

Subsurface Geological Evaluation of the Central Sumatra Basin in Relation to the Presence of Heavy Oil

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ABSTRACT - Central Sumatra Basin has been proven as a mature basin that produces large amounts of conventional oil. In fact, some of the existing oil fields are heavy oil containing such as Duri, Sebang, Rantau Bais, and Kulin fields with their API Gravity values of lower than 25°. Apart from those oil fields the Central Sumatra Basin is expected to bear significant heavy oil potential. In this light, this paper emphasizes discussion of subsurface geological evaluation on suspected fields/areas that contain heavy oil. This evaluation serves as a preliminary step in investigation of heavy oil resources/reserves in the basin. Analysis results on stratigraphic sequence and seismic interpretation provide information support facts over presence of heavy oil that are usually associated to main faults of Dalu-Dalu, Rokan, Sebang, Petapahan, Pulau Gadang, and Kotabatak. Large tectonic events as a compression phase in the Middle Miocene – recent developed regional uplift and formed main thrust faults system, anticline structures due to the creature of basement highs, during which the F3 was deposited. The thrust faults system are important in the process of heavy oil generation in which surface water encroached into uplifted oil traps hence triggering heavy oil transformation mechanisms of biodegradation and water washing. This study provides illustration over sequences the heavy oil is generated in and their dimension in relation to area of structural anticlines. Based on available data, evaluation on subsurface geology has shown that anticlinal structures containing heavy oil tend to be characterized by near surface uplift (Basement up to 500 - 750 ms), whereas structures with lesser certainty in heavy oil containment tend show lower degrees of uplift marked by basement depth around 1000 ms or deeper. In general, seismic interpretation has shown that heavy oil is contained some sequences within sequences of 4 to 7 (equivalent to Menggala, Bekasap, Bangko, and Duri-Telisa formations).

Keywords: Heavy oil, subsurface geological evaluation, Central Sumatra Basin.

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INTRODUCTION

The Central Sumatra Basin (CSB) is known as a mature basin with abundant light and medium oil productions. Presumably, this basin also has significant heavy oil potential. Despite its well-known heavy oil production - i.e Duri steam flood project - existence of the heavy oil potential in this basin has not been studied in more detail. Knowledge over the basin's

heavy oil potential might surge national oil reserves. With decrease in the amount of lighter - hence more favourable - oil reserves, any additional heavy oil reserves that can be identified may provide solutions to boost Indonesia's national oil reserves and production in the future.

In the effort to identify accumulation of heavy oil in Central Sumatra Basin an integrated study

some scientific disciplines is required. This includes subsurface geological study. The study which results are presented in this paper emphasizes on how subsurface geological conditions are related to the presence of heavy oil in several fields/structures in the basin. There have been various definitions made to describe heavy oil but in this study the upper limit of 25° API gravity (Paszkievicz, 2012; McKinsey & Company, 2020) is adopted. In this light, several fields such as Duri, Batang, Kulin, and Rantau Bais oil fields have been proven as producing heavy oil with API gravity values of less than 25° and as a matter of fact those fields are located around the main thrust faults of Dalu-Dalu, Rokan, Sebang, Petapahan, and others (Figure 1). Figure 1 is the structure, paleograben and field distribution maps in the Central Sumatra Basin. Therefore, this provides a presumption that presence of heavy oil in the Central Sumatra Basin is strongly influenced by the existence of the thrust faults.

Condition in the Central Sumatra Basin is characterized with very limited information regarding laboratory tested heavy oil samples, hence many of discovery wells with heavy oil potentials do not have API gravity data which in turn complicates efforts to confirm the heavy oil presence in those thrust faults associated (i.e. Basement highs) areas. Any wells having heavy oil API gravity data are used as a reference, and subsurface structural highs containing such information are regarded as proven exemplary cases. Utilizing these, integration of sequence stratigraphic analysis and seismic interpretation are made to support overview over subsurface geology, and accordingly how distribution of heavy oil in sequences/formations in the Central Sumatra Basin are estimated.

METHODOLOGY

Supporting data used in this study includes several well logs, check-shot data, and 2D seismic data. The 2D seismic data belongs to an array of origins with many vintage types mostly within period of 1969-1997. The check-shot data used to assist the “well to seismic tie” process as well as to seismic data interpretation are taken from 32 wells in the structurally high locations. Seismic data quality is moderate, whereas biostratigraphic and API gravity data are available but in limited quantity. If API gravity data is not available but has relative density (dr) data, then the API gravity value can be

approximated by using the following formula (Meyer, *et al.*, 2007):

$$API = \frac{141.5}{dr} - 131.5,$$

dr is the relative density (specific gravity) with respect to water, measured at 60°F.

The API Gravity data is indeed of the most important data in the early step because this data is used to identify the type of oil in each of the well. In this data rarely, categorization of certainty is therefore applied with all available support from qualitative/quantitative log analysis results and any other sources of information.

Evaluation of subsurface geological in this paper is based on the results of sequence stratigraphic analysis and interpretation of seismic data. Schematically, the complete methodology of this study is presented on Figure 2, even though activities are emphasized in the few main steps. Those activities are substantially described as: 1) Sequence stratigraphic sequence analysis; 2) Well correlation (especially for wells proven /suspected as heavy oil); 3) Seismic interpretation on several key lines, with focus is given to lines passing through wells that are suspected of having the potential to produce heavy oil; and 4) Subsurface geological evaluation.

Stratigraphic sequence analysis starts from wells that have complete information/data. Beside the biostratigraphic data, the selected wells should have well log data (having at least gamma ray, resistivity, sonic, and density logs), check-shot, and API gravity value (if any, this would be better). The quality control (QC) and pre-condition of seismic data, as well as depth structure mapping, are not discussed in this paper. Having 2D seismic data with various vintage years, pre-condition of seismic data (such as mistie analysis and amplitude balancing) is performed.

Sequence stratigraphy analysis was interpreted by using several kinds of data. The main data is biostratigraphy that give the guidance of age, biozones, and support to interpret paleoenvironment. Biostratigraphy data indicates abundance and diversity of micro-fossils, information that is very useful to assist sequence stratigraphic interpretation such as sequence boundary (SB). Another important data is gamma ray (GR) log and lithological data. Based on GR and lithological data reservoirs and porous/permeable beds within the sequence stratigraphic

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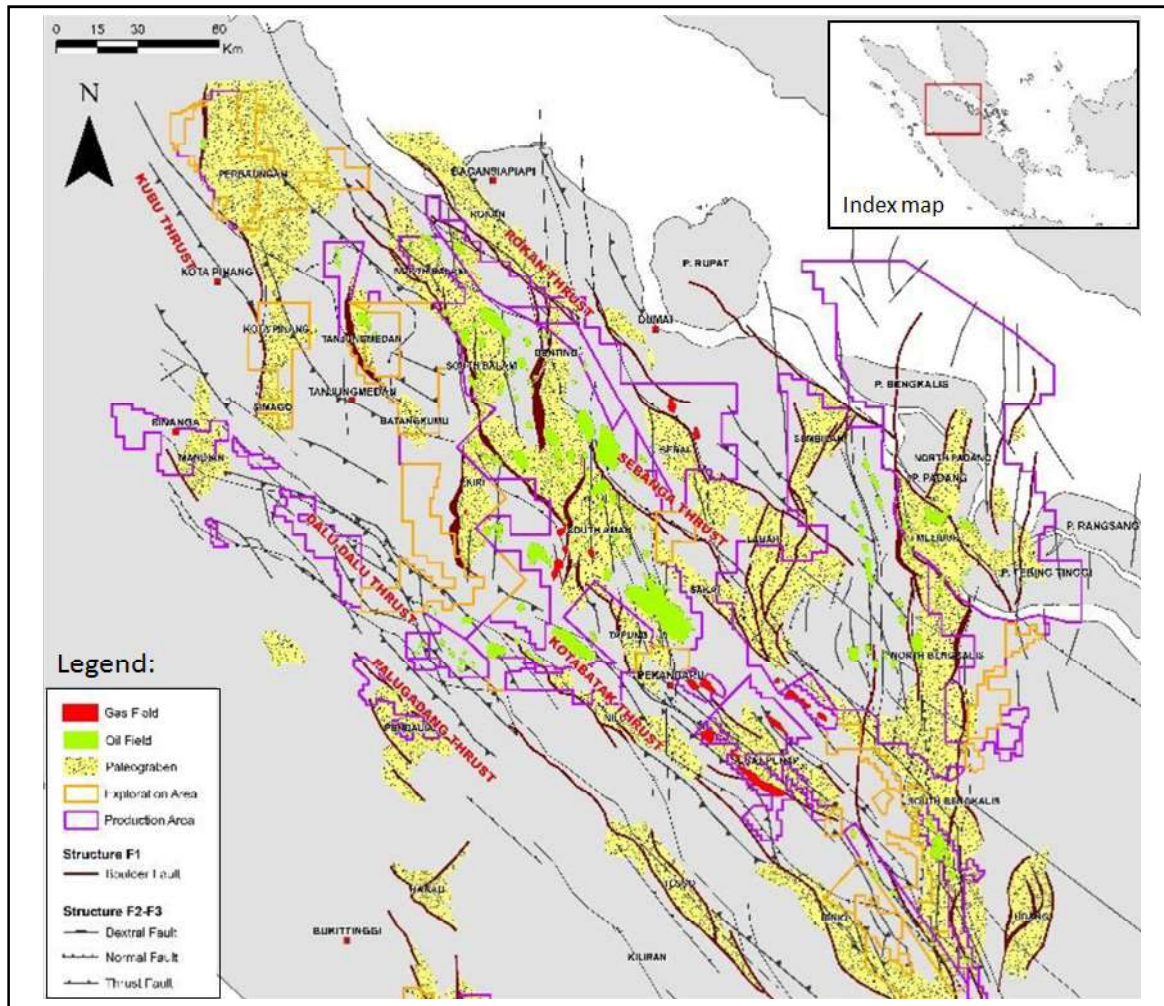


Figure 1
Structure, paleograbens and field distribution map in the Central Sumatra Basin.

framework are identified. Furthermore, GR and lithological data supports in facies interpretation. API gravity data is also needed to confirm and/or to infer over the permeable zones' fluid contents.

