International Journal of GEOMATE, Nov., 2018 Vol.15, Issue 51, pp.201-208
Geotec., Const. Mat. & Env., DOI: https://doi.org/10.21660/2018.51.23451
ISSN: 2186-2982 (Print), 2186-2990 (Online), Japan

RESERVOIR COMPARTMENT ASSESSMENT: A CASE STUDY OF BANGKO AND BEKASAP FORMATION, CENTRAL SUMATRA BASIN INDONESIA

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ABSTRACT: The reservoir compartment assessment for a case study of the Agur field, Central Sumatra Basin has been successfully carried out by using fault seal analysis (FSA). The objective of this paper is to asses subsurface fault properties in term of the fault sealing that was defining the hydrocarbon reservoir compartment. In this work, the FSA was performed by integrating juxtaposition, shale gouge ratio (SGR) and transmissibility analysis over fault plane that was identified within reservoir layers on the Bangko and Bekasap formation. The juxtaposition seal is intended to assess how the reservoir layer is juxtaposed across the fault plane over either reservoir or non-reservoir layer. The SGR analysis is applied to estimate the shale content in the fault plane, which is caused by the fault movement of sequence stratigraphy. The last analysis of transmissibility is carried out to calculate the capacity of a reservoir to drain the hydrocarbon through a fault plane. Faults architecture (throw, heave, and orientation) and the reservoir layer target were identified based on 3D seismic and well log data interpretation. The FSA is applied to nine faults that formed nine reservoir compartments within three reservoir layers, which are obtained from 3D seismic and well log interpretation. The fault characteristics were classified and the fault seal distribution map was produced to identify the reservoir connectivity among the faults. The FSA results show that nine identified compartments in the first reservoir layer are clustered into five compartments. In addition, the FSA clustered nine identified compartments in the second reservoir layer into four compartments. In contrast, nine compartments in the third reservoir layer were connected each other that are clustered into one compartment. These results are useful not only for evaluating future hydrocarbon traps but also for future field development.

Keywords: *Reservoir compartment assessment, fault seal analysis, Central Sumatra Basin.*

1. INTRODUCTION

Understanding the geometry of the reservoir compartment is believed to be helpful in optimizing the strategy to increase the hydrocarbon production of the field [1, 2]. Hydrocarbon trap is generally controlled by the presence of a fault, which is caused by sequence stratigraphic movement. Fault compartmentalization provides strategic analysis in reservoir simulation, requires the knowledge of structural model, controlled by faults. Further, understanding the properties and the role of fault in migrating hydrocarbon is useful in reservoir management [3, 4]. This paper aims to assess the properties of faults in defining the boundary of reservoir compartment. The fault plane that was bounding the reservoir layers is assessed in terms of sealing or leaking behavior. Thus, the migration pathway of hydrocarbon can be traced [5, 6].

The case study of this work is located in the Central Sumatra Basin, which is the biggest tertiary sedimentary basin producing hydrocarbon in Indonesia. In terms of tectonic setting, this basin is classified into the back-arc basin, which is situated in an active margin caused by geological activities of plate tectonic collision between the Indian and Australian plates [7]. Geographically, this basin is located between the South Sumatra and North Sumatra basins, bounded with highlands such as Asahan in the northwest, Tigapuluh in the southeast, Sunda Shelf in the east, and the Bukit Barisan in the southwest [7, 8]. The study area is one of the oil fields in this basin that has been explored since 1971 and commenced production in 1974. The main reservoir in this field is a sandstone layer from the Bangko and Bekasap formations [9]. The reservoir was deposited in the depth range of 200 to 350 m. The field production in 2008 has been reaching 62,23 MMBO and keeps striving to increase.

The reservoir compartment of the study area is mainly controlled by faults due to the complexity of geological structure in the central Sumatra basin that has undergone four tectonic periods which affected basin formation [8]. The seismic interpretation revealed that the reservoir consisted of three layers of reservoir sands and was surrounded by different faults, where faults could be sealing or leaking, or even both, in one fault plane for each sand layer. The distribution of fault character in terms of sealing or leaking is varying depending on the properties of the sand layer of the fault plane, such as permeability and shale volume. Further, the paper proposed detailed fault properties to classify the fault role whether as a barrier or a conduit in migrating hydrocarbon.

