Seismic Expression of a Complex Tectonic Wedge in the South-central Alberta Foothills

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Summary

The 3D geometry of a triangle zone in the south-central Alberta Foothills was interpreted from high-quality 3D reflection seismic data constrained by wells. This work provides a detailed interpretation of both regional- and local-scale structures observed and the structural styles determined to be controlling the deformation within the tectonic wedge, providing a framework within which future 3D interpretations of triangle zones may be evaluated. Two important mechanisms controlling deformation within the tectonic wedge were interpreted to be small displacements along ramps creating duplexes and fault propagation (both along strike and dip), resulting in differential shortening throughout the stratigraphic succession. Within the study area, this differential shortening has been interpreted to be accommodated by backthrusting and layer-parallel shortening.

Introduction

Triangle zones define the foreland extent of deformation in the Rocky Mountain Fold and Thrust Belt. They are characterized by two fault detachments that contain an extraneous volume of rock between them, referred to as a tectonic wedge. The tectonic wedge is formed predominantly by low-angle blind thrust faults, which sole into the basal décollement. Exploration interest in these structural plays has increased recently because of gas accumulations in Cretaceous sandstones in the hanging walls of blind thrust faults. Knowledge of their structural style and their lateral variations is crucial to exploration success. Through the evaluation of natural examples in fold-thrust belts, structural geologists have attempted to understand the kinematics involved for the purpose of the prediction of subsurface structures in the presence of sparse data or data of limited quality. Through the interpretation of 3D reflection seismic volumes, insight into the complex internal geometry of triangle zones can be gained.

The study area is located on the eastern extent of the south-central Alberta Foothills, over the triangle zone present northwest of Calgary, Alberta. A high-quality seismic survey covering an area of approximately 155 km^2 (Figure 1a) was interpreted to understand the 3D geometry of the tectonic wedge.

The stratigraphic section in the south-central Alberta Foothills is composed primarily of Mesozoic and Cenozoic clastics that overlie Paleozoic carbonates. A generalized stratigraphic column is shown in Figure 1b, qualitatively depicting the placement of competent carbonates beneath mechanically weaker clastics.

Detailed surface geologic mapping has been performed previously (Soule, 1993) and past subsurface structural interpretations of the study area include work by Abaco (2003), Lawton et al. (1996), Soule

(1993), Soule and Spratt (1996), and Sukaramongkol (1993). These studies relied on 2D seismic data, well data, and cross-section balancing techniques to constrain the subsurface interpretation of the triangle zone. The availability of 3D seismic data for this study provides additional information on the 3D geometry of the triangle zone. Furthermore, the data quality permits the interpretation of smaller-scale deformation and structural styles within the tectonic wedge, extending the understanding of past works.