After the single-well based sequence stratigraphic interpretation, next step taken is to build well-to-well correlation. Through well correlation state of reservoir lateral continuity is known, and support to seismic interpretation is available. This includes, whenever data permits, seismic tying to wells that have been proven as penetrating heavy oil bearing zone(s). After establishing the well to seismic tie seismic interpretation is performed to identify sequence peaks and boundaries, from which anticlines and faults in each SB. Seismic interpretation is carried out on several regional seismic lines passing through some major thrust faults of Rokan, Dalu-Dalu, Sebang, and Pandalian. These main faults are suspected to be the cause of heavy oil in several surrounding areas/wells.

The last step is the evaluation of the results obtained from the previous step. The evaluation is carried out to explain how condition of the sub-surface geological structure in the area/well is proven containing and suspected to contain heavy oil. This evaluation is indeed the mainstay of seismic interpretation support to the objective to understand heavy oil presence in the CSB, and accordingly help to map the heavy oil distribution in the basin. This will hopefully serve as an example over how seismic interpretation may help in supporting efforts to understand heavy oil potential in other sedimentary basins in Indonesia.

RESULTS AND DISCUSSION

Regional Stratigraphy

Regional stratigraphy of the Central Sumatra Basin is composed by several formations/groups from the old (Paleogene - Pliocene) to the young (quaternary), namely the Basement, Pematang Group, Sihapas Group, Petani Formation, and Minas

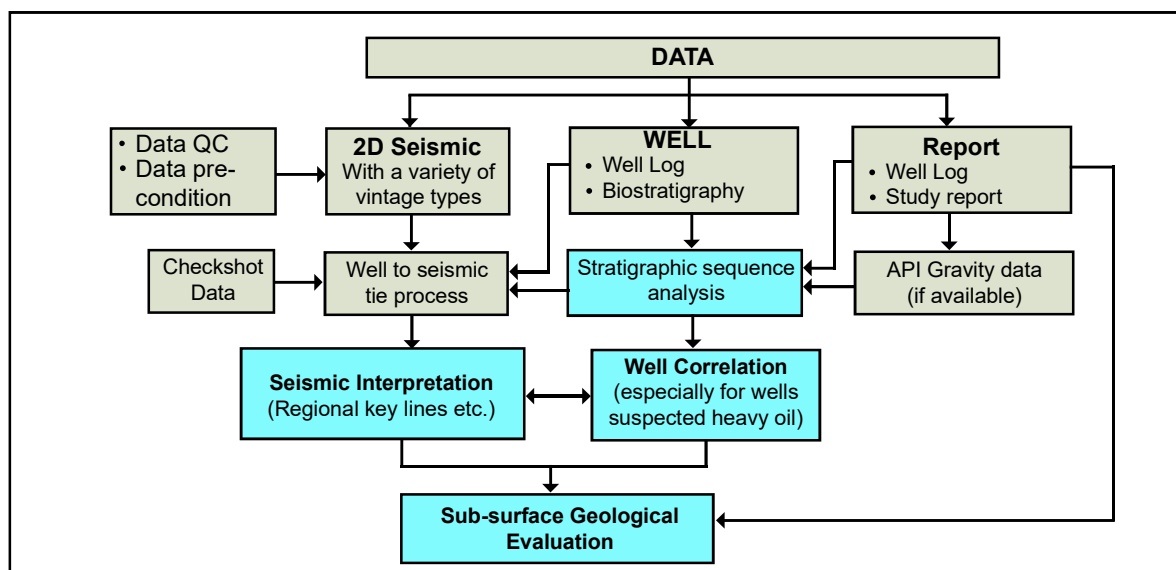


Figure 2
Methodology of the study, but in this paper the discussion only emphasizes a few main steps (light blue colour box).

Formation. Tectonic process is the main factor for deposition in the Central Sumatra Basin, while changes in sea level (eustasy) are only of secondary factor. All unconformities in this basin are likely due to the interaction between tectonic plates and changes in relative movement of these plates, so that the regional stratigraphic configuration of the Central Sumatra Basin is discussed in a tectonostratigraphic framework (Figure 3). In the tectonographic chart, F0 is Late Paleozoic (345 million year ago, ma) to Mesozoic (65ma) for generation of Basement, while F1 is Eocene to Oligocene (50ma-26ma) that generated half graben and graben structures trending north-south, and then was accompanied by Pematang group deposition. The F2 is Early-Middle Miocene (26-13 ma) that occurred in basin transgression and was accompanied by the Sihapas Group deposition, whereas F3 is Middle Miocene to Recent (13-0 ma), occurring under basin regression accompanied by formation of Petani group and Minas Formations.

Stratigraphic Sequence Analysis

Based on the well stratigraphic sequence analysis and previous studies (Lemigas, 2020), it is known that there are eleven sequences ranging from Middle Eocene to Pliocene which are equivalent to the Pematang group to the Minas Formations. Eleven sequence units from old to young are based on the upper boundaries of the sequence (Table 1). Determination of the sequence boundary age refers to the results of regional biostratigraphic studies from Dawson, *et al.* (1997).

- Among the wells utilized in the subsurface geology evaluation, Jng-1 and Sdg-1 wells are wells with complete supporting data for biostratigraphic analysis. Figure 4 and Figure 5 present the sequence stratigraphic analysis and summary of sequence boundary for JNG-1 well, respectively, whereas Figure 6 depicts interpretation of stratigraphic sequence for SDG-1 well (Lemigas, 2020). Sequence boundaries (SB) was identified based on Sdg-1 and Jng-1 wells. From older to younger there have been identified five (5) important SBs which are interpreted as containing heavy oil:
- SB 25.5 ma is the top of Sequence 3 equivalent to Upper Red Bed Formation, Late Oligocene. Sequence 3 is dominated by fluvial facies such as braided and meandering facies.
- SB 22.0 ma is the top of Sequence 4 equivalent to Menggala Formation, Early Miocene. Sequence 4 is dominated by fluvio deltaic and transition facies such as delta tidal facies.
- SB 21.0 ma is the top of Sequence 5 equivalent to Bekasap Formation, Early Miocene. Sequence 5 is dominated by shallow marine facies such as tidal sand bar and shore line facies.
- SB 17.5 ma is the top of Sequence 6 equivalent to Bangko Formation, Early Miocene. Sequence 6 or Bangko is the deeper facies of Bekasap Formation. Bangko Formation is dominated by deep marine sediment such as shale and sand brake.

Subsurface Geological Evaluation of the Central Sumatra Basin in Relation to the Presence of Heavy Oil (Julikah, *et al.*)

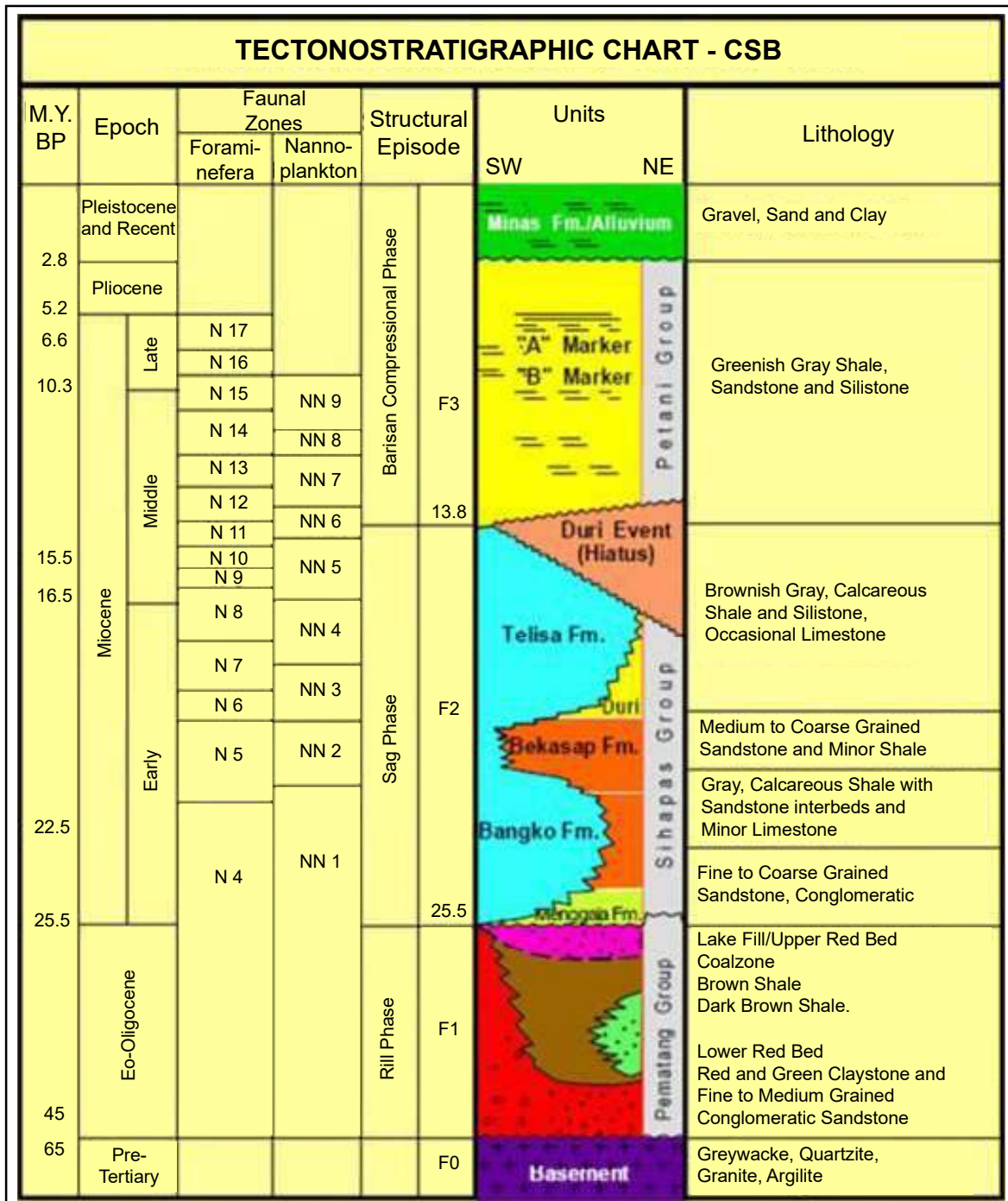


Figure 3
Tectonostratigraphic chart of Central Sumatra Basin (Heidrick & Aulia, 1993).

