Introduction

Oseil field locates at northeast of Seram Island, Indonesia, which covered with mountains. The structure is a long axis anticline which is dislocated by a series of NW-SE thrust and transgression distorted faults, several traps developed on the main anticline. Fracture is the unique pathway for hydrocarbon migration and reservoir. But in recent exploration and development, several wells didn't show good production, which partly due to no clear recognition of the high angle fracture. Thus, the accurate and detailed description for the fractured carbonate is an urgent task needed to be solved.

The main productive layer is Manusela carbonate reservoir in Callovian-Oxford, Jurassic. Manusela formation is widespread in area coverage and extend several thousand meters in vertical, which can be divided into four zones: the fracture zone, middle fracture zone, lower stylolite zone and lowest tight zone.

The seismic acquisition and process work have encountered great difficulties in the relief surface condition cause the poor quality of seismic data with low SNR and 15Hz main frequency (Fig.1). Traditional technique can't reach the accuracy of tiny fault & micro-fracture and also highly depend on the quality of post-stack seismic data. How to solve the low quality seismic problem and how to analysis the reliability of the prediction result, which is a formidable difficulty worth to be solving.

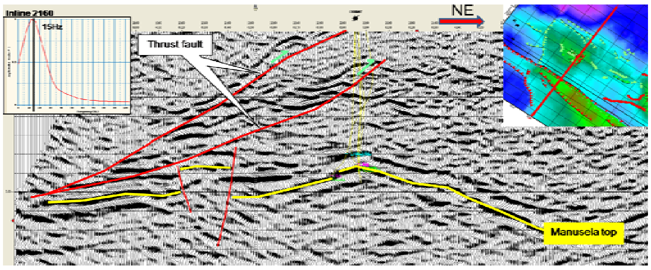

Figure 1 *Seismic profile inline 2160, Oseil2 block. Left part is spectrum analysis in Manusela, the right is location map of the seismic line*

Method and/or Theory

In order to solve the series of difficulties and avoid the uncertainties, we select the rock-physics forward modeling method (Assad and Tatham,1992) combined with the pre-stack seismic anisotropy analysis technique (Feng *Shen*, *Sierra,and etc, 2002)*to describe the fractured reservoir feature. The main workflow is as following figure shows:

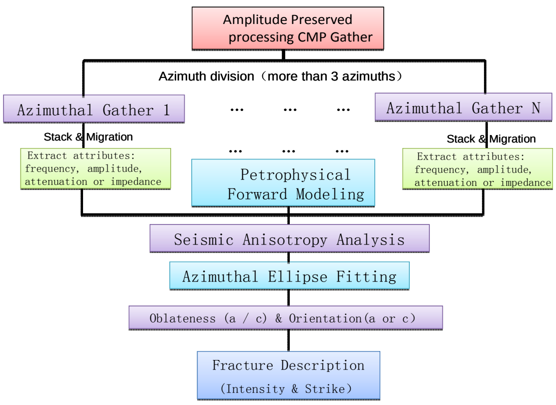

Figure 2 *The main workflow for fractured reservoir description*

Examples

Petrophysical anisotropy forward modeling

A series of petrophysical forward modeling work have been carried out in order to make clear the seismic response induced by the fracture. At the beginning, simulate the seismic reflection at different fracture developed depth, calculate the anisotropy value, compare it with the FMI logging data and summarize the regulation. Then, modeling seismic anisotropy of different wells in the selected formation, compare the result with the logs and geological recognition, then judge the feasibility of seismic based fracture description.

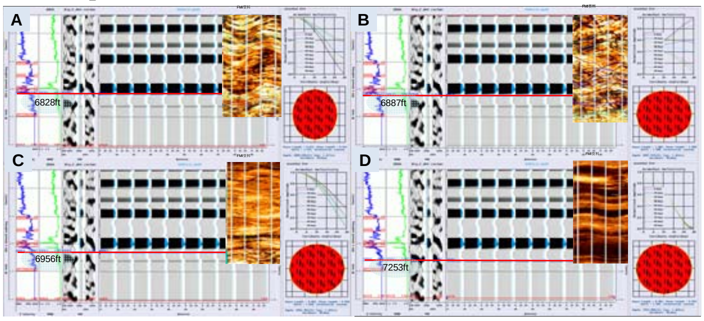

Figure 3 *Petrophysical forward modeling in Oseil 4 at different depth. A. anisotropy modeling at depth 6828ft; B. anisotropy modeling at depth 6887ft; C. anisotropy modeling at depth 6956ft; D. anisotropy modeling at depth 7253ft;Fractured reservoir can induce the seismic anisotropy, as the left part of A, B, C and D show differentiation of azimuthal amplitude.*