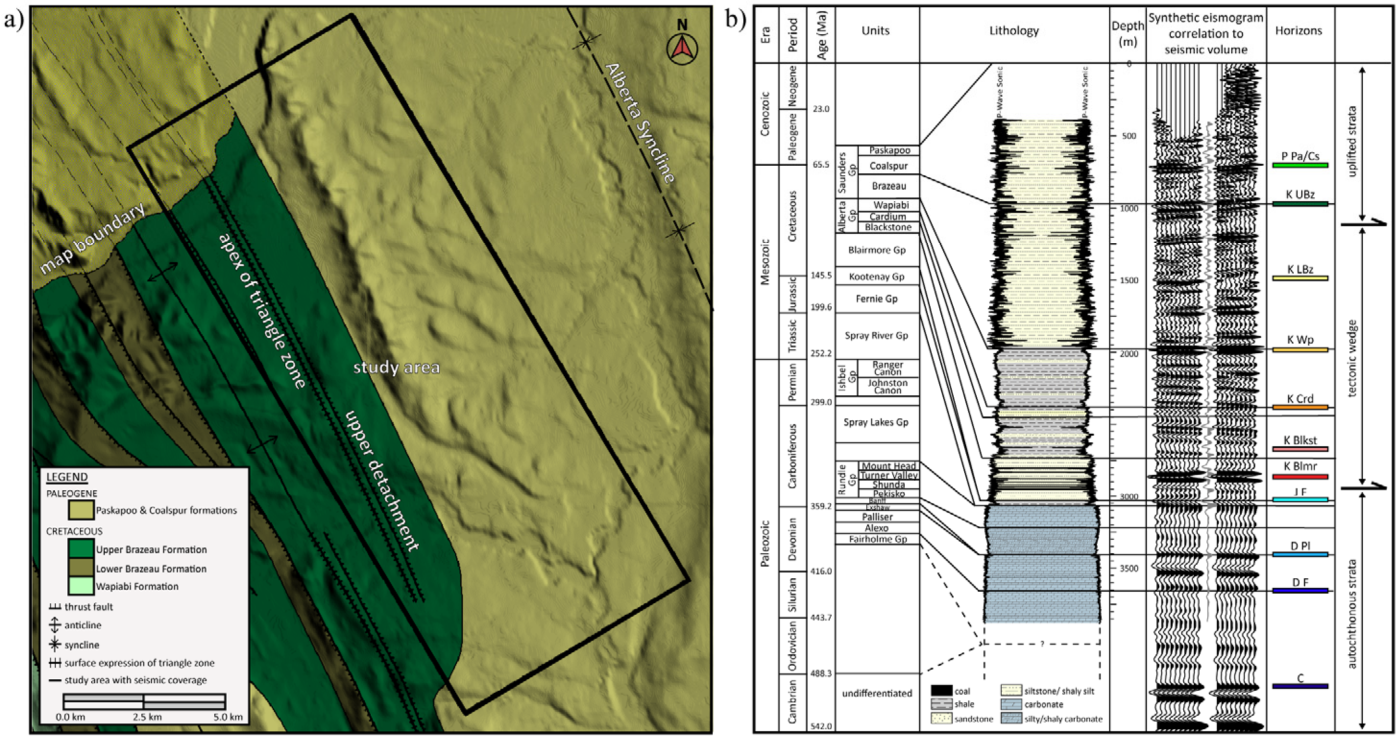

Figure 1: a) Surface geologic map illustrating the approximate location of the seismic survey. The surface geology is based on mapping performed by Soule (1993). b) Generalized stratigraphic column of the south-central Alberta Foothills. The stratigraphy was correlated to the seismic volume using synthetic seismograms. The synthetic seismogram shown was generated from a well located in relatively undeformed strata. The horizons interpreted throughout the seismic volume are also summarized. The inferred locations of detachment zones bounding the tectonic wedge are indicated by arrows.

Regional Subsurface Interpretation

The seismic sections shown in Figure 2 illustrate the subsurface complexity of the study area, indicating that numerous foreland-verging blind thrust faults control the structural framework of the tectonic wedge. They merge into a deformed zone beneath a thrust fault that forms the upper detachment of the wedge. Overlying Upper Cretaceous and younger strata have been uplifted. The basal décollement has been interpreted to be within Lower Cretaceous strata and is observed to cut up-section towards the foreland. Deformation within the tectonic wedge is contained entirely within Mesozoic clastic rocks.

Within the study area, the tectonic wedge has been divided into regions based on the structures observed (Figure 3). In the west, it is dominated by foreland-verging thrust faults separating horses that rapidly change in geometry along strike. The resulting laterally extensive structure, where most of the shortening within the tectonic wedge occurs, is interpreted as a hinterland-dipping duplex. Immediately east of the duplex, the tectonic wedge contains both foreland- and hinterland-verging thrust sheets, creating pop-up structures that exhibit an en échelon geometry beneath the upper detachment. Quantitative displacement distributions evaluating the 3D geometry of the thrust faults suggest that the development of pop-up structures within the triangle zone is complex, involving the interaction between and/or coalescing of individual faults. The strata east of the pop-up structures are relatively undeformed, as indicated by conformable seismic events.