SB 15.5 ma is the top of Sequence 7 equivalent to Telina Formation, Early Miocene. Sequence 7 is dominated by thin sand intercalated with shale.

The two wells are used as references in seismic interpretation, in which the JNG-1 well is used as reference for the South Aman area and SDG-1 well for the North Aman area. Figure 7

shows locations of the two wells in the Central Sumatra Basin.

Based on information from well reports and Lemigas (2020), it has been confirmed that parts of the Sebang, Kulin, Rantau Bais, Batang, and Duri fields contain heavy oil with API gravity value of less than 25°. There are also several wells around the Rokan thrust fault that are thought to have heavy

oil potential, such as the AK-1 well. Figure 8 is the geochemical analysis and API gravity values from one of the samples in the Duri and Rantau Bais (Lemigas, 2020). Meanwhile, according to well reports in several wells in the Kulin and Batang fields as well as in the AK well have API gravity values ranging from 17-22°.

Furthermore, correlation of the sequences was established using wells from fields/wells that are proven/suspected to containing heavy oil, such as Sebang North, AK, Dalu-Dalu, PS, PL, and LC fields/wells (Figure 9). Potential of heavy oil appear to occur in the sequence levels of Sequence 1 to Sequence 7.

Using the well correlation data, stratigraphic sequence analysis has been interpreted as having the following sequences:

- Sequence-1 (equivalent to Pematang Fm. - Lower Redbed member) corresponds to graben that developed during the initial syn-rift phase. This Sequence-1 consists of fluvial, marginal lacustrine and distal lacustrine. ;
- Sequence-2 (equivalent to Pematang Fm. - Brown shale member) is the main source rock in the Central Sumatra Basin, and is known as the Brown shale. The Brown shale was deposited on distal lacustrine which was anoxic and low sedimentation rate and little clastic input;
- Sequence-3 (equivalent to Pematang Fm. - Upper Redbed member) was the final deposit in the syn-rift phase. The Sequence-3 facies consist of fluvial, lacustrine marginal, and lacustrine distal. The Sequence-3 consists of conglomeratic sandstones and red claystones was deposited in braided and meandering river

environments and floodplains which are the main targets of the reservoir;

- Sequence-4 (equivalent to Menggala Fm.) was deposited at the beginning of the post-rift phase. The microfossil markers were the initial appearance of the planktonic foraminifera *primordious Globigerinoides* (base N4) and the initial appearance of limestone nannoplankton *Helicosphaera kampt-neri* (base NN1). Whereas the final appearance of the planktonic foraminifera *Globorotalia kugleri* (top N4) which was equivalent to the initial appearance of the nannoplankton *ampliaperta Helicosphaera* (top NN1), the upper boundary of the planktonic foraminifera (zone N4) or the limestone nannoplankton (zone NN). The sequence-4 facies consist of five (5) facies consisting of fluvial, upper deltaic, lower deltaic, tidal shelf, and open marine;

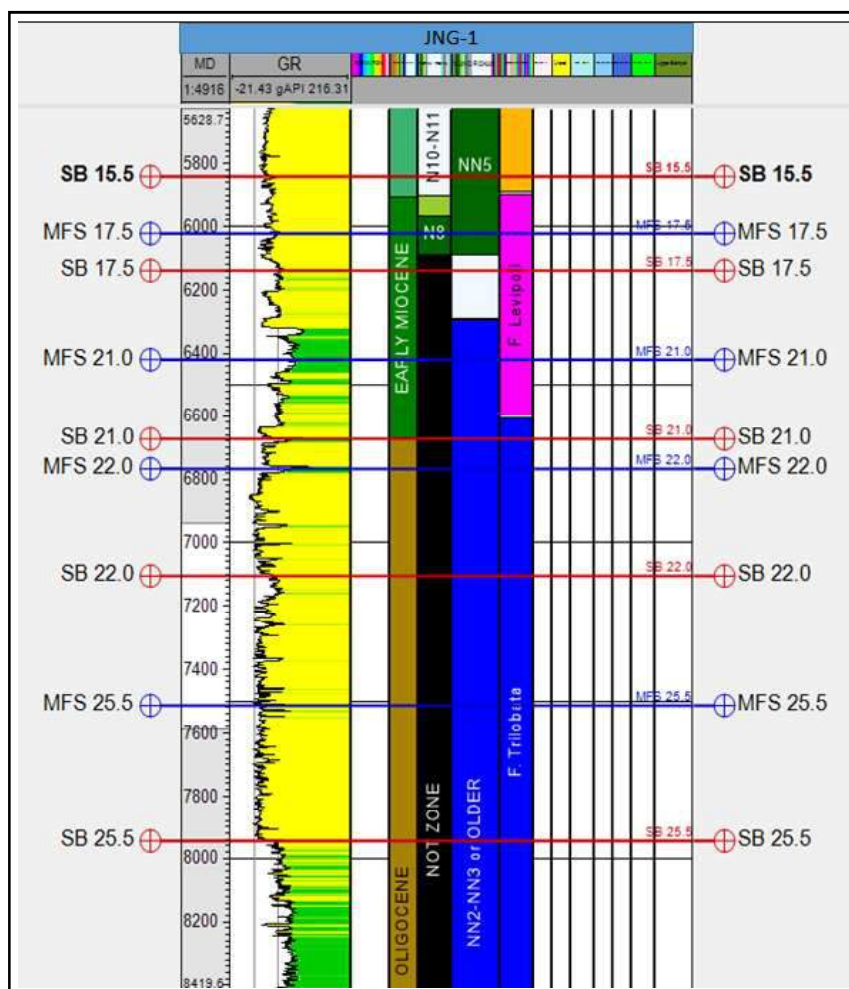


Figure 4
Stratigraphic sequence analysis at JNG-1 well, this well is used as a reference for other wells, especially in the South Aman area (source: Lemigas, 2020).

Subsurface Geological Evaluation of the Central
Sumatra Basin in Relation to the Presence of Heavy Oil (Julikah, *et al.*)

Table 1
Description of stratigraphic sequence boundaries in the Central Sumatra Basin

Sequence	Well tops	Remarks
1	Basement	Top of Pre-Tertiary Formation
	Event 38 ma	Eq. Lower Red Bed Formation (Pematang Group). Middle Eocene
2	Event 30 ma	Eq. Brown Shale Formation (Pematang Group). Early Oligocene
3	SB 25.5 ma	Eq. Upper Red Bed (Pematang Formation). Late Oligocene
4	SB 22.0 ma	Eq. Menggala Formation (Sihapas Group). Early Miocene / NN1 Zone
5	SB 21.0 ma	Eq. Bekasap Formation (Sihapas Group). Early Miocene / NN1-NN2 or N4-N5 Zone
6	SB 17.5 ma	Eq. Bangko Formation (Sihapas Group). Early Miocene / NN2-NN3 or N5-N6 Zone
7	SB 15.0 ma	Eq. Duri-Telisa Formation (Sihapas Group). Early to Middle Miocene / NN4- NN5 Zone or N7-N9 Zone
8	SB 10.5 ma	Eq. Petani Formation. Middle Miocene / NN6-NN9 or N10-N15 Zone
9	SB 5.5 ma	Eq. Petani Formation. Late Miocene / NN10-NN11 or N16-N17 Zone
10	SB 1.8 ma	Eq. Minas Formation. Pliocene / NN12-NN18 or N18-N21 Zone
11	SB 0 ma	Eq. Minas Formation. Pliocene-Recent / NN19-NN21 or N22-N25 Zone

