Abstract

Challenging situation happens in development of a carbonate reservoir (Kujung Formation) in ‘X’ Field, East Java, Indonesia, in contrast with overpressure and sloughing shale above it. The presence of sour gas with 7000 ppm of H2S increased the level of complexity in drilling operations. The actual carbonate top formation (Top Kujung Formation) is difficult to be predicted only from seismic data, as in some area of deposition there are development of “reef talus” which could lead to wrong interpretations and premature casing set which could bring unwanted consequences. One well was facing premature casing set, the other well was drill thru the carbonate and facing severe losses and cannot be cured by loss circulation material and cement which increased the drilling cost. Learning from previous drilling operations, a formation Resistivity forward modeling which including real time modeling with Logging While Drilling (LWD) and integrated with rock cutting analysis. Formation Resistivity modeling was developed based on four wells previously drilled in the structure. Two different Resistivity models that might be encountered during drilling and model update during drilling operation is a must to avoid drilling deeper into the carbonate. Upper layer easily recognized using log correlation, followed/calibrated with confirmation from mud logging cutting data by real time correlation and forward modeling with LWD geoVISION Resistivity and Array Resistivity Compensated (GVR-ARC mark of Schlumberger) from 50 - 100 meters from the expected top carbonates. This paper provide detailed method of precise top carbonate determination in this case Top Kujung Formation for the one recently drilled wells in the structure “X”, improving zone isolation with precise casing setting depth, integrated with Resistivity forward modeling where this method has been successfully implemented.

Introduction

Field ‘X’ is the gas field located at East Java – Indonesia (fig.1) with Kujung Carbonate (Kujung Formation) as a reservoir which has high potential risk and high H2S gas content (± 7000 ppm). Because of that this reservoir needs careful effort both in planning and drilling operation.

The main feature of Field ‘X’ is the unique subsurface characteristic where overpressure zone (formation pressure above normal gradient) and sloughing shale present in Tuban Formation (above Kujung Formation) and loss kick potential in the Formation Kujung. Formation Kujung itself has different subsurface characteristic both in its spreading and thickness so that the accuracy in determining the depth of Top Formation Kujung becomes very important to ensure the proper casing point determination.

In previous drilling the estimate of Kujung Top Formation only based on seismic interpretation where it is characterized by a pretty good seismic marker. Kujung Top Formation is a clear strong reflector. In reality, the seismic interpretation is not sufficient to specify Top Kujung as some Top Kujung well which were found a few hundreds meters from the interpretation result. Therefore, it needs another more accurate method to overcome this problem. This method is the Resistivity model which is applied and proved to be successful in next drilling.

This paper will describe the method used in determining real time Kujung Top Formation. It applies Resistivity model which has been made previously and integrate it with LWD (Logging While Drilling), rock cutting analysis and other drilling parameters generated during drilling operations. This method has been applied in the
next development well and has effectively avoided the premature of set casing due to Kujung Top Formation improper determination, plug cement loss and H2S exposure to the surface.

Background
Regional Geology

In geological structure, this area is located at East Cepu High, at North East Java Basin. Base is marked by some high and low structure with northeast-southwest (NE-SW) orientation, which generally is confined by high angle faults. At the south and southeast of this basin, east-west (E-W) tectonic pattern is found, and its northeast-southeast (NE-SW) complement. The north East Java basin is formed at the time of Eocene as a back arc basin which associated with volcanic basic located at south side of it.

The formation development of north East Java basin was started at the end of Cretaceous when Asia Plate and Pacific Plate subducted. Subduction zone was created along the southeast edge of Sunda Craton. It produced mélange accretion sediment and igneous rock during Cretaceous to Paleocene. This NE-SW structure pattern keep reactivating, event when subduction was in the south of Java at Oligocene from time to time until now. The change of tension from pulling to compression during above geological time scale produced north-south (N-S), east-west (E-W), and northwest-southwest (NW-SW) structure pattern. This geological structure activity and pattern contribute to the carbonate reservoir characteristic in this field, especially the implication to the possibility of permeability barrier which creates structural compartmentalization (fig.2)

The geological characteristic of Kujung Carbonate Reservoir

The Carbonate deposition geological structure of Kujung Formation On the end of Oligocene-early of Miocene, Kujung formation is unconformably deposited on top of basement. The carbonate from the deposit cycle widely spread out and its top is the best seismic marker. Two carbonate types can be recognized in this area. The shelf of the end of Oligocene and the carbonate reef of early of Miocene. The shelf of the end of Oligocene associated with the transgressive phase which consist of fine grain sediment which equivalent with the lower part of Kujung formation. In general, the Kujung Unit II Carbonate is classified into carbonate-siliclastic rimmed shelf which is controlled by Pre-Kujung grain structure.

