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Interpretation of natural fractures from the traveltime variation with source-receiver azimuth in the Alberta Foothills

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Summary

Fracture analyses from 3D P-wave data were conducted for the Cabin Creek overthrust area in the Alberta Foothills. Mapping event traveltime differences on prestack-migrated, limited source-receiver azimuth sections is a new developed method of fracture characterization. Good fold and azimuth/offset distribution allowed extension of the method to include cross-correlation of common-azimuth stacked data for both shallow and deep events. A second method applied was azimuthal traveltime inversion, based on moveout ellipticity. By using two different wide-azimuth processing techniques, the objective was to determine if the fracture model can be realized when some of the most critical parameters (matrix velocity and symmetry axis direction) are unknown. The orientations predicted are consistent within dipping Cretaceous strata, and correlate with fracture orientations from well data. The symmetry axis direction rotates with depth, and a fluid contact was interpreted within a Cretaceous fold. Analysis for sub-horizontal Jurassic, Paleozoic and Cambrian events showed both similarities and differences in the results.

Introduction

In azimuthally anisotropic media, the moveout velocity varies with azimuth even if the layer is horizontal and homogeneous. For fracture analysis, this concept is particularly important for a qualitative description of fracture orientation and relative density. The horizontal velocity is higher for waves travelling parallel to the fractures, than for waves travelling perpendicular to fractures. Interpretation of fractures is derived from the theory that intensity and orientation of azimuthal anisotropy are related to the geometry and mechanics of fractures: orientation, dimensions, spacing, compliance, fluid type and saturation.

Within Western Canada sedimentary basin, the contemporary stress trajectories are useful in predicting the orientation of fractures. In general, below depths of about 350 m (*Warren and Cooper,* 2009) or 500 m (*Bell et al.,* 2009), fractures are expected to be vertical and parallel to the maximum horizontal stress direction. As every seismic technique for fracture prediction relies on the assumption that fractures are vertical, the precision of the results depends on how accurate is this critical approximation.

Figure 1 shows the Cabin Creek area situated within the central Alberta Rocky Mountain Foothills, near the easternmost segment of the Rocky Mountains fold and thrust belt (left), and the stratigraphic column used in the interpretation of seismic data (right). Within this area of thrust-dominated structures, potential sandstone reservoirs are in the Cardium, Dunvegan, Luscar and Kootney Formations, while the Nordegg and Wabamun formations contain carbonate reservoirs.

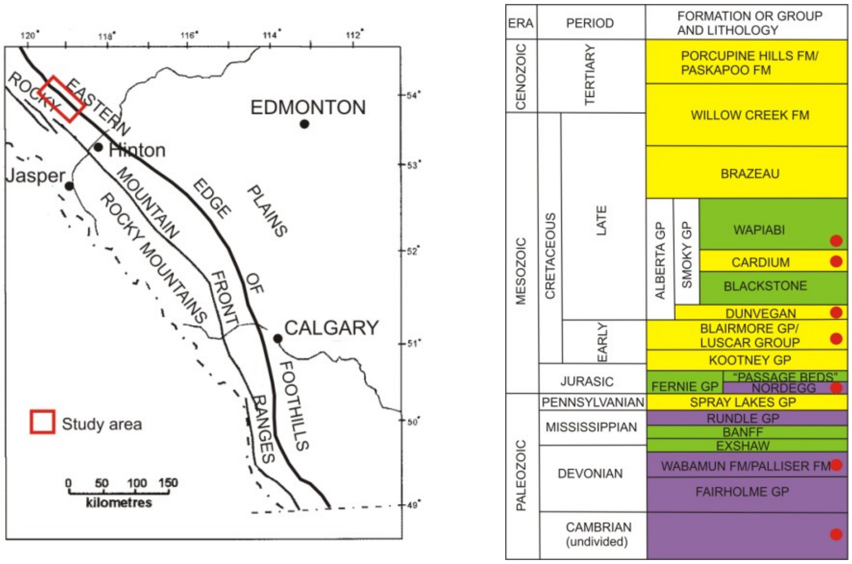


Figure 1: Approximate location of the study area (left), and the Alberta Foothills generalized stratigraphic column used in the interpretation, modified after *AGAT Laboratories* (right). Sandstones are displayed in yellow, shales in green, and carbonates in purple. The red dots represent the formation tops interpreted in the seismic data.