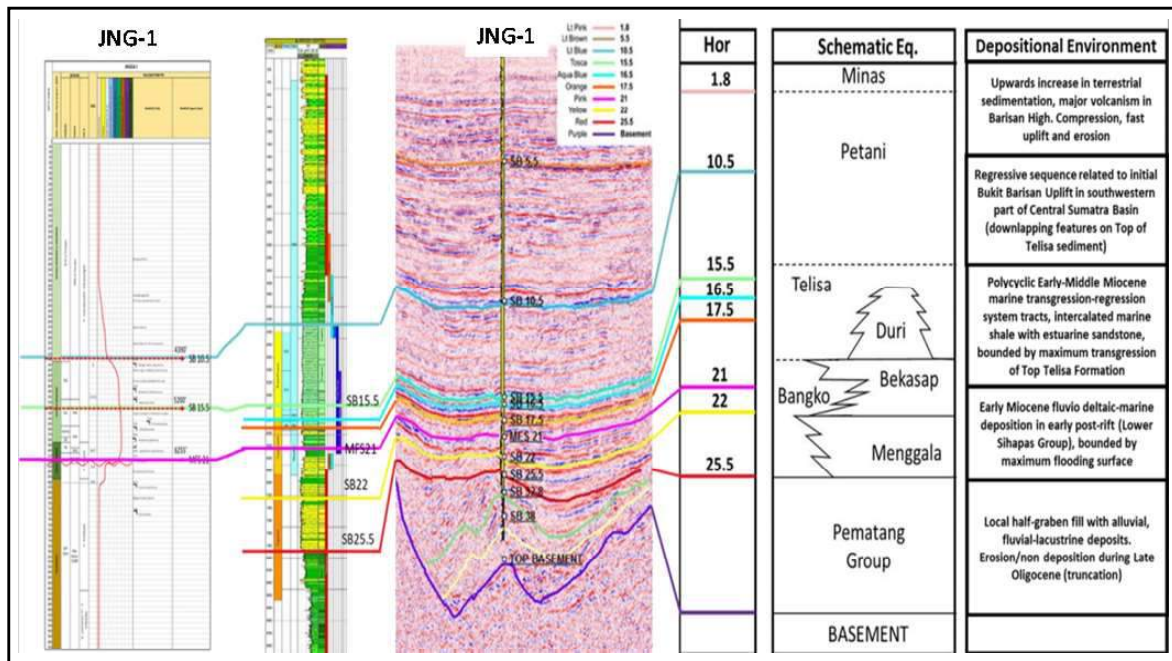


Figure 5
Summary of sequence boundaries at JNG-1 well (Lemigas, 2020). This well is one of the reference wells in seismic interpretation because it has complete data availability.

- Sequence-5 (equivalent to Bekasap Fm.) was deposited in the post-rift transgressive phase. The microfossil marker as the upper limit of Sequence-5 was the final appearance of the planktonic foraminifera *Globigerina noides ciperensis* (top N5) and the final appearance of limestone nannoplankton *triquetrorhabdulus carinatus* (top NN2). Meanwhile, the microfossil

marker of the lower limit of Sequence-5 was the final appearance of the planktonic foraminifera *Globorotalia kugleri* (top N4) which was equivalent to the initial appearance of the nannoplankton *ampliaperta Heli-cosphaera* (top NN1). This Sequence-5 consists of five facies, including: fluvial, upper deltaic, lower deltaic, tidal shelf, and open marine;

- Sequence-6 (equivalent to Bangko Fm.) was deposited in transgression conditions so that the bathymetry in the central area of the Central Sumatra Basin reaches the outer neritic to the upper bathyal (100-200m of water depth). The planktonic foraminifera marker as boundary of Top zone N6 was the final appearance of *Globorotalia unicava* supported by the final appearance of *Globigerinoides ciproensis*. While the marker of the top zone of limestone NN3 nannoplankton was *Sphenolithus belemnus* and supported by the top zone of NN2 limestone nannoplankton in the form of *Triquetrorhabdulus carinatus*. The Sequence-6 consists of six facies: fluvial, upper deltaic, lower deltaic, tidal shelf, off-shore bar, and open marine; and
- Sediment of Sequence-7 (equivalent to Duri and Telisa

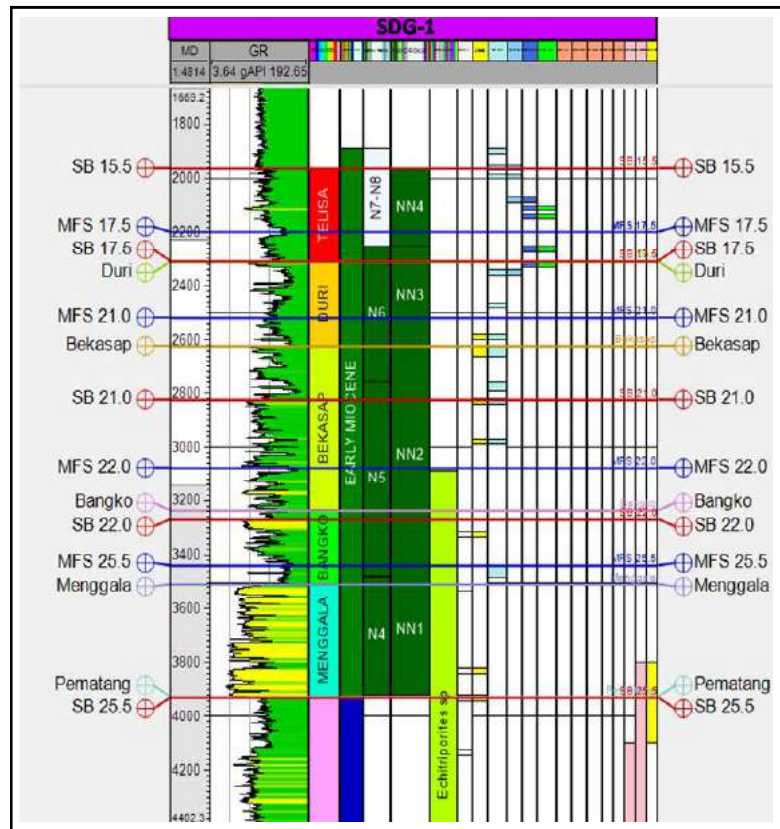


Figure 6 Interpretation of the stratigraphic sequence for SDG-1 well (source: Lemigas, 2020). This well is used as a reference for other wells, especially in the North Aman area.

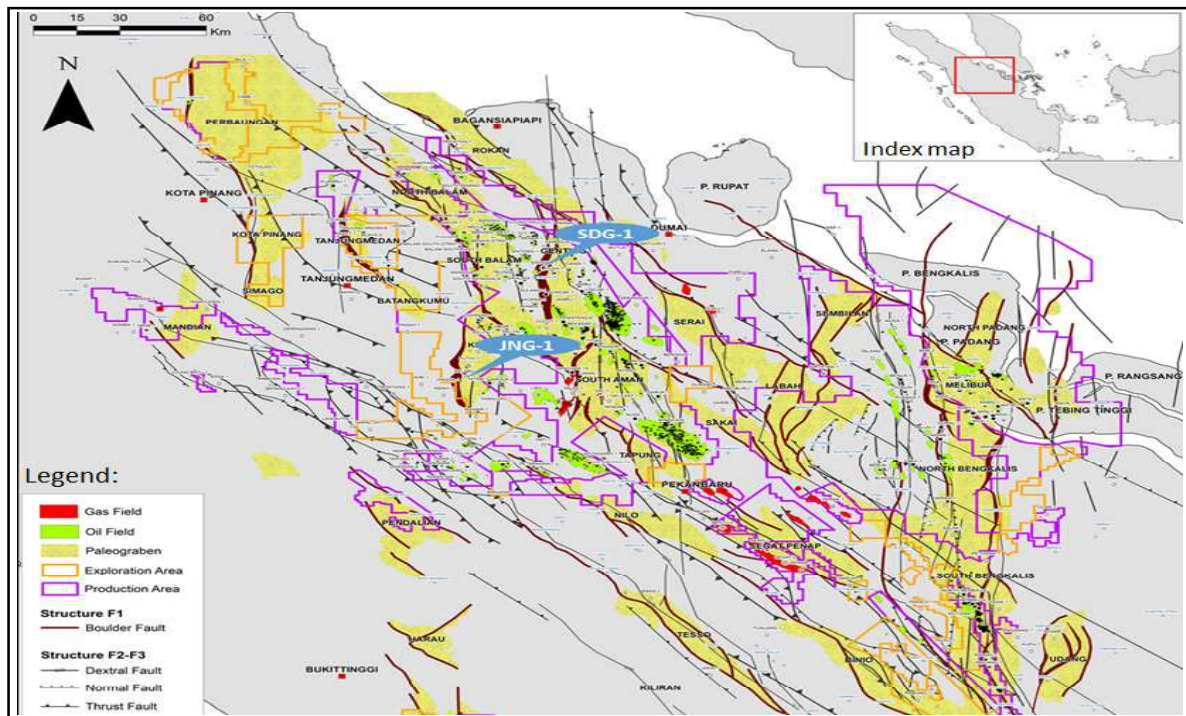


Figure 7 Locations of the two wells (JNG-1 and SDG-1 wells) in the Central Sumatra Basin, the JNG-1 well is used as reference for the South Aman area and SDG-1 well for the North Aman area.

Subsurface Geological Evaluation of the Central Sumatra Basin in Relation to the Presence of Heavy Oil (Julikah, *et al.*)

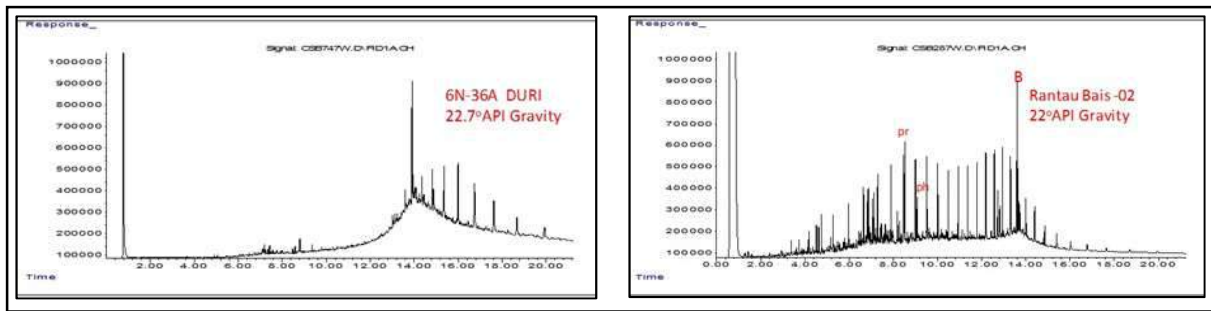


Figure 8
Gas chromatography (GC) test chromatograms of crude oil samples in Duri (a) and Rantau Bais (b) Central Sumatra basin, which have undergone biodegradation.

