Analysis of Time-lapse Multicomponent Seismic Data from a Potash Mining Area in Saskatchewan, Canada*

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Search and Discovery Article #41275 (2014)*
Posted February 25, 2014

*Adapted from extended abstract prepared in conjunction with presentation at CSPG/CSEG/CWLS GeoConvention 2012, (Vision) Calgary TELUS Convention Centre & ERCB Core Research Centre, Calgary, AB, Canada, 14-18 May 2012, AAPG©2014

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Abstract

Seismic anisotropy is a subsurface property that can have a severe impact on the quality of subsurface seismic imaging. In this study, a multicomponent, time-lapse seismic survey is interpreted to investigate seismic anisotropy in a potash mining area in Saskatchewan. The focus of this study is the Devonian Dawson Bay Formation, a fractured carbonate overlying the Prairie Evaporite Formation. The full azimuth stacked seismic volumes were divided into 4 azimuthally sectored sub-volumes that are made up of a stack of source-receiver ray paths covering a 45 degree aperture. Through interpretation and travel-time analysis of these data, we have observed weak azimuthal velocity anisotropy within the Dawson Bay carbonates. Furthermore, interval velocity analysis shows an increase in Vp/Vs ratio indicating a decrease in shear wave velocity through the Dawson Bay Formation. These results support the hypothesis of a Dawson Bay Formation that is fractured.

Introduction

This study analyses 3D seismic data for azimuthal anisotropy in Devonian carbonates that are possibly fractured, and which overly potash ore deposits currently being extracted using the room and pillar method in Saskatchewan (Zhang, 2010). Through these fractures the downward propagation of aquifer fluids may be leading to localized dissolution of potash. The cause of the fractures is unknown, however the analysis of anisotropy present should provide insight into fracture orientation and extent within the Dawson Bay Formation, as well as constrain the possible mechanisms of fracture activation.

Theory and Method

In order to determine the extent of fracturing and the preferred orientation, anisotropy must be analyzed. In the Dawson Bay Formation, we expect seismic anisotropy to manifest itself in the form of horizontal transverse isotropy (HTI). HTI is seen where vertical fractures are present in an isotropic medium. P-waves propagating parallel to the fractures do not experience anisotropy, whereas P-waves propagating perpendicular to the fracture will experience a reduction in acoustic velocity due to reduced cohesion across the crack (Ruger, 1997). HTI can be detected as an increase in travel-time associated with a reflected or refracted wave. Should the fracture network be large enough, and have a preferential orientation, a travel-time anomaly would be created in the seismic data, and would be accentuated when focusing on the wave propagating perpendicular to the fracture direction. The Dawson Bay carbonates in Saskatchewan have a tendency to produce vertical fractures, which would cause a seismic wave to propagate slower in the plane perpendicular to the strike of the fractures (Dunn, 1982).

To test the hypothesis of preferentially oriented, vertical fracture networks in the Dawson Bay Formation, the seismic data was split into 5 volumes (Figure 2). One full azimuth stack volume and 4 azimuthally sectored volumes containing a stack of source-receiver ray paths from a 45 degree sweep. In order to detect possible HTI, 5 main horizons were populated in each of the volumes: the Birdbear Formation, the Dawson Bay Formation, the Prairie Evaporite Formation, the Winnipegosis Formation and the Winnipeg Sandstone Formation. To determine the magnitude of travel-time differences which would indicate HTI, the horizons picked from the azimuthally sectored volumes were compared to each another. This was done through creating difference grids between the picked horizons, placing a focus on orthogonal azimuthally sectored volumes as the largest travel-time differences will be found when subtracting the horizons picked in the fast direction (parallel to fracture orientation) from those in the slow direction (perpendicular to fracture orientation).

In these difference plots (Figure 1), a positive two-way travel-time difference indicates that the travel-time for the first sectored volume (t1) is less than that of the second sectored volume (t2). If $t1 < t2$, then $V1 > V2$ (shown in red on all difference plots). Similarly, if $t1 > t2$, then $V1 < V2$ the travel-time difference will be negative (shown in blue on all difference plots).

To further support our hypothesis, interval velocity analysis was performed from dipole sonic logs in order to determine the Vp/Vs ratio in each of the layers from the top of the Souris Valley Formation (top of well logs) to the Dawson Bay Formation (bottom of the well logs) (Figure 3). The travel-times between tops were determined by placing tops into Syngram (CREWES Software Package) and determining the travel-times associated for both primary and secondary waves through each interval. Vp/Vs was then calculated using Equation 1, and compared to the results taken directly from the arithmetic mean determined from the well logs,

$$Vp/Vs = (2dts-dtp)/dtp \qquad (1)$$

where dtp = vertical component interval time, and dts = converted-wave interval time.

