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Application of a Tomographic Velocity Model to the Prestack Depth Migration of a Buried Valley

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Summary

To better characterize a buried valley, we have generated a tomographic velocity model from refracted and reflected traveltimes. In addition, the reflection seismic dataset has been processed in a sequence optimized to suppress source-generated noise. Combining these images with a depth migrated profile that uses the velocity field from the tomography provides an enhanced image of the valley.

Introduction

Glacially buried valleys are beneficial in that they can be sources of substantial amount of water, aggregates and even natural gas. The glacial sediments, of Quaternary age (< 2 Ma), that fill these paleovalleys are mostly unconsolidated and could contain mixtures of clay, till, silt, sand and gravel of varying degree in composition and configuration. The often apparent contrasts in the physical properties of the bedrock and the rock constituting the buried valley provide a basis for the use of geophysical methods to map out these valleys.

This contribution uses the seismic dataset described in Ahmad et al. (2009) and further builds on the results from Ogunsuyi et al. (2009) by showing the result of a tomographic velocity model, the reprocessing of the reflection seismic and its corresponding depth migration using velocities derived from the traveltime tomography to assist in the interpretation of the buried valley. The velocity model was created by a traveltime inversion procedure of the refracted and reflected events. The seismic reflection data was processed in a sequence optimized to suppress noise (steps include radial and linear τ–p processing). The corresponding pre-stack depth migration (PSDM) of the reflection profile using the velocity model from the tomography was later carried out. This contribution focuses only on the novel aspects of the reprocessing of these data, a detailed discussion of these may be found in Ogunsuyi and Schmitt (2010).

Method

The procedure used to generate the tomography is a linearized traveltime inversion algorithm primarily created to model 2-D crustal refraction and wide-angle data (broadly explained in Zelt and Smith, 1992 and applied in Song and ten Brink, 2004).The model is made up of layered, unevenly assembled trapezoids describing the velocity field of the subsurface. The model parameters are boundary nodes (defining the structure) and upper and lower velocity values (typifying the velocity distribution). Rays are traced through the model to determine the traveltimes between sources and receivers; these calculated traveltimes in combination with observed traveltimes are used to develop an inverse problem. The inverse problem is solved by damped least squares technique to determine the changes that needs to occur in the model parameters for the differences in the calculated and observed data to be reduced. After modifying the model parameters with the changes, the whole procedure of tracing rays, calculating changes and updating model parameters is repeated until satisfactory fit to the picked traveltimes is achieved. Schijns et al. (2009) provide a recent example of the application of this algorithm in determining complex static corrections in a recently glaciated region.

The high-resolution seismic reflection profile was processed with a robust sequence aimed at suppressing noise in the data. Apart from the conventional processing steps carried out to reduce noise and enhance reflections (i.e. spiking deconvolution, bandpass filtering); we performed also radial and linear *τ–p* processing. In the case of radial domain processing, linear events (guided waves) maps into relatively few radial traces with apparent frequencies shifting from the seismic band to lower frequencies when the seismic data is transformed from normal x-t into apparent velocity versus two-way-time (radial or r-t) domain (Henley, 1999). After transformation to r-t domain, a low-cut filter can then be applied to the radial traces to eliminate the coherent noise mapped to lower frequencies and the data subsequently transformed back to x-t domain to obtain a relatively noise-free data. Source-generated noise was also reduced by mapping the data into linear *τ–p* (or slant-slack) coordinates wherein linear and hyperbolic events in *t-x* domain are mapped into points and ellipses, respectively, in linear *τ–p* domain during linear *τ–p* transformation (Yilmaz, 2001). Due to the separation of events in *τ–p* domain, one can define and apply a pass filter to eliminate the source-generated noise in the slant-stack domain and then re-map the clean data back to *t-x* coordinates. Using the velocity field derived from the traveltime tomography, pre-stack depth migration was carried out on the data. The PSDM algorithm used was split-step (Stoffa et al., 1990) shot-profile (Biondi, 2003) migration.