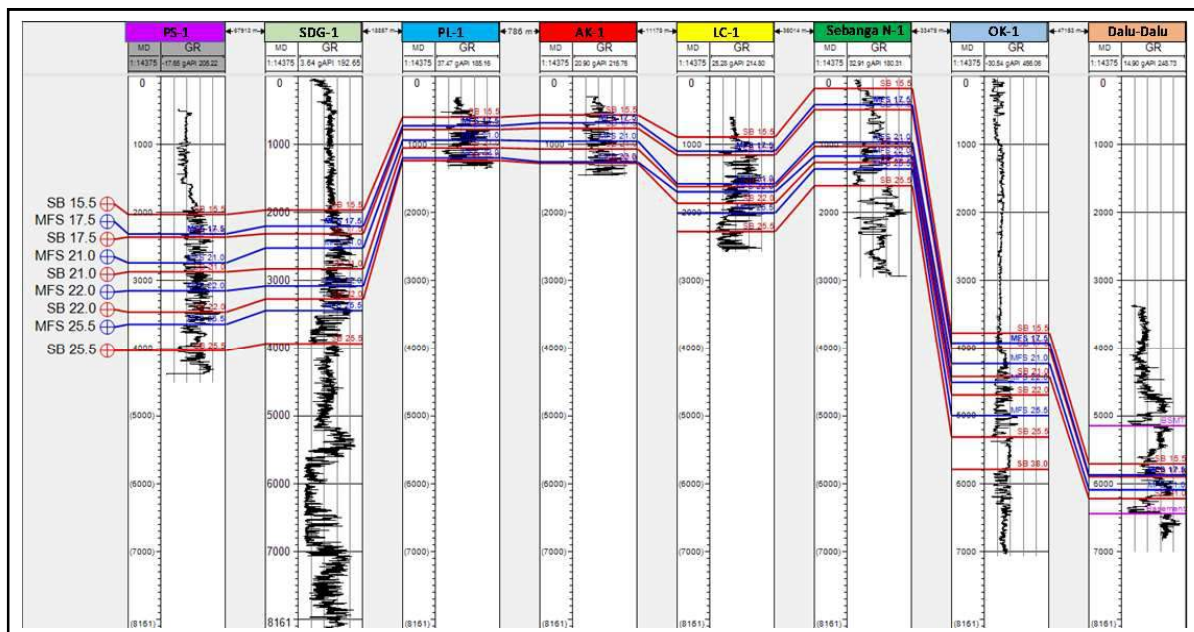


Figure 9
Well correlation by using wells that has been proved as containing heavy oil (AK, Sebang and Dalu-dalu wells) and wells that are suspected to contain heavy oil (PS-1, PL-1, LC-1 and OK-1 wells), (source: Lemigas, 2020).

Formations) consists of fluvial, upper deltaic, lower deltaic, tidal shelf, offshore bar and open marine. The Sequence-7 has the characteristics of fine to moderate sandstones, shale, and slightly limestone and are radiant with finer grained sedimentary rocks as the bathymetry changes deeper toward the west of the basin. The facies of sandstones from this age interval appear as highstand prograding deltas were generally lenticular and discontinuous, so that sandstones can be mapped only within a limited area.

C. Petroleum system

Petroleum system in the Central Sumatra Basin is presented on Figure 10, all supporting elements of

the petroleum system are proven to work well. The Pematang/Kelesa Formation is the main source rock that has been proven as a producing large amounts of oil and gas and fill the existing reservoir/traps rocks in the basin. The main reservoir rocks are post rift sedimentary rocks from the Sihapas group. The Sihapas Group (equivalent to Sequence 4 - 7) consists of five rock formations, namely the Menggala, Bangko, Bekasap, Duri, and Telisa Formations. The shale that is rich in foraminifera from the Telisa Formation acts as the best cap rock for trapping hydrocarbon in the reservoir. Paleosols formed after Upper Red Bed deposition due to regression and subaerial erosion may also serves as cap rocks (e.g Yarmanto, *et al.*, 1995).

Heavy oil in the Central Sumatra Basin

As a matter of fact, heavy oil of some fields/wells in the Central Sumatra Basin is associated with the existence of thrust faults, especially the main thrust faults of Sebang, Rokan, Dalu-dalu, Pulau Gadang, Petapahan, and Kotabatak (see Figure 1). The main thrust faults have caused the existing structure to lift up. This lifting process occurred in the tectonic phase of compression took place in the Plio-Pleistocene with compression trend in west - east direction. Provided condition permits, the uplifted reservoir structures contain oil (i.e originally light/medium weight oil) might undergo further processes of biodegradation and water washing which transform the trapped oil into becoming heavy oil. Theoretically biodegradation (microorganisms-led) and water washing (hydrodynamism-led) processes occurred at shallow depths and under temperatures of lower than 80°C (Santos, *et al.*, 2014). Shallow depths may easily be associated with encroaching surface water into the reservoirs through existing faults and any other fluid conduits, which encourage the two mechanisms to take place. These shallow depths are usually shallower than 1,000 feet (300-400 meters) depending on the distribution of geothermal gradient in the region. Referring to these shallow depths, more evidence of heavy oil presence in several wells in the basin is obtained, such as in Genting and Akar structures around the Rokan thrust fault; and

Langgak, Kumis, Pendalian, Wilis, and Dalu-dalu around the Dalu-dalu thrust fault.

Seismic Interpretation and Heavy Oil Occurrences

Seismic interpretation has been initiated from reference wells (mainly the JNG-1 and SDG-1 wells), utilizing sequence boundary markers generated by sequence stratigraphic analysis. Based on the analysis results, there are eleven (11) sequence boundaries (SB), see Table 1.

Figure 11 presents some of the regional key lines that pass through several of the main thrust faults. These lines pass through several wells that have been seismically synthetic (such as JNG-1, TRT-1, DK-1, EL-1, BRG-1, Kotagaro-1, GR-1, AH-1 and TL-1) and also through fields/wells proven as heavy oil containing (Sebang, area around Kulin, and Kotabatak). According to available information, Kotabatak and Kotagaro reservoirs have been proven as containing tar/oil sands.

Furthermore, Section B-B' on Figure 12a crosses the main fault structures of Dalu-Dalu fault complex, Aman graben, and Sebang High. In the cross section it can be seen that several anticline structures have been lifted closer to the surface, which tectonic evolution occurs during the basin's compression episode (deformation phase F3) hence triggering heavy oil transformation. From the composited

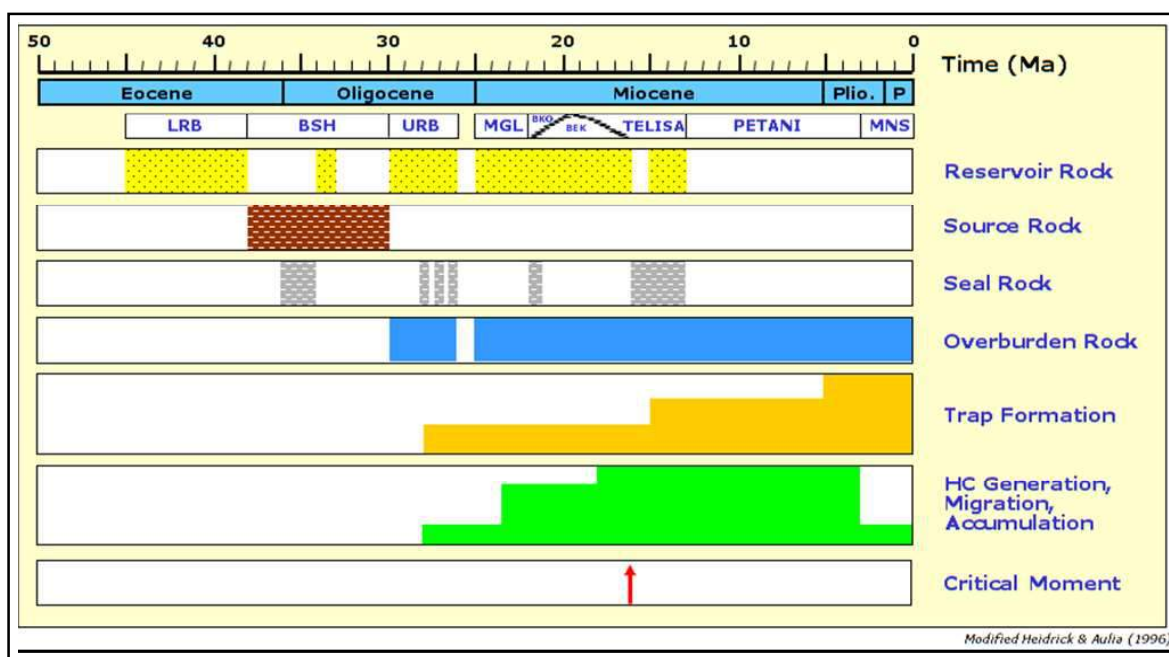


Figure 10
Petroleum system in the Central Sumatra Basin (modified from Heidrick & Aulia, 1996).
Several elements supporting the petroleum system have proven to work very well.