Vp/Vs in the logged interval remains relatively constant at 1.87 throughout the top of the logged section, from the Birdbear Formation to the top of the Dawson Bay Formation, at which point the Vp/Vs increases to 1.98. This sudden increase can either be attributed to an increase in P-wave velocity, or to a decrease in shear wave velocity in the Dawson Bay Formation. As the stratigraphy above the Dawson Bay is also made up of carbonates, the change in Vp/Vs is likely due to a decrease in shear wave velocity experienced because of the presence of fractures, as shear wave velocities are decreased through a medium with open and fluid filled cracks.

Conclusions

The results obtained through analysis of the two-way time difference plots show the possibility of a dominant reduction in seismic velocity in north-south orientation, supported by the increase in Vp/Vs in the Dawson Bay Formation. The stratigraphy above the Dawson Bay has travel time differences that are relatively small with respect to that of the zone of interest implying very low levels of anisotropy in the overlying formations.

These findings support that the Dawson Bay Formation may exhibit fractures. The cause of the azimuths of slowness exhibited by the two-way travel-time grids associated with the Winnipegosis and Winnipeg Sandstone formations is unclear, as the anisotropy could originate in the above Dawson Bay Formation or within the Prairie Evaporite and Winnipegosis formations.

Acknowledgements

We thank RPS Boyd Petrosearch for access to this dataset and the CREWES Sponsors for their continued support of this research.

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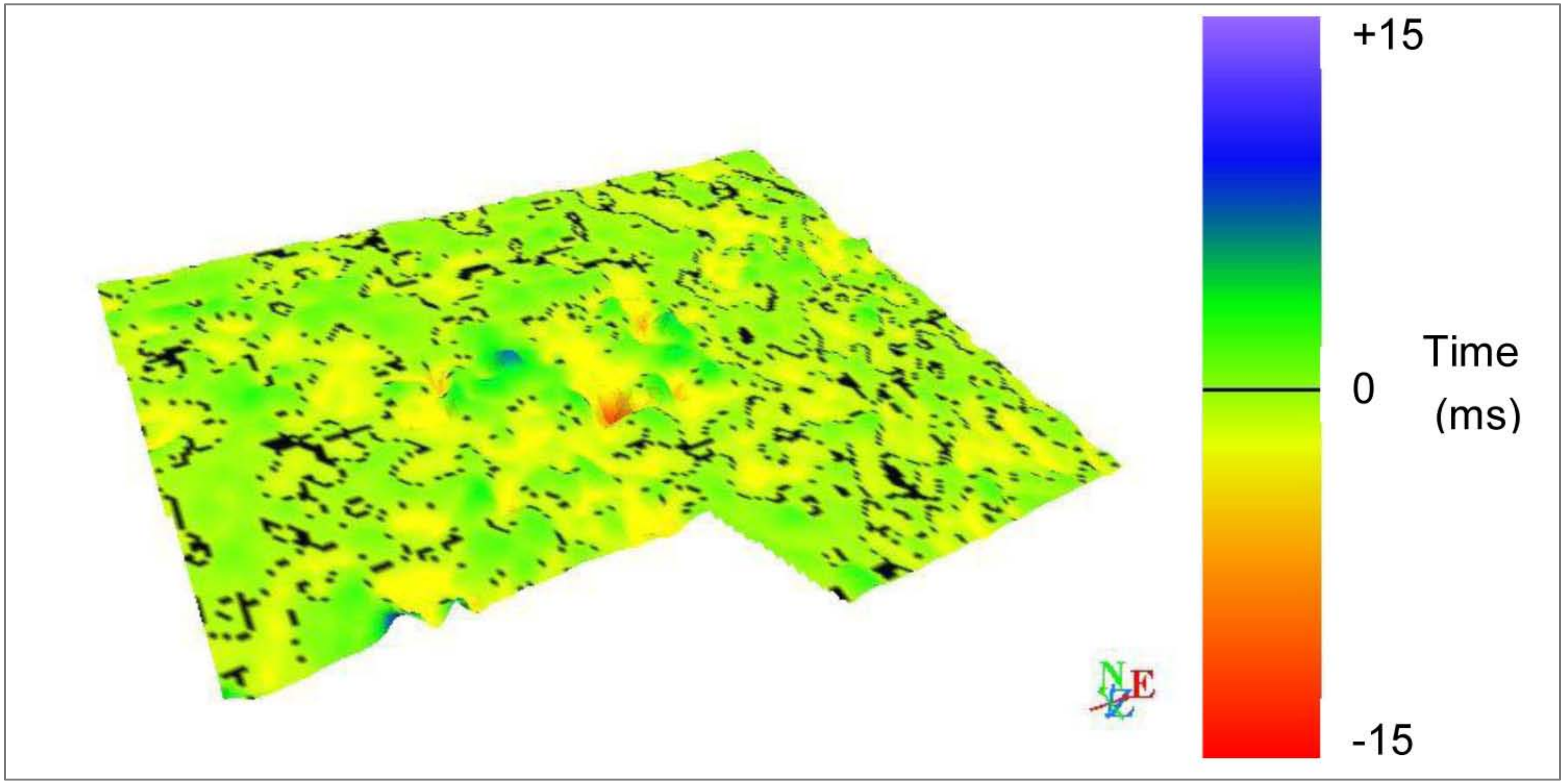

