Seismic to Geological Modeling Workflow, an Integrated Approache to Determine the Reservoir Quality of a Fractured Limestone: Oseil Field Example

Arie K. Lapulisa, Roy Andrianto & Anggoro S. Dradjat
CITIC Seram Energy Ltd., Indonesia

Summary

Natural fractured carbonate reservoir is extremely challenging in terms of reservoir characterization due to its high heterogeneity of reservoir property and also of its low oil recoveries. This paper will show how the integration of seismic data and well data had helped significantly for the well placement and also in the well completion stage.

The datasets that are available and being used in this process are 3D seismic, seismic Inversion, seismic attributes, conventional log and borehole image log. All these data are being utilized in an integrated way to characterize the fractures behavior of the reservoir.

Introduction

Oseil field is a naturally fractured carbonate heavy oil reservoir in folded thrust belts which presents extreme reservoir engineering and geological challenges and opportunities. These types of reservoirs are the extreme setting for large-scale high contrast and discontinuous reservoir properties. The presences of bottom water in conjunction with high viscosity oil result in low oil recoveries. Initial production stage experienced early water breakthrough, water cut rising and then stabilizing.

The reservoir in the Oseil field is the Jurassic Manusela Formation. Skeletal, oolitic limestones, deposited as a shallow water shoal, dominate the succession in the Oseil-1 and Oseil-4 area, and change to a muddier facies in the Oseil-2 area. In Oseil-1, Oseil-4 and East Nief- 1, the limestones were diagenetically altered to dolomite in discrete layers.Effective matrix porosity in all the Oseil wells is low. The Manusela Formation is however, extensively fractured on a macro and micro scale. The macro fractures provide both storage capacity and permeability. Intersection of macro fractures is required to achieve oil flow rates of hundreds of barrels per day.

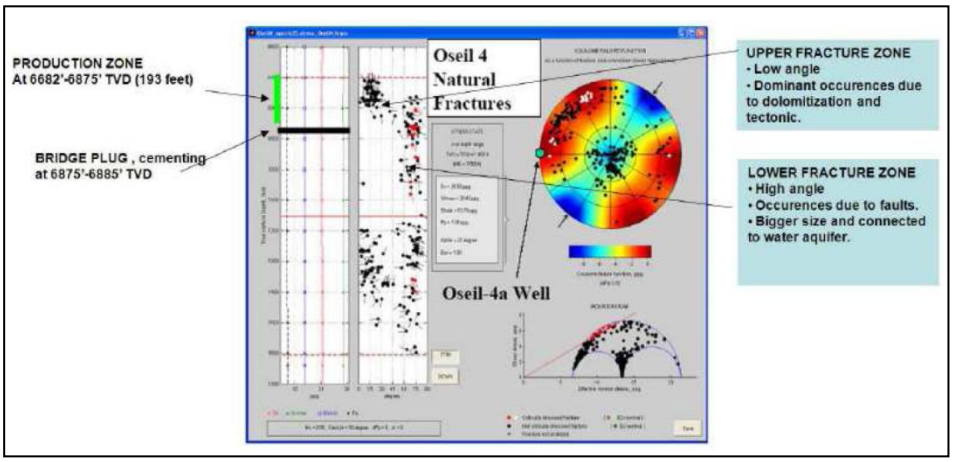


Figure 1. Output screen from GMI*MohrFracs indicating the likelihood of slip on natural fractures seen in image data collected in the Oseil-4 well