2. FAULT SEAL ANALYSIS

In the petroleum system, hydrocarbon trapping and migration from source rock is generally controlled by the presence of a fault. Faults play either as a conduit for hydrocarbon migration or boundary of compartment [10, 11]. The potential of fault for sealing or leaking can be assessed by fault seal analysis.

The detailed fault assessment is a key factor for fault seal analysis. The sealing characteristics of fault plane can be identified using many methods. The most common method for identifying the fault seal is Allan diagram that correlates structural geometry of fault plane or horizon intersection [12]. However, the generation of the diagram may be significant but there is a blind spot of the diagram in detail. The diagram is generated by the assumption that fault throw is represented in seismic section as a single fault plane, which is contrary complex in the real condition.

Another method, for example, in the case study of fault seal analysis performed on Colombus basin by Gibson and Bentham, the analysis of reservoir connectivity by faults can be simply done by the SGR analysis [13]. The SGR analysis provides an only probability of sealing or interconnectivity across the fault planes [14]. A further example, a case study of fault seal analysis using seismic attributes to illustrate fluid flow along the fault plane [15]. However, this technique remains provides a risk of uncertainties.

In this paper, we integrated juxtaposition and SGR analysis and completed by considering transmissibility analysis derived from permeability parameter. By integrating these three approaches, we may improve the level of confidence with respect to the previous methods [12, 13, 15].

3. THE APPLICATION OF FSA FOR RESERVOIR COMPARTMENT ASSESSMENT

The seismic interpretation is a key step to identify the presence of a fault and their attributes, which is carried out by identifying the unconformity of sequence stratigraphy and reservoir target. The first FSA is juxtaposition analysis, which assessed the lithology variation of the juxtaposition of the fault plane and fault attributes such as throw and fault type. These two parameters play an important role in determining the fault character, whether it is sealing or leaking [4, 5]. By assessing the juxtaposition, the connectivity of sand reservoir can be defined based on the fault plane [4, 5]. This means that a sealing or leaking fault can be identified from reservoir hydrocarbon-water contact in the fault plane [16, 17]. The reservoir contact, which is indicated by sand-sand juxtaposition, is known as a leaking fault. In contrast, the reservoir contact with sand-shale or shale-shale juxtaposition is classified as a sealing fault.

In a fault plane contact of sand-sand juxtaposition, the presence of shale in the form of a granule that can be laid out in the top or bottom reservoir layer should be accounted for as its character could become a seal. On the other hand, the juxtaposition parameter only provides information of the contact position of the reservoir. No information is provided of shale percentage inside the fault plane that can be a barrier in between sand-sand juxtaposition. Thereby, the SGR analysis is applied to get the percentage of shale volume information between sand-sand juxtaposition. The SGR presents the shale percentage inside sand-sand juxtaposition, which is calculated from shale volume in a reservoir layer and throw of the fault movement [18-20]. This means that the percentage of SGR strongly controls the character of faults in terms of sealing or leaking. The high SGR drives the sand-sand juxtaposition and tends to become sealing.

After performing sand-sand juxtaposition and SGR analysis, the transmissibility analysis, that makes sure sealing or leaking character, is then applied. The transmissibility is the capacity of a reservoir to drain the hydrocarbon through a fault plane. The transmissibility is directly determined from the permeability of sand-sand juxtaposition. The transmissibility is related to the hydrocarbon that can be drawn from the reservoir through fault plane. This means that higher permeability tends to be a leaking character, while lower permeability tends to be a sealing character [21-23]. Further, a comprehensive assessment of the reservoir compartment is carried out by combining sand-sand juxtaposition, SGR, and transmissibility for each reservoir sand layer.

4. RESULTS AND DISCUSSION

Prior to performing fault seal analysis, we carried out integrated interpretation over 3D seismic that consists of 389 inline and 270 cross line and 30 well log data for building reservoir compartmentalization. The seismic interpretation of horizon picking is focused on Bekasap and Bangko formation. Figure 1 shows the identified horizon and fault that were passed through well-1. An anticline structure that plays as a trapping is crossed by several faults.

