FRACTURED RESERVOIRS: USING VSPs TO BRIDGE THE SCALE GAP BETWEEN IMAGE LOGS AND SEISMIC

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SUMMARY

The optimization of field development requires an understanding of the structural geometry of the reservoir over a range of scales. Where complex fracture networks exist the integration of VSP data with image logs and surface data leads to a more robust understanding of the reservoir. This study utilized specialist reprocessing of VSP data that were acquired in two wells to interpret structural features and determine their geometries. The reprocessing involved undertaking 3-component Image Point Transform (IPT), polarization analysis and dip determination The interpreted VSP reflectors were validated and integrated with the analysis of image logs and the interpretation of surface seismic data. The integration of these data constrains the structural model that can then be applied in areas away from well control and provides a starting point for seismic interpretation in areas where structural geometries are poorly imaged on surface seismic.

INTRODUCTION

This study was undertaken for a low porosity fractured carbonate reservoir with a complex fracture network resulting from several phases of tectonic activity. Optimization of field development necessitates understanding the geometry and permeability of complex fracture networks across several orders of magnitude. Typically, characterization of the geometry of the fracture network involves integration of fractures imaged in the well bore using image logs with lower resolution but wider coverage surface seismic. In this study area the integration was problematic due to:

1. The complexity of the image log signature. The image log showed large numbers of faults and fractures with a great variability in dip and dip direction and it was unclear how the small scale fracturing seen in the well bore related to seismic scale features and
2. the variably poor quality seismic data made interpretation of seismic scale faults difficult.

For these reasons specialist VSP processing techniques were used to identify and map reflectors in 3D. The results were integrated with image logs highlighting seismically significant elements of planes identified within the dipmeter. Moreover it provided a starting point for the interpretation of faults on surface seismic and helped to constrain the structural model to be used in interpretation away from well control.

VSP REPROCESSING AND IMAGING

In the initial study, data from two wells were reprocessed with the specific objectives of:

- imaging fracture systems and other geological features, displaying a contrast in reflectivity and to map these in 3D space and
- producing geometric information on any structures identified that could be integrated with the interpretation of the well log information and the seismic interpretation.

The ability to meet these objectives is clearly dependent on the limitations imposed by the frequency content of the data, the number of components recorded (i.e. single or three component data) and the available geometries between source points, well and receiver string.

The VSP data from one well consisted of one zero offset and three far offset data sets with the far offsets located approximately 1600 metres from the well head. Whilst the available dataset from the other well consisted of one zero offset and one far offset source approximately 2625 metres from the well head. The VSP data for both wells were acquired using a Vibrator source, with the data being recorded using 3-component geophone receiver tools with 20 metres between levels. Signal-to-noise ratio of the data was high, with the raw data having well defined and therefore easily identifiable first onsets and all three components were used in the reprocessing of the VSP data sets.

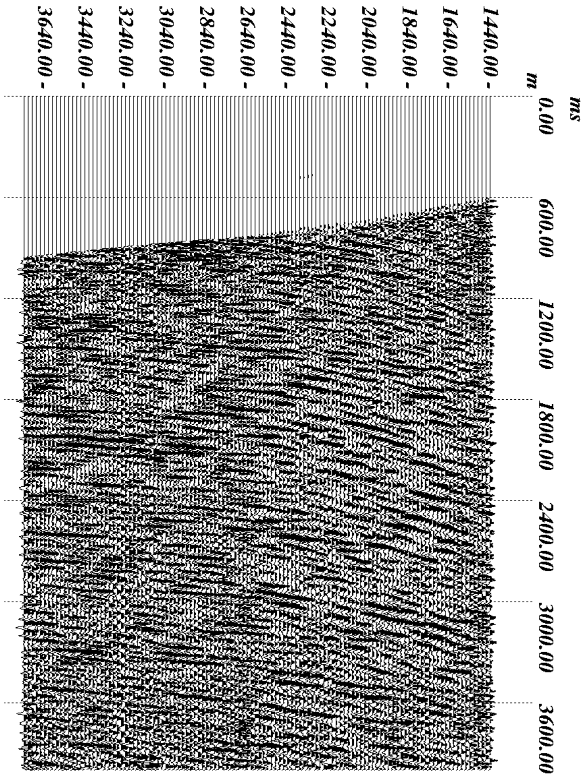

Figure 1: Z-Component data following standard processing.

The processing was carried out in two stages, in the first, a relatively standard sequence was undertaken including, time picking, rotation of the horizontal components; frequency analysis, velocity determination and wavefield separation. On completion of the first stage, whilst a large amount of reflected energy, with interfering reflections, was visible it was largely masked by non-coherent back scattered energy and the principal reflectors could not be seen clearly (Figure 1).

