shales could also be seen from their VR values as well, which showed that the shale has reached thermal maturity at 4478.3 ft depth and has reached the peak maturity at 5200.1 ft depth. The hydrocarbon generated from the shale is mainly gas with the total mass of hydrocarbon generated approximately 29 TCF.

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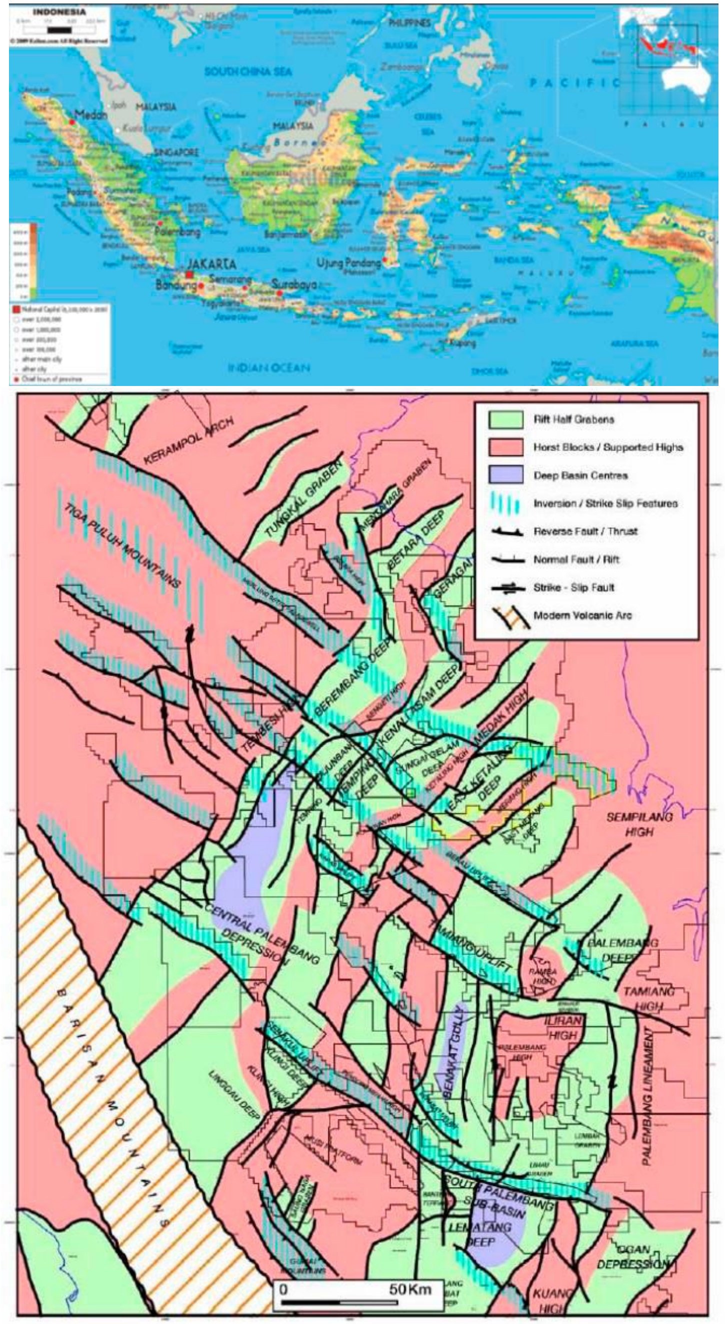

Figure 1. Key structural elements of the South Sumatra basin (Ginger, 2005).

