Interpretive Velocity Model Building for Seismic Data Acquired Across a Complex Structure in Southern Alberta

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We processed in time and depth two seismic lines from an area of extremely complex geology in the Turtle Mountain area of Southern Alberta. The time processing was desinged to attenuate noise and enhance signal in the data. To develop a velocity model for pre-stack depth migration (PSDM) we integrated all available sources of velocity and geological information into the interpretation of preliminary depth migrated seismic data. We used the near-surface velocity models derived from refraction statics analysis together with constant velocity migrations for velocity information in the shallow section. The location of velocity pull-ups on the time migrated sections acted as a guide to the extent of high-velocity carbonates carried in the hangingwall of a major thrust fault. We integrated the mapped surface geology, geological cross-sections, well depths and interval velocities from sonic logs into the velocity model. The depth processed sections show a more realistic geometry than the time sections for the reflectors at depth. The seismic data cannot image the shallow, steeply dipping strata in Turtle Mountain itself. Our interpretation is based upon published geological models, surface geology maps, well data and the seismic character where the reflections are imaged adequately.

Time Processing

Before embarking on PSDM we processed the data in time to attenuate noise and enhance signal. We applied an f-k filter to reduce the surface noise and applied deconvolution and a coherency filter to the shot gathers. Refraction statics were calculated using GLI3D (Hampson and Russell, 1984). We also calculated and applied residual statics. The sub-weathering velocities from GLI3D corresponded well with the mapped surface exposure of high velocity Palaeozoic strata and formations of the lower velocity Brazeau and Alberta Groups. We integrated this near-surface velocity information into the velocity models for PSDM.

Despite the knowledge that time processing does not produce a properly focussed image or realistic velocities in such complex geology, we still processed the data to obtain stacked and post-stack time migrated images to help us design a velocity model for PSDM.

The post-stack time migrated sections are displayed in Figure 1. These time migrated lines show some very complex structures and faulting and are not easy to interpret. The deepest reflectors are expected to be fairly undeformed and the apparent structure observed on the west side of both lines is interpreted to be a seismic time artefact caused by velocity pull-up. We know from the surface geology and some local wells that the Livingstone Fault, a major thrust fault, brings high velocity Palaeozoic rocks to the surface. The location of these rocks correlates well with the velocity pull-up observed on the time section of line A. On line B the surface location of the Livingstone Fault is further east than the observed velocity pull-up. We infer that the fault does not carry carbonates in its hangingwall beyond the location of the observed velocity pull-up and we used this observation in our velocity models for line B.

Depth Processing

In areas of complex geology one cannot use a basic layer down approach to velocity model building as can be done successfully in simple geological settings. To design a velocity model for PSDM we integrated all the sources of geological and velocity information that we had: constant velocity migrations, the GLI3D near-surface velocities, mapped surface geology, geological cross-sections, sonic log interval velocities and the observed pull-up on the time sections. We iteratively interpreted the depth migrated sections and modified the shapes of polygons in the velocity model, trying to focus the reflections and flatten the deepest horizons, which we do not believe to have significant structure, and to match the depths encountered in a few wells close to the lines. Constant velocity polygons were designed to represent packages of formations with similar interval velocities. We found that the shape of the polygons in the velocity model in the top 2000 m could have a profound effect on the alignment of the reflectors at 7000 m depth. The data were pre-stack depth migrated from topography using a shot-based Kirchhoff migration developed in FRP (Lawton, 2005) and a fairly simple velocity model.

Interpretation

Interpretations of the data on the depth sections are shown in Figure 2. We honoured the surface geology and well depths and utilized geological cross-sections for this difficult interpretation (Jones, 1993; Norris, 1993; MacKay, *pers. comm.*; Langenberg, *pers. comm.*). The geology is much more complicated than presented here. There are many more, smaller, faults, more folded strata and more detachment horizons than annotated here. We have kept the interpretation fairly simple so as to show the overall structure and the major controlling faults, which are annotated.

Beneath the Livingstone Thrust is a complex structure caused by thrust faulting and folding. A major regional detachment is present in the Fernie shales and has been itself folded and faulted by further tectonic events. It is the fault immediately above the Palaeozoic section below 4000 m depth. Many of the faults are interpreted to sole out in this detachment. There is also a major detachment in the Blackstone (Norris, 1993; Mackay, *pers. comm.*).

We interpret two major faults that affect the Palaeozoic at depths below about 4000 m. The deepest, more easterly fault (the Burmis Thrust; BT) is clear on both sections and is confirmed by well data. This fault carries the easterly leading edge of the carbonate thrust sheets in its hangingwall. The second thrust fault is much harder to interpret. It is interpreted as a splay off the Burmis Thrust on the west side of the lines. How it relates to the faults in the Mesozoic section is hard to determine. We feel justified in interpreting this fault because introducing it into the velocity models enhanced the focussing and continuity of the deep reflector at 7000 m.