From the anisotropy forward modeling maps at different depth in Oseil4(Fig.3), we can conclude that with the depth increment from Manusela top, FMI indicates the degree of fracture intensity is getting weaker with depth, while the seismic anisotropy having the same trend at the same depth. It is suggested that the fracture information could be reflected from the seismic, and the seismic response is highly consistent with the well condition.

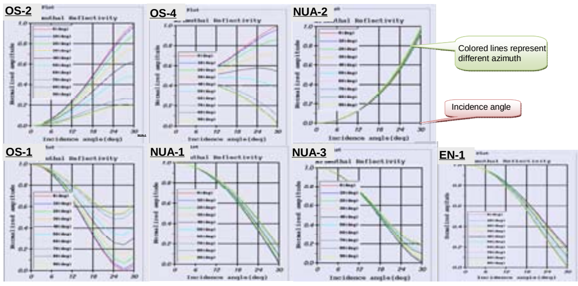

Figure 4 *Anisotropy modeling result of 7 wells in Oseil oilfield. Fractured reservoir can induce the seismic anisotropy, as the differentiation of azimuthal amplitude shown.*

High-angled macro fracture is more developed in Oseil2 block and Oseil1/4 area which separately locate at northwest and the middle of the study region, but Nief-Utara block (including NUA1,2,3 and EN1)develops few micro-fractures in small scale which is related with coarse grain limestone by analyzing FMI and UBI data from the 7 known wells(Fig.4). The forward modeling also has the similar result: Oseil1, 2, 4 show strong seismic anisotropy in different azimuth, but not so obvious in NUA1, 2, 3 and EN1.The differentiation of the fracture in every well can be identified, and it is consistent with the geological recognition. Thus, fractured reservoir description by geophysical methods is a practical way.

Azimuthal seismic process

The CMP gather must to be divided in order to get the azimuthal data. The offset of pre-stack seismic is from 18m to 3558m, the fold is inhomogeneous distribution with average 16 times fold (as Fig.5), but the effective offset is only from 200m to 2000m. CMP gather can be divided into four azimuthal areas: 0° -30° ,30° -60° ,60° -110° and 125° -180° . The fold time of each azimuthal gather is quite even, about 7 to 8 times in average. By partly stacked and migrated the azimuthal data, we got the azimuthal stack-migrated seismic cubes for the further fracture study.

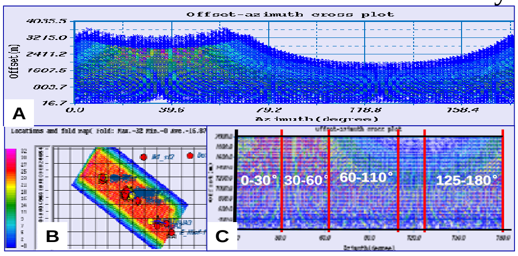

Figure 5 *CMP gather analysis. A: pre-stack gather analysis; B: folds distribution map; C: azimuthal division on effective offset.*

Fracture intensity detection

Laboratory experiments show that the dynamic parameters (such as amplitude, frequency, phase and etc.) are much more sensitive than the kinematic parameters (as travel time and velocity) for the fracture detection when the seismic wave propagates in the fractured media. The accuracy and sensitivity of the result can be greatly enhanced, if we choose the azimuthal seismic attributes other than original P wave seismic data for seismic anisotropy analysis. Combined the study for the attenuation-absorption attribute, amplitude and frequency attribute of the azimuthal cubes, the amplitude attribute especially relative impedance is more robust and effective than other attributes for fracture detection in this low SNR situation.