Fracture interpretation

Two seismic methods were used to estimate fracture parameters from the Cabin Creek data. The first method estimates the orientation and density of fractures by quantifying the traveltime differences for two perpendicular directions, parallel to the geological dip and strike orientations, respectively. The second method estimates fracture parameters from the inversion of the reflection traveltime moveout (*Jenner, 2001*), which is azimuthally variable.

Figure 2 shows the general style of deformation with imbricate thrust sheets on two interpreted seismic lines extracted from the seismic survey.

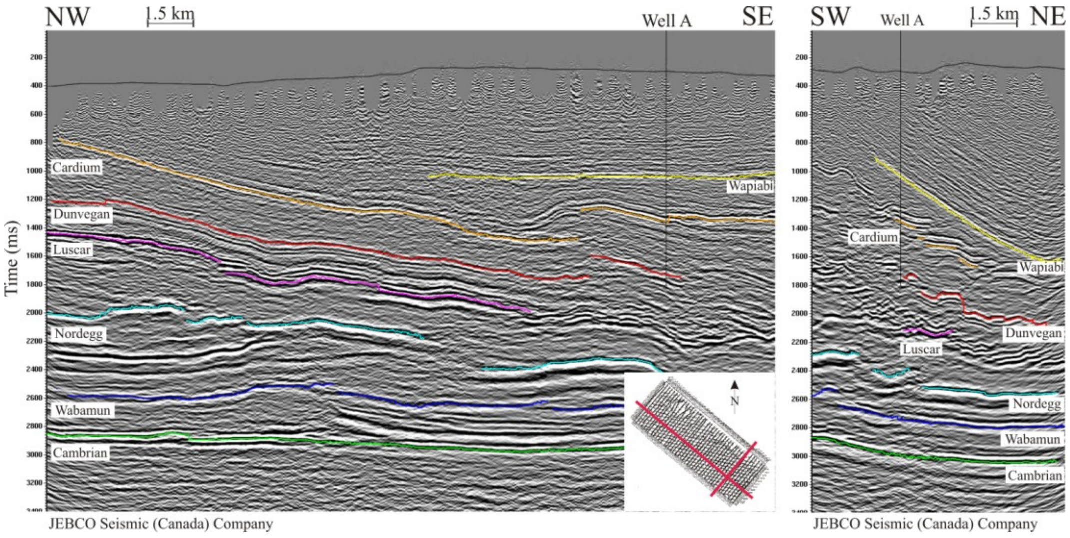


Figure 2: Interpreted crossline and inline showing the structural style, with their positions shown in the inset. The formation tops are displayed below each interpreted horizon, and the distance scales are shown at the top. The vertical exaggeration is approximately 2x.

Figure 3 show expanded views of two seismic images through Well A for the dip azimuth (left) and strike azimuth (right) volumes.

