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GEOCHEMICAL AND PETROPHYSICAL ASSESSMENT OF TELISA SHALE GAS RESERVOIR: A CASE STUDY FROM SOUTH SUMATRA BASIN, INDONESIA

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ABSTRACT: The geochemical and petrophysical assessment of a shale gas reservoir in Telisa Formation in South Sumatra Basin was carried out to identify the gas potential distribution. The assessment was performed based on geochemical and petrophysical data, which were integrated with and seismic attributes to spatially distribute the organic richness of the shale gas reservoir. The objectives of this paper are to characterize core samples in terms of the total organic carbon (TOC), kerogen type and thermal maturity of shale gas layers that were derived from the well log data. In addition, seismic attribute analysis such as acoustic impedance, which is associated with TOC, was explored to spatially distribute the shale gas potential. The assessment results showed that the organic richness of the Telisa shale gas reservoir is classified into fair quality with TOC in the range of 0.75-1 weight (wt) %. The kerogen type of the Telisa shale gas reservoir is considered as a mixture of type II/III (oil/gas prone) to type III (gas prone). In terms of vitrinite reflectance, the Telisa shale reservoir is categorized as in a mature stage, representing an oil window up to a wet gas window. The prospective reservoir distribution is indicated by a shale lithology characterized by a high acoustic impedance range of 20000-24000 ((m/s). (g/cc)).

Keywords: Geochemical and petrophysical assessment, TOC, Kerogen type, Thermal maturity, Telisa Formation, South Sumatra Basin.

1. INTRODUCTION

The gas potential from the shale gas reservoir has been intensively developed for finding the new alternative energy resources of fossil fuel. The abundant and uniqueness of shale gas system have made the shale gas become an interesting play for unconventional energy, which is useful to overcome the declining of petroleum production and the uplifting of expense for petroleum production. The shale gas might open challenges for shale gas to be an alternative to energy consumption [1].

The research field is located in the South Sumatra Basin that is the biggest oil producers oil in Indonesia. The province, as illustrated in Figure 1, is a Tertiary basin with the base of the igneous and metamorphic rock and is dominated by clastic and carbonate sedimentary rock. For the Eocene up to the lower Oligocene, the sedimentary layer is composed of lacustrine shale of the Lahat Formation. This laminated layer is overlain by lacustrine and deltaic coaly shale of the Talang Akar Formation, deposited during the Oligocene up to the lower Miocene [2]. The Lahat and Talang Akar Formations are believed to be the source rock in the South Sumatra Basin, and in some areas are in the deepwater depositional environment [3]. However, the younger Baturaja and Gumai Formations also possibly serve as source rock [4]. The identified hydrocarbon potential in the South Sumatra Basin is predicted at around 4.3 Billion Barrel of Oil Equivalent (BBOE) [5], with the exploration cycle continuing [6].

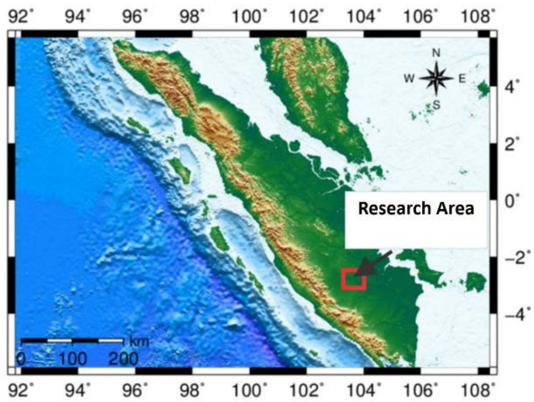


Fig. 1 Location of the study area in South Sumatra province.

Many play types have developed in the South Sumatra Basin, including the Transgressive sand of the Talang Akar Formation, which has been proven to produce productive reservoirs [7] such as the east Benakat oil field, derived from the Batu Raja and Talang Akar Formations [8], and unconventional hydrocarbon plays derived from the fractured basement in the Kuang area [9]. Reevaluation of the Telisa Formation has suggested that this formation is a potential reservoir, although a special technique known as hydraulic fracturing is likely required to increase gas production.

This paper presents the geochemical and petrophysical assessment of an exploration target in the shale gas reservoir of the Telisa Formation to delineate the gas potential distribution. The assessment is integrated with a seismic attribute of acoustic impedance to delineate the shale gas distribution. The geochemical assessment focuses on well log analysis in terms of organic richness, hydrocarbon type, and maturity level. Spatial distribution of the shale gas potential derived from the acoustic impedance of seismic inversion, which is then transformed into the TOC parameter.