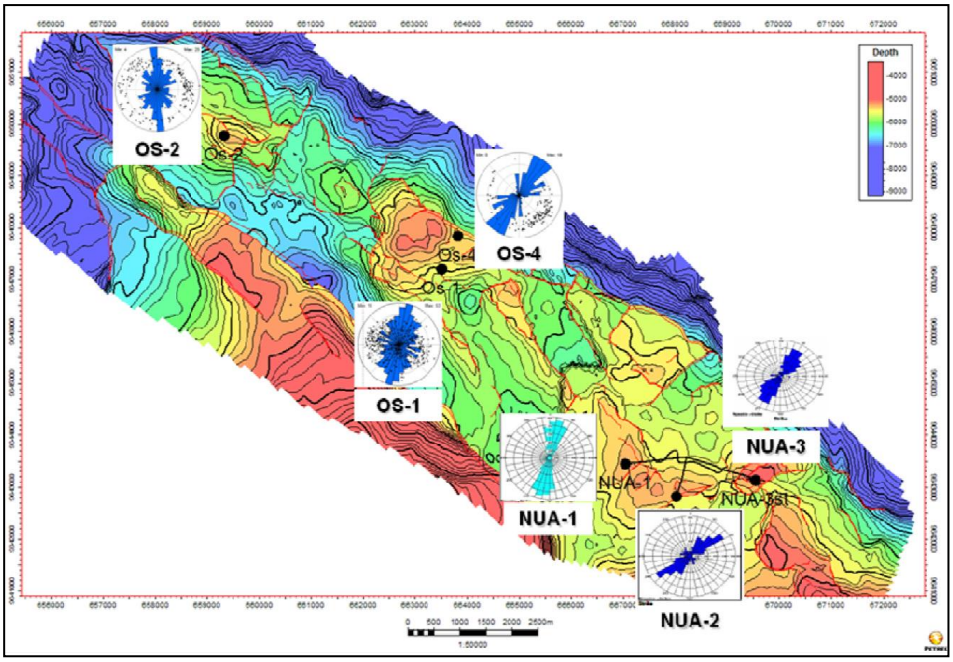


Figure 2. Manusela Depth Structure Map showing the fracture orientation of the 6 exploration wells.

The fracturing mechanism was related to tectonic and carbonates mineralization (dolomite). Manusela oolitic carbonate was developed during

basin extension, and it was followed by uplifting, (Fraser et al, 1993) mineralization and then marine transgression of Kola shale.

In the compression phase, stress generated were related to Australian movement which continue SW to NE direction starting in the age of late Miocene. As near surface of Manusela carbonate contains more dolomite mineral, which means easier to break compared with deeper carbonate, the near surface were fractures with low angle fracture as the rock were folded.

Extensional normal fault were dominated during development of Seram basin and extending to the end of Manusela sedimentation, high angle extensional fracture were developed. In compression phase basin inversion had happen and all normal faults reactivated to became reverse, create large high angle fractures and reopen existing fracture.

Two fracture systems were found in Oseil field, FMI log and dip meter data indicate distinct boundary (Fig 1 Oseil-4 dip meter). 100 feet upper part of Manusela carbonate zone is the zone dominated by low angle fracture and it is also the zone with high oil saturation. As they were low angle fracture, they created horizontal permeability and not connected to the aquifer. The deeper part is dominated by high angle fracture, which clearly found on logs and outcrops and this fracture having larger aperture, very high permeability and connects to the aquifer. As drilling the deeper part has high potential of hitting high angle fracture which are high risk of the well having high water cut, it is then recommended to drill the shallow part and avoiding the deeper part.

