Shale structure implication in hydraulic fracturing production results: Case study in low resistivity low quality reservoir, offshore North West Java area

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Abstract. Low-resistivity & low-quality reservoir has been successfully developed in ONWJ area by using hydraulic fracturing stimulation method to optimize production gain due to low-permeability reservoir property. The purpose of this research is to understand implication of shale structure for increasing gain production after hydraulic fracturing stimulation. Implementation of hydraulic fracturing was first completed at BerylE-1 and the well could produce 455 BOPD at 560 psi in reservoir 33 and 35. This reservoir was found in Upper Cibulakan Formation that consists of various lithology’s such as very fine-grained sandstone, shale, siltstone & thin tight carbonate that deposited in shallow marine neritic to littoral environment. Production anomaly occurs after hydraulic fracturing stimulation. Some of well in this reservoir show good incremental production, but in the other well there was no significantly incremental production in this reservoir. There were three types of shale structure classification based on effective porosity distribution: laminated shale, structural shale and dispersed shale. Shale structure for each well has been defined based on Thomas Stieber plot and calibrated using petrographic analysis from 8 sample depth point. Based on this method, reservoir 33 is dominated by structural shale while reservoir 35 is dominated by laminar shale. Production data and shale type from each well has been compared and it shows that hydraulic fracturing simulation will increase effective porosity and will also increase effective permeability value. In BerylD-1 well hydraulic fracturing only completed in reservoir 35 and produced 340 BOPD with initial water cut 0 %. Laminar shale that dominates in reservoir 35 has high factor to increasing production gain after hydraulic fracturing was applied. Release of clay that caused by hydraulic fracturing will increase effective porosity and permeability.

Keywords: Hydraulic fracturing, low resistivity reservoir, shale structure, upper Cibulakan
1. Introduction
Low-resistivity reservoir R33 and R35 has been developed and produced in Offshore North West Java area including Beryl field as one of the main fields productions in this area. Hydraulic fracturing stimulation is needed to produce this reservoir due to its low permeability value [1]. Low resistivity in 33 and 35 reservoirs characterized by 1.2–1.8 ohm with very interlaminated shaly sand, high reading gamma ray and high total gas reading [2]. Anomaly of production result after hydraulic fracturing brings up issue that internal character in this reservoir give effect in it. Defining of shale structure can be applied by using log data approach based on petrophysical analysis [3, 4]. On the other hand, shale structure should be calibrated by using petrography analysis to assume maximal porosity each layer of reservoir [2]. In this research, we have compared shale structure to production anomaly data.

2. Method
The data used in this research consisted of 23 wells data that contains petrophysical properties (porosity, shale volume), production data and core data including petrographic analysis. Petrophysical properties was derived using probabilistic approach that was called as multiminal method [5]. The resulted petrophysical properties was then calibrated using core data that contains information of grain density, porosity and permeability.

Having the calibrated petrophysical properties, these data were used for the shale structure typing that was conducted using Thomas Stieber plot [6, 7]. The total porosity and shale volume were plotted in Thomas Stieber plot to differentiate between structural shale and laminar shale. Maximum porosity and clay porosity were adjusted as a start and end point. Maximum porosity was defined as porosity of the clean sand, and clay porosity was defined as the porosity of 100 % of shale. When the data close to the clay point the concentration of the lamination shale increased. The third point was defined as the structural shale that calculated using the two-end point (maximum porosity and clay porosity) using the equation 1. When the data close to the third point the concentration of the structural shale increased.

The two target reservoirs of R33 and R35 have a same parameter (maximum porosity and clay porosity), because the reservoir have a similar depositional environment. The resulted shale structure type in every depth point was then validated using the petrographic analysis.

\[ \phi_{\text{structural}} = \phi_{\text{max}} + (1 - \phi_{\text{max}}) \cdot \phi_{\text{clay}} \]  

(1)

3. Results and discussion
Petrophysical analysis in this reservoir has been done by using probabilistic method (figure 1). There are eight tracks that showed in figure 1 the log from the first track to the eight tracks as follows; Gamma ray, Depth, Resistivity, Neutron Density, Porosity, Permeability and Water Saturation. R33 and R35 is one part of upper Cibulakan formation, so that all of picking parameters taken from upper Cibulakan input. Porosity value has been calibrated using core data. There was difference between total porosity (Phit) and effective porosity (Phie) which caused by high shale content in this reservoir. Average of effective porosity is around 0.13–0.19 v/v and volume shale are around 0.51–0.68 v/v. Permeability has been calculated around 5–8 mD based on linear regression core function. High saturation water (Sw) is around 0.78–0.92 v/v due to low resistivity that caused by thin bed lamination.