During that period, the northern Madura shelf and the other structure high and ridge is closed mainly by the shelfal carbonate facies, on the contrary the sentral basin and other sub-basin are dominated by basinal deposition. Kujung Unit II has basal sandstone at the bottom and carbonate at the top. According to the chronostratigraphy reconstruction, the carbonate shelf of the end of Oligocene laterally change its facies to slope basinal facies which can be analyzed from Kujung siltstone. In general, the deposit process in basinal area is characterized by the slope-basinal facies carbonate formation, while the shelf area is characterized by shelf facies sedimentation. The early Miocene tectonic is associated with the regional basin deposit slope in East Java deposit, it is characterized by the massive carbonate deposit which widely spread out (Fm.Kujung unit I). The Kujung Unit I deposit spread is influenced by the NE-SW and E-W orientation from Pre-Kujung structure. In general, the early Miocene carbonate is mainly formed by the carbonate cycle with aggradasional type. To the western direction, the mid of Miocene carbonate cycle is mainly formed by the dolomitic limestone at the bottom and packstone and dolostone in the middle, and boundstone and grainstone at the top. This cycle is interpreted as the sub littoral deep bank carbonate deposition. At the top of this succession, there is erosional surface disharmony which separate the mid of Miocene and the end of Miocene cycle (fig.3)

Available Data

The data of 4 (four) wells used in this study consist of well log such as gamma ray, log Resistivity, NPHI, RHOB, etc. and complete with another drilling data such as lithology log, rock cutting sample, and other drilling parameters as supporting data and 3D seismic high resolution

The Workflow of Resistivity Model

The initial stage of this work begins with collecting data from 4 (four) wells previously drilled and other necessary data inventory such as well log Gamma Ray, NPHI, RHOB and the most important thing is the availability of log Resistivity LLD or RT, high resolution 3D seismic data, and drilling data such as lithology log and rock cutting samples.

Hereinafter quality control is conducted to the available data. For well log in particular, editing process, depth matching, splice logs are applied. Environmental correction log is applied especially for log Resistivity derived from LWD. This process absolutely must be done as the hole is not really in good condition. The use of OBM (Oil Base Mud) to anticipate the nature of reactive shale Tuban formation most likely will affect the value of the log reading.

The next process which is the core of this study is log Resistivity analysis (the characteristic, trend, and correlation with other log), well seismic tie, interpretation integration with seismic data, and supported by other data (log lithology, rock cutting sample and drilling parameter. All analysis which are done starts from the understanding of
The geological condition of the area so that the output will be used to create a Resistivity model that fits with local geological characteristic.

The final product of this study is the Resistivity forward modeling which is the result of the integrated analysis of various data just as mentioned above.

Resistivity Model Making

Log Resistivity is obtained from 4 (four) wells previously drilled (fig.4) i.e. 2 (two) exploration wells (X-1 and X-2) and two (2) development wells (X-06ST, X-). In general, the log Resistivity analysis process carried out several following steps:

1. Characteristic analysis of log Resistivity LLD, RT supported by data such as lithology log and rock cutting sample.
2. Seismic Interpretation based on log Resistivity characteristic.

The following are the details of the process mentioned above:

1. Characteristic Analysis of Log Resistivity

The characteristic analysis of log Resistivity from 4 (four) current drilling wells which are X-1, X-2, X-4, X-6ST shows that there are different characteristic, especially 50-100 m above Kujung Top Formation. From those four log Resistivity, we can be classified them into two types of characters:

a. **Type A**
   - X-2, X-4, X-6ST are characterized by 1-2 ohm.m gradual increasing in Resistivity value for approximately 50 - 100 m above Kujung Top Formation. After penetrating Kujung Top Formation, the Resistivity value is high (average ± 1500 - 2000 ohm.m).

b. **Type B**
   - X-1 is characterized by the sharp rise in the Resistivity value with Resistivity background from 1 ohm.m to 20 ohm.m which appears above the top of Kujung Formation that we identified as limestone stringer. From limestone stringer to Kujung Top Formation is filled by Calcareous Shale Kujung with 50 meters thickness and 2-3 ohm.m Resistivity. In type B we did not found gradual increasing Resistivity before penetrated top Kujung Formation