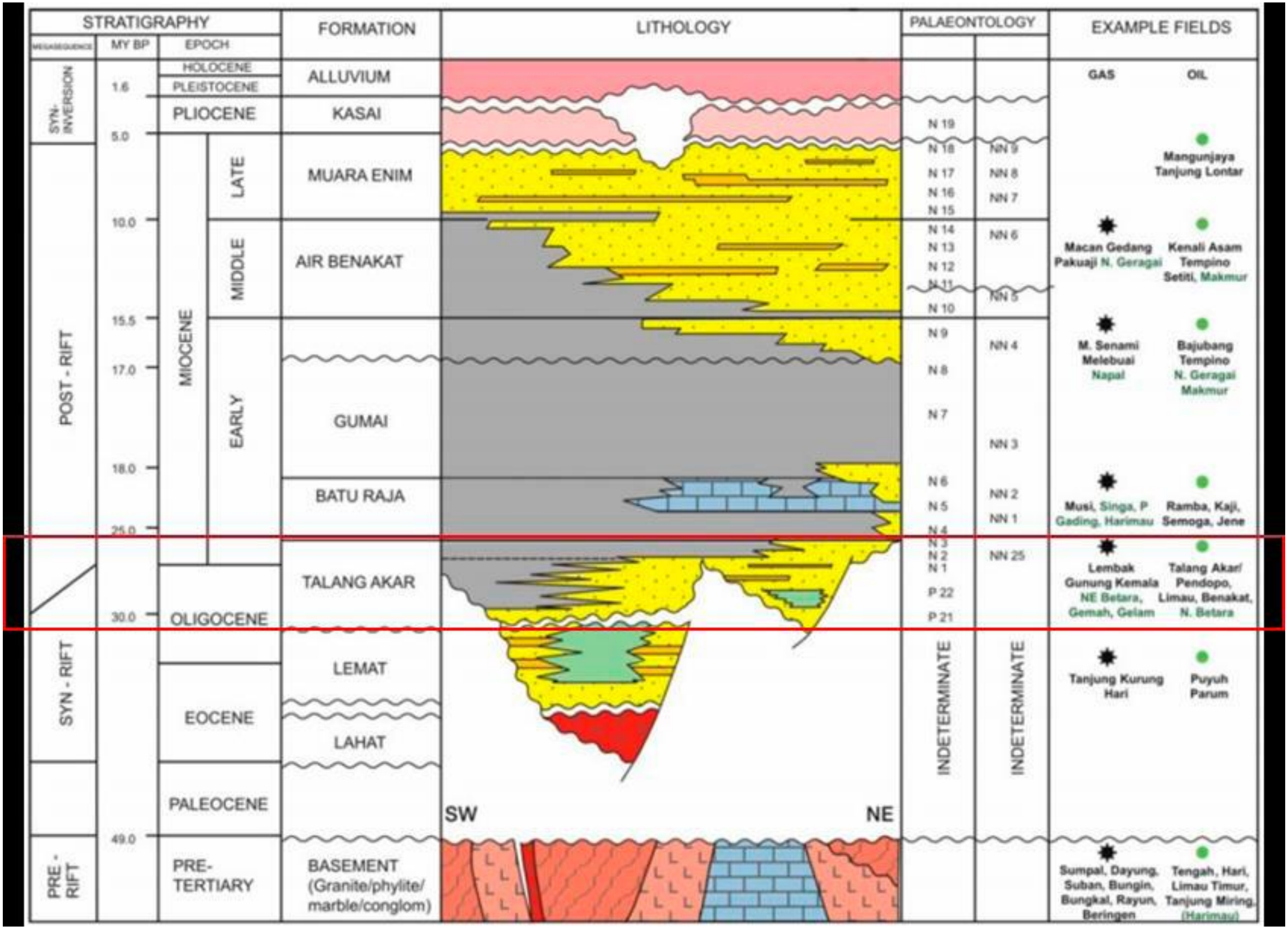

Figure 2. Talang Akar Formation as the Source Rock Targets.

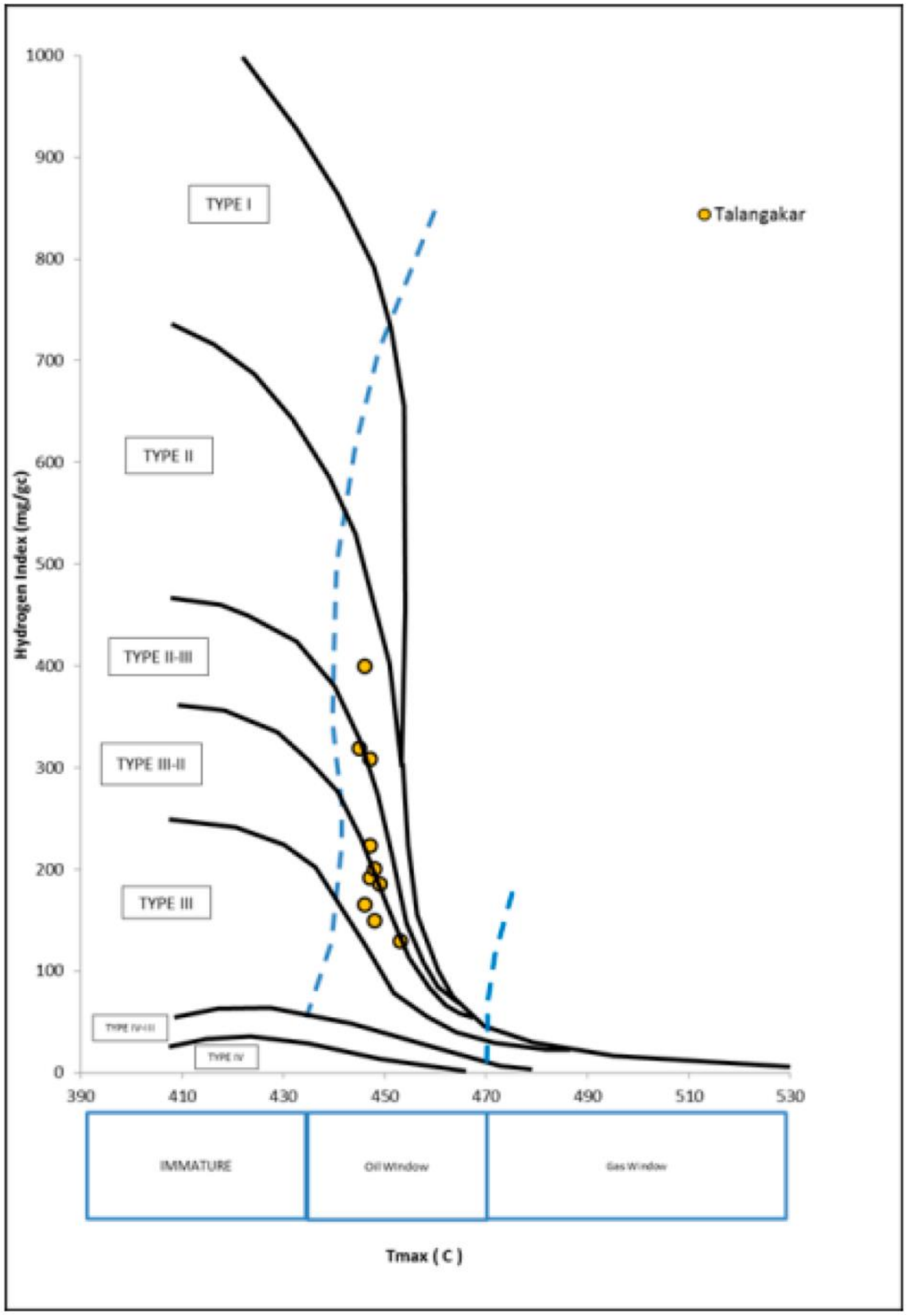

Figure 3. HI and Tmax cross plot diagram of well RAY-1 (Peters and Cassa, 1994; van Koeverden et al., 2011).

