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Integrated Fault Seal Analysis Methods For Step-Out Development Wells: A Case Study; Pematang Lantih Field, South Sumatra Basin, Jambi-Indonesia

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Abstract. Fault seal analysis has been widely applied in hydrocarbon exploration and field development. In exploration, analysis of the sealing capacity of fault could assess the probability of finding hydrocarbons that involve the definition of spill point, column height, juxtaposition, and compartmentalization. In field development, fault can provide seals, baffles and/or conduits to fluid flow. Proposing a step-out development well beyond main producing area separated by major fault carries subsurface uncertainties. The amount of well and reservoir data from nearby main producing field is an advantage. However, associated risks in the new area without well penetration particularly on the fault characteristics need to be assessed. This paper elaborates the study of fault seal characteristics separating main field and new step out area. Pematang Lantih consists of several structures that are bounded by faults. Pematang Lantih field (main structure) has been developed since 2015 and infill development program has reached its effective hydrocarbon drainage radius. Subsurface evaluation of the area suggests that the structure to the southeast of the main field has a potential hydrocarbon. A step-out well was then proposed to be drilled in the southeast block. The NNE-SSW normal fault separated the southeast block from the main field. Although the southeast block is relatively at the downthrown side of the fault, seismic attribute analysis showed considerable hydrocarbon potential. The size of the fault and the magnitude of its displacement suggest that the fault might potentially act as a barrier between the main field and the southeast block. A combination of methods was performed in this study. The first method was Geomechanical study derived from various data evaluation of well-logs, drilling parameters and regional data. Field Stress model related to fault integrity and reactivation risk were resulted from this first approach. The second method applied the triangle juxtaposition diagram which represents across-fault relationship and sealing capacity from a single well. The fault's throw and field stratigraphy were used to generate juxtaposition diagram. Membrane seals were assessed by using Shale Gouge Ratio (SGR) where shale material (vshale) was incorporated into the fault as a function of fault throw. The third method involved 3D fault model where stratigraphic juxtaposition on fault plane and seal properties derived from 3D grid model can be displayed in three dimensional. This provided a relatively more accurate view of potential leaking or sealing zone and also guided the well geometry to be drilled in the area adjacent to the fault. The study helped in understanding the fault characteristics (integrity, reactivation risk and seal capacity). As a result, this will help in the more confidence placement of the proposed step-out well location and the determination of subsurface target.

Keyword(s): Fault Seal, Geomechanics, Juxtaposition, Shale Gouge Ratio.

1 Introduction

Fault Seal Analysis has been widely applied in hydrocarbon exploration and field development. In exploration, analysis of the sealing capacity of fault could assess the probability of finding hydrocarbons that involve the definition of spill point, column height, juxtaposition, and compartmentalization. In field development, fault can provide seals, baffles and/or conduits to fluid flow [1]. Pematang Lantih Field was discovered by Dutch BPM in 1939. However, the development and production of the field commenced in 2015. The infill drilling has been the primary field development program. Due to its relatively small structure, the spacing of infill well location for optimum drainage radius has been reached with the distance between wells at reservoir level approximately 200 m. Geological and Geophysical study of the Pematang Lantih structures revealed that the downthrown block to the southeast of main Pematang Lantih Field has considerable hydrocarbon potential. The southeast downthrown block is separated by NNE-SSW normal fault from the main field. The size of the fault and the magnitude of its displacement suggest that the fault might potentially act as a barrier between the main field and the southeast block. In order to have a better understanding of the fault and to justify a step-out development well in the southeast block, a comprehensive fault seal analysis method was conducted.

1.1 Geology Overview of Pematang Lantih Field

Pematang Lantih Field is located within South Sumatra Basin on Sumatra Island, Indonesia (Figure 1). The South Sumatra Basin is a tertiary back-arc basin with the axis parallel to the long axis of the Sumatra Island. The Tungkal Block where Pematang Lantih located lies on the northwestern margin of the South Sumatra Basin which is separated from the Central Sumatra Basin by the Tiga Puluh High. The western margin of the South Sumatra Basin is bounded by the Plio-Pleistocene Barisan Mountains. The regional tectonic of South Sumatra Basin is dominantly affected by the anti-clockwise basin rotation that occurred during Late Paleogene. Wrench Fault System structural patterns were formed approximately during Early to Middle Neogene. Folds were formed by compressional tectonic regime during the Late Neogene. Figure 2 shows major structural features in the South Sumatra Basin [2]. Pematang Lantih Field is an elongated northwest-southeast structure. The field is divided into segments separated by northeast-southwest trending faults. The main segment is Pematang Lantih producing field. Southeast segment is separated by northeast-southwest normal fault. Hydrocarbon accumulation are found in the multiple sand reservoir of Talang Akar Formation. This formation is composed of interbedded Conglomerates, Sandstones and Shales with occasional Coal beds. The Early Miocene Upper Talang Akar Formation was deposited unconformably over the Lower Talang Akar Formation. The sandy facies of the lower part of the Upper Talang Akar was gradually replaced by the shaley facies of the upper part of Upper Talang Akar Formation. Deposition of lower part Upper Talang Akar Sandstones was restricted to surrounding areas of the Tungkal Block and shaled out southwards into the Jambi Sub-basin. The clastic sequences of the Lower Talang Akar and Upper Talang Akar Formations pinch out to the east against the basement high of the Tiga Puluh Mountains. The general stratigraphy of South Sumatra Basin shown by Figure 3 [3].