Subsurface Geological Evaluation of the Central Sumatra Basin in Relation to the Presence of Heavy Oil (Julikah, *et al.*)

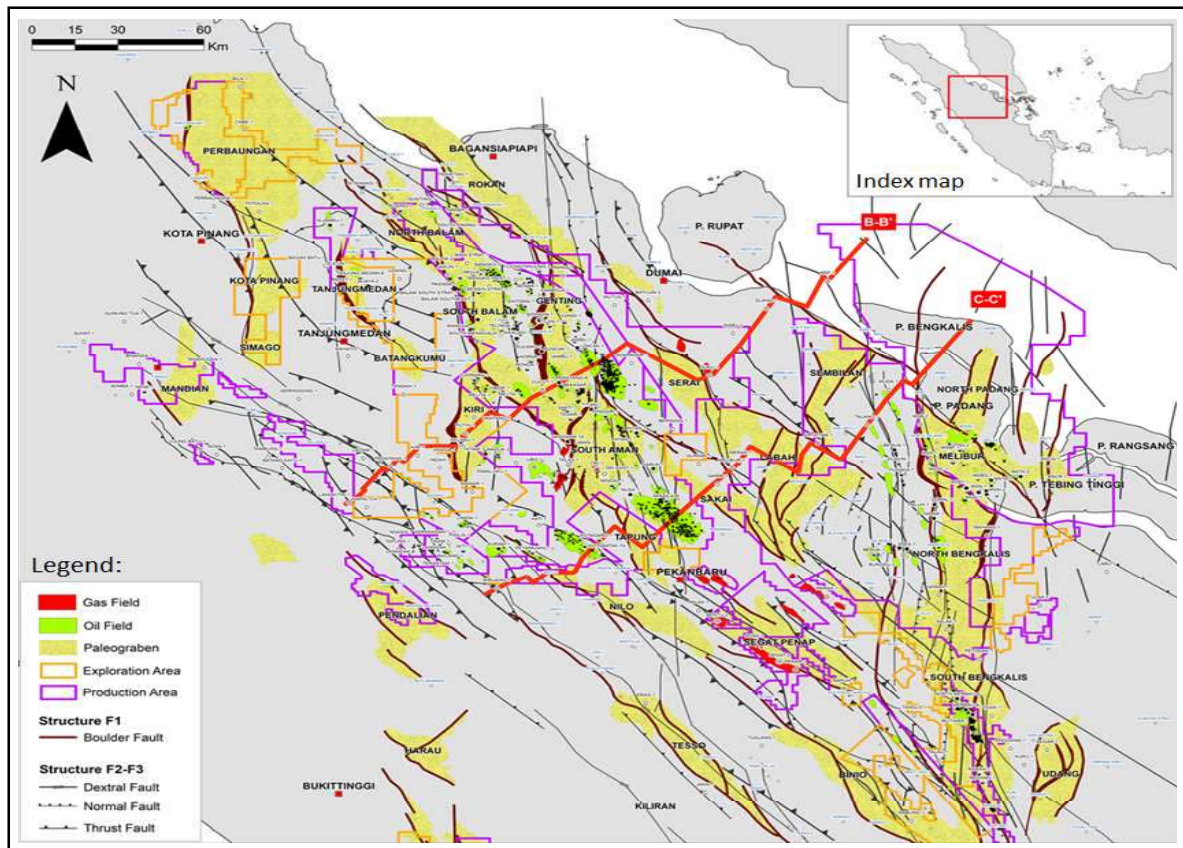


Figure 11
Regional key lines (B-B' and C-C') passing through several main thrust faults in Central Sumatra Basin. The ensuing cross-sections clearly show uplifted structures containing or estimated to contain heavy oil (source: Lemigas, 2020).

seismic section B-B', there are several anticline structures that have been proven to produce heavy oil, namely the Kulin and Sebang structure. Another anticline structure such as LKT is also thought to have the potential of heavy oil, even though this well does not have API gravity data to support this assumption. The assumption has instead been based on similarity to geological model of the Sebang structure.

The other cross-section is the Section C-C' that crosses the Kotabatak thrust fault, Minas structure, and continues further to Bengkalis Island (Figure 12b). In this section, there is no data to support presence of heavy oil except for the Kotabatak structure. According to the available information there is a potential for tar sand in the Kotabatak and Kotagaro structures. When compared to the section B-B', the fault structure in the section C-C' is not too complex, and there is no large fault in the Minas structure. Therefore, all existing oil reservoirs are relatively spared from surface water encroachments

leading to no factors that can cause generation of heavy oil.

One of the wells in the Sebang field containing heavy oil is Sebang-North-1 well (adjacent to the Sebang-6 well). Figure 13 shows the presence of heavy oil in the Sebang-6 well logs, where from the sequence stratigraphic analysis results can be seen that the presence of heavy oil occurs in sequence 4. While the figure below is a subsurface image where sequence 4 (eq. Menggala Fm.) is purple.

Figure 12 - Regional key lines (B-B' and C-C'), of which B-B' seismic cross section (a) passes through several anticline structures containing heavy oil such as in Kulin and Sebang, and C-C' seismic cross section (b) that passes through Minas anticline structure that does not contain heavy oil (source: Lemigas, 2020).

Beside the regional section, there is a local seismic section with a northwest-southeast direction, which passes through the Dalu-Dalu thrust fault (Figure 14). Some shallow anticline

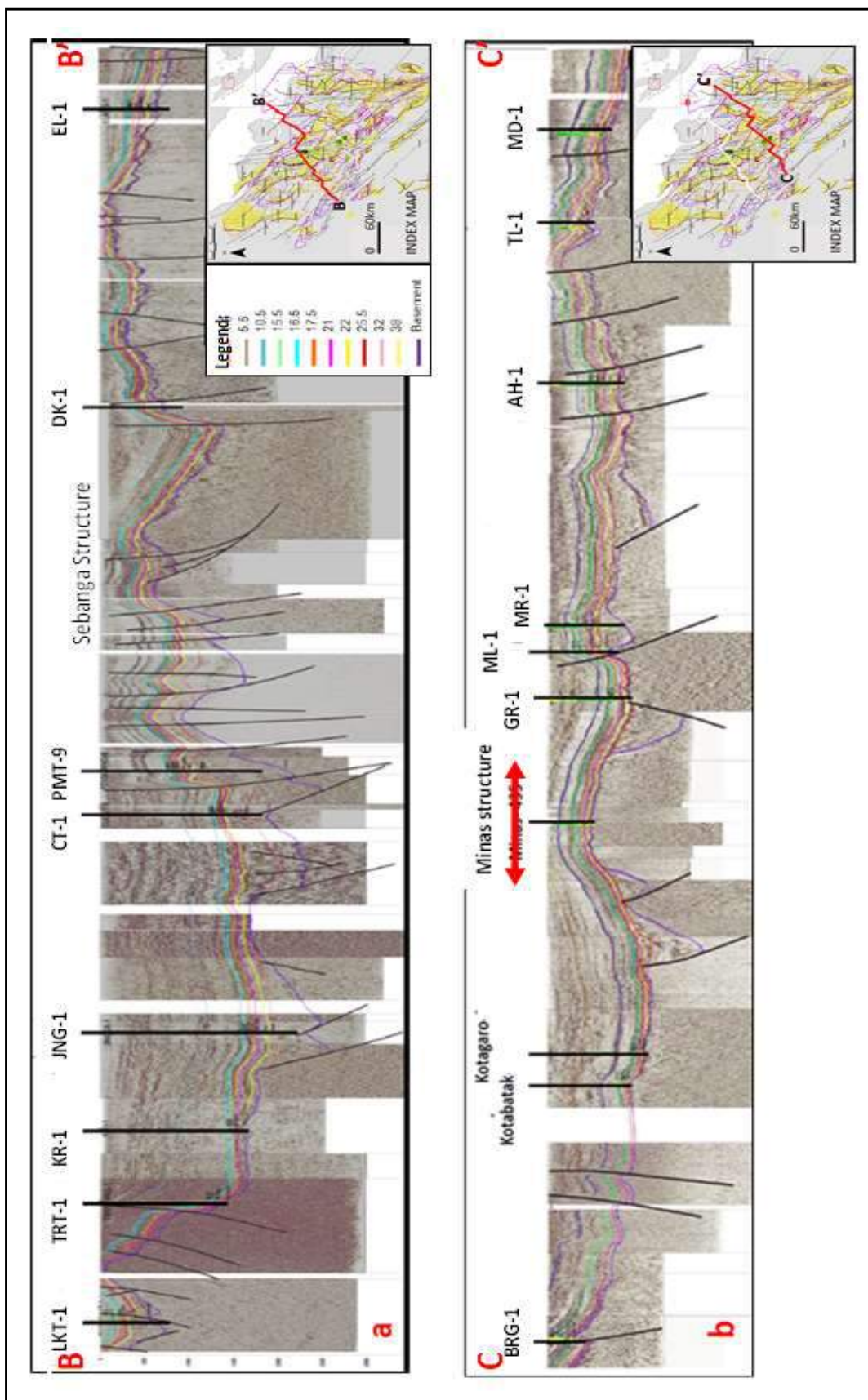


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Subsurface Geological Evaluation of the Central Sumatra Basin in Relation to the Presence of Heavy Oil (Julikah, *et al.*)

structures, as well as the complex faults can be seen in this section. The anticline structure in the Wilis well is proven containing heavy oil/tar sand (depth of within 360m-405m), while the other structures around the LKT-1, NP-1, KPN-1 wells are still at the suspected levels containing heavy oil. Based on well reports/well logs, there is tar-sands in depth of 360-405m and for the suspected levels in the LKT-1, NP-1, KPN-1 wells are respectively in depths of 397-517m, 155-475m, and 505-556m.

Other examples of the suspected structures containing heavy oil are several structures in the AK-1 well (Figure 15) and PDL-1 (Figure 16). The two structures pass through the Rokan thrust fault and the Dalu-Dalu thrust fault, respectively. The anticline structure in the AK-1 wells was uplifted due to the Rokan thrust fault.