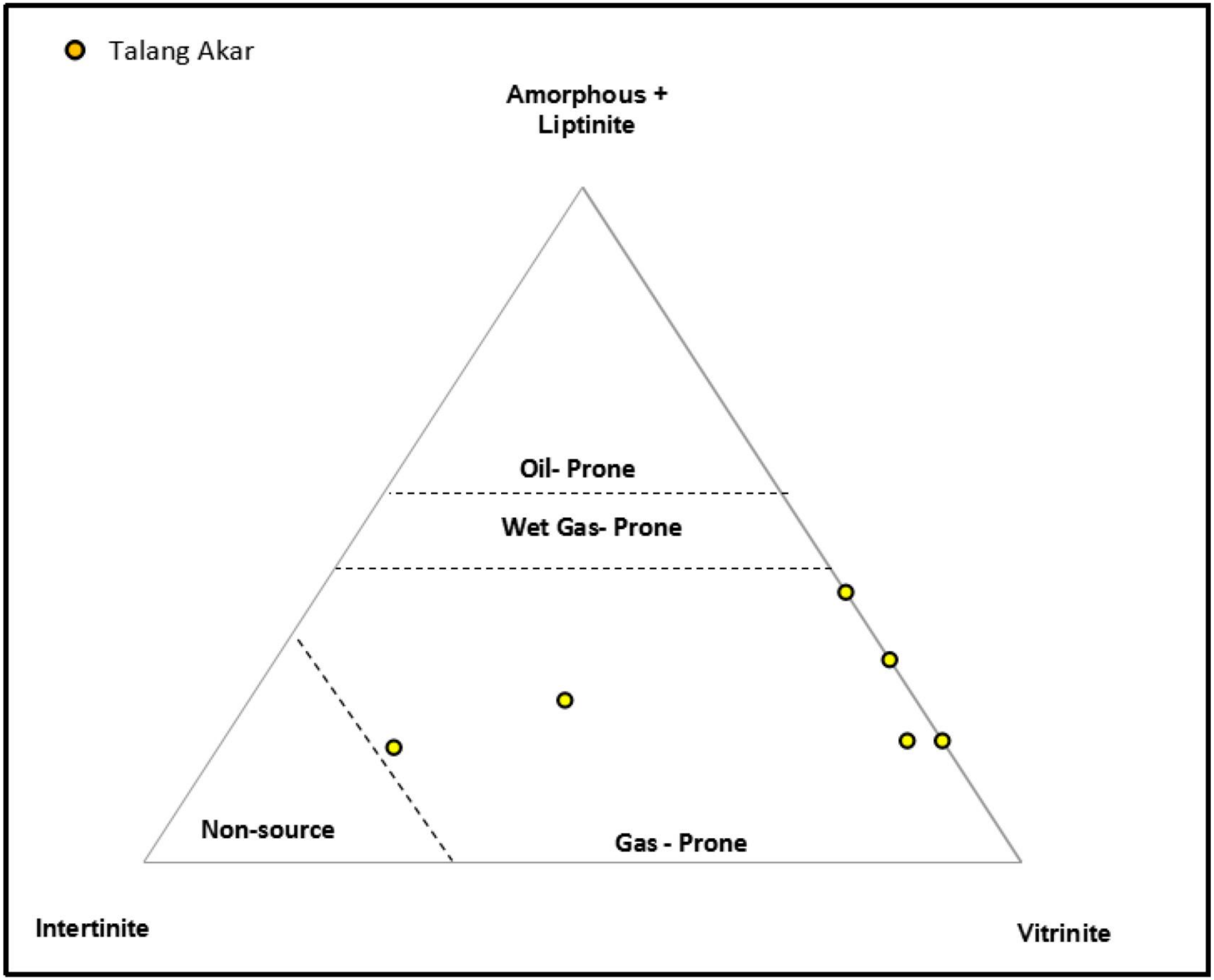

Figure 4. Ternary Plot of macerals Vitrinite, Inertinite, and Amorphous + Liptinite of well RAY-1.

