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Fracture prediction verified by well results and forward modeling

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Summary

Over the last few years Lukoil has published the results of two exhaustive studies into the problem of fracture detection. Several conventional fracture prediction methods were tested as well as a new type of pre-stack depth migration called Dulplex Wave Migration (DWM). We concluded that the DWM technique was the most reliable method for fracture permeability detection (Khromova et al., 2011). Lukoil planned a 2010 drilling program for horizontal wells based on DWM technology and this paper will report on the results of that 2010 drilling program. Two horizontal wells were drilled into a limestone interval and extensive well log measurements were taken. The well results illustrate that the location of the fracture systems as predicted by DWM were accurate to within 25 metres. The DWM amplitude maps and well log results will be shown to illustrate the success of this fracture prediction technique. Also, the ability to use these actual well results, along with full wave forward modelling, and DWM technology to push the boundaries of reservoir characterization prediction using an integrated seismic-based methodology is investigated.

Introduction

This paper is a further report on the work published in the January, 2011 edition of First Break entitled “Comparison of seismic-based methods for fracture permeability prediction” (Khromova et al, 2011). In that paper we studied fracture prediction methods based on reflection amplitude, reflection curvature and its derivatives, coherency cube, spectral decomposition, ant tracking technology, azimuthal anisotropy of P-wave velocity, and duplex wave migration (DWM) amplitude cube analysis. We concluded that the DWM technique was the most reliable method for fracture permeability detection. Lukoil planned a 2010 drilling program for horizontal wells based on DWM technology and this paper will report on the results of that 2010 drilling program.

Two horizontal wells were drilled into a limestone interval and extensive well log measurements were taken. The well results illustrate that the location of the fracture systems as predicted by DWM were accurate to within 25 metres. The DWM amplitude maps and well log results will be shown to illustrate the success of the fracture prediction technique. The next stage of our investigation endeavours to understand what level of reservoir chararcterization information can be realistically obtained using seismic-based methods.

For example, we would like to know whether or not we can use DWM to answer fundamental questions about the type of fluid that fills the fractures – is it oil or water? Also, can we perform a variant of AVA analysis on vertical geo-bodies using DWM? Many papers have been written recently that attest to the strong absorption characteristics of fluid filled fractures – can we use DWM technology to observe different levels of absorption? Also, we suspect that strong levels of mode conversion in the area of the fracture systems is likely to occur – can we use DWM to measure local shear wave velocities. To answer these questions, and more, we need to utilize full wave elastic forward modelling, DWM technology, and the detailed well log measurements.

Method

Our main purpose is to use an integrated technologies approach to establish a clear linkage between seismic-based methods and enhanced reservoir characterization. This work can only be done as part of an ongoing reservoir engineering exploitation project. We need to have already used seismic-based methods to predict the location, intensity and permeability of fracture systems. Then we need to have drilled the horizontal wells and carried out extensive logging measurements. At that point a complete correlation of the predictive capabilities of the seismic-based technologies with the well results can be performed.

Next, we need to test the robustness of the process to predict more subtle reservoir characteristics. We start with detailed well log measurements from 400 metres of horizontal drilling within a limestone reservoir. We can then use this known well log information to build a realistic model of the actual reservoir. High end full wave elastic forward modelling can then be used to generate synthetic data that simulates the response of seismic waves to these various geologic conditions. We then subject this synthetic data to the same set of DWM processing procedures as were used on the original data. We then are in a position to verify that the variations we see on the DWM amplitude map generated from the real data can actually be explained using full wave forward modelling. Further to this, we can make subtle changes to the known model and redo the forward modelling process to find out whether or not these changes in the reservoir model can actually be detected using seismic-based methods such as DWM.

The DWM technology is well described in previously mentioned paper (Khromova et al, 2011) and others given in the reference list. Also, full wave forward modelling for elastic, anisotropic, and absorptive media of all levels of complexity have been described in several previous papers (Kostyukevych, 2009). In this paper we would like to emphasize the importance of using a processes in which a specific set of technologies are used in an integrated way to enable the use of seismic-based methods to enhance the ability of the reservoir engineer to accurately understand the flow patterns in the fracture systems to optimize recovery rates. Figure 1 provides a conceptual image of how this feedback loop process is intended to work.