The good log interpretation has identified three sand layer reservoirs, where two sand layers come from the Bekasap formation and one sand layer from the Bangko formation. The seismic interpretation identified nine faults that form nine compartments. Figure 2a illustrates the fault configuration in 3D view that was extracted from seismic interpretation. The fault configuration in the map view, which is representing reservoir compartmentalization is shown in Figure 2b.

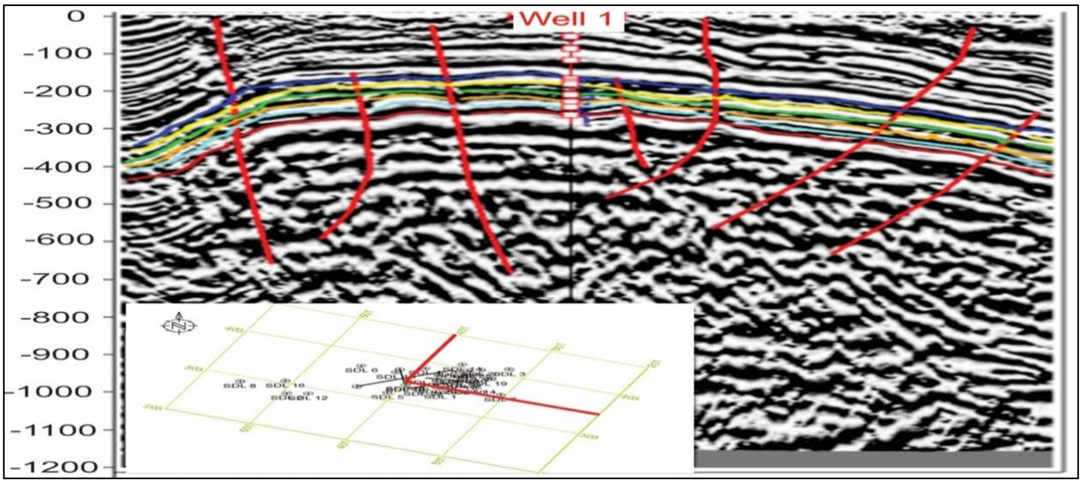
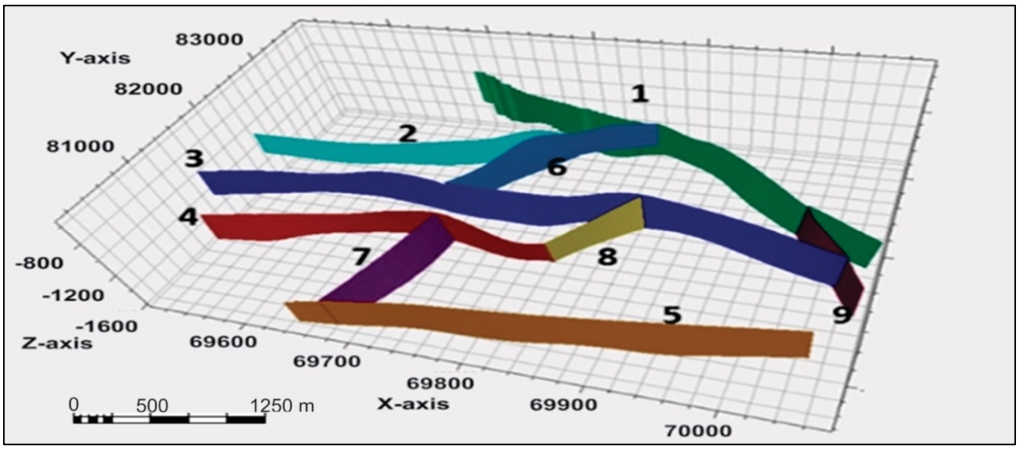
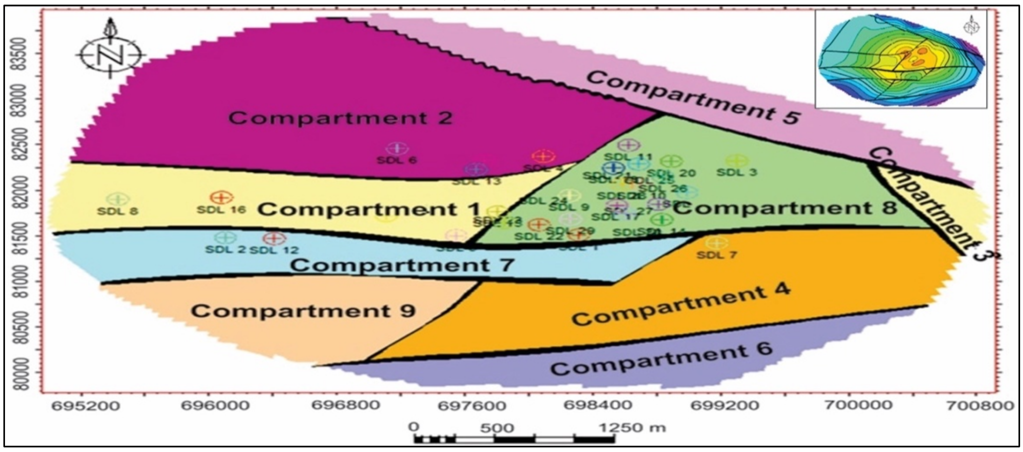