Turtle Mountain is seen best on Line B as the topographic high on the west end of the line. A major influence on the structure in this area is the Livingstone Thrust, which carries Palaeozoic strata in its hangingwall, over Cretaceous rocks in the footwall. We used the fault's depth in wells, its mapped surface location and the character of seismic reflections to estimate its subsurface trajectory. There is very complex faulting and folding above the Livingstone Thrust and in some places the Kootenay and Fernie formations are thickened and highly deformed. The tight folding and steep dips of the Palaeozoic carbonates above the Turtle Mountain Thrust contributed to the Frank Slide, which was a disastrous collapse of part of the mountain in 1903. It is not possible to image such complex geology on the seismic data so the interpretation is based mainly on geological knowledge. What we do see, especially on Line B, are the Kootenay coals that were mined in the Hillcrest and Bellevue mines and which are present in the Bellevue syncline.

We had difficulty interpreting Line B above the most easterly part of the Livingstone Thrust. If there are no carbonates here, as we interpret, then the Fernie must be greatly thickened by complex folding and multiple thrust faults, which we are unable to resolve with the seismic data. In our velocity model building, introduction of high velocities into this area, as though carbonates were present, was detrimental to the imaging of the deepest reflectors at 7000 m.

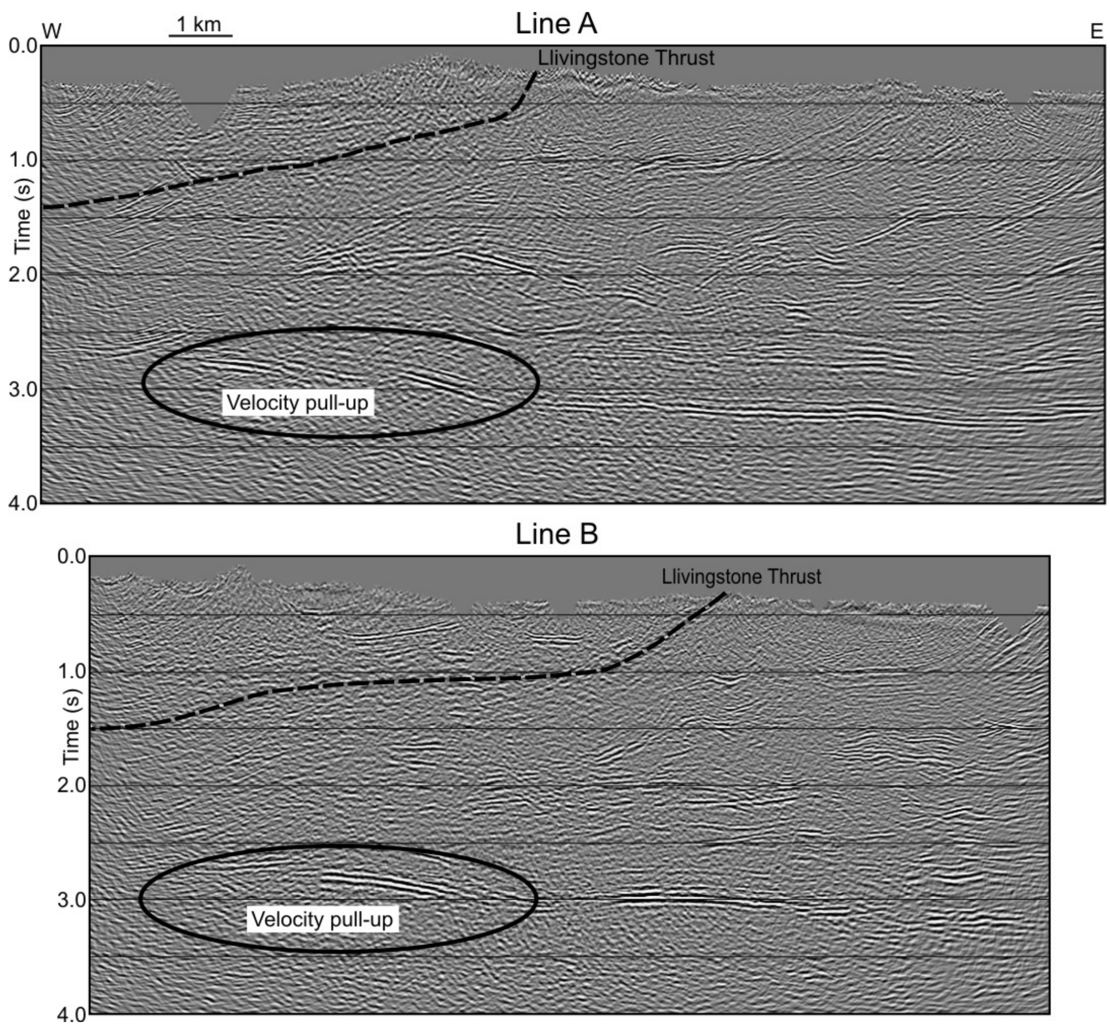

Figure 1. Post-stack time migrated sections. The Livingstone Thrust carries some high velocity carbonates in its hangingwall, which contribute to a velocity pull-up on the time sections.