2. GEOCHEMICAL AND PETROPHYSICAL ASSESSMENT

In the unconventional shale gas system, the Telisa shale Formation serves as both source rock and reservoir rock [10]. Therefore, accurate geochemical and petrophysical analysis of this shale gas system is essential. In this study, the assessment is applied to well log data from four wells and seismic attribute of acoustic impedance.

The most important characteristic of any shale gas reservoir is the quality and the quantity of organic richness contained in the deposited shale. This is typically assessed in terms of TOC and hydrogen content, which, when combined with thermal maturity data, is a key to identifying the shale gas potential [11].

The content of organic material in a shale gas system is generally represented by the TOC parameter, values of which vary between different shale reservoirs. High TOC values typically range from 0.3 to over 20 wt.%, but in general are less than 5 wt.%. The measured TOC illustrates the volume of organic carbon retained in shale that is converted into hydrocarbons, as well as organic carbon that is not able to produce any hydrocarbons [12].

The next parameter used to characterize the shale gas system is the maturity of the shale gas reservoir, as indicated by vitrinite reflectance (Ro). Ro is generally regarded as the most suitable parameter with which to determine thermal maturity. Three evolutionary processes occur when thermal maturity increases during the sediment burial process: diagenesis, catagenesis, and metagenesis. Diagenesis is closely related to a stage during which the value of Ro is below 0.5% and therefore the kerogen is immature. During catagenesis, Ro values are typically between 0.5% and 2%, with this process taking place after a significant increase in temperature during burial in sedimentary basins. Finally, metagenesis is associated with Ro values of between 2% and 4% and generally occurs in a zone of dry gas.

The kerogen type of shale formation is controlled by the content of the main kerogen components, i.e., carbon, hydrogen, oxygen, and nitrogen, as well as insignificant amounts of sulfur. The type of kerogen is characterized by its compound evolutionary track in the Krevelen graph (O/C versus H/C) [13]. The kerogen type I is characterized by the atomic ratio of H/C greater than 1.5, and the atomic ratio of O/C less than 0.1. The kerogen type II is indicated by relatively low H/C values (less than 1) and O/C values, ranging from 0.20-0.30. Finally, kerogen type III is derived from mainly terrestrial plants and generally has a lower hydrocarbon-generative capacity, predominantly producing gas [14].

In this works the petrophysical analysis was conducted using three different methods: Passey, multi-linear regression (MLR), and Bowman. Passey and MLR were used to predict TOC values for the entire depth of the well logs, while the Bowman method was employed to determine the hydrocarbon indication based on a resistivity parameter, with high hydrocarbon potential characterized by high resistivity values.

According to the Bowman method, a graph was produced plotting the logarithm of resistivity against sonic log values. Based on this plot, the low resistivity shale line can be interpreted as the baseline of the shale layers, with the relationship between resistivity log and sonic log values expressed by Eq. (1) as follows:

$$DT = 126.71 - 75.92 \log R \qquad (1)$$

where DT is sonic log and R is resistivity log.