Fig. 1. Seismic data interpretation for identifying horizons and faults.



(a)



(b)

Fig. 2 Fault configuration, which is extracted from seismic interpretation, displayed in 3D view (a), 2D map view represents reservoir compartmentalization (b).

The analysis, which is based on the juxtaposition, is intended to trace the layer continuity in terms of lithology type. This means we analyzed the hydrocarbon drainage through a fault plane in the context of sand-sand or sand-shale correlation. Figure 3 demonstrates a fault plane of fault 6 that presents the juxtaposition section passing through fault 2. We identified several juxtaposition features that correlate between two units. The juxtaposition analysis shows that unit to unit correlation is dominated by cross-juxtaposition (relation between two different units). This means the continuity of sand layer in contact with sand from a different unit. In general, the juxtaposition only provides reservoir layer connectivity pass through fault plane. In this case, the detailed reservoir layer connectivity is not well observed in the presence of another material (shale) inside the layer unit. Thereby, we performed detailed analysis by considering the shale volume inside the layer unit by applying the SGR analysis.

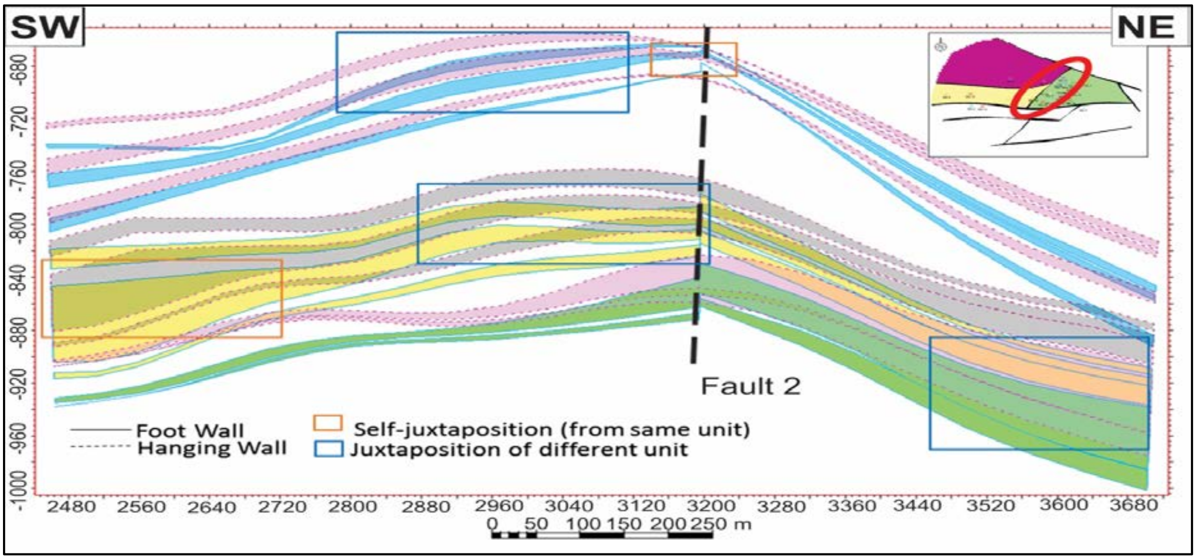


Fig. 3 The fault plane of fault 6 that crosses the fault 2, where the juxtaposition analysis was carried out by correlating lithology types such as sand-sand or sand-shale continuity.