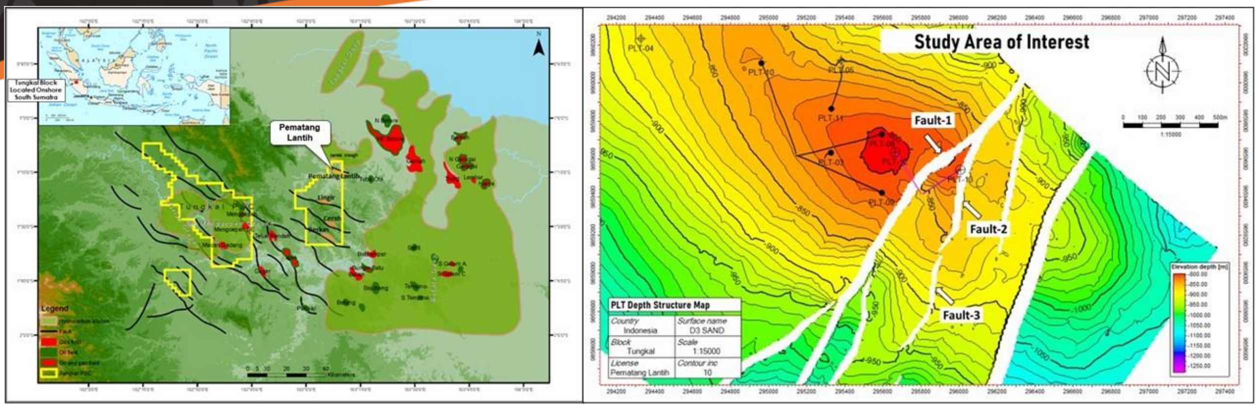

Figure 1. Pematang Lantih Field location in South Sumatra Basin (left) and Structure Map (right).

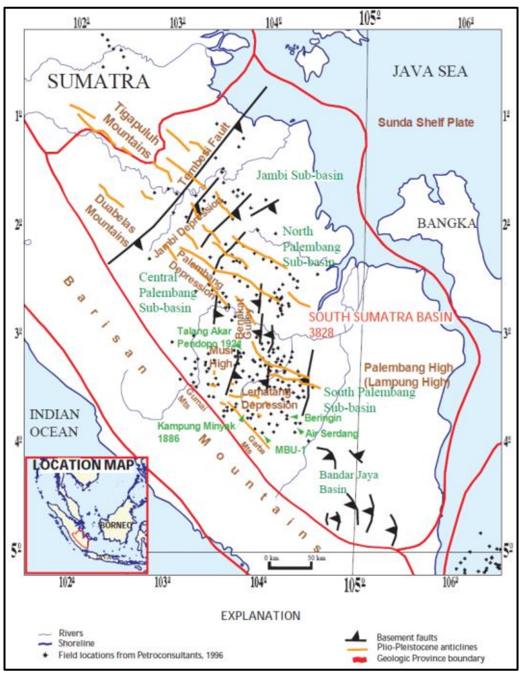

Figure 2. Major structures features
In South Sumatra Basin [2]

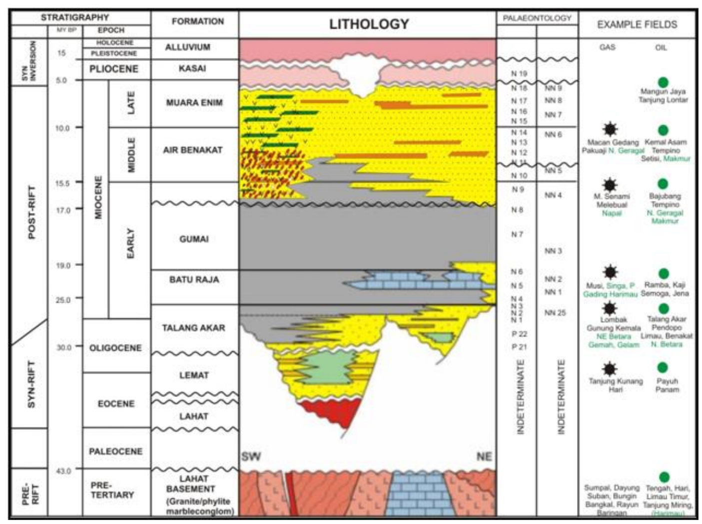

Figure 3. Stratigraphy of South Sumatra Basin [3]