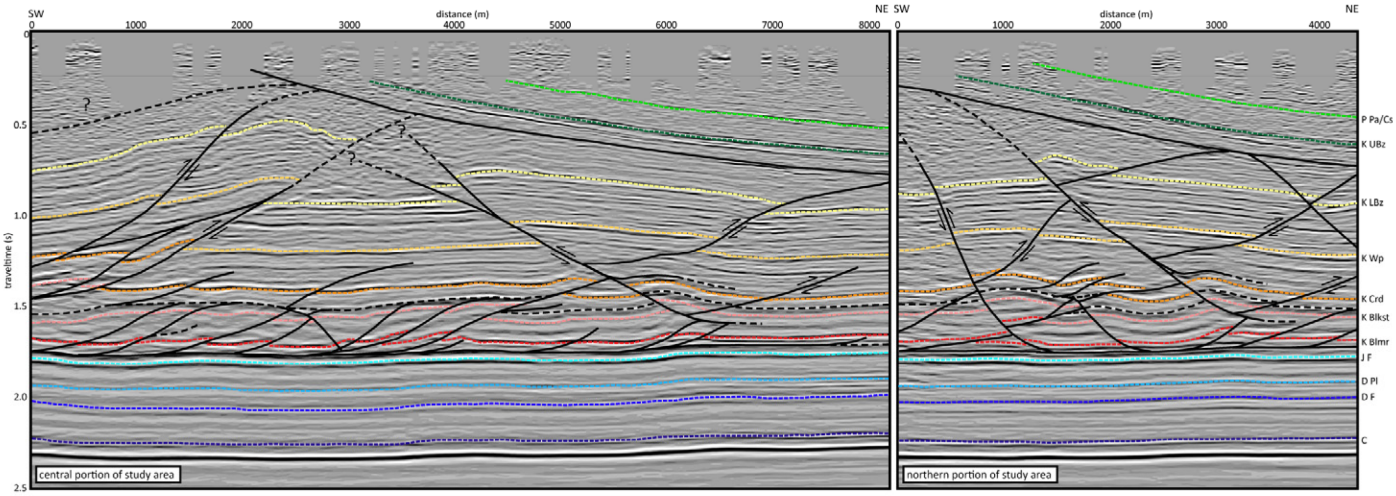

Figure 2: Seismic sections oriented parallel to the predominant dip direction of structures within the study area.

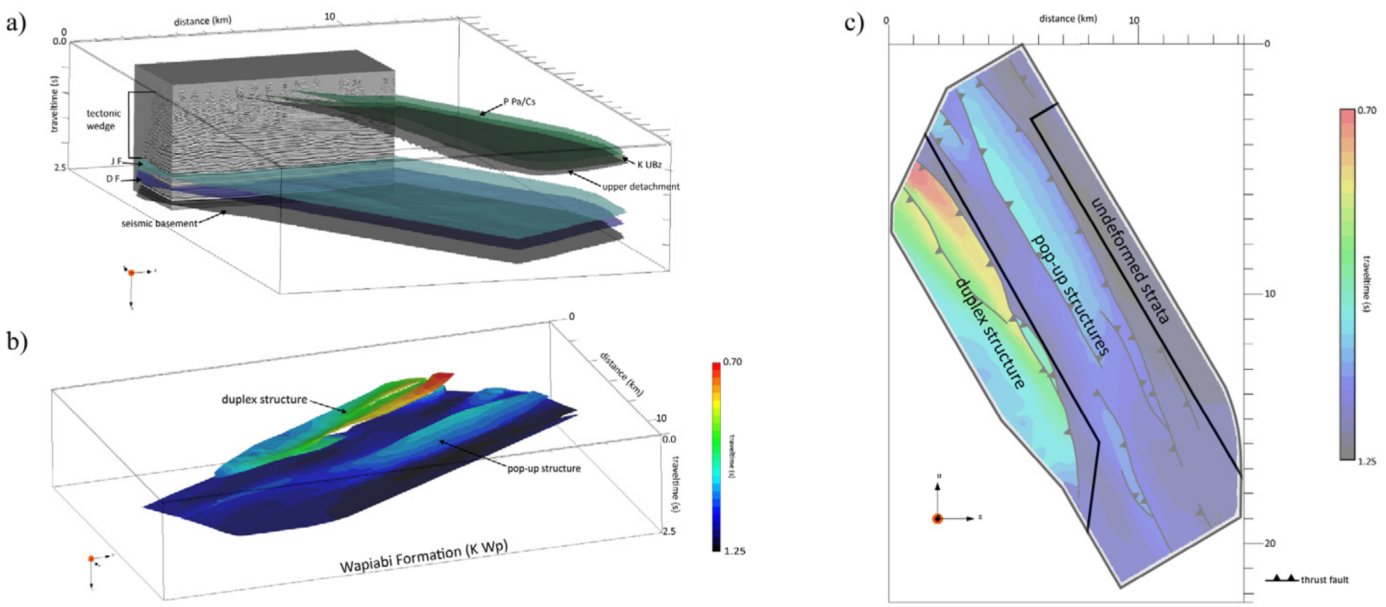

Figure 3: a) 3D perspective view of the undeformed strata below the basal décollement and the uplifted strata above the upper detachment. The light blue horizon (Jf) represents strata immediately underlying the basal décollement. b) 3D perspective view of the Wapiabi Formation (K Wp). c) Time structure map of the Wapiabi Formation (K Wp) illustrating the distinct structural regions present within the tectonic wedge.