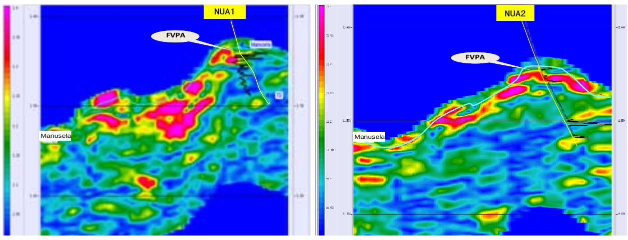

Figure 6 *Fracture Intensity profile in NUA-1 and NUA-2.*

Thrust tectonic movements impact and improved the Manusela fractured carbonate reservoir after the Jurassic. From the anisotropy analysis, the high anisotropy areas developed at the top of Manusela in vertical, which may related with the much tight tensile stress concentrated at Manusela top when thrusts happened. While, the deeper part's anisotropy is not so strong may due to the weaker tensile stress or the closed/ filled fracture. When we compared FVPA with anisotropy intensity, they matched quite well which indicates the high reliability of the predicted result（as Fig.6）.

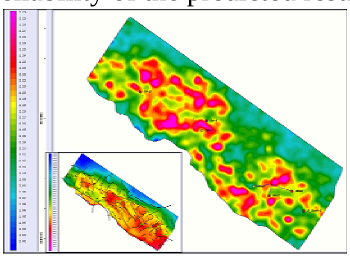

Figure 7 *Fracture intensity distribution map in Manusela formation top. Lower left is the structure map of Manusela top.*

The fractured reservoir distribution (Fig.7) has the following characteristics:

①The fracture most developing area located in relative structure high, mid-north of the workblock (near Os2 & Os1/4 area), but not the highest point in Nief-Utara block. It is suggested that fracture distribution is related to the tectonics, but not controlled by it only. The main lithology in Oseil area is medium-fine grain limestone, while coarse-grained limestone with high porosity appeared in Nief-Utara area. It is inferred that the lithology maybe another important factor for the fracture development.

②There is some similarity between fracture and the fault distribution, which is suggested that the macro fault can influence the fracture development in certain extent. But the difference between them indicaes that high angled opening fracture (HTI media) can be detected by seismic anisotropy analysis. The methodology is not so sensitive for the closed or filled cracks. To some extent, the fracture predicted by anisotropy analysis is effective fracture.

Strike description of the fractured reservoir

The workblock located in the foreland thrust belt, encountered several thrust movement in NE-SW direction, so that the stress field is relative complicated. Under the complex influence during different period, the fracture strike is inclined to be dual direction and the major orientation is NEE (Fig.8). But the strike in Nief-Utara is single orientated and the major one is NNE. Compared with FMI data in the well location, the seismic based fracture orientation show high credibility and reliability.

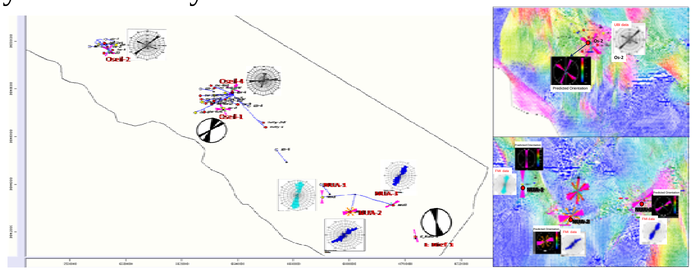

Figure 8 *Fracture strike comparison map between anisotropy analysis and FMI log. Left part rose map in well location represent the anisotropy analysis result; Schmidt map is from the FMI log. Right part is the fracture description in Oseil2 and Nief-Utara block, warm color indicates strong fracture intensity, "sticks" indicate the strike of the fracture.*

Conclusions

The seismic anisotropy analysis technology for fractured carbonate reservoir description under the amplitude preserved and low SNR seismic can be effective to avoid the uncertainty from the different post-stack processing methods. In 2010, Seram oilfield newly drilled wells Oseil12 and Oseil 18 which designed under the supervision of the fracture prediction with the production of 300 and 500 BOPD separately. The methodology indicates high credibility and reliability for fractured carbonate reservoir description and has a broad application prospects for exploring other types of fractured reservoir.

Acknowledgements

The author would like to acknowledge all the CITIC Seram and LandOcean staffs whose work contributed to this paper.

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