Figure 1. The 2004 two-way travel time difference grid for the Winnipegosis Formation shown in 3D. The blue represents a negative travel time difference and the red represents a maximum positive travel time difference of 13 ms between the horizon picked from the 45 and 225 degree sectored volume and the horizon picked from the135 and 315 degree seismic volume.

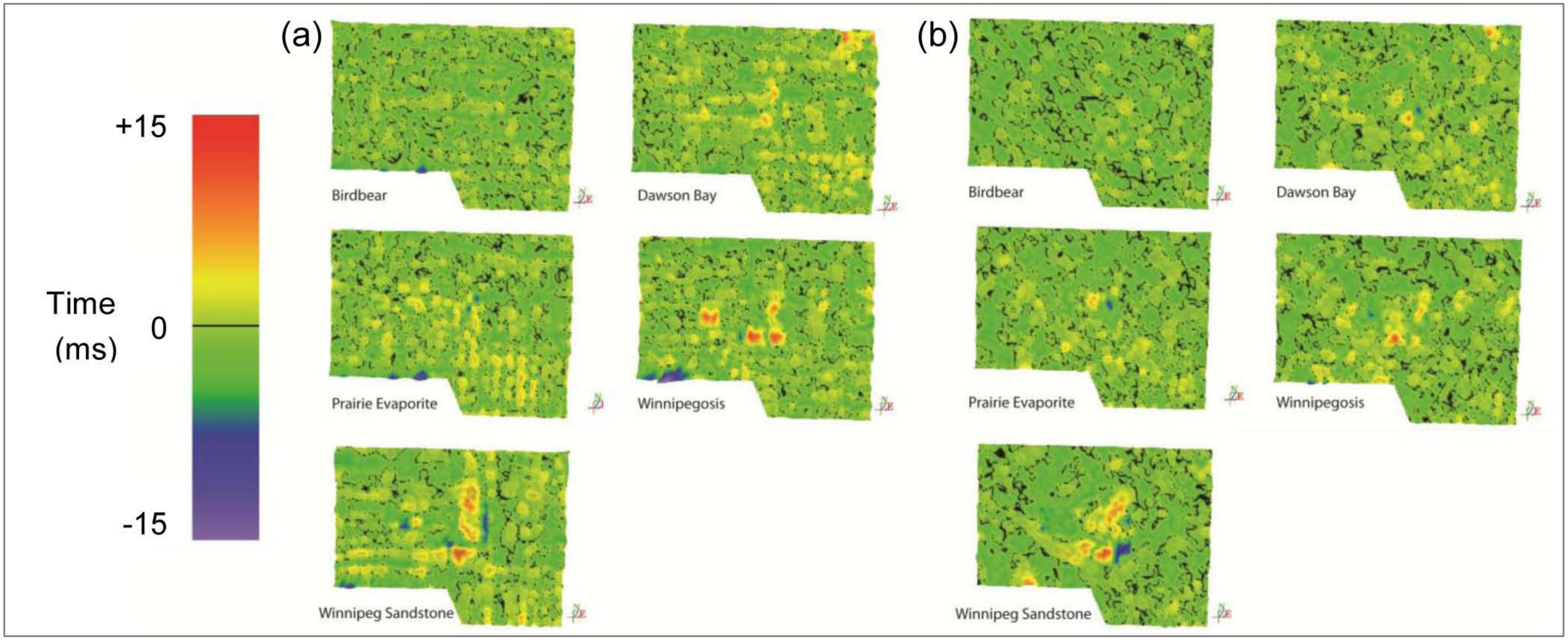

Figure 2. 2004 difference plots with positive and negative travel time differences. The difference plots in (a) indicate a preferential fracture orientation in the 90 and 270 and 0 and 180 directions respectively. Some mine workings are also visible in the Prairie Evaporite and Winnipeg Sandstone difference plots. The difference plots in (b) indicate preferential fracture orientation in the 135 and 315 and 45 and 225 directions respectively.