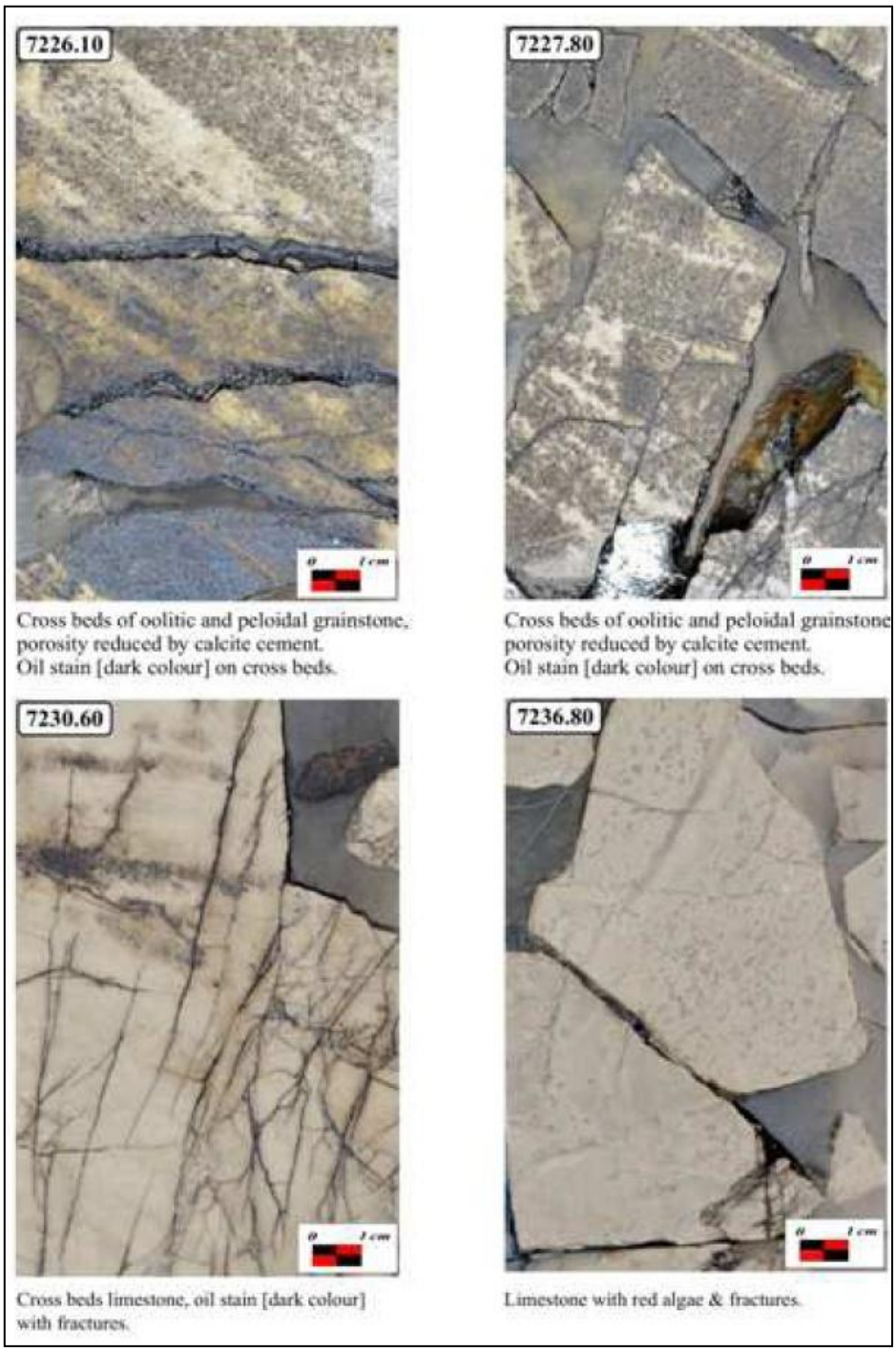


Figure 3. Close-up whole core photographs well NUA-3 of Manusela Formation Plate 2

Background & Workflow

One of the main challenges of this field is the fact that the matrix porosity of Manusela carbonate is very low, hence the quality of the reservoir rely heavily on the presence of fractures. On the other hand the early water break-through that happened in several wells that was mainly derived by the fractures and faults.

We need to characterize area where it have sufficient amount of fractures but must avoid those areas that have fractures connect to aquifers. By only utilizing well data, i.e conventional logs and borehole images, we are limited by a small localized area. Since the heterogeneity of this reservoir is very high, then a more regional approach to define the fractures characteristic distribution is required.

To have a more regional understanding of the fault, we have utilized our 3D seismic data by applying a Pre-Stack Anisotropy Inversion to detect the distribution of the fracture in this field. The next step is to utilize the information from this seismic data to simulate the dynamic behavior of the reservoir. A dual porosity permeability model was built by generating a Discrete Fracture Network (DFN) base on the combination of well data (mainly image interpretation) and the result of the Pre-Stack Seismic Anisotropy.

The result of the seismic anisotropy, 3D model building & simulation then was used to place new infill wells. During the testing & completion mode of the new drilled wells, all the well & seismic data are continuously being used to monitor the performance of the well. One of the very useful is the Ant-Tracking Attribute that was derived from the original 3D seismic data.

