Teasing out the faults within the Permian Carbonate using an azimuth-rich seismic data – a Thailand case study

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SUMMARY

Land seismic data was acquired over a Permian carbonate field with a wide azimuth acquisition template, such that the recorded 3D seismic data is inherently source-to-detector azimuth rich. This geometry allows the data to be subdivided into azimuth sectors, so that stacks of different "illumination" directions can be generated. Subsurface faults and families of fractures are generally better characterized when illuminated normal to their dip, i.e. head on against the faults.

The fault and fracture family patterns from each of the sorted shot-to-receiver azimuth sets portray a slightly different illumination of the continuity and development of these faults as shown in time-slices.

The paper will describe the azimuth sorting process, followed by the methodology to sharpen the fault pattern within each dataset. The acquisition of seismic data in a wide-azimuth configuration has shown that with appropriate processing, it is possible to illuminate subtle faulting and fractures quite distinctively within the targeted hard rock reservoir.

Key words: Carbonate, fault, fracture, wide-azimuth, illumination.

INTRODUCTION

Petroleum concession 4/2551/95, comprising onshore exploration Block L15/50, was awarded to Salamander Energy on the 21st January 2008. The block area covers 3,934 sq km, and is located 25 km west of Khon Kaen in NE Thailand. The block lies within the Loei – Petchabun Foldbelt, in the more uplifted, western part of the Khorat Plateau. Hydrocarbon exploration in the area has been undertaken by several companies since the 1970's, culminating in the drilling of the Dao Ruang-1 well in 1993, by Texaco. The well targeted a pronounced anticlinal feature, cored with Permian Pha Nok Khao carbonate, which is the primary reservoir at the Sin Phu Horm and Nam Phong fields, 50-70 km to the northeast and east. The well encountered good gas shows in the carbonate, particularly within discrete zones that appeared to be fractured, and also within volcanic intervals deeper in the section. The section was subsequently tested but flowed gas only at minor, sub commercial rates.

In 2009, Salamander Energy acquired 3D seismic data in a wide-azimuth configuration to further delineate the structure and to try and detect enhanced porosity and fracture development within the Pha Nok Khao carbonates, essential for flowing commercial quantities of gas. Tight rock reservoirs such as limestone often produce more from secondary fracture porosity than from primary porosity. Consequently, mapping fracture density and direction is important to identify sweet spots. Because of in-situ stress, many fractures are aligned and are often close to vertical, rendering the reservoir azimuthally anisotropic. This azimuthal anisotropy can be captured in wide azimuth recorded seismic data, which will exhibit similar azimuthal variations. By using appropriate azimuthal processing it is possible to illuminate subtle faulting and fractures quite distinctively within the targeted hard rock reservoir.

METHOD AND RESULTS

Azimuthally varying velocity is a common phenomenon in wide azimuth land 3D seismic data. The anisotropy can be an effect of vertically aligned fractures and/or unequal horizontal stresses. When azimuthal velocity anisotropy is not dealt with in seismic processing, the seismic image is degraded. Azimuthal velocity analysis allows the measurement and correction of azimuthal velocity anisotropy effects in the data. The result is an improved seismic image including better reflector continuity and higher stratigraphic resolution.

Conventional seismic processing groups traces from different source-receiver pairs that share a common midpoint into a gather that is then stacked. This allows the effects of different source-receiver offsets and azimuths to mix, degrading image quality and losing valuable information about azimuthal changes in seismic attributes that relate to rock properties like fracturing and stress. A better approach, developed in the last decade or so, is to use offset vector tiling (OVT) methodology. OVT-sorted data groups similar offsets and azimuths, thereby optimally preserving offset and azimuth integrity. Offset vector tiles can be extracted for near, mid- and far offsets. Sorting and processing the data in this manner allows for robust methods of interpolating for missed shots, statics processing, noise attenuation, data migration and azimuthal analysis. New imaging and analysis tools can then be used for the extraction of fracture information from the subsurface.

Azimuthal processing of the 3D seismic was tested using azimuth sectoring versus the OVT method. Figure A shows a comparison of the two methods. The OVT method causes less primary reflection damage during noise attenuation, and common midpoint cells within the offset vector tiles are better populated before migration, yielding a better migrated image.

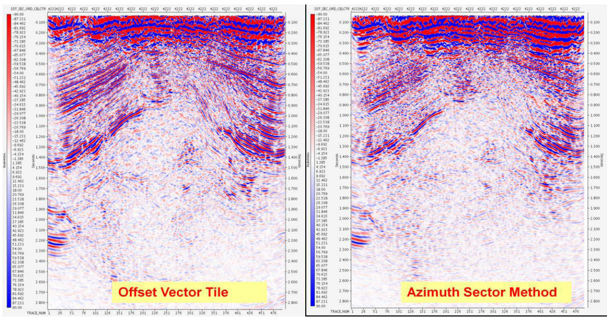

Figure A. OVT processing vs azimuth sectoring

After the Wide Azimuth (WAZ) seismic processing where the final data are sorted into the 4 Azimuthal sectors a fault/fracture tracking technique was applied to characterize and visualize the fault patterns. Figure B shows a seismic profile from the 2D data with conventional processing with structure and faults interpretation. The crestal part of the structure is interpreted as heavily faulted, and hence the WAZ azimuthal sector separations should illuminate and emphasize the faults better from different angles of view.