The SGR analysis was carried out based on the percentage calculation of shale volume in the sand layer unit. In this work, we defined the satisfying SGR. Figure 4 illustrates the SGR section of fault 6 passing through fault 2. The low SGR, which is indicated below 50%, was found in almost sand-sand juxtaposition. The low SGR was found in the reservoir layer unit of the Bangko formation. This means the reservoir connectivity of the reservoir layer unit is able to drain the hydrocarbon. However, the high SGR was found in the reservoir layer unit of the Bekasap formation. This means the reservoir connectivity of the reservoir layer unit causes difficulty to drainage the hydrocarbon. The detailed analysis to measure the reservoir connectivity of the reservoir layer unit is based on the transmissibility analysis, which is controlled by a permeability parameter.

The transmissibility analysis was carried out based on the permeability properties of the fault rock in the fault plane. Figure 5 shows the transmissibility of fault plane of fault 6. Referring to the transmissibility section, the connectivity of the reservoir layer unit by means of leaking or sealing is clearly defined. In this case, the transmissibility of reservoir unit of the Bekasap formation is dominantly sealing. In contrast, the reservoir unit of the Bangko formation is leaking. The transmissibility feature has a good match with the juxtaposition and SGR feature. The reservoir connectivity of the reservoir layer unit of the Bekasap formation is poorly connected. Therefore, the fault, in this case, works as a structural trap and barrier for reservoir compartmentalization. In contrast, the reservoir connectivity of the reservoir layer unit of the Bangko formation shows a good connectivity. This means the fault has the capability to migrate the hydrocarbon through the fault plane.

The geological analysis between the Bekasap and Bangko formations in relation with FSA can be understood by the detailed investigation of reservoir unit properties. The reservoir unit of the Bekasap formation is dominantly containing thin sand layers and cross-juxtaposition. This situation is confirmed by a high SGR that represents the shale content in the reservoir unit. In contrast, the reservoir unit of the Bangko formation is dominantly containing thick sand layers and self-juxtaposition. The SGR is also showing less shale content that opens the reservoir connectivity.

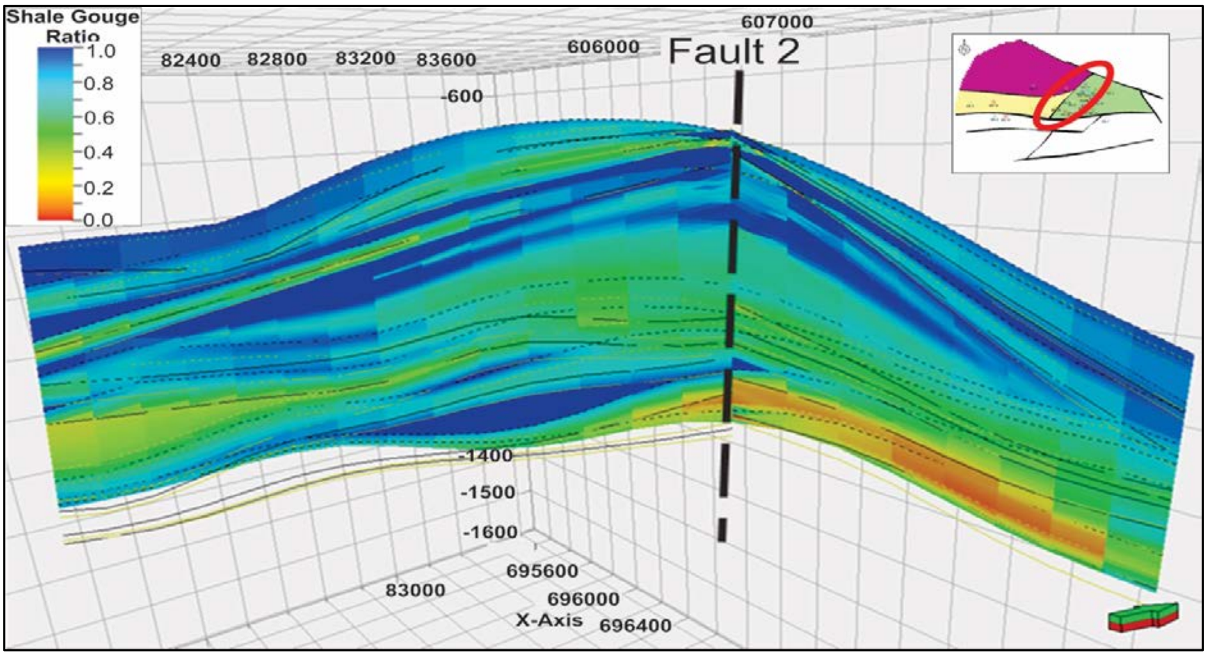


Fig. 4 The SGR section of fault plane 6 that crossing fault 2.