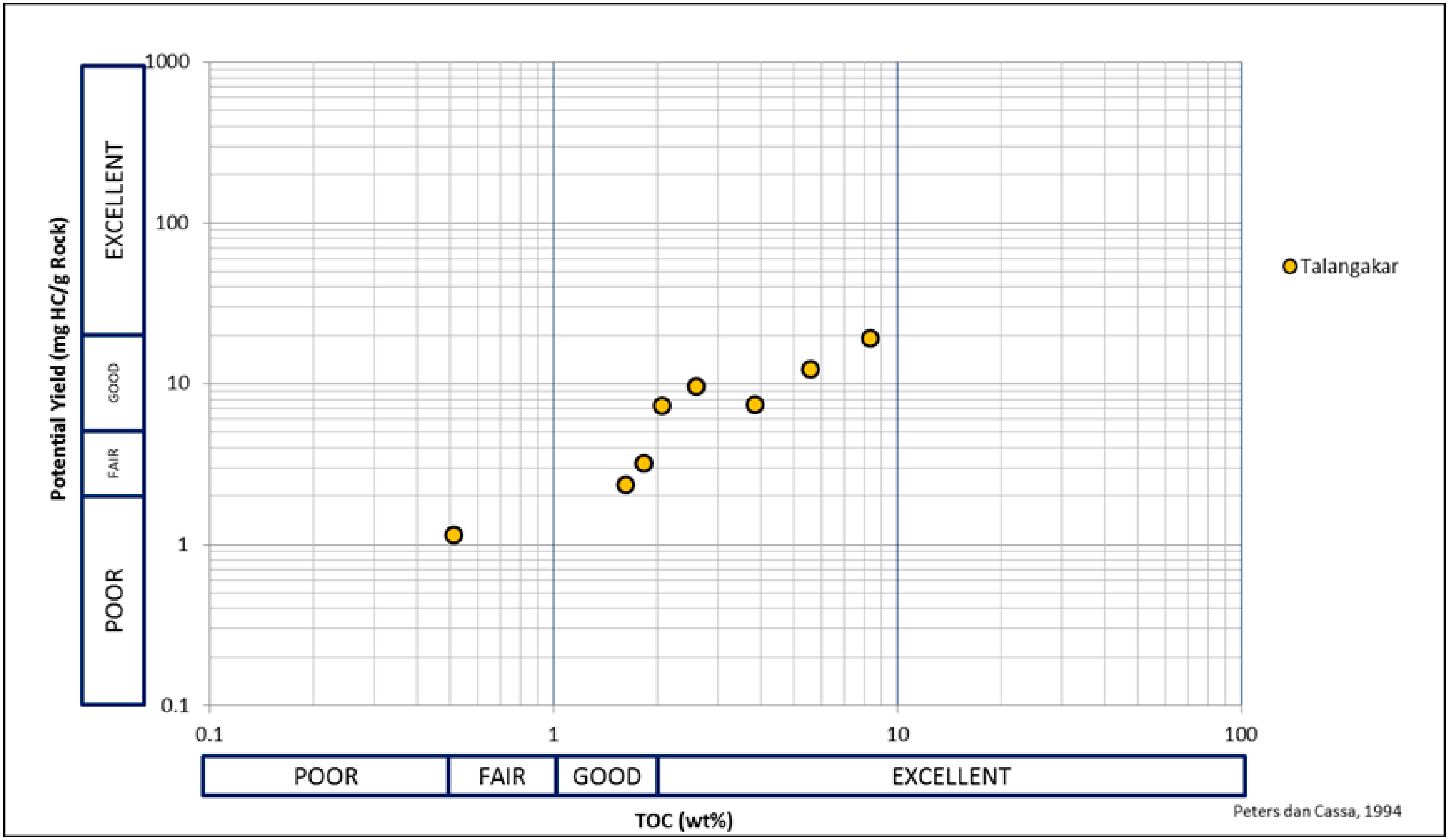

Figure 5. Potential Yield and TOC cross plot diagram of well RAY-1 (Peters and Cassa, 1994).