Based on data from the AK-1 well, it can be seen that indications of heavy oil are found in Sequence-5 to Sequence -7 which is equivalent to the Early Miocene to Middle Miocene ages. These structure was uplifted to a depth of less than 600 meters. This is also true for the Pentalian anticline structure in the western part of the CSB whis had been uplifted significantly by the Pulau Gadang thrust fault. Information from PDL-1 well confirms presence of heavy oil traps in the uplifted structure. Another example is the anticline structure is the LC-1 well. The structure at the LC-1 well was uplifted by the Rokan thrust fault. Interpretation of heavy oil presence is in the Sequence-5 (Equivalent to the Bekasap Fm. and in Sequence-6 (Equivalent to the Duri Fm.). Both sequences are of Early Miocene (Figure 17).

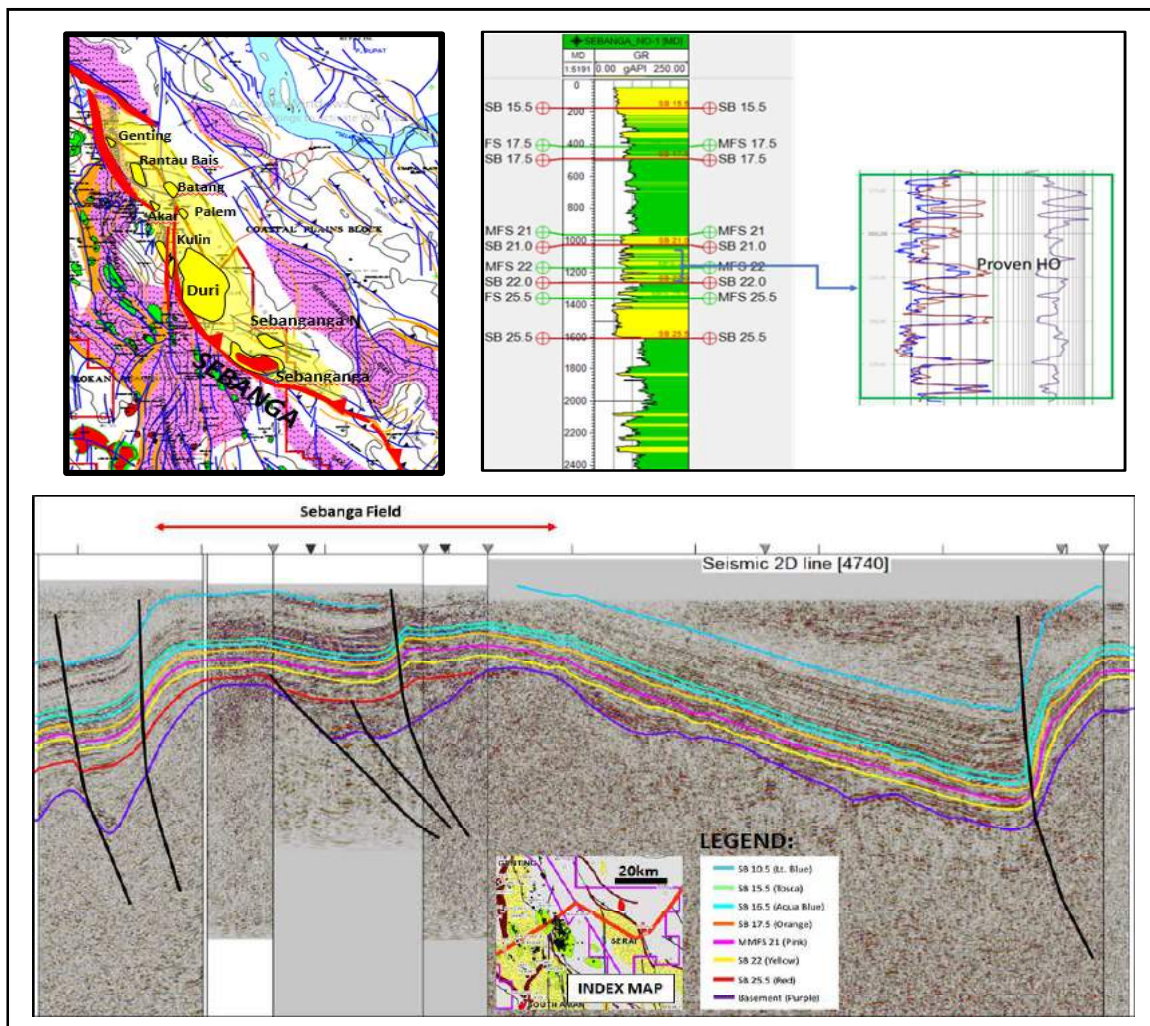


Figure 13
Division of stratigraphic sequence units at the Sebang North-1 well (above) and an indication of the presence of heavy oil in Sequence 4 (Equivalent to the Menggala Formation), Early Miocene (below), (source: Lemigas, 2020).

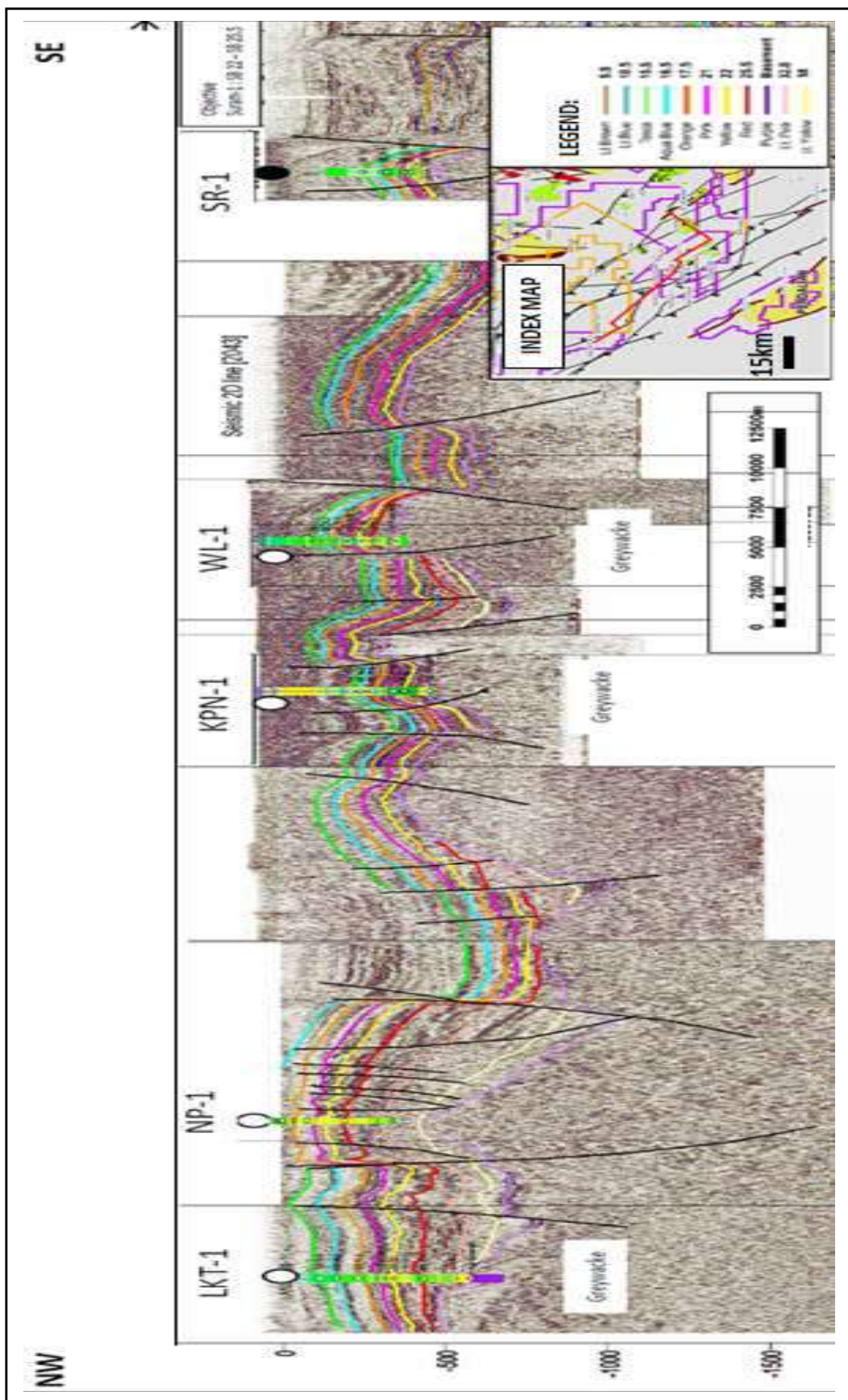


Figure 14 Key seismic line around Dalu-Dalu thrust fault; the fault has uplifted the anticline structure in this area. Beside the main fault, there are many other faults that may serve as a supporting factor for biodegradation and water washing process through surface water encroachment into the uplifted reservoir(s), (source: Lemigas, 2020).

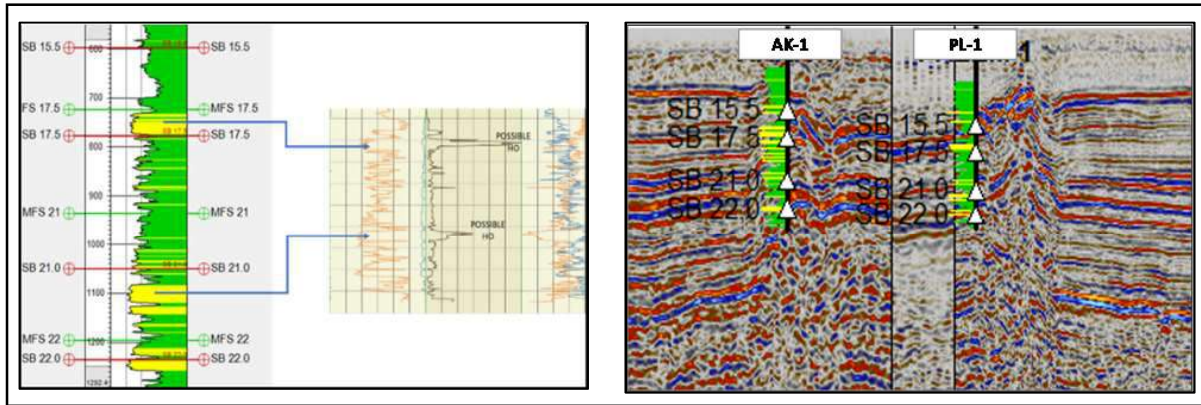


Figure 15

Indication of heavy oil at AK-1 and PL-1 well in Sequence-5 to Sequence-7, the equivalent of the Bekasap-Bangko-Duri Telisa Formation, Early Miocene to Middle Miocene age (source: Lemigas, 2020).