Summary

Building velocity models for pre-stack depth migration of seismic data acquired in areas of complex geology is not an easy task. One almost needs nicely imaged data first so that one can make an interpretation and assign velocities to polygons for the migration. Integration of velocity information from refraction statics analysis and constant velocity migrations was useful for the shallow section. We integrated all sources of geological and velocity information and also utilized the observation of velocity pull-ups observed on the time sections to design the final model.

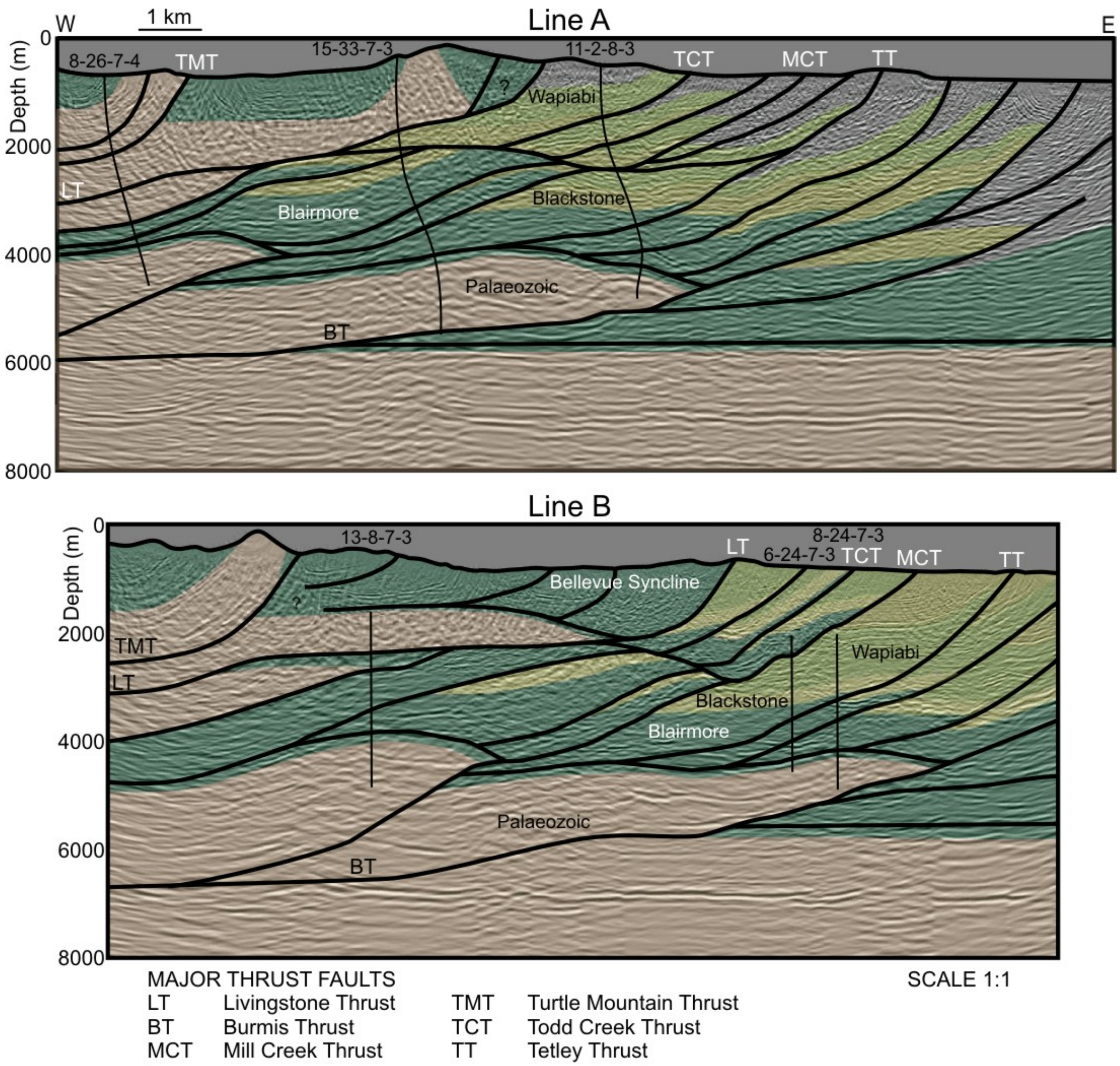

Figure 2. Pre-stack depth migrated sections with simplified interpretation.

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References

Hampson, D. and Russell, B. H., 1984, First break interpretation using generalized linear inversion: Journal of the CSEG, **20**, No. 1, 40-54.

Jones, P. B., 1993, Structural geology of the modern Frank Slide and ancient Bluff Mountain Slide, Crowsnest, Alberta: Bulletin of Canadian Petroleum Geology, **41**, 232-243.

Lawton, D. C., 2005, Interpreter-driven depth imaging with FRP anisotropic depth migration code: FRP Annual Report, **11**, 9.1-9.18.

Norris, D. K., 1993, Geology and structure cross-sections, Blairmore (West Half), Alberta, Geological Survey of Canada, Map 1829A, scale 1:50,000.