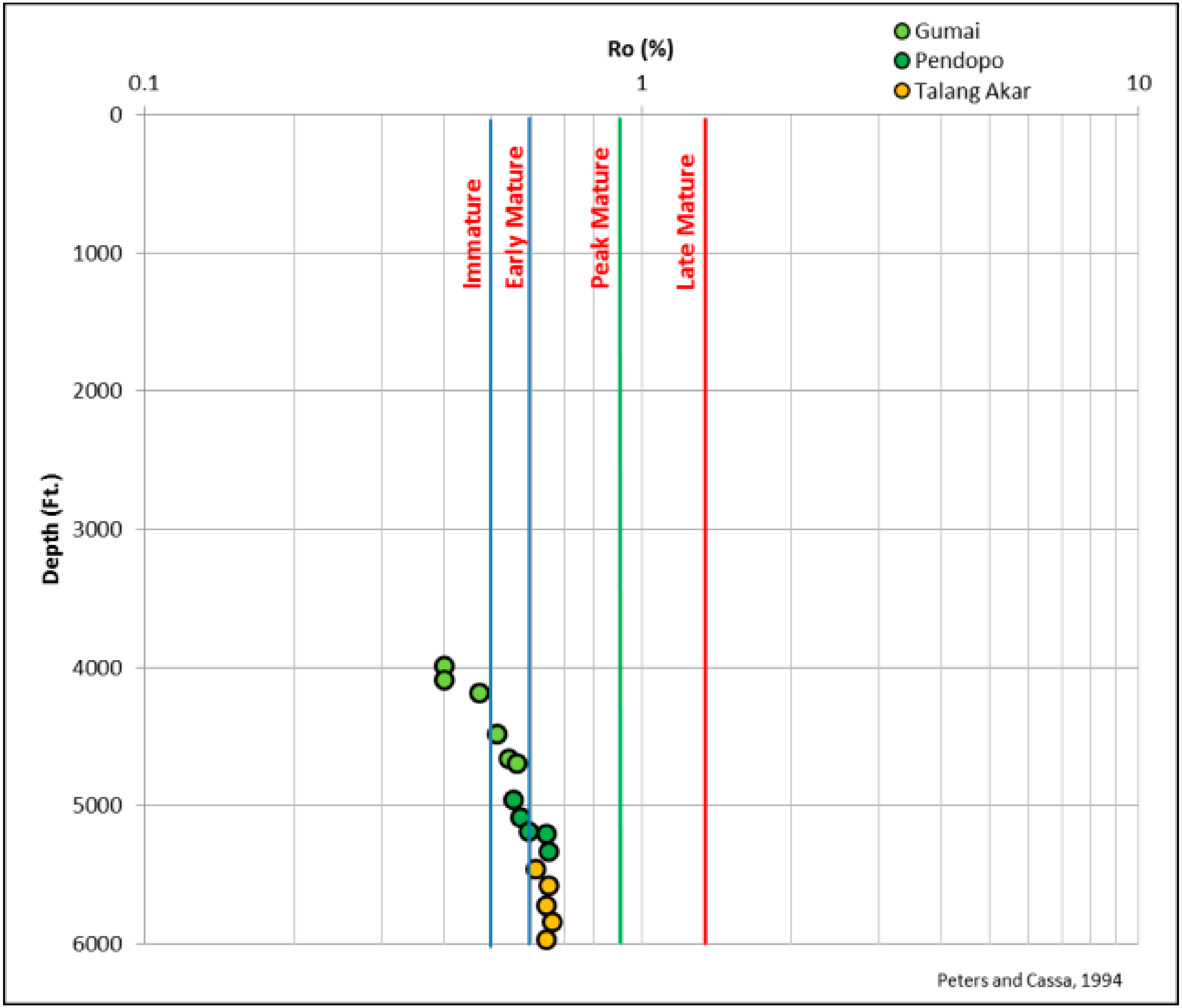

Figure 6. Depth and Vitrinite Reflectance cross plot diagram of well RAY-1 (Peters and Cassa, 1994).

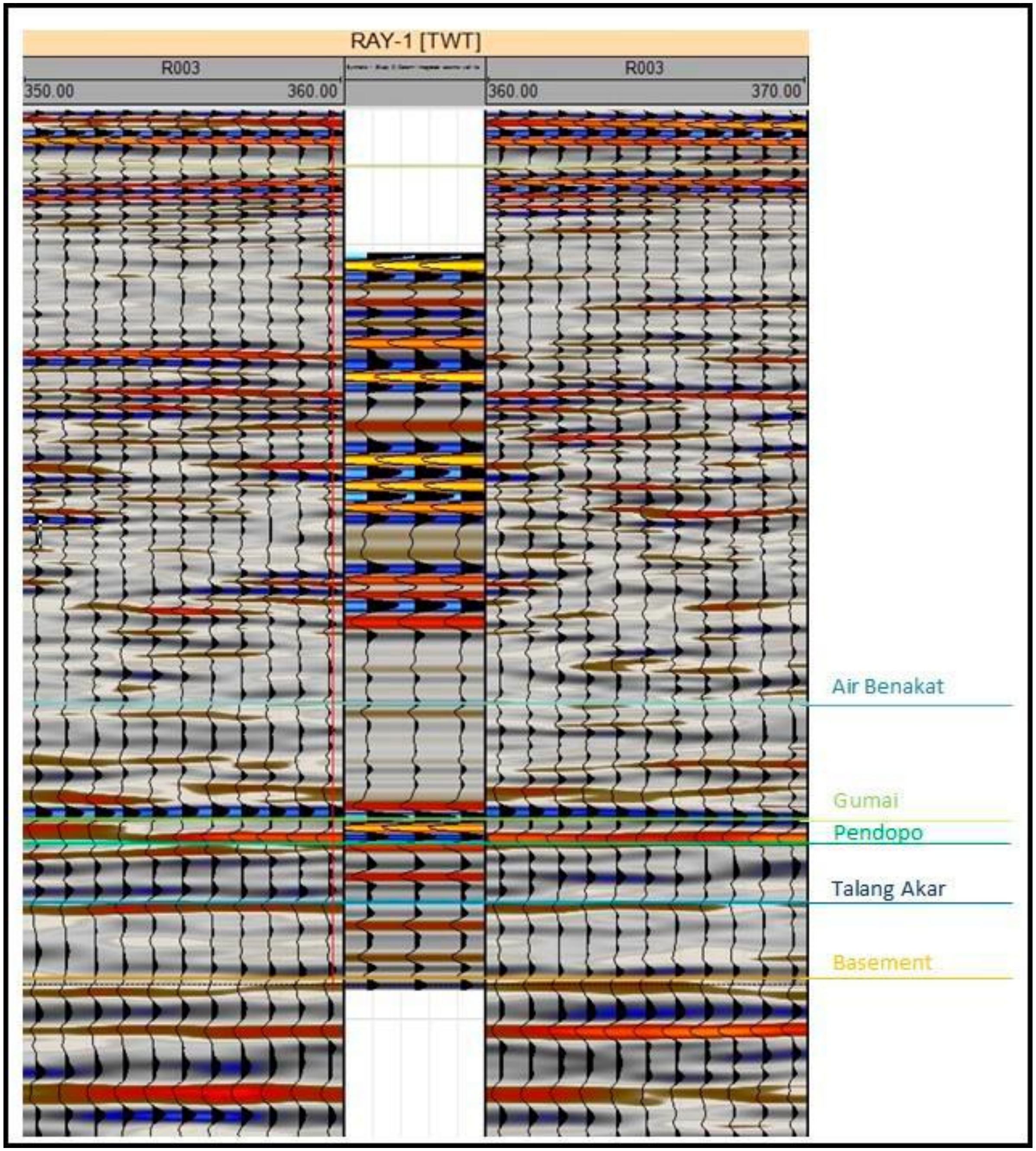

Figure 7. Well to Seismic Tie of well RAY-1.