Examples:

The DWM amplitude map that was used to design the 2010 Lukoil drilling program is illustrated in figure 2. The well log results for Well A are shown in figure 3. Note the clear indication of three major fracture systems encountered along the horizontal bore hole path and the prediction of these fracture systems on the DWM amplitude map.

Conclusions

This paper reports on the actual well results that were predicted using DWM technology that was described in an earlier paper (Khromova et al, 2011). Further, we have investigated the ability to utilize a set of specific fracture detection related technologies including DWM amplitude cubes, full wave forward modelling and actual well results to draw direct linkages between seismic-based methods and enhanced reservoir characterization. This work is intended to push the boundaries of seismic-based methods to contribute to enhanced recovery by enabling the creation of more detailed and accurate reservoir models. We conclude that geophysicists must make a sustained effort to communicate with reservoir engineers through the provision of information that is relevant to the exploitation process.

Acknowledgements

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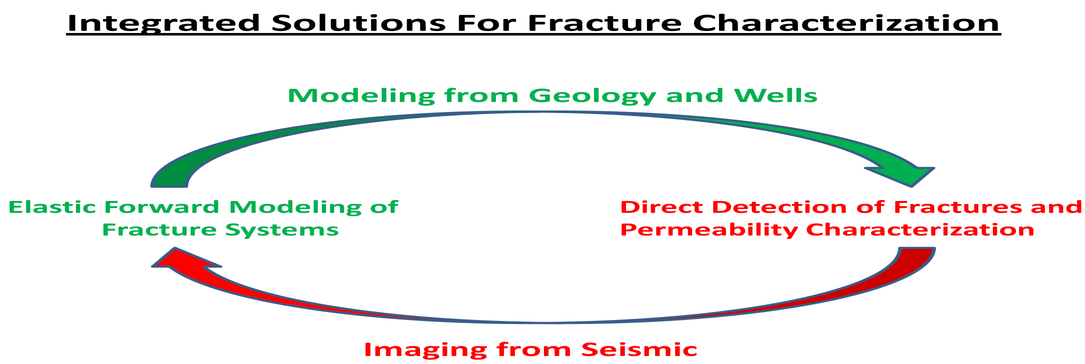

Figure 1: Integrated technologies to establish a clear linkage between seismic-based methods and enhanced reservoir characterization