From several examples of seismic sections passing through the proven and suspected heavy oil fields wells, it can be clearly seen of how differently subsurface geological conditions are. Although almost all fields/wells are always associated with existence of major thrust faults (i.e. Rokan, Sebang, DaluDal, Petapahan and Pentalian), there are differences in the lifting strength/level of each anticline structure. In case of fields/wells that have been proven containing heavy oil (such as the Sebang field, PDL-1, WL-1, and AK) the anticline structures are significantly uplifted, this is marked by all Top sequences approaching the surface (Basement of up to 500-750ms) while in fields/wells that are merely suspected to contain heavy oil (e.g. LKT-1, NP-1, KPN-1, and LC-1 wells) structural lifting is marked with lower Basement level of around 750-1000 m and lower .

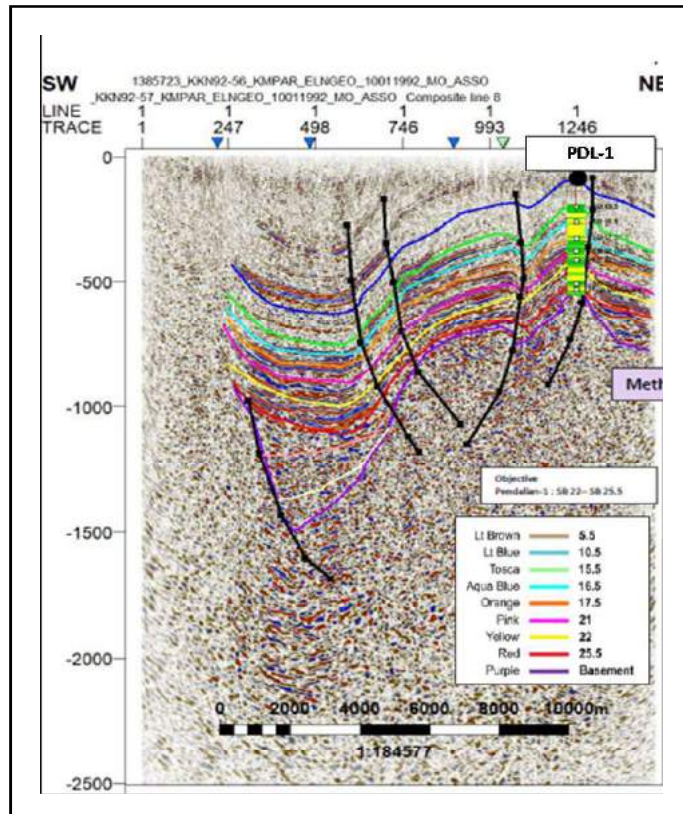


Figure 16

Anticline structure at PDL-1 well location. The uplifted oil reservoir is confirmed containing heavy oil (Lemigas, 2020).

CONCLUSIONS

Strong tectonic events of deformation phases of F3 at Late Miocene - Recent period had uplifted the Central Sumatra Basin and created the major thrust faults of Rokan, Dalu-Dalu, Sebang, Kotabatak, Petapahan, and Pentalian. These faults are important to generate the heavy oil. The surface water encroached penetrated into oil traps triggering heavy oil transformation mechanisms of biodegradation and water

washing. Therefore the presence of heavy oil is almost always associated with the large thrust faults and other associated micro faults surrounding them.

Based on integration between study stratigraphic sequence analysis and seismic interpretation, supported by API gravity data (if any) and well log data (especially resistivity logs), structural anticlines that had been uplifted by thrust faults can be evaluated

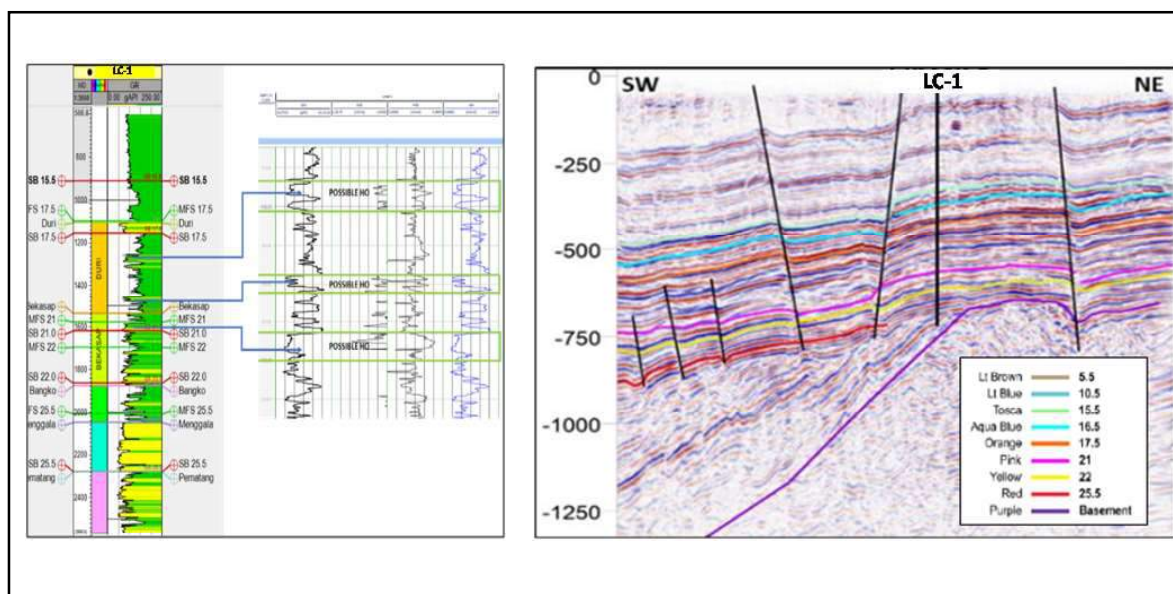


Figure 17
Structure in LC-1 well with suspected heavy oil presence (left),
uplifted due to the Rokan thrust fault (source: Lemigas, 2020).
Interpretation of the suspected heavy oil presence is in sequences 5 and 6 (right).

for their corresponding heavy oil contents. This is strongly related to the oil bearing reservoir depths, of which shallower reservoirs are related to certain heavy oil contents whereas deeper depths show less certain heavy oil contents.

Evaluation on subsurface geology has shown that anticline structures containing heavy oil (such as in the Sebang field and in the WL-1, AK-1, PDL-1 wells) tend to be characterized by near surface uplift (Basement high, up to 500 – 750 ms), whereas structures with lesser certainty in heavy oil contents (such as in the LKT-1, NP-1, KPN-1, and LC-1 wells) tend show lower degrees of uplift marked by 1000 ms sequence or lower. In general, seismic interpretation has shown that heavy oil is accumulated in sequences 4 to 7 (equivalent to Menggala, Bekasap, Bangko, and Duri-Telisa formations).

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GLOSSARY OF TERMS

Symbol	Definition	Unit
API	American Petroleum Institute for Oil Gravity	degree (°API)
SB	Sequence Boundary, the defining surface in sequence stratigraphy	

REFERENCES

- Dawson, W., Yarmanto, U., Sukanta, D. K. & Sangree, J., 1997. *Regional Sequence Stratigraphic Correlation Central Sumatra Basin, Indonesia*. Jakarta, Indonesian Petroleum Association.
- Heidrick, T.L. & Aulia, K., 1996. *Structural Geology of the Central Sumatra Basin, Indonesia*, CPI Intern Report.
- Heidrick, T. L. & Aulia, K., 1993. *A Structural and Tectonic Model of the Coastal Plains Block, Central Sumatra Basin Indonesia*, Indonesian Petroleum Association.
- LEMIGAS, 2020. *Kajian Potensi Minyak Berat (Oil Sands) dan Bitumen di Cekungan Sumatera Tengah*, Jakarta: PPPTMGB “LEMIGAS”, R&D Agency .
- McKinsey & Company, 2020. *Energy Insights*. [Online] Available at: <https://www.mckinseyenergyinsights.com> [Accessed December 2020].

Subsurface Geological Evaluation of the Central
Sumatra Basin in Relation to the Presence of Heavy Oil (Julikah, *et al.*)

- Meyer, R., Attanasi, E. & Freeman, P.**, 2007. *Heavy Oil And Natural Bitumen Resources In Geological Basins Of The World*, Reston, Virginia: U.S. Geological Survey.
- Paszkiwicz, L.**, 2012. *Extra Heavy Oils In the world Energy Supply*, Canada: CSR Field Trip.
- Santos, R. G., Loh, W., Bannwart, A. C. & Trevisan, O. V.**, 2014. An Overview of Heavy Oil Properties and Its Recovery and Transportation Methods. *Brazilian Journal of Chemical Engineering*, 31(3), pp. 571 - 590.
- Yarmanto, Heidrick, T. L., Indrawardana & Strong, B. L.**, 1995. *Tertiary Tectonostratigraphic Development of the Balam Depocenter, Central Sumatera Basin, Indonesia*, Indonesian Petroleum Association.