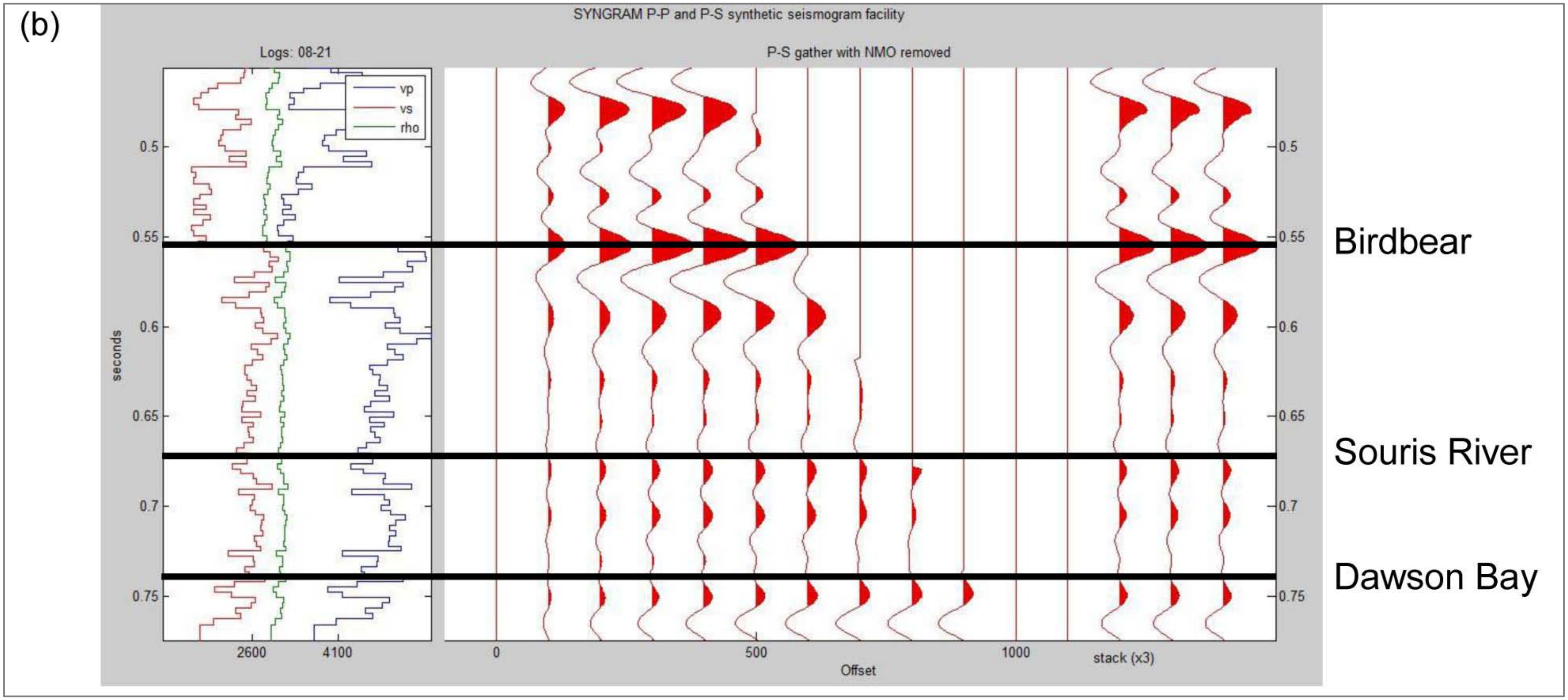

Figure 3. The blocked Vp and Vs logs on the left correlate to the synthetic seismograms on the right. The PP synthetic (a) is produced using a zero phase, 5-10/100-120Hz Ricker wavelet and the PS synthetic (b) is produced using a zero phase, 5-10/40-50Hz Ricker wavelet to match the frequency content of their respective seismic volumes.