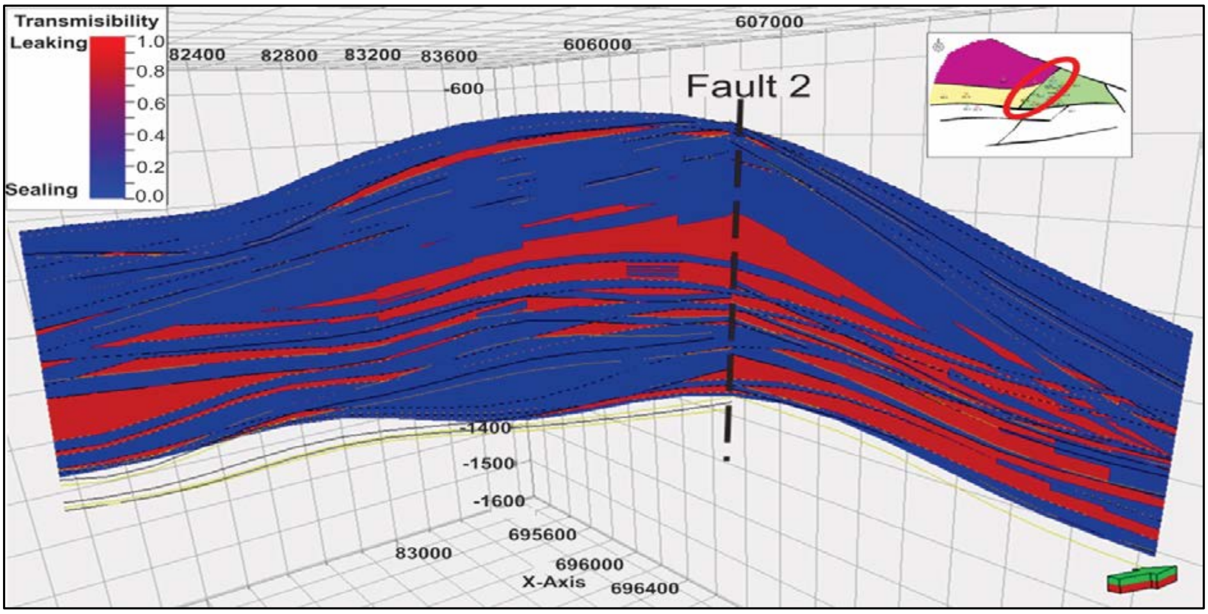


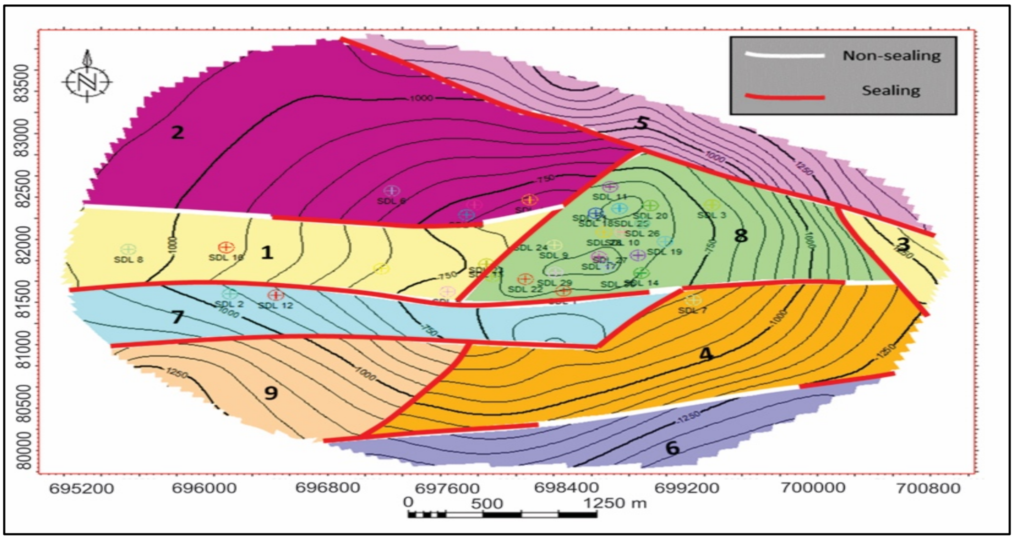
Fig. 5 Transmissibility distribution for fault plane 6.