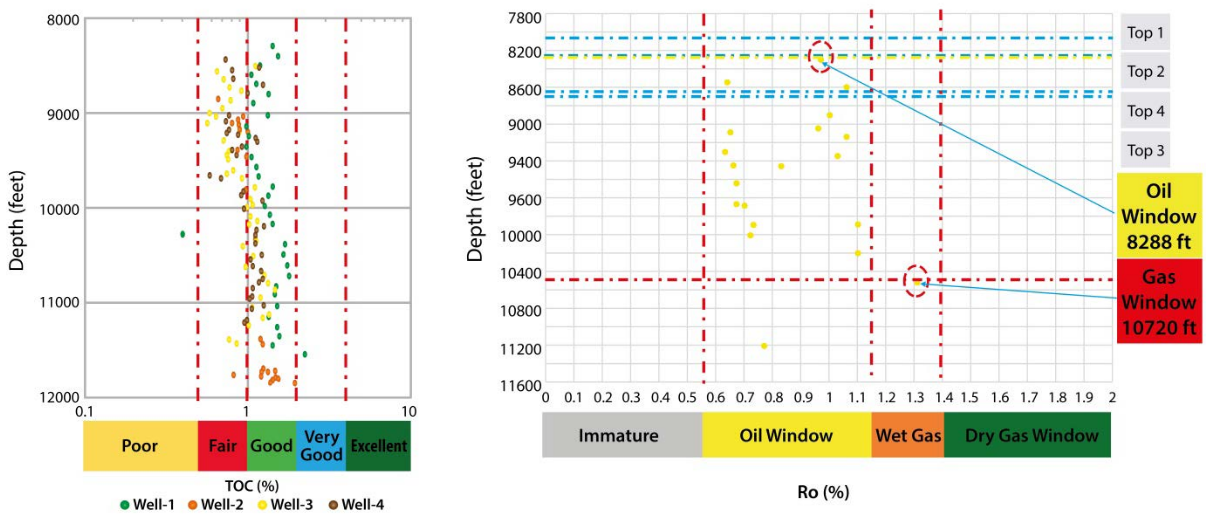
To achieve the objectives of this work, shale properties were first characterized based on laboratory work including accurate measurements of organic matter, together with detailed seismic interpretation. Following this, approximation models were derived to determine the relationship between field measurements and the calculated petrophysical data [1].

3. RESULT AND DISCUSSION

The following section presents the geochemical data obtained from the core and petrophysical analysis, which were then employed to predict TOC values for the entire depth of the well logs. The empirical relationship between acoustic impedance and TOC was then derived to distribute the TOC values throughout the study area based on seismic data.

3.1 Geochemical Assessment of the Telisa Shale Gas Reservoir

Geochemical assessment of shale core samples obtained via core cutting for each well included measurement of TOC, mineralogy, maximum temperature (TMAX), and kerogen type. The following results are shown in distinct colors for each of the four wells, with green representing Well-1, orange for Well-2, yellow for Well-3, and brown for Well-4. Geographically, Well-1 is located some distance from Well-2, Well-3, and Well-4, which are clustered close to each other. Figure 2a shows the organic richness in the shale of Telisa Formation based on data from the four wells, with quality ranging from fair to good.

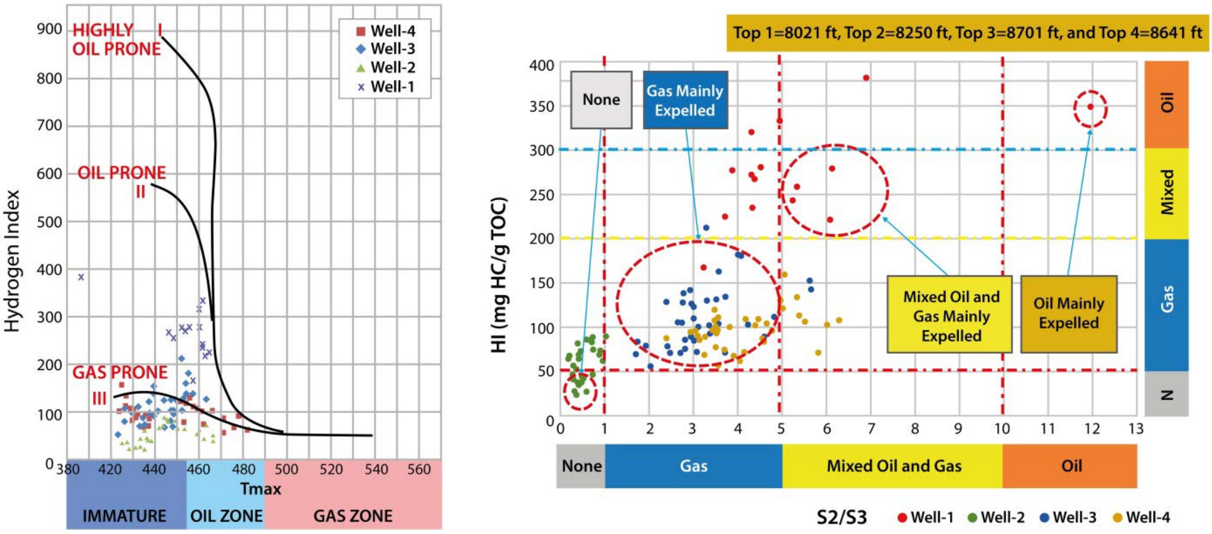


(a) (b)

Fig. 2 Geochemical analysis of the organic shale Telisa Formation: (a) organic richness (TOC), and (b) maturity level in terms of vitrinite reflectance (Ro) as a function of depth.