Structural Styles

The regional interpretation of the triangle zone has been extended to address small-scale (in terms of seismic resolution) deformation and structural styles observed within the tectonic wedge, concentrating on the relationships between detachment folds, duplexes, fault-propagation folds, and backthrusts.

Within the leading edge of the tectonic wedge, small-scale duplexes and associated imbricates are observed beneath the Cardium Formation within the Blackstone Formation and Blairmore Group (Figure 4). Through area-balanced models, it was demonstrated that the development of these duplexes results in significantly less shortening in the Cardium Formation and younger units than the underlying intensely deformed units.

Evaluation of the seismic dataset gives strong evidence that faults nucleate at or near the basal décollement and then propagate up-section. Significant differences in displacement along faults are observed between units beneath and units above and including the Cardium Formation (Figure 4). Through kinematic modelling, geometries similar to those observed within the seismic dataset were predicted, providing insight into the magnitude of differential shortening resulting from the inability of a fold to adequately accommodate all of the slip occurring on the developing fault below. It has been shown that strata not originally cross-cut by faults contain smaller amounts of shortening. This corresponds to less shortening within the Cardium Formation and younger units.

Although the structures interpreted are kinematically linked, it can be shown that the increased amount of shortening within units beneath the Cardium Formation results primarily from the development of small-scale duplexes. This differential shortening can be "balanced" by additional deformation of the Cardium Formation and younger units through backthrusting and layer-parallel shortening. It is suggested that backthrusting is the preferred deformation method of balancing shortening, explaining the prevalent presence of backthrusts in strata overlying the Cardium Formation within the study area.

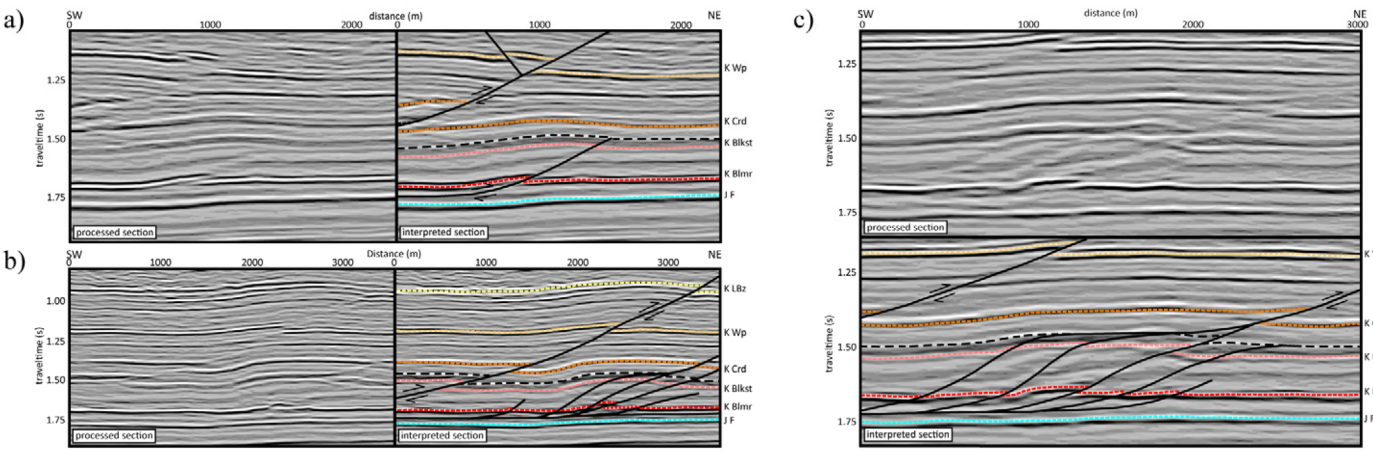

Figure 4: Seismic sections illustrating: a) the fault geometry during the initial stages of development of fault-propagation folds, b) a fault with a systematic decrease in displacement up-section, and c) a typical small-scale duplex and associated imbricates observed within the study area. The dashed line represents the approximate location of a possible detachment surface internal to the tectonic wedge.

Conclusions

The interpretation of a 3D seismic volume in the south-central Alberta Foothills successfully delineated structures present within the triangle zone. It indicates that foreland-verging thrust sheets create the structural framework of the triangle zone. Pervasive shear surfaces accommodate the movement of the tectonic wedge towards the foreland, which delaminates and uplifts Upper Cretaceous and younger strata. It was determined that fault propagation and small displacements along ramps creating duplexes and imbricates are the important deformation mechanisms with backthrusts developing in response to differential shortening.

Acknowledgements

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