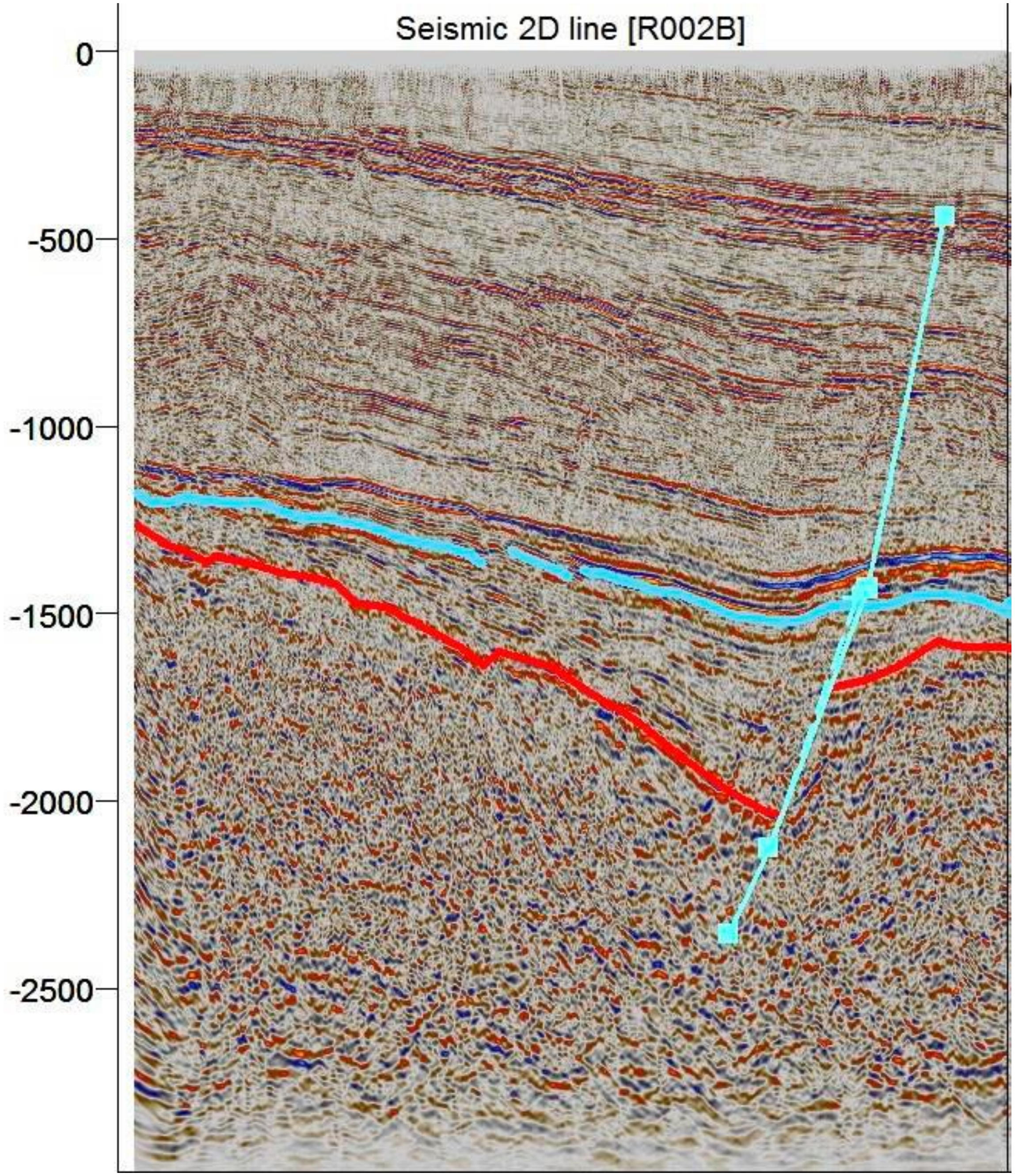

Figure 8. Horizon and fault interpretation of a seismic line in the research area.