The prospect potential of the shale in Telisa Formation is classified in terms of hydrocarbon generation, maturity level analysis, which is carried out by cross-plotting Ro versus TMAX values. The potential value of the Telisa Formation greatly depends on whether it can be classified into the type of hydrocarbon such as (oil, wet or dry gas) and whether they are immature, mature, or over-mature. Based on the obtained Ro values, the Telisa Formation can be classified into the range of an oil window to a wet gas window, with TMAX analysis indicating maturity levels ranging from immature to mature. Figure 2b shows the maturity range of the shale in Telisa Formation as represented by Ro as a function of depth. This figure shows that the top marker of Top 1 is defined at a depth of 8021 ft, Top 2 at 8250 ft, Top 3 at 8701 ft, and Top 4 at 8641 ft. In general, most of the data indicate an oil window at a depth of 8288 ft, with only a few values associated with a wet gas window at a depth of 10720 ft.

Figure 3a presents an analysis of kerogen type of Telisa shale Formation, which is based on hydrogen index and TMAX values. The analysis has classified as kerogen type III, reflecting its gas-producing capacity (gas-prone). Figure 3b also indicates a gas-prone dominated kerogen type, together with a small mixed oil and gas component associated with higher maturity areas. The predominance of gas-prone shale in the Telisa Formation is analogous to that found in the Baturaja Formation, which is unsurprising as these two formations are clustered within the same reservoir type in terms of the petroleum system. In addition, the Telisa Formation was originally deposited in a marine depositional environment, which is commonly associated with type II kerogen. Considering the formation's burial mechanism and the subsequent evolution of pressure and temperature, the kerogen type likely changed from type II to type III. This theory is reinforced by the argument that the Telisa Formation was deposited in a shallow marine environment and so exhibits high vitrinite reflectance, as is typical of type III kerogen (either wet or dry gas-prone).



(a) (b)

Fig. 3 Kerogen type classification presented as the relationship between the hydrogen index and (a) Tmax, and (b) the ratio of hydrocarbon content in the rock.

3.2 Petrophysical Analysis

The potential shale prospect zone, in this case, is indicated by sonic log values above 63 us/feet and resistivity log values higher than 1 ohm.m [15]. Unfortunately, no shale prospect zone in the Telisa Formation field can be identified based on the Bowman criteria, as shown in Figure 4, with no data lying within the red ellipse. The shale prospect zone can alternatively be manually interpreted using pseudo sonic and resistivity log data, with prospect shale associated with low pseudo-sonic log values and high resistivity log values.

In addition, the Passey method was applied using vitrinite reflectance, together with sonic and resistivity log data. Level of maturity was derived from the MLR of vitrinite reflectance, as shown in Figure 5, with Delta log R, derived via Eq. (2) as follows:

$$DeltalogR = \log\left(\frac{RT}{RT - RT_{Base}}\right) + 0.02(DT * DT_{Base}) \qquad (2)$$

(2)

where R is resistivity log, DT is a sonic log, and RT is true resistivity log.

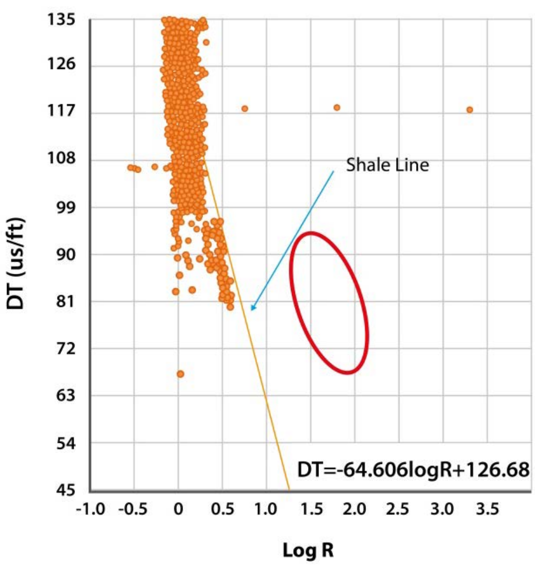


Fig. 4 The relationship between logarithmic resistivity versus sonic log. The orange line indicates the shale line and the red circle a

no/low potential shale zone based on the Bowman criteria.