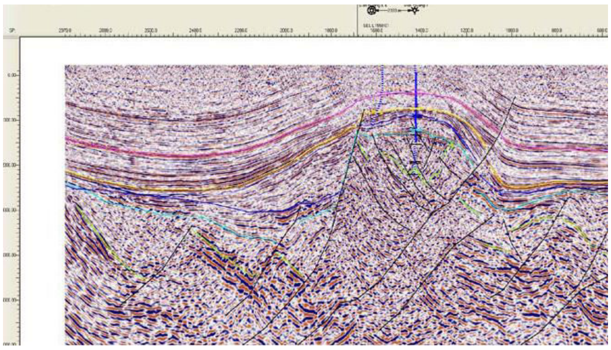
Figure B. NW(left)-SE 2D semi-regional seismic line through Dao Ruang-1 drilled in 1993. Note the increased intensity of faulting within the core of the Dao Ruang structure.

Figure C shows a seismic profile through the core of the Dao Ruang structure illuminated from the different azimuth sectors. Visually it is possible to observe differences in events and discontinuities.

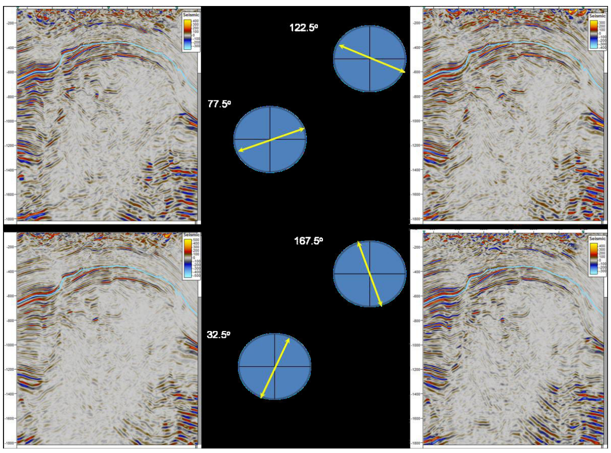

Figure C. Azimuthally processed seismic profiles using the OVT method.

Figure D shows the same profiles as figure C after ant-tracking. Figure E shows a composite of the four various fault families interpreted from the ant-tracking.

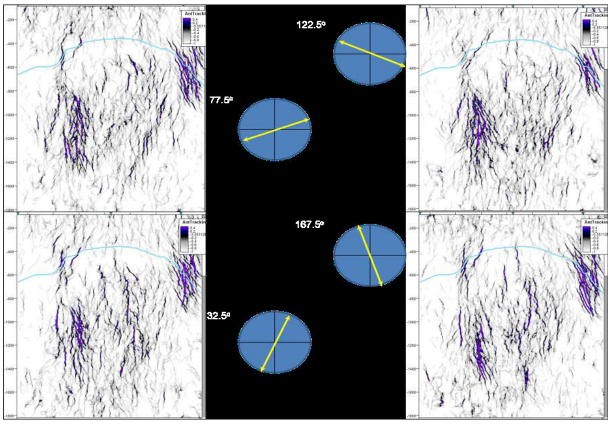

Figure D. Profiles through the four azimuth sectors, after variance (coherency) and ant-tracking analysis.

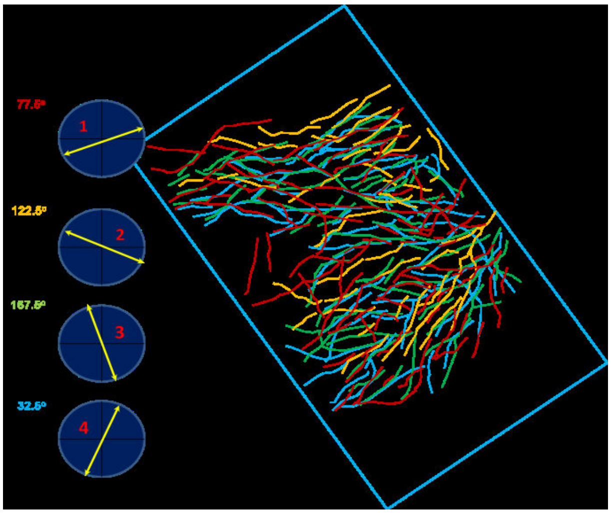

Figure E. Composite interpretation of the faulting system illuminated by the 4 different Azimuth sets.

CONCLUSIONS

The L15/50 Land 3D survey with shots and receiver lines in wide azimuth, orthogonal orientation provided the basis for Wide Azimuth processing (WAZ).

The WAZ processing technique using Offset Vector Tiles (OVT) proved to be useful in yielding optimum migrated images for fault analysis.

The Ant-tracking on each of the 4 azimuthal sector migrated seismic shows definite faulting/fracturing emphasis according to the azimuthal angle range.

By tying in the azimuthal interpretation with the geomechanical analysis from Dao Ruang-1, it has been possible to identify areas of the Dao Ruang structure where open fault and fracture networks may be preferentially developed.

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