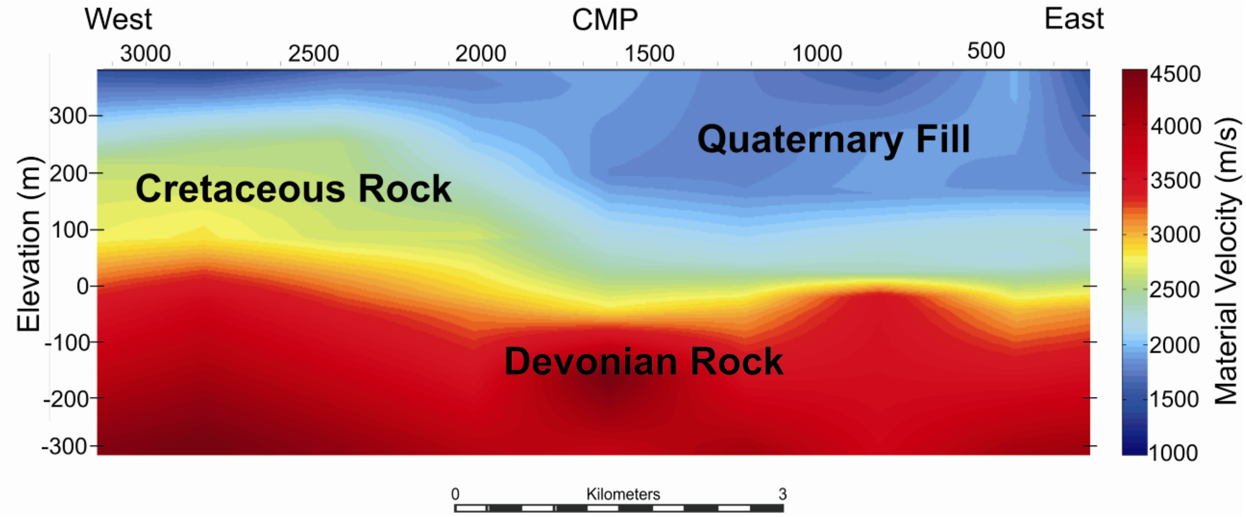

Figure 1: The material velocity field of the subsurface as obtained from the traveltime inversion with a vertical exaggeration of about 5. The vertical-axis is elevation (m) above sea level with mean sea level at 0 m; elevation above sea level is positive, depth below sea level is negative.

Examples

A compressional wave seismic dataset was acquired in Northern Alberta, Canada in 2004 over a paleovalley which was first discovered by drilling. The seismic survey was a high resolution 2D profile of about 10 km in length in east-west direction. The purpose of the survey was to image the structure above a sub-Cretaceous unconformity (top of Devonian rock) over which lies the buried valley (Ahmad et al., 2009) that cuts through surrounding Cretaceous sediments and is capped by glacially derived materials. Ahmad et al. (2009) gives a description about the location and acquisition parameters of the seismic survey in the Sousa Creek area between Rainbow Lake and High Level, north-west Alberta. The surficial geology of the region has been extensively studied over the last decade (Levson, 2008); with the area immediately over the profile investigated by Plouffe et al. (2004) and Paulen et al. (2005).

The reflection seismic was processed conventionally in addition to radial and linear *τ–p* processing and the result is shown in Figure 2. Better resolution and more continuous events characterize the final stack of the newly processed time reflection profile. The complex architecture of the paleovalley and the different layers of rock in the subsurface are imaged decently in the resulting reflection profile and this provides valuable information about the depositional history of the numerous sedimentary interfaces.

Finally, the velocity model from the inversion was used to perform a prestack depth migration on the seismic dataset after carrying out the noise suppression procedures. The result of the PSDM overlaid with the velocity field is shown in Figure 3. From this image, correlation of different events with depth values can be made. However, the depth to the sub-Cretaceous unconformity (strong horizontal event between elevations 85 m and -15 m above sea level on the seismic profile) as observed in the depth migrated seismic was different from that witnessed in the tomography on the eastern part of the survey line. The cause of this problem is unknown; it could be from the traveltime inversion procedure (non-uniqueness of fitting models) or the inadequacy of the migration algorithm used.