The comprehensive analysis for defining the reservoir compartmentalization can be observed by integrating juxtaposition, SGR, and transmissibility analysis. This comprehensive analysis is illustrated in the fault seal map, which is shown in Figure 6. This figure shows a fault seal distribution map that was extracted from different reservoir layers unit. Figure 6a illustrates that there is connectivity between compartment 4 and compartment 6, which is indicated by the wide connection. The white color indicates the connectivity between compartment 4 and compartment 6. Compartment 1 and compartment 2 is also showing the wide connection. For the deeper surface, which shown in Figure 6b, the reservoir compartmentalization is changing, where the compartment 4 and compartment 6 is not connected. The reservoir connectivity is shown by compartment 5, which is connected to compartment 2 and compartment 8. The reservoir compartmentalization for the third layer as shown in Figure 6c is totally different with previous two layers. This means inter compartment is more open, where the compartments 6, 4, 8, and 5 are connected in one flow.

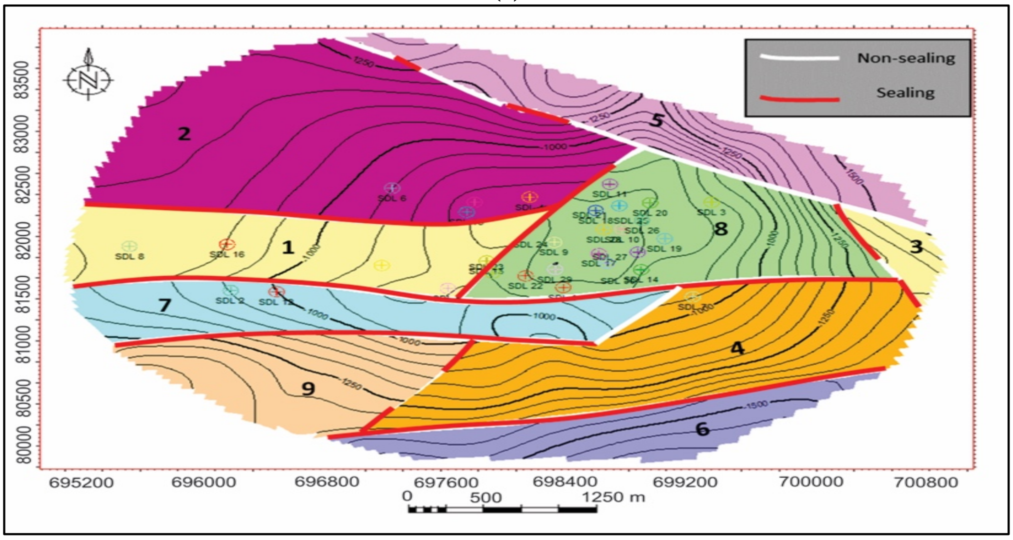
The compartment analysis in three layers can be summarized as follows. In the first layer, we found that nine compartments were clustered into five compartments. The distribution of compartment cluster as follows: cluster 1 (compartment 1 and 2), cluster 2 (compartment 4, 6, 7 and 8), cluster 3 (compartment 9), cluster 4 (compartment 5) and cluster 5 (compartment 3). In the second layer, we clustered nine compartments into four compartment cluster as follows: cluster 1 (compartment 2, 3, 5 and 8), cluster 2 (compartment 4, 7 and 9), cluster 3 (compartment 1) and cluster 4 (compartment 6). The third layer, we found that all the compartments were connected each other.