Well Based Fracture Analysis

There are 6 wells that have complete image data of this field. Base on the image interpretation, it can be seen that to the east the main orientation of the fractures is NNE-SSW while to the west it's tends to orient more to the NE-SW to E-W direction (Figure 2).

Core data are also available, and base on core, the apertures of the fractures was measured. From two wells, the aperture width of the fractures falls within range 0.00 mm – 5,5mm. While based on image data, the range of aperture width is between 0,00 to 0.57mm (Figure 3).

From the borehole image, there are several types of fractures/faults that can be classified (figure 4).

Below are the different types of fractures:

1. Conductive Continues Fracture (CCF),
2. Conductive Discontinues Fracture (CDF),
3. Conductive Micro Fracture (CMF),
4. Conductive Vuggy Discontinues Fracture,
5. Stylolites,
6. Vuggy Stylolites,
7. Faults.

Pre-stack Seismic Anisotropy for Fracture Detection

Studied on reservoir fractures intensity in Oseil field using pre stack 3D seismic data are based on P-wave reflection amplitude. P-wave seismic amplitude exhibiting variable attenuation with difference fracture orientation have an anisotropy orientation, which is captured by the seismic anisotropy as a result of this process Fractures especially vertical one will generate seismic anisotropy. By analyzing the seismic anisotropy we can detect the most possible area where high intensity fracture occurs. The end result of this process is a Fracture Intensity cube.

There are several steps were used to generate fracture intensity cube from well and 3D seismic data. First performed reserved amplitude processing, well and seismic correlation, rockphysical modeling of fractured reservoir based on rock physical studies were built to model seismic anisotropy.

Then four azimuth seismic data sets were achieved by selecting and combining seismic data set in the range of 0-2000 meters offset and 0-180 degree azimuth; and calculated different azimuth amplitudes and analyzed their azimuth variations.

The next step is the spatial distribution of amplitude azimuth ellipse that represents amplitude decay along different direction. This anisotropy

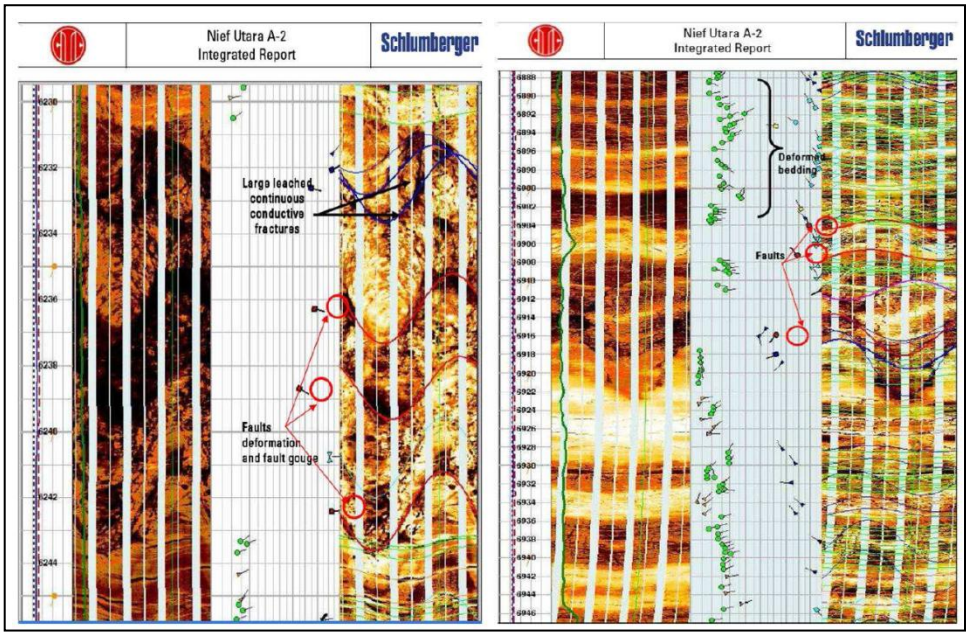


Figure 4. An example image log from NUA-2 wells showing different type of fractures.