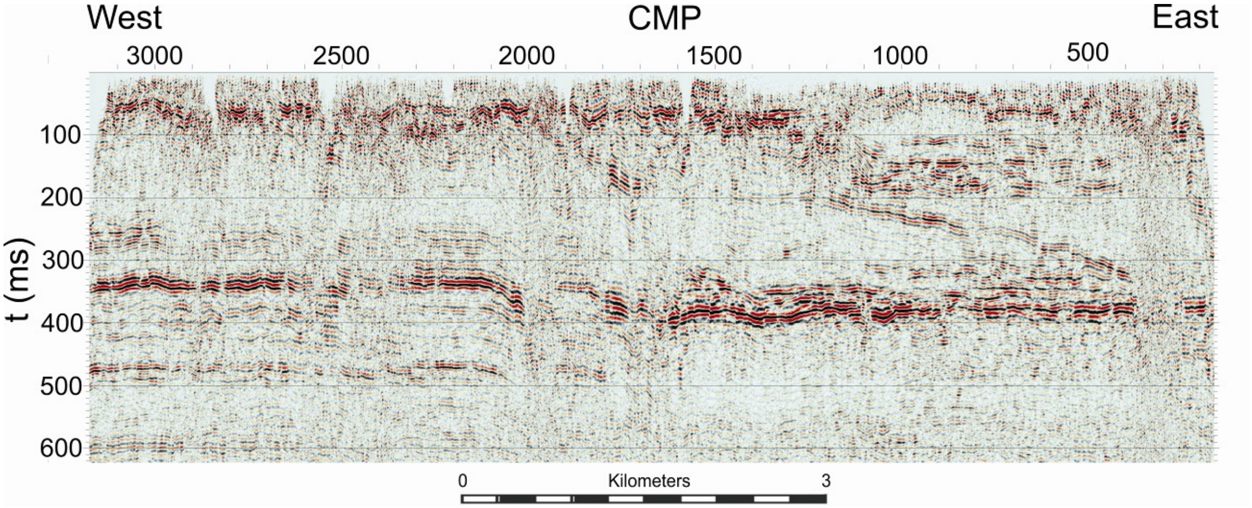

Figure 2: Final unmigrated time seismic reflection profile.

Conclusions

We have shown the results of a traveltime inversion, the processing of the associated reflection seismic data optimized to suppress noise and its corresponding depth migration using velocities derived from the traveltime tomography to facilitate a better interpretation of a buried valley. From the resulting material velocity model, one can mark out the outline of the buried valley and hence delineate it from the surrounding bedrock. Moreover, the final time profile from the reflection data processing was able to outline the internal structure of the valley which the velocity model could not image well due to its low resolution. However, the PSDM data presented a different depth to the sub-Cretaceous unconformity on the eastern side of the survey line in comparison to that observed in the velocity model. The cause of this discrepancy in depths is unknown and further analysis is needed to determine the origin, although it is likely related to the smoothing inherent to any such tomographic method. Detailed wellbore information, close to the survey line, may prove useful in determining the source of this mismatch. Nonetheless, satisfactory interpretations can still be made from the ensuing images about the structure above the sub-Cretaceous unconformity.

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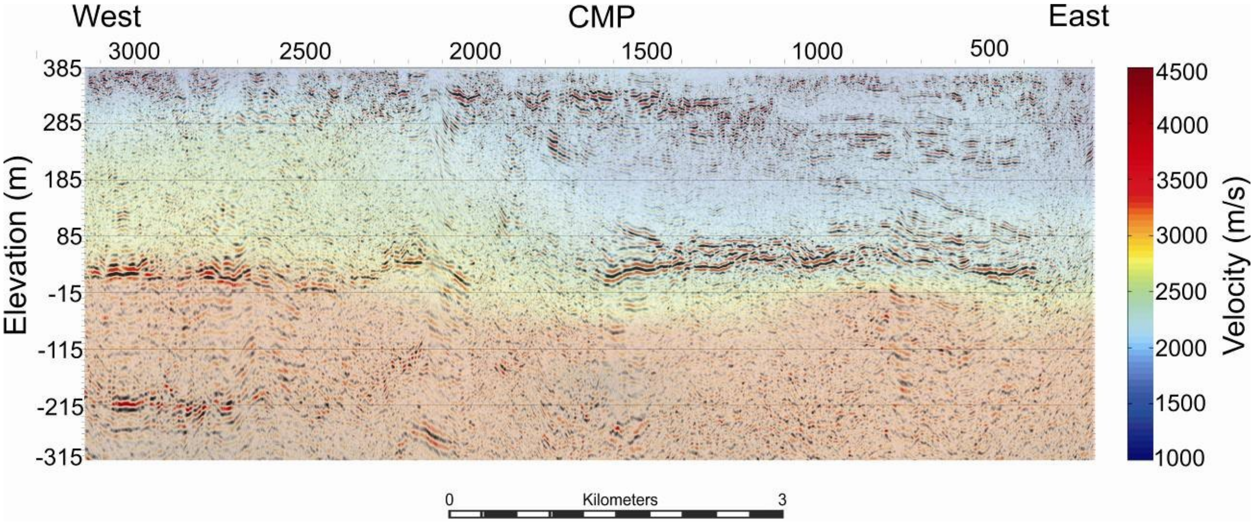

Figure 3: Final Prestack depth migrated seismic overlaid with the traveltime inversion velocities.

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