1.2 Data

The 3D seismic horizon and fault interpretations have been utilized in the stratigraphic framework, fault geometry and 3D geological modeling. A detailed QC of horizons and faults were performed to build a reasonable structural framework model to be used to generate juxtaposition diagram (Allan Map) on the fault surface [4] and to represent a reasonable fault displacement. The petrophysical data from Pematang Lantih Main Field have been used in the fault's property calculation and evaluation. The volume of shale is used to calculate Shale Gouge Ratio and hence predict the fault sealing behavior [5]. A series of special logs (e.g. FMI, DSI) , well data (e.g. well tops, trajectories) and drilling parameter (e.g. EMW, LOT, FIT) were also utilized to develop geomechanics model of the field.

2 Methodology

2.1 Geomechanics Analysis

The geomechanical analysis and modeling are used to predict the likelihood of stress regime in the reservoir and hence assess the risk of fault reactivation for the trap-bounding faults. Fault Analysis Seal Technology (FAST) technique was applied to measure reactivation in terms of pressure difference required to activate a fault [6]. The in situ stress tensor and fault rock strength estimation were utilized to generate relative risk of reactivation stereonets for critical reservoirs and consider the risk of reactivation for the relevant fault geometry (fault strike and dip magnitude) at a particular depth [7].

2.2 Juxtaposition Diagram and Membrane Seals

Triangular fault juxtaposition diagrams [8] are frequently used to quickly assess cross-fault relationship and sealing capacity from a single well. The underlying concept is to represent a layer-cake stratigraphy offset by a hypothetical fault with linearly increasing displacement. Membrane seals are generated by incorporating finer grained shale material into the fault as a function of fault displacement. This can be assessed by estimating Shale Gouge Ratio (SGR) and assume that vshale corresponds with clay content. Critical cross-fault pressure difference can be inferred from SGR using empirical failure envelopes [9].

2.3 3D Geological Model and Fault's Properties

3D grid geological model generated to represent stratigraphic and structural framework. Twelve reservoir zones were generated to be utilized as a basis for reservoir juxtaposition diagram on fault surface (Allan Map). Reservoir properties (i.e. vshale, porosity, permeability) were calculated and populated in the 3D grid. The grid properties were later utilized to calculate and predict fault's properties and behavior. The 3D model visualization enable the accuracy of well placement in three dimensional to the reservoir target.

3 Results

Stress modelling shows that a maximum horizontal stress orientation of 045°N from well data is consistent with regional stress orientation from the World Stress Map. Stress models indicate a dominantly strike-slip regime (Shmin < Sv < Shmax) and have similar Shmin magnitude. Although, one of the model shows higher Shmax magnitude. The stress models were used to assess the risk of reactivation of faults bounding the Pematang Lantih southeast block. No orientations are predicted to actively reactivating under either stress case (Figure 4).

Single well juxtaposition diagrams for the reservoir sections across the fault were constructed using stratigraphy from respective wells. SGR is assessed for each reservoir adjacent to the faults to consider seal integrity where sand-on-sand juxtaposition is predicted (Figure 5). SGR predicted for reservoir adjacent to the fault separating Pematang Lantih main block and southeast block is sufficient to sustain oil column heights exceeding 1500m for the reservoir A to E1 and can sustain a 500m column for E5.