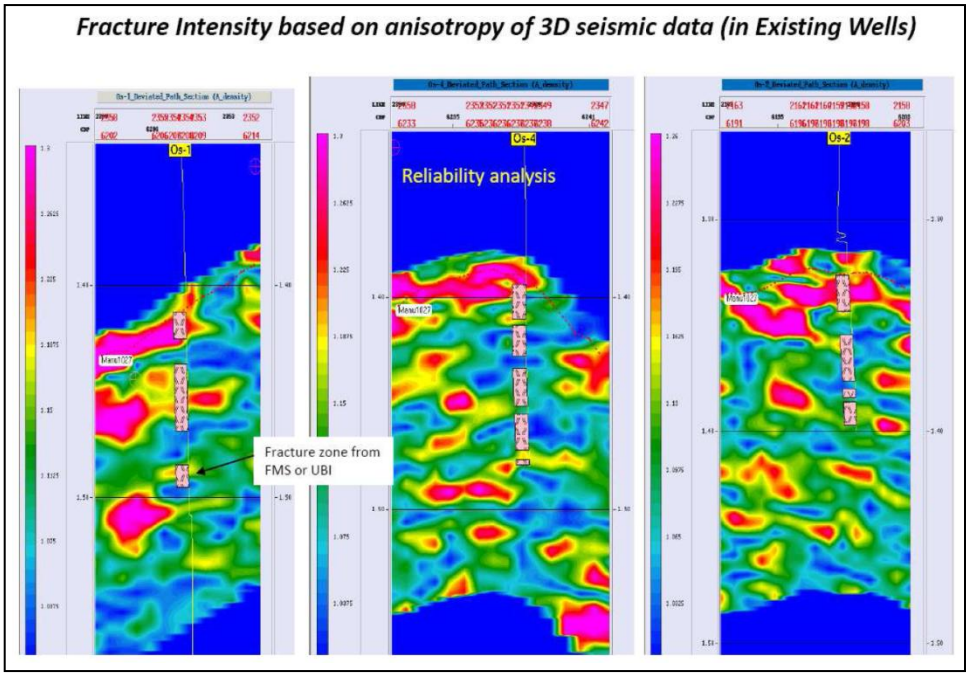


Figure 5. Fracture intensity correlation between wells and seismic relatively match.

curvature attribute then finally converted to fracture intensity cube.

Geological Modeling

3D geological modeling is an integrated reservoir study combining seismic data, well data, geological information and reservoir data. This model will be used later for in-place hydrocarbon volume estimation of the field and also upscaled for simulation purposes.

For a fractured reservoir, there is additional step required in order to generate a dual porosity permeability

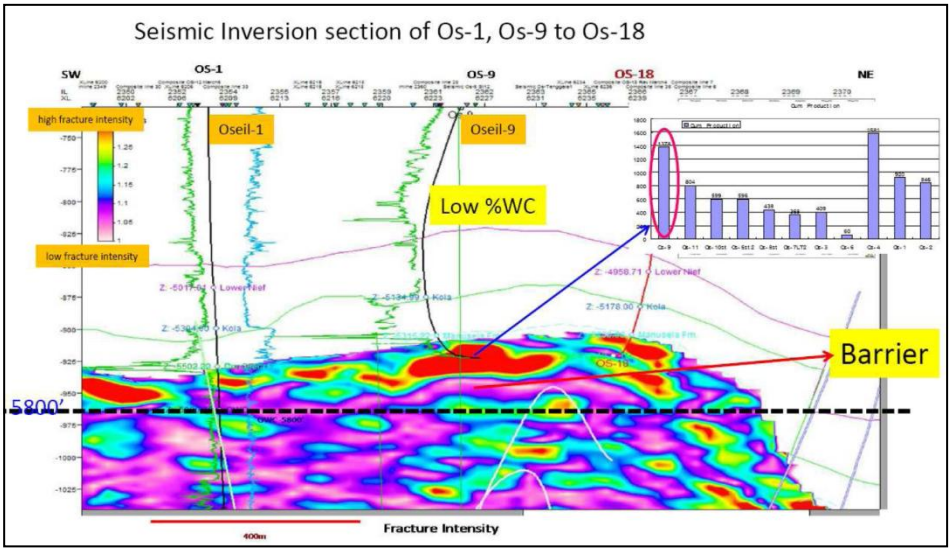


Figure 6. A seismic section of the fracture intensity cube along Os-1, Os-9 to Os-18, showing wells penetrating high intensity fracture zone.