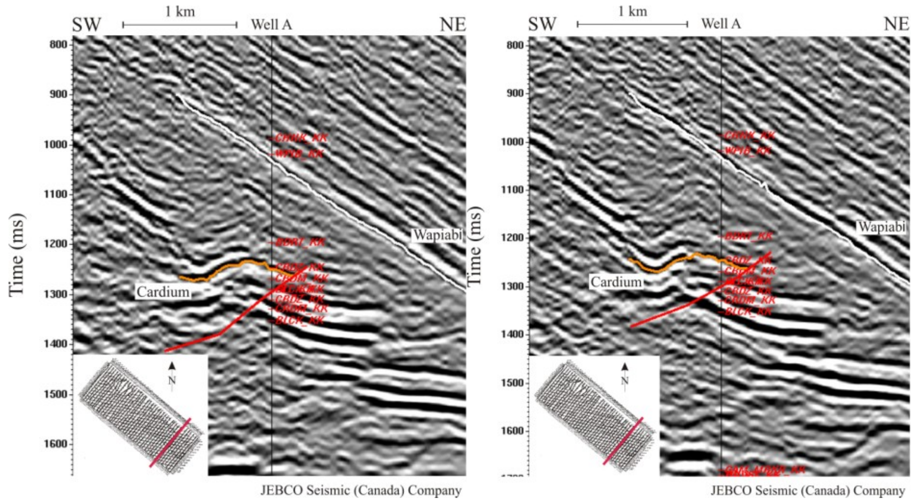


Figure 3: Close-up of the Cardium structure (in orange) interpreted on the dip azimuth data (left) and strike azimuth data (right), showing the repetition of the Cardium Formation. The interpreted Wapiabi Formation top is shown in white, while the fault carrying the Cardium strata is displayed in red. The inset maps shows the seismic line position.

The isochron map in Figure 4 (left) was generated by subtracting the event time differences of strata above the Wapiabi top from the time differences measured at the Cardium top. The traveltime differences between dip and strike directions are predominantly negative, indicating that the orientation of the fast velocity is parallel to the geological dip direction (type 1 fractures). This is in close agreement with the fracture measurements from image log at Well A, which is located within the centre of this area. The simplified fracture model is shown in Figure 4 (right), showing areas above the forelimb and crest of the Cardium fold with dominant fractures oriented SW-NE.

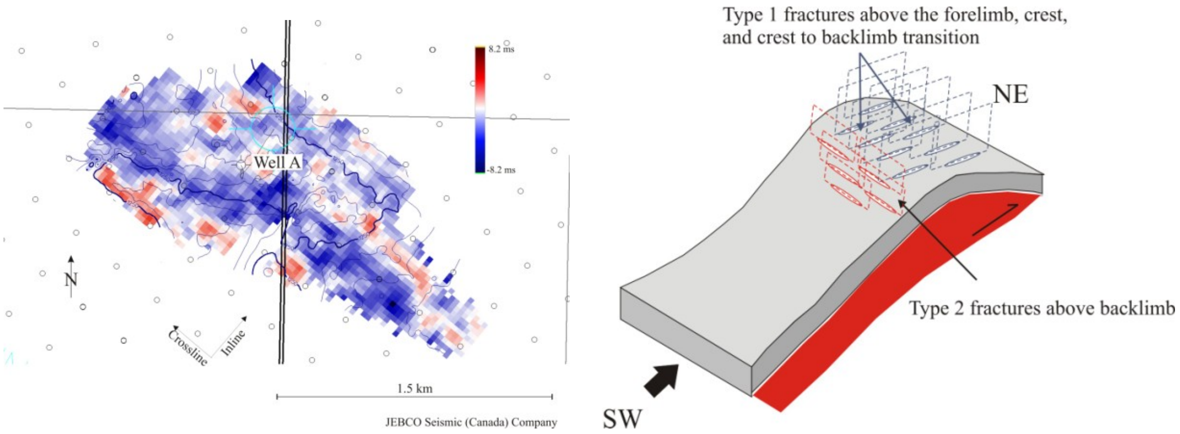
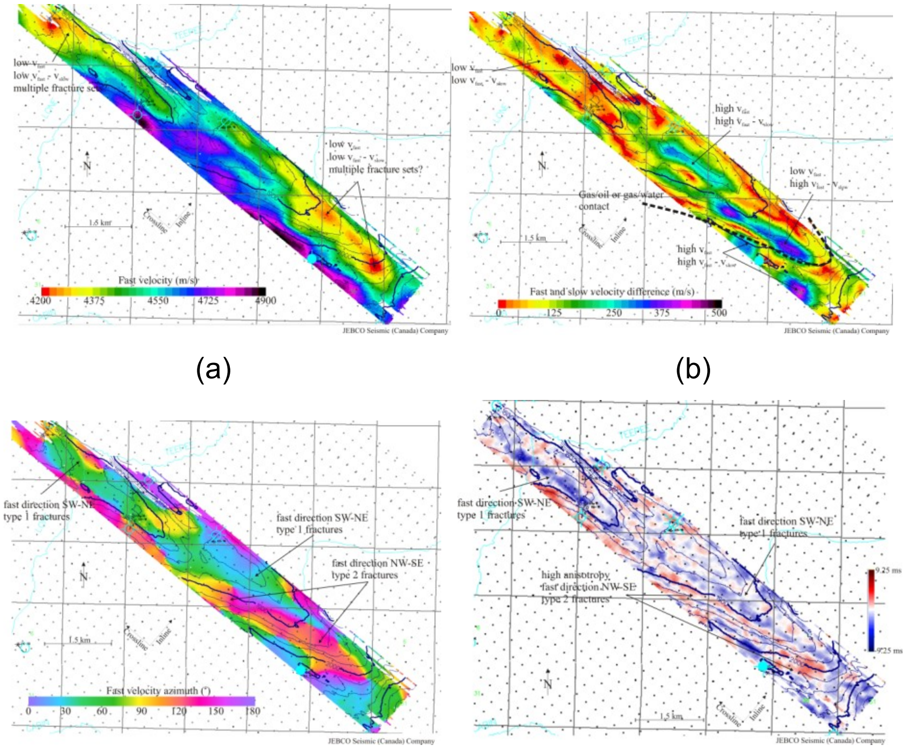