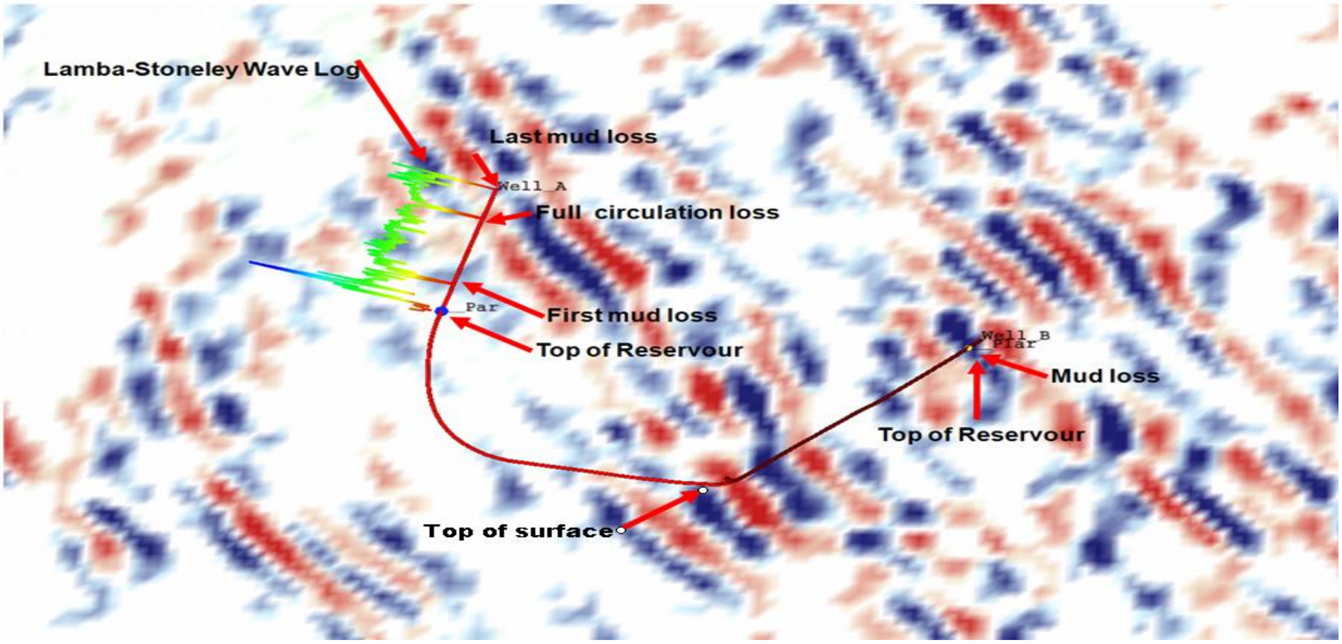

Figure 2: DWM amplitude map used to determine horizontal drilling locations for the 2010 drilling program. Curve of Lamba-Stoneley Wave's Amplitude is shown from Top of Reservoir along Wellbore A.

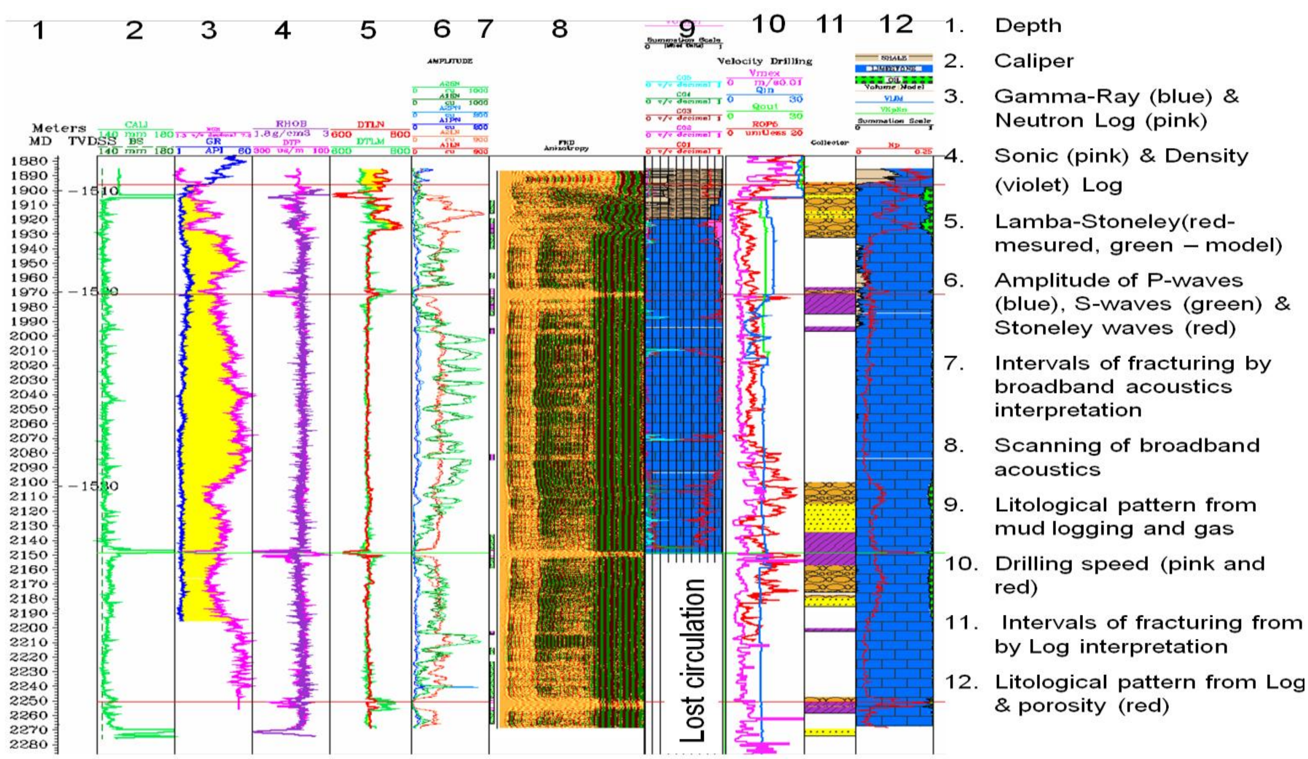

Figure 3: Well log results from horizontal well A. Note that the actual depth of the horizontal well bore within the limestone interval is indicated to the right of the well bore length measurement.