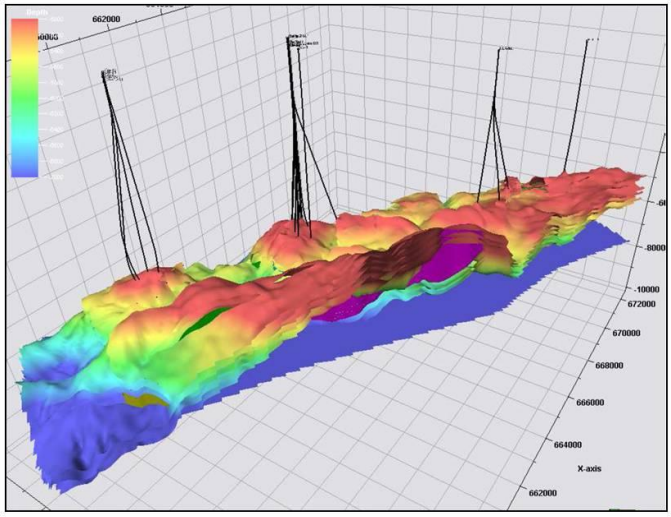


Figure 7. Modeled Reservoir Top Horizons in Oseil field showing the structural faremwork.

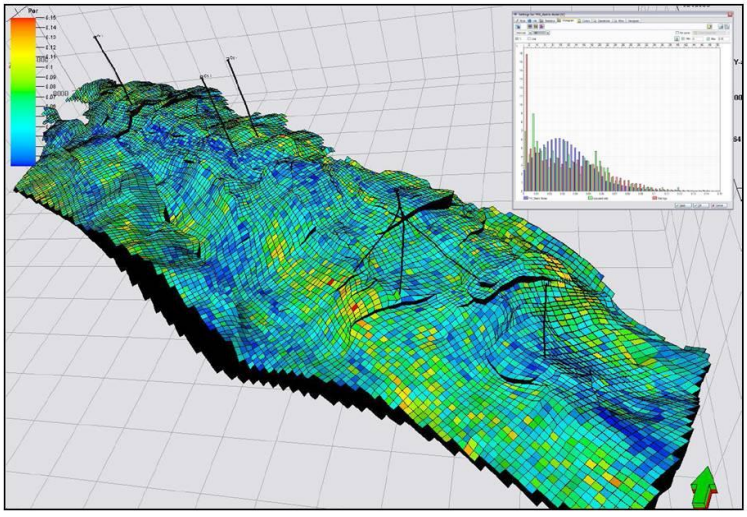


Figure 8. The matrix porosity model of the Manusela Reservoir.

model. A discrete fracture network (DFN) was built to create simulation properties to predict the reservoir dynamic behavior.

A 3D fine scale geological model was developed integrating all available data. The faults from seismic were modeled in 3D after defining their interrelations. The depth converted seismic horizons were incorporated into the 3D model, and together with the already existing fault then were used to construct the structural framework of the 3D model. (Figure 7).

The structural framework then was populated by petrophyscial properties to define the matrix property of the reservoir. They are the porosity matrix porosity, matrix permeability and water saturation. (Figure 8).