Figure 4: Isochron map reflecting the dip and strike event traveltime difference between the Wapiabi and Cardium reflections (left), and the interpreted fracture pattern (right).

Figure 5 shows the interval fast velocity, the fast and slow velocity difference, the fast velocity azimuth, and the time difference isochron map for the Dunvegan Formation (a, b, c, and d, respectively). Within the Dunvegan fold, type 1 fractures developed on the crestal area in multiple sets toward the NW, and in a single set toward the SE, transitioning to type 2 fractures on the backlimb. Predictions on the type of fluid within the porous system were made based on Thomsen's theory of equivalent media, which considers that the medium containing the fractures is permeable. Therefore, the interaction of the pore space with fractures is very important (*Thomsen,* 2002). The interpretation of the observed fast and slow velocities in comparison to velocities predicted by the theory permitted to establish a possible fluid limit within the Dunvegan fold.



(a) (b)

(c) (d)

Figure 5: Fast interval velocity (a), fast and slow velocity difference (b), fast velocity azimuth (c), and time difference isochron map for the Dunvegan strata (d). The velocity and distance scales are shown below, and the time difference scale on the right. Blue contours show the top of the Luscar Formation time structure.

Conclusions

The Cabin Creek study demonstrates that predictions about the orientation and possibly density and fluid infill of the fractures can be obtained from azimuthal moveout measurements even in very complex deformed geological settings such as the Rocky Mountain Foothills. The fracture patterns determined from dip and strike event traveltime differences are in general similar to the models determined from the velocity ellipse. In addition, the cross correlation method applied to dip and strike stack data for two areas with deformed Cardium strata, and the sub-horizontal Cambrian event, respectively, showed results consistent with findings from the other two methods.

Acknowledgements

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References

Bell, J.S., Price, P.R., and McLellan, P.J., 2009. In-situ Stress in the Western Canada Sedimentary Basin, Geological Atlas of the Western Canada Sedimentary Basin (WCSB).

Jenner, E., 2001. Azimuthal anisotropy of 3-D compressional wave seismic data, Weyburn field, Saskatchewan, Canada, Ph.D. Thesis, Colorado School of Mines, Golden, CO, United States, 197 p.

Thomsen, L., 2002. Understanding seismic anisotropy in exploration and exploitation, 2002 Distinguished Instructor Short Course, Distinguished Instructor Series, No. 5, p. 3-27.

Warren, M., and Cooper, M., 2009. Structural geology for geophysical interpreters, Course notes.