More details of the log Resistivity characteristic classification can be seen in the following picture (fig.5). The above analysis is also reinforced by lithology log and rock cutting analysis. In Type B, the Resistivity characteristic which we interpret as a limestone stringer has 100% limestone. Under the limestone, it is fill up with calcareous shale. It fits with the characteristic analysis of log Resistivity Type B. In Type A, limestone stringers is not found, the rock cutting composition is 90% shale and 10% limestone. The limestone content keep increasing along with the depth which finally become 100% limestone in the Top Kujung Formation. For more detail see fig.6

2. Seismic Interpretation

Before processing the seismic interpretation, firstly we do the binding of well data to seismic (well-seismic tie). By using 30 Hz Ricker Wavelet, there are two different patterns in Kujung Top Formation as shown in the fig.7

In the X-1 well, Kujung Top Formation is in peak trace synthetics, while in X-2, X-4 and X-6ST Kujung Top Formation is in trace trough synthetics. Based on these two types, there is the same group with part (1) the characteristic analysis of log Resistivity. After well-seismic tie, the next step is to look seismic characteristic which passes through each well in particular. As shown in the fig.8 there are seismic characteristic differences in Kujung Top Formation for both wells (Type A and Type B). In Type A, Kujung Top Formation is in trough seismic trace and in Type B Kujung Top Formation is in peak seismic trace. This pattern also matches with the synthetic seisnograms pattern for both well in this area.

The geological information which can be interpreted from these two characteristic patterns of Kujung Top Formation is there is a carbonate facies difference between type A (X-2, X-4, X-6ST) and type B (cluster X-01). This difference is closely related to sub-surface target position (well position in Kujung Top Formation) where type A is in the west of Kujung Top Formation structure, while type B is in the east of the structure fig 4. From the regional geology of carbonate in this area, it is known that the wells located at the west of this structure are in Kujung fore-reef carbonate while wells which located in at the east are Kujung back-reef
carbonate. The occurrence of Kujung carbonate in this area is strongly influenced by the rise and fall of sea level so that the onlapping reflector pattern in Kujung Formation is clearly seen at the forereef section.

The differences between carbonate facies at the west and the east of Kujung Formation structure are seen from the seismic section fig.9 which reflect in the seismic characteristic difference (Kujung Top Formation at the west is in trough seismic trace, while in the east is in peak seismic trace). It can be interpreted as the reef talus where the main substance is carbonate material however due to sea water high during the diagenesis of Kujung Carbonate. This seismic characteristic is not exist in the eastern structure of Kujung Formation so that the reef talus facies is not found in this area as sea water low energy restrains it. The conclusion is in Type A wells (cluster X-2, X-4, X-6ST) Kujung Top Formation are in trough seismic trace which interpreted as the reef talus, whereas Type B well (X-1) Kujung Top Formation is in peak seismic trace without the reef talus on it.

Connection between Characteristic Analysis of Log Resistivity, Seismic Interpretation and Cutting Sample

Trend of increasing Resistivity value 50 - 100 m above Kujung Top Formation as seen in Type A (cluster X-2, X-4, X-6ST) which discussed in the log Resistivity modeling and associated with the result of seismic interpretation and lithology log, we get conclusion as follows:

1. Seismic interpretation shows that seismic characteristic of X-2, X-4, X-6ST wells (Type A), are in the fore-reef of Kujung Carbonate which its formation process is influenced by the high energy of sea waves so that reef talus deposit is formed in the slope of Kujung core carbonate. This kind of Seismic characteristic is not exist in the X-1 Well (Type B).

2. Seismic data interpretation, lithology log and cutting analysis while drilling wells X-2, X-4, X-6ST wells (Type A) show that there are alternating limestone in the Tuban formation shale, especially 50 – 100 m above Kujung Top formation where the percentage level tends to increase close to Kujung Top Formation. The limestone is possibly found in Tuban Formation as the result of the ruins in Kujung Formation Kujung. The fig.9 shows that Kujung fore-reef has the slope which is pretty quite steep so that the collapse possibly happens due to sea water high energy. While in 50-100 m Kujung Top Formation, seismic characteristic shows that there is no mounded pattern or reef which indicates the carbonate formation separated from Kujung carbonate. In the X-1 Well (Type B) there is no any alternating limestone with Tuban Formation shale at 50-100 m above Kujung Top Formation. It concludes that the back-reef deposition of Tuban shale is more influenced by lagoonal system (low energy) so that the limestone collapse of Kujung Formation does not happen and shale formation is more compact compared to the fore-reef section.