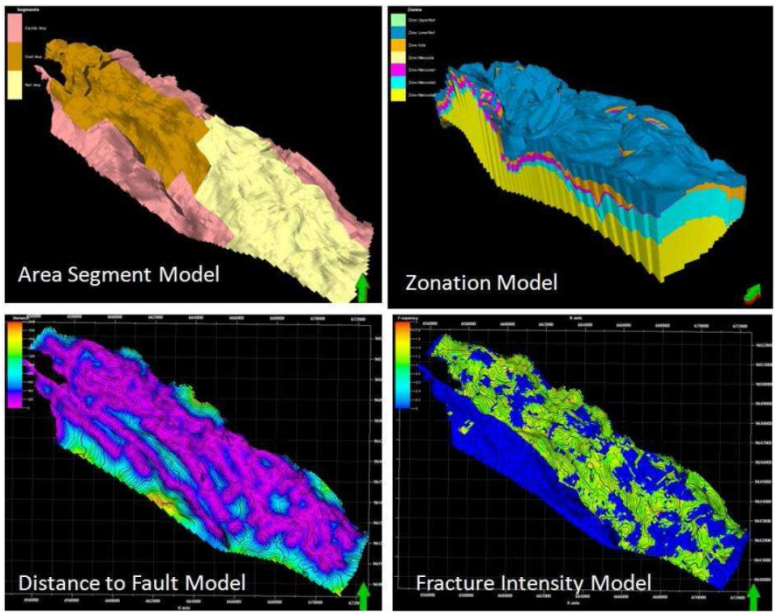


Figure 9. Several fracture drivers base on different parameters.

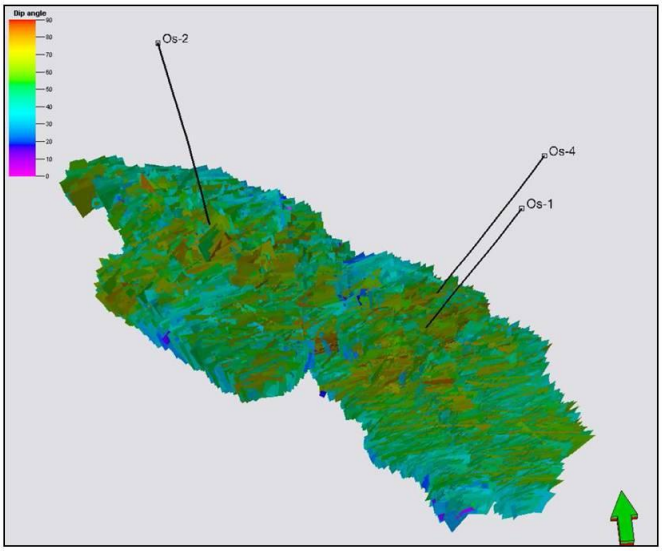


Figure 10. DFN result of Oseil field using the fracture intensity cube as the distribution control.

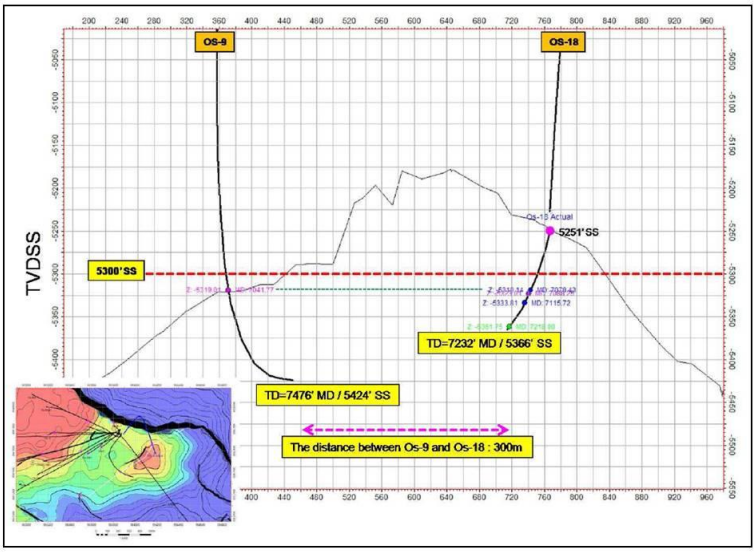


Figure 11. Section of Manusela Depth structure from Oseil-9 to Oseil-18.

Prior the discrete network building, model parameters need to be defined since they are the object that will control the intensity of the fracture. This is called the fracture drivers.