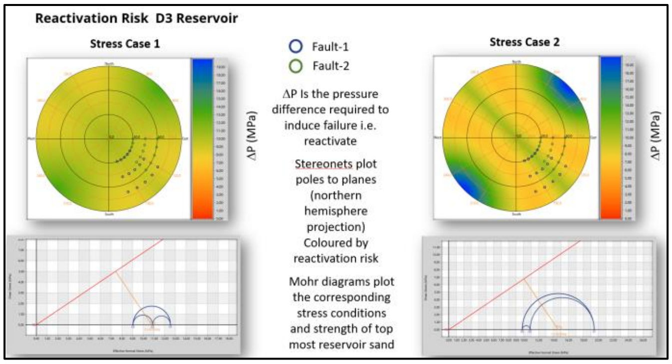

Figure 4. Example of Stress Case Reactivation Risk At Sand D3

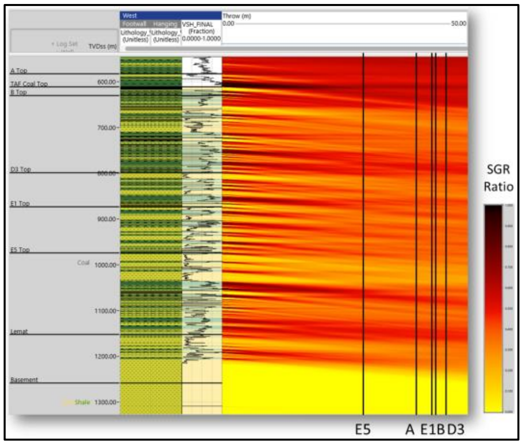

Figure 5. Example of SGR Diagram

3D Structural Grid and Fault Analysis Model have been built for Pematang Lantih Field (Figure 6). Detailed evaluation conducted for the northeast-southwest normal fault separating Pematang Lantih main block and southeast block. Juxtaposition diagrams (Figure 7A) shows that sand-on-sand juxtaposition occurred mostly in the deeper reservoir interval (Sand D3 and below). Although, some reservoir juxtaposition also occurred at shallower reservoir interval (Sand A to Sand C). Fault clay prediction (Vshale, SGR, Smears) indicates value for most fault plane is above 30% which is considered as sealing (Figure 7B). A lower SGR value less than 30% observed at sand-on-sand juxtaposition between Sand D5 (Upthrown) and Sand D3 (Downthrown). The findings from step-out well drilling implied that Sand C2 of southeast area is in communication with Sand C2 of the main field. Formation pressure data that was acquired at Sand C2 from step-out well showed significant depletion compare to Sand C2 from well in the main field. Initial evaluation that Sand C series are juxtaposed each other particularly at the northern edge of the fault. Sand D2.2 reservoir pressure at southeast block is also lower than initial condition. It was observed that this D2.2 local sand juxtaposed against Sand D3 from the main field that has been the main producing sand in Pematang Lantih main field. Formation pressure data from the rest of the reservoir in southeast block show that the reservoir pressure are in initial condition. The potential cross-fault permeable zones (Figure 7C) and cross-fault transmissible zones (Figure 7D) were also observed from 3D fault seal analysis. This permeable and transmissible zones correspond with lower value of SGR such as at the reservoir juxtaposition between Sand D5 and Sand D3.

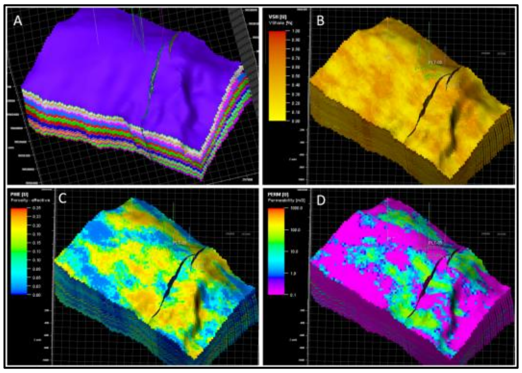

Figure 6. 3D Grid Model and Properties

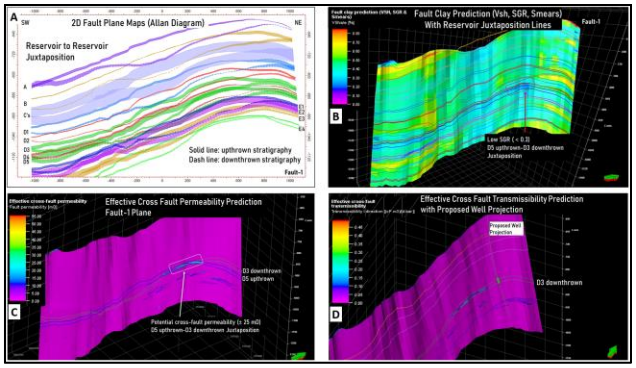

Figure 7. 3D Fault Juxtaposition and Properties

4 Conclusions

Fault seal integrity assessment of the Pematang Lantih faults indicates that the fault is not actively reactivated.
The shale gouge development is sufficient to maintain significant buoyancy pressures in reservoir unit where sand to sand juxtaposition may exist.
3D structural and fault seal analysis show more detail feature of reservoir (sand to sand) juxtaposition and fault plane properties. These features enable careful evaluation and prediction of potential partial leaking fault in the area particularly where further development of step-out block next to mature/producing field is to be commenced.

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Acknowledgments

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