3. Cutting sample (fig.6) during drilling show that in Type A there is alternating limestone with shale in Tuban Formation whereas in Type B no alternating limestone in particular 50 – 100 m above Top Formation Kujung. This information fit with analyzed from log Resistivity and seismic interpretation

Application of Forward Resistivity Model During Drilling X-3TW

Forward Resistivity model is applied to the next drilling wells (X-3TW) with following methods:

1. The proposal trajectory well plot to seismic (seismic well tie) by “borrowing” the X-1 checkshot. The X-3TW well surface coordinates is adjacent to the X-1 and its target subsurface is interpreted in the same one facies with X-1 so that there is possibly no significant interval change in velocity checkshot in the target zone (Kujung Formation) for X-3TW fig.10

2. From plotting proposed well to seismic we can conclude that this well will have Type B but Calcareous Shale (below top limestone stringer) is onlap terminated to Top Kujung on this well and we predited that we will not found limestone stringer as X-1 (fig.11)

3. Monitoring and checking are simultaneously done while drilling operation in real time log Resistivity characteristic (LWD) and cutting (on each additional 1 m) especially at the depth of 50-100 m before penetrating Kujung Top Formation. From the model (Resistivity and seismic), we predicted the rock cutting will show shale 100% above Top Kujung fig.12

The integration of all parameter and data to determine the top of Kujung Formation is proven correct. It is showed when drilling continues to the next hole with only 1 meter interval after penetrating the casing shoe loss circulation happens which is general characteristic of the Kujung Formation.
Conclusion

From the results of forward Resistivity model created for X Field, there are two log Resistivity characteristic: of Type A and Type B. In type A (X-2, X-4, X-6ST) there is a trend of gradual increasing Resistivity value 50-100 m before Kujung Top Formation for ± 1-3 ohmm, whereas in Type B (X-1) any trend of increase in value Resistivity is not exist.

The different characteristic pattern of these two log Resistivity is also related to the difference of seismic characteristic at the top of Kujung formation, i.e. the east side (X-1) Top Kujung is located at the Peak while the west side (X-2,X-4,X-6ST) is located at Trough. Most probably this difference is caused by the low and fall of sea level which effect to Kujung carbonate deposit. In Kujung fore-reef, the limestone ruins of Kujung core carbonate is controlled by sea high energy while in Kujung back-reef, it is controlled by low energy (lagoonal) so that characteristic is not found in fore-reef.

From discussion above, for the next subsequent wells drilled in the field "X", it is important to stress the position of sub-surface targets at Kujung Top Formation so that we are able to know what Resistivity model will be used (Type A or Type B) and integrate the analysis with other data during real time drilling operations (cutting rock sample and ROP).

Acknowledgements

We would like to thank BPMIGAS and Pertamina EP for permitting us to publish this work and we are indebted to PPGJ and Schlumberger for allowing us to write the paper. We also say thank you to Dody Sasonoko as a General Manager PPGJ Pertamina EP who contributed during various stages of the project.

References


Fig. 1 Field “X” Location at East Java - Indonesia

Fig. 2 Tectonic Regional North East Java Basin (Pertamina-Amerada Hess Joint Study, 1999)
Fig. 3 Stratigraphic column showing the main lithostratigraphic units within Field "X".

Fig. 4 Basemap Structure "X".
Fig. 5 The classification Log Resistivity based on the Increasing of Resistivity value 50-100 m above Top Fm.Kujung. In Type A gradual increasing value of Resistivity and no limestone stringer, whereas in Type B no gradual increasing value of Resistivity but fill up with calcareous shale and limestone stringer ± 50 m above Top Formation Kujung.

Fig. 6 Comparison of Lithology between Type A and Type B from rock cutting analysis. Type A show that limestone alternating with shale in Tuban Formation (50-100 m above Top Fm.Kujung), whereas in Type B no alternating limestones with shale in Tuban Formation.
Fig. 7 Synthetics Seismogram for Type A and Type B generated from wells X-2 and X-1 using wavelet Ricker 30 HZ.

Fig. 8 Differences between “Old and New Seismic Interpretation” after generated synthetics seismogram and correlated with log Resistivity analysis also rock cutting information, Top Formation Kujung is different “pick” in East and West side.
Fig.9 "Red dashed" which located on west structure "X" can be interpreted as the reef talus where the main substance is carbonate material however due to sea water high energy during the diagenesis of Kujung carbonate. Reef talus stacking on fore-reef Kujung and onlapping pattern along fore-reef Kujung (west side body)
Fig. 10 Position target of X-3TW, near X-1 and located on East side Structure X

Fig. 11 Plotting well X-3TW to seismic section showed that Top Limestone stringer is onlap to Top Kujung and based on the data we predicted the rock cutting on X-3TW will not found limestone stringer as X-1.
Fig. 12 Rock cutting from Well X-3TW fit with our prediction based on Resistivity analysis and seismic interpretation for Type B