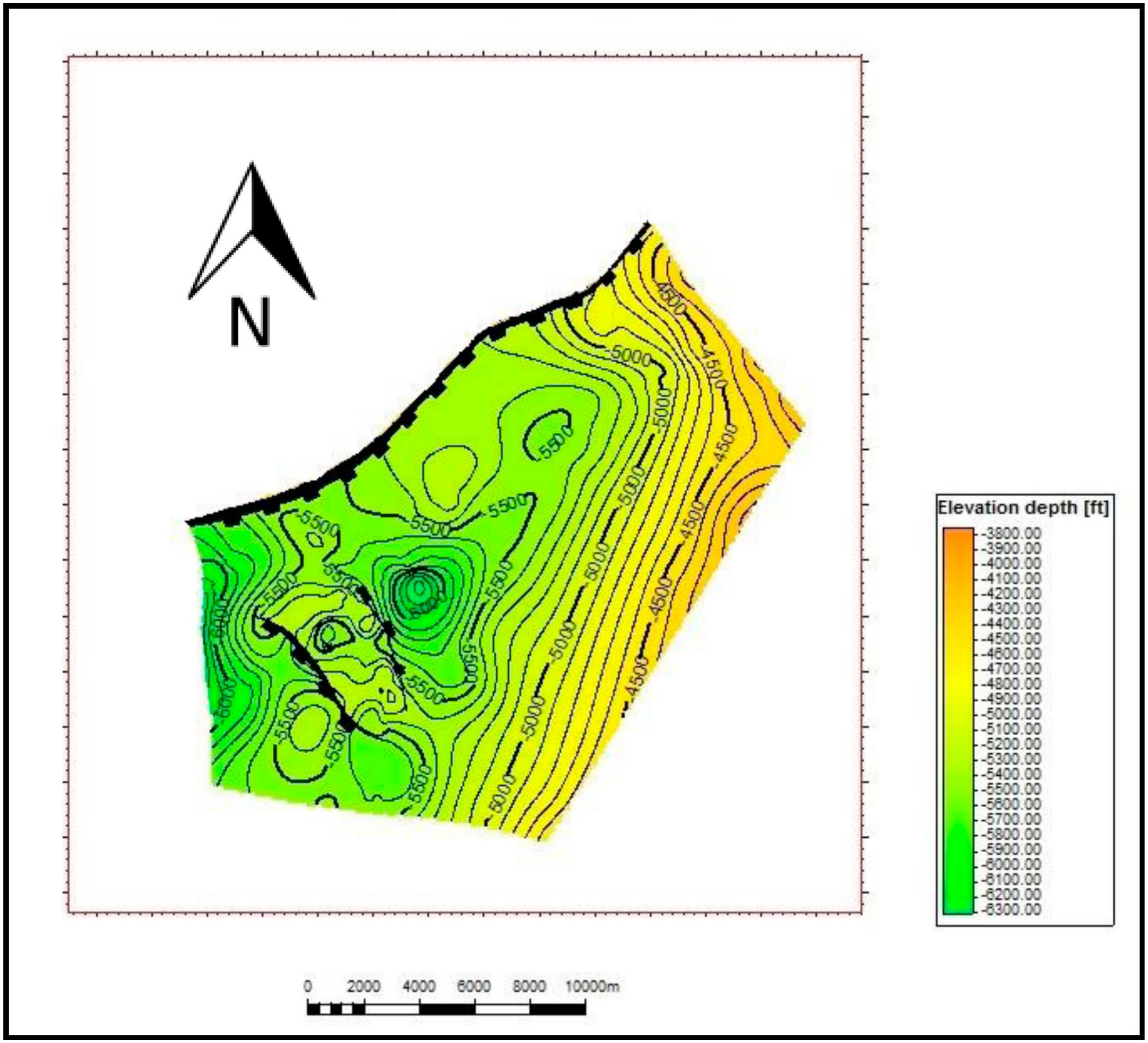

Figure 9. Depth structure map of the research area.