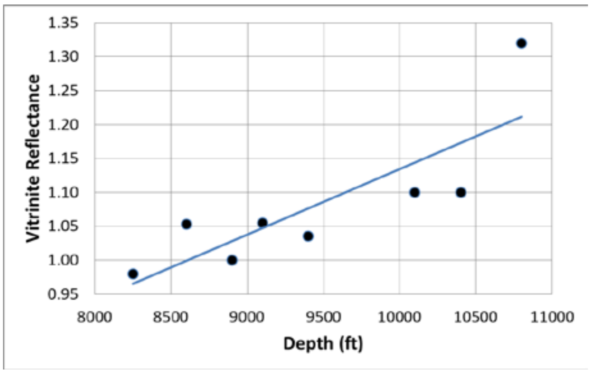


Fig. 5 Linear regression plot of vitrinite reflection, representing the level of maturity.

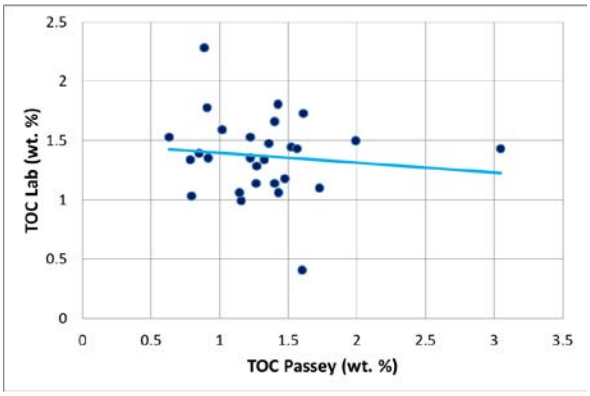


Fig. 6 The relationship between predicted TOC (Passey method) versus actual TOC data.

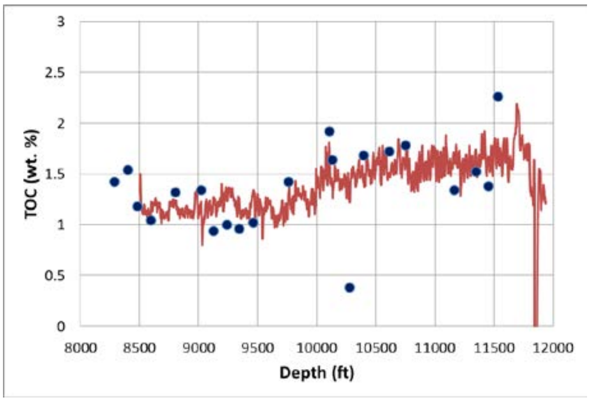


Fig. 7 The plot of predicted TOC from multilinear regression overlaid with actual TOC data.

Level of maturity and Delta log R values were used to derive predicted TOC values using the Passey equation shown in Eq. (3) [16], with the predicted and actual TOC data plotted to validate the accuracy of TOC prediction. Correlation analysis between the predicted and actual TOC data produced a low correlation coefficient of 0.0093 and a standard error of 0.597 (Figure 6).

$$TOC_{Passey} = deltalogR\left(10 * (2.297 - 0.1688LOM)\right) \quad (3)$$

where LOM is level of maturity, as derived from MLR.

An alternative method of TOC prediction was conducted using MLR, based on four different logs (Sonic, Gamma Ray, Resistivity, and Density). These predicted TOC values showed a better correlation with actual TOC data, producing a correlation coefficient of 0.335 and standard error of 0.3. A plot of predicted TOC values overlaid with actual TOC data is illustrated in Figure 7. It can be seen that the predicted TOC is close to the actual TOC data, albeit with several outliers.

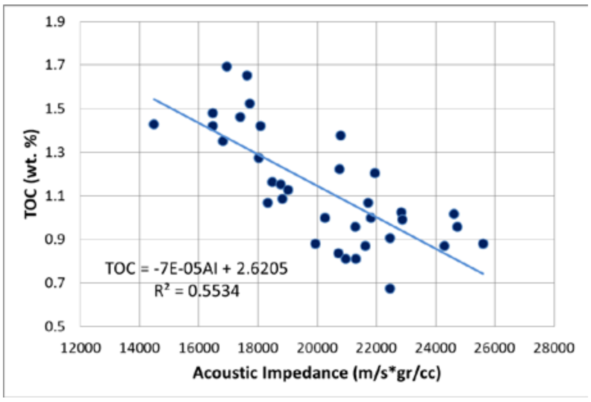


Fig. 8 The empirical relationship between acoustic impedance and TOC.