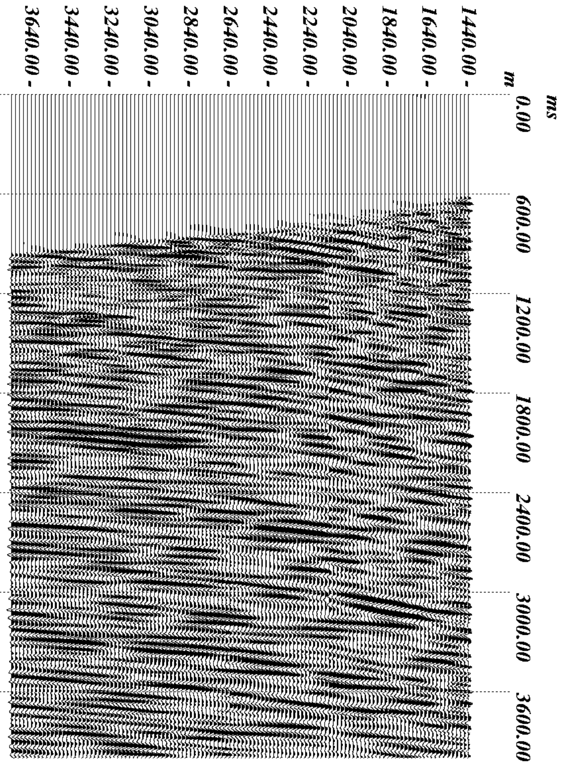

Figure 2: Inverse IPT transformed Z-Component data.

The second processing stage uses leading edge processing capabilities to separate reflected energy from back-scattered energy and to determine the spatial position of the reflectors in 3D space. This phase involved 3-component Image Point Transform (IPT), polarization analysis and dip determination. The IPT was used both as an interpretation tool and to enhance weak reflections. Following IPT processing, the resultant sections were inverse transformed (Figure 2). The difference in these two images (Figures 1 and 2) is striking, following the removal of back scattered source generated noise, with reflectors more clearly visible. This approach permitted the determination of both the 3D position and local orientation of the observed reflectors. Polarisation analysis allowed an estimate of the azimuth of the events to be determined. The dip information for individual reflectors was then determined by additional interpretative modeling techniques following polarisation processing.

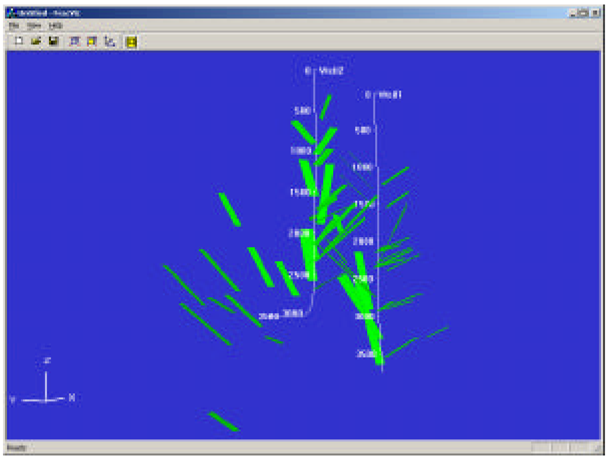

Figure 3: Visualisation of interpreted reflector elements.

The interpretation of the data was based upon the ability to identify and locate reflectors within the sections following IPT processing. Although the IPT processing enables reflectors to be identified, it does not provide information on the direction to the reflector, this is provided by polarisation analysis. Reflectors are interpreted from the processed data by fitting hyperbolae corresponding to potential reflectors on the processed sections, with their directions being determined by simultaneously fitting these on several VSP sections acquired with different azimuths and searching through the polarisation processed data.

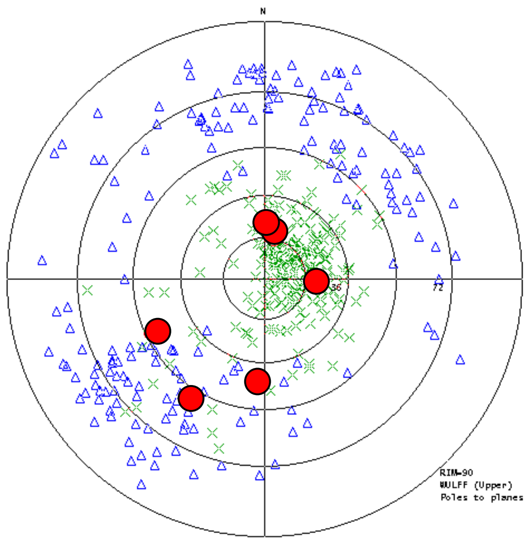

Figure 4: Stereonet comparing planes identified by VSP processing (large dots) and image log analysis (faults and fractures shown as open triangles, bedding planes as crosses) for the reservoir section in one of the study wells.