The strategy to develop and enhance field production can be performed by analyzing the detailed reservoir compartmentalization. In the case of the first sand layer, it can be seen that there is potential for development in compartment 3, 5 and 9. This situation can be understood because the three compartments are isolated by the existence of sealing faults. This condition is very possible for drilling new wells on those three compartments. A more detailed illustration can be seen in Figure 6a. In the second sand layer, the compartment 6 still has the potential to be drained as it was isolated from other compartments and the absence of production wells in this compartment. A more detailed illustration can be seen in Figure 6b. For the third layer of sand where all the compartments were connected each other and hydrocarbon has been effectively drained. However, this condition should be considered to maintain the reservoir pressure. A more detailed illustration can be seen in Figure 6c.

In general, the fault seal analysis by integrating juxtaposition, SGR and transmissibility approach has been successfully applied to assess the compartmentalization of sandstone reservoirs in the Agur field. The assessment result may significantly increase our confidence level and strategy for developing the field.



(a)



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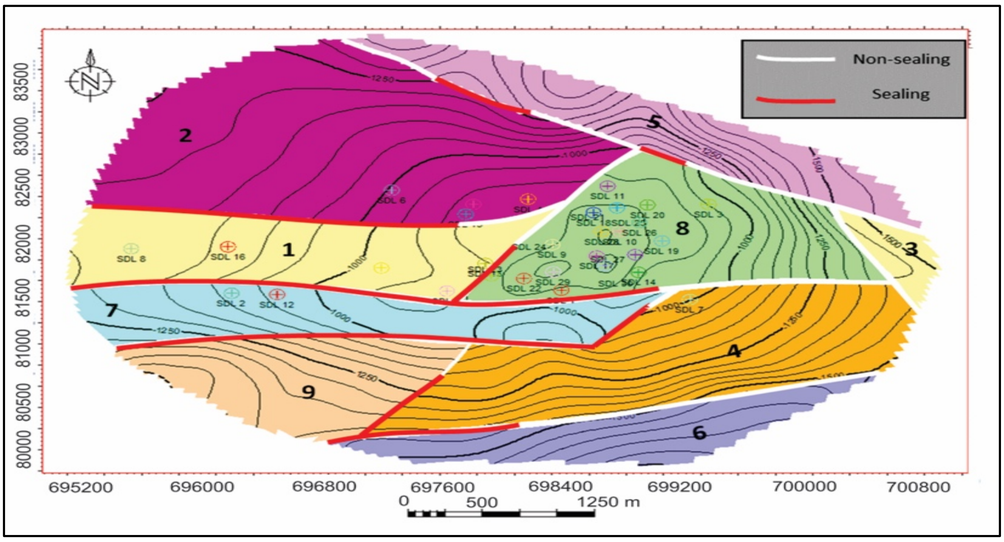

(c)

Fig. 6 Fault seal distribution map for first a), the second b), and third sand c), which is illustrated in reservoir units surface from the top to the bottom respectively. The first and second surface is part of the Bekasap formation and the third surface is part of the Bangko formation.

5. CONCLUSIONS

The comprehensive analysis for defining the reservoir compartmentalization has been successfully carried out for a case study of the Agur field, Central Sumatra Basin. The assessment of reservoir compartmentalization was carried out by performing fault seal analysis that includes juxtaposition, SGR, and transmissibility analysis. Seismic interpretation and well log analysis have identified nine faults that form nine reservoir compartments. In addition, three sand reservoir layers were identified from well log data interpretation, where two sand layers come from the Bekasap formation and one sand layer from the Bangko formation.

The comprehensive assessment of fault seal analysis shows that the reservoir unit of the Bekasap formation has less open compartmentalization, which dominantly contains thin sand layers and a cross-juxtaposition relation. This situation is confirmed by the high SGR that represents the shale content in the reservoir unit. In contrast, the reservoir unit of the Bangko formation has more open compartmentalization which is indicated by thick sand layers and self-juxtaposition. The SGR is also showing low shale content that opens the reservoir connectivity.

6. ACKNOWLEDGMENTS

The authors would like to thank Basic Research Excellent Grant for University from Kemenristekdikti with the contract number: 384/UN2.R3.1/HKP05.00/2018 for supporting this fund’s research. Moreover, the authors hope that this paper might be useful for scientific developments, especially in reservoir geoscience.

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