Although TOC prediction was carried out for the entire depth of the well logs via petrophysical analysis, it was limited to only one well location. Spatially distributed TOC map derived from empirical approximation (Figure 8) was employed to transform the inverted acoustic impedance (AI) of the seismic data into TOC values, with the MLR-derived TOC log values then distributed throughout the study area to delineate the sweet spot area indicated by high TOC. The correlation coefficient between AI and TOC was calculated to equal 0.5534, with the empirical relationship expressed by Eq. (4) as follows:

$$TOC = 2.6025 - 7E5AI \quad (4)$$

Figure 9 displays the AI map of the upper Telisa Formation. The area indicated by the arrow represents

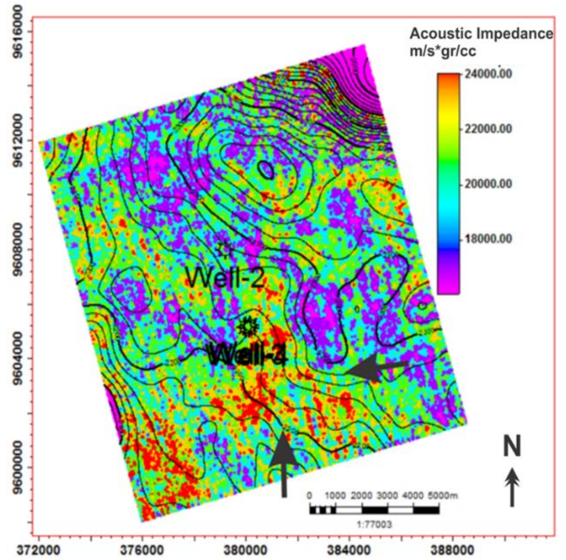


Fig. 9 Shale lithology distribution in terms of inverted acoustic impedance.

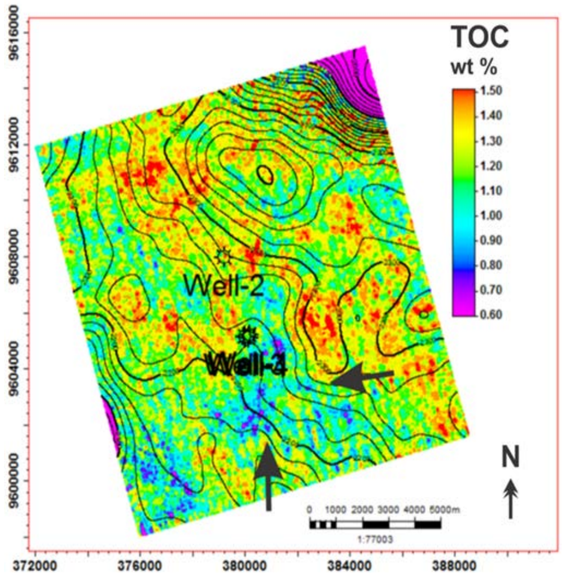


Fig. 10 The sweet spot of shale gas distribution in terms of TOC

a shale lithology associated with a high acoustic impedance range of 20000-24000 ((m/s). (g/cc)). In contrast, the shale lithology distribution also presents a low TOC range between 0.75 and 1 wt.%, as shown in Figure 10. Higher TOC values correspond to a lower acoustic impedance because a lithology with a higher organic material content is softer compared to surrounding rock. This figure indicates that the organic richness of the Telisa shale formation can be classified as fair in quality across the entire study area.

4. CONCLUSION

The geochemical and petrophysical assessment was performed to identify the sweet spot of the shale gas reservoir within the Telisa Formation in the South Sumatra Basin, based on shale organic richness (TOC), level of maturity (Ro%), kerogen type, and gas content. Analysis of the organic richness of the Telisa shale formation revealed quality levels ranging from fair to good. Kerogen within the Telisa Formation can be classified as type III, dominated by gas-prone kerogen but with a small part characterized by mixed oil and gas, with a high maturity level. The shale gas sweet spot was indicated by an AI range of 20000-24000 ((m/s).(g/cc)). In contrast, the sweet spot distribution reflects low TOC values ranging from 0.75-1 wt.%, representing fair kerogen quality.

5. ACKNOWLEDGMENTS

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