INTEGRATION

The results of the specialist VSP processing were validated by comparing identified reflectors against the results of image log analysis. From Figures 3 and 4 it can be seen that the results appear to show that two reflector families have been identified from the VSP data.

- Low angle planes interpreted as bedding and sub-parallel to bedding planes identified from the image log analysis. In depth, the low angle VSP reflectors correspond to well bedded intervals in the wellbore as determined from the image log.
- High angle planes interpreted as faults and sub-parallel to one of the two major fracture sets identified by image log analysis. In depth these high angle VSP reflectors correspond

to the zones of intense fracturing, suggesting that seismic scale faults represent an envelope of intensely fractured carbonate at the wellbore scale. The complexity of image-log fracture distributions within seismic scale fault zones make reconstructing large scale fault geometry extremely problematic without the additional information provided by VSP processing.

VSP reflector elements can be loaded into seismic interpretation workstations and integrated with the well and surface seismic information. This process is illustrated in Figure 5 where

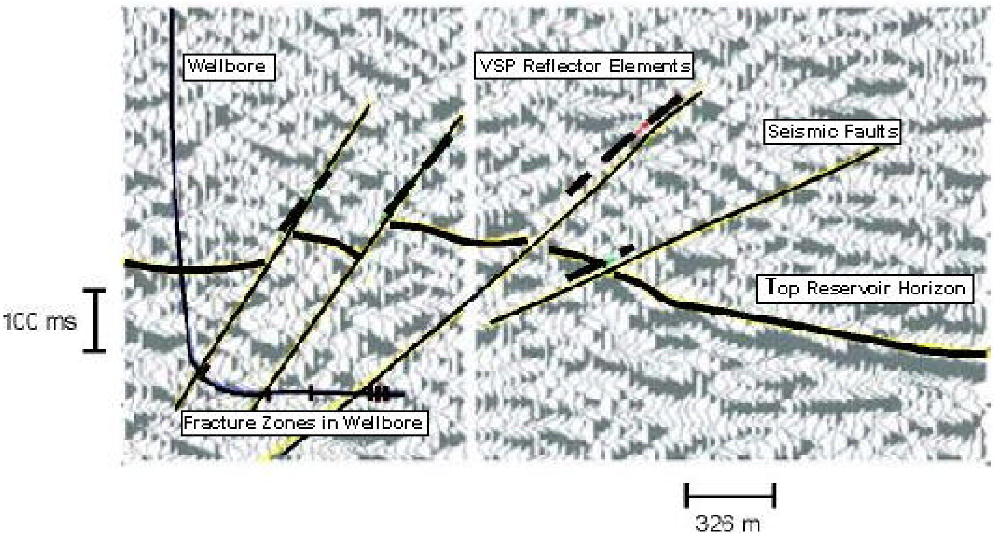

Figure 5: Seismic line through well showing how integration of seismic (solid lines), VSP (dashed lines) and well-derived information enables a well-constrained subsurface structural model to be produced.

VSP reflector elements that do not intersect the wellbore can be correlated with fracture zones identified by image log analysis. Furthermore, integration of this fault geometry with the Top reservoir reflection on the surface seismic strongly suggests that the two faults on the left, closest to the wellbore (Figure 5) are extensional or strike slip faults, whilst the lower angle faults on the right of this section are probably thrust faults. This provides a constrained structural model that can be used to interpret seismic geometries away from well control.

CONCLUSIONS

The results of specialist reprocessing of the VSP data were integrated with the image log data and seismic interpretation contributing to the understanding of the reservoir. The study shows:

- That VSP is a powerful tool for fractured reservoir characterization. Integration with the image log highlights elements of image log analysis that are important at the seismic scale.
- It provides starting points for seismic interpretation in areas where structural geometries are poorly imaged on surface seismic.
- Integration of image log, VSP and surface seismic constrains structural model that can then be applied in areas away from well control.

The reflector elements derived from the VSP processing added significant detail and enhanced resolution to the structural model of the reservoir. The reprocessing of the 2D VSP data sets indicated that structural features can be imaged and located in 3D space. As a consequence of this study further specialist VSP processing is being undertaken for other parts of the field.