Analysis of petrography data in BerLD-13 well (figure 2) shows that there are two types of shale structure in R-33. Petrography analysis in depth 3839 feet shows that most of grain is dominated by quartz 39 %, feldspar 3.2 %, and detrital matrix that consist of laminar shale 26 %. In the other depth 3860 feet shows most of shale structure consist of structural shale.
Figure 1. Petrophysical analysis using probabilistic method (multimineral), petrophysical properties has been calibrated using core data.

Figure 2. Integration shale structure typing using Thomas Stieber plot that calibrated using petrographic analysis in BerylLD-13 well. Laminar shale (green shading) from Thomas Stieber plot has been checked by petrographic data that also show laminar shale in thin section.

The next step, after petrography analysis, is defining shale structure based on Thomas Stieber plot. R33 and R35 is a part of shallow marine depositional environment, so that Thomas Stieber plot can be used together in both of this reservoir R33 and R35. Each type of shale structure highlighted to get
shale structure in every interval for each well. Both of step previously calibrated by petrography analysis that has been done before to validate shale structure type. The result from this method shows that reservoir R33 is dominated by structural shale and R35 is dominated by laminar shale. Figure 3 shows shale structure distribution that correlated based on well.

Most of productions data consist of commingle well from R33 and R35 in Beryl field. It was because this reservoir should pursue productivity and production target. Average from this reservoir both of R33 and R35 is around 348.12 BOPD as shown in table 1. However, there were some wells that produce from single zone only (R33/R35). From this data average production from R33 is 152 BOPD taken from BerylID-10S and average production from R35 is 244 BOPD taken from BerylLB-2ST2 & BerylID-1 as shown in table 2. It means that R35 reservoir contributes more than R33 after

![Figure 3. Distribution of shale structure for each single well and well correlation based on top and base reservoir marker that contains shale structure distribution.](image)

| Table 1. Production data from 8 wells that produced by comingle from R33 & R35. |
|---|---|
| No | Well | Zone | Production |
| 1 | BerylLB-10S | R-33/35 | 381 |
| 2 | BerylLB-14S | R-33/35 | 370 |
| 3 | BerylLB-7 | R-33/35 | 493 |
| 4 | BerylLB-9ST4 | R-33/35 | 260 |
| 5 | BerylC-1 | R-33/35 | 223 |
| 6 | BerylID-2ST | R-33/35 | 232 |
| 7 | BerylE-1ST | R-33/35 | 455 |
| 8 | BerylIB-6ST | R-33/35 | 371 |
| | Average production | | 348.125 |

| Table 2. Production data from every single zone R33 & R35. |
|---|---|---|---|
| No | Well | Zone | Production | Average production each zone |
| 1 | BerylID-10S | R-33 | 152 | 152 |
| 2 | BerylLB-2ST2 | R-35 | 149 | 244.5 |
| 3 | BerylID-1 | R-35 | 340 | |
Figure 4. Proposed model of shale structure after hydraulic fracturing stimulation. Laminar shale has good incremental production gain due to increasing effective porosity & permeability.

hydraulic fracturing stimulation is applied. Contribution in R35 reservoir is around 62 %, meanwhile R33 contributes for 38 %. R35 is dominated by laminar shale, and we propose to make new shale structure model after implementing hydraulic fracturing (figure 4).

4. Conclusion
This research result is to identify correlation between shale structure types with productivity index after hydraulic fracturing stimulation. Laminar shale has good incremental production gain after hydraulic fracturing which caused by increasing effective porosity & permeability after hydraulic fracturing stimulation. Percentage of contribution in laminar shale is up to 62 % if both reservoirs produce by commingles. New model for laminar & structural shale is proposed to understand shale structure behavior to production contribution after hydraulic fracturing.

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