Discrete Fracture Network Generation

A discrete fracture network (DFN) was built to create simulation properties to predict the reservoir behavior. There

Well Placement

Base on this integrated study, three development wells were proposed and drilled in 2010-2011. The new wells produced oil with initial rate as much

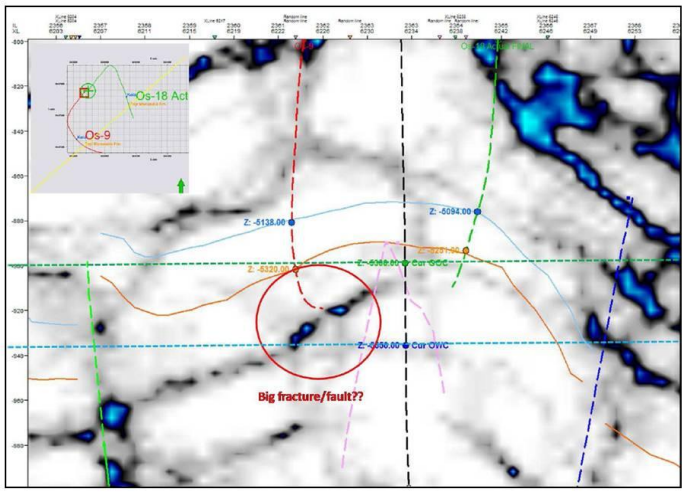


Figure 12. Section of An-Track cube showing that Os-18 might possibly hit a major fracture at the bottom of the well.

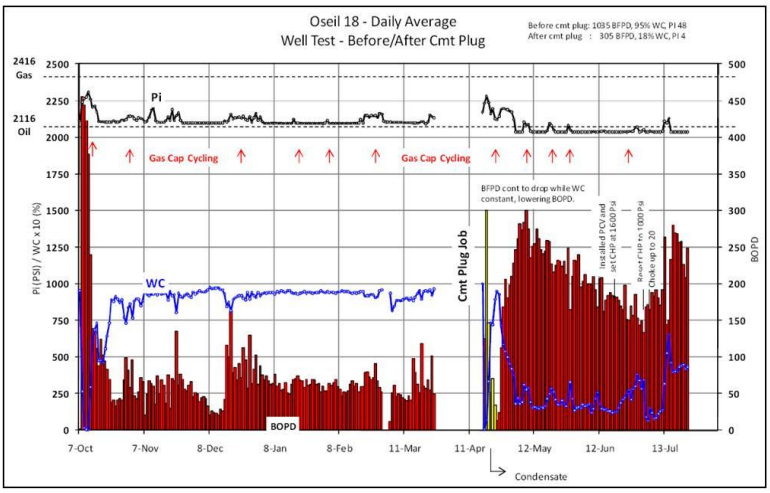


Figure 13. Oseil-18 Daily Average Well Test – Before/After Cement Plug.

Generally fracture drivers are made base on assumption. For instance fractures are more intense along the fault zone, hence the distance to fault model is built. In our case, we already have the Fracture Intensity cube from the Pre-Stack Seismic Anisotropy. By integrating the fracture intensity cube in the 3D model, we can have a more reliable distribution of the fractures (Figure 9).

are 6 wells with image interpretation. The fracture interpretation based on image log is the main input for the DFN parameter setting. In addition to the image interpretation, the fracture intensity cube was used as a secondary variable to populate the density of the fracture. A linear relationship was taken from the intensity value from seismic and the density of fracture from wells to ensure that the distribution of fracture will honor the well data.

as 300-500 bopd. It was proven that the study had successfully characterized the quality of the reservoir by detecting the high intensity fracture.

However, one of the well (Oseil-18) experienced an early water break-trough. This is quite unexpected because the TD of this well is shallower 67 ft SS with the nearest well Oseil-9 with distance less than 300m (Figure 9).

We suspect there is sort of connection of Os-18 to aquifer which is not happening with nearby Os-9.

From the original seismic amplitude, no fault was interpreted so the other possibility is the existence of major fracture that connects Os-18 to bottom water.

Seismic Attribute (Ant-Tracking)

By applying the Ant-tracking workflow to the 3D seismic cube, we had successfully recognized the zone where a vertical fracture exist and act as a conduit for the water (Figure 10).

This zone then later was plugged by cement to prevent or minimize bottom water produced by the well. By this approach, the water cut was reduced from 95% up until 18 % (Figure 11).

Conclusion

The integration of well data and seismic data in the reservoir characterization of a fractured carbonate reservoir is beneficial especially to have a comprehensive understanding of the subsurface.

Maximizing information of each data source will enable reliable decision making and adding value to the data itself.

All the study results have been compared with the actual drilling & production result and have shown consistency between them.