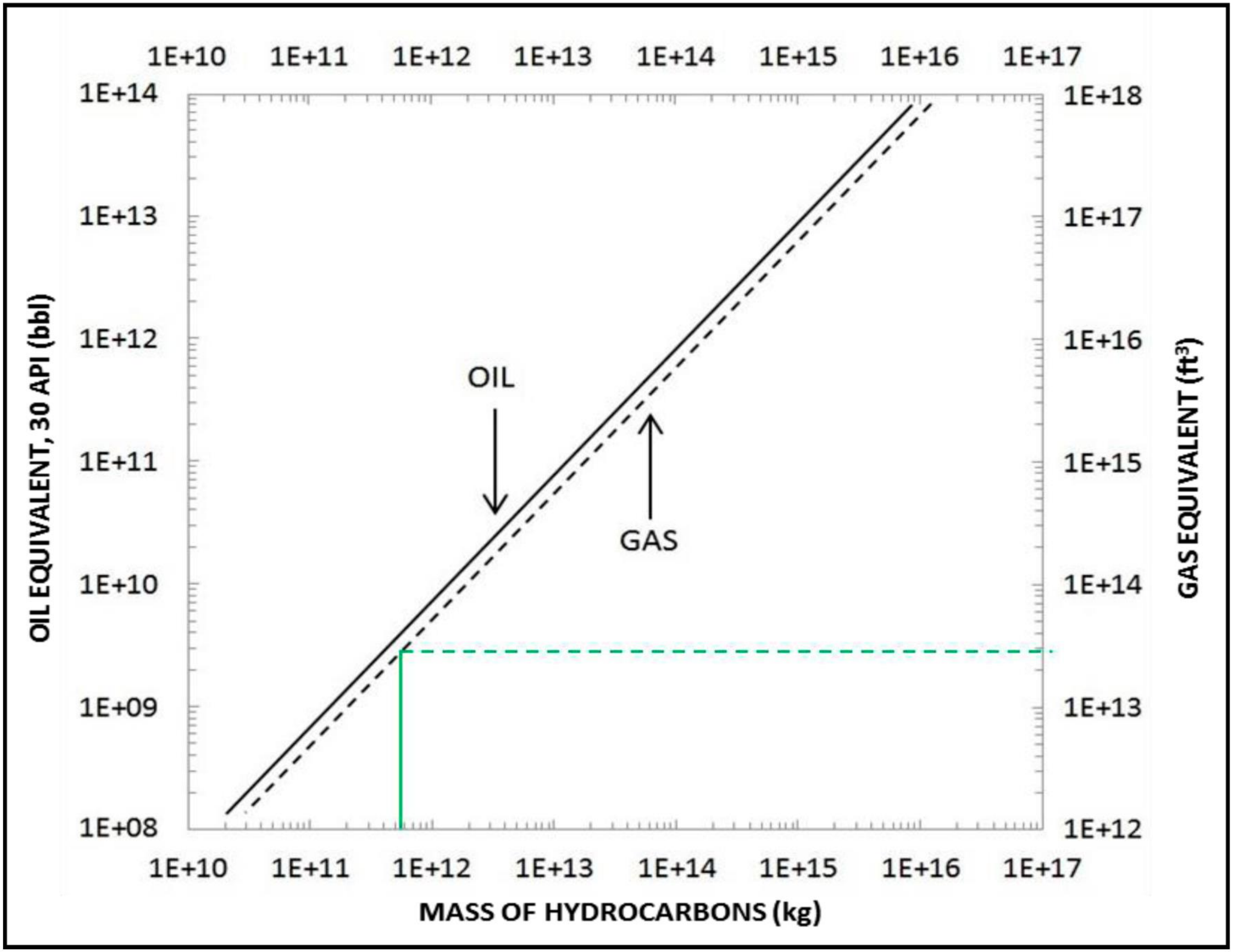

Figure 10. Graph to convert mass of hydrocarbons to equivalent barrels of oil or cubic feet of methane (Schmoker 1994).

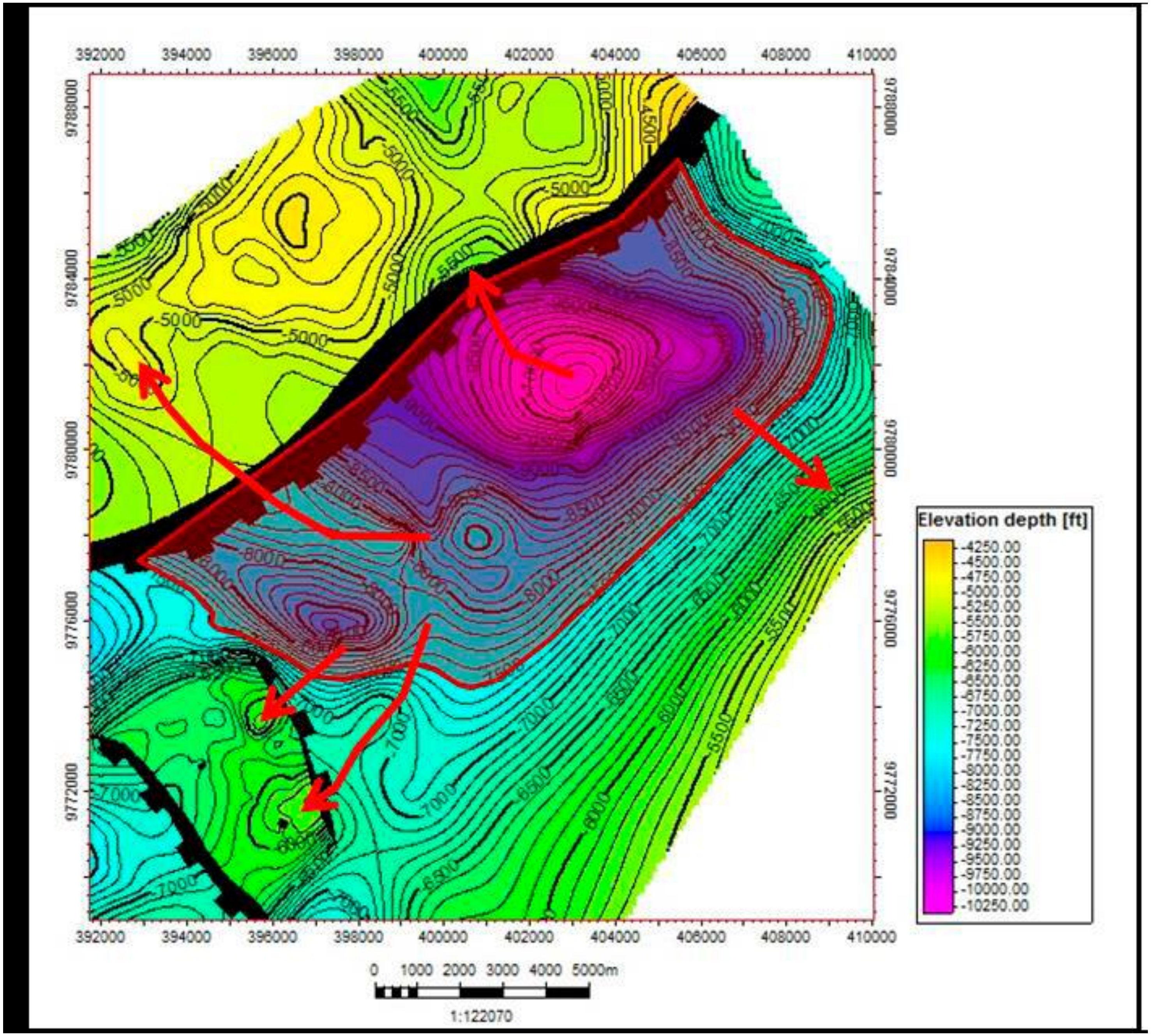

Figure 11. Migration Pathway of Talang Akar Formation in Research Area.