Imaging Taglu: Anisotropic PSDM in a Permafrost Environment

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Abstract

A case history of anisotropic prestack depth imaging of data recorded over the Taglu Gas Field in the MacKenzie River Delta is presented. Seismic data processing in general, and PSDM in particular, faces a significant challenge in the presence of permafrost. Specifically, perennial water bodies act to create melt zones in the otherwise frozen near-surface, resulting in a complex pattern of low velocity anomalies that induce significant travel time distortions in surface seismic data. First-arrival turning ray tomography proved useful during the initial time domain processing for deriving statics corrections to minimize these distortions. The ultimate processing objective however was to generate an image in depth using prestack migration that takes anisotropy into account. For this purpose, the near-surface velocity model derived from the turning ray tomography was used as the shallow layer of the depth model, with the travel time effects of the permafrost calculated directly by ray tracing rather than by statics corrections. The deeper parts of the anisotropic depth model were then derived by more traditional common image gather analysis. Special effort was taken to calibrate both the shallow and deeper layers of the model with a suite of check shot, crystal cable, sonic logs and tops information.The various imaging challenges encountered and the solutions developed to overcome them will be presented as one possible workflow for performing anisotropic PSDM in a permafrost environment.

History/Background

The Taglu Field is located approximately 120 km north-northwest of Inuvik and was discovered in 1971 by the G-33 exploration well. The field contains natural gas and condensates within a stacked succession of early Eocene fluvio-deltaic sandstone reservoirs that are located some 2250-3150 meters (m) below the surface. A total of seven wells have been drilled during the exploration/delineation phase of the field. Five of the wells penetrated the field of which two wells were drilled to test potential traps within the hanging wall block to the north and found to be dry and was abandoned.

In 1988, a three-dimensional (3-D) inline seismic survey was conducted over the Taglu field. The 3D survey was acquired in an inline-swath configuration using dynamite with a 60 m station interval and 360 m shot interval.

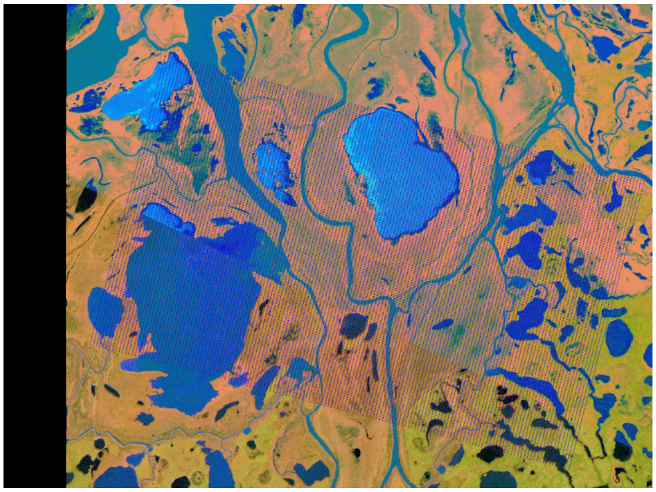


Figure 1. Satellite map with seismic grid overlayed

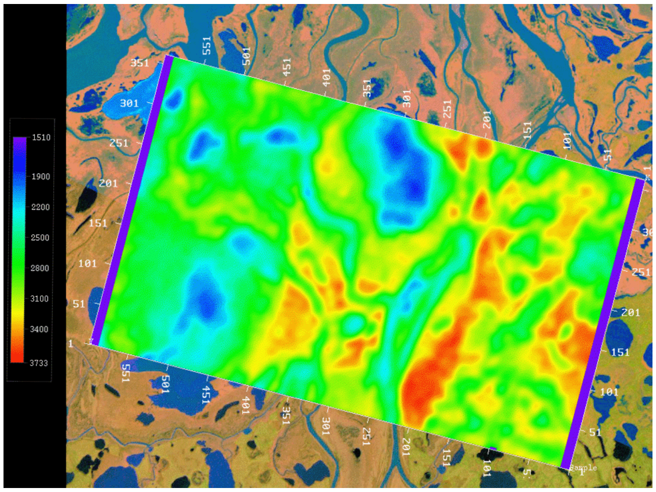


Figure 2. Satellite map with velocity model overlayed

There are a numerous lakes and rivers channels throughout the survey area (Figure 1) beneath which permafrost melting occurs. These rapid lateral variations in the near surface permafrost complicated seismic imaging and the time-to-depth conversion. Poor or noisy sub-fault plane imaging (fault shadow) at the reservior interval is also a problem. In order to ameliorate some of these problems, an anisotropic prestack depth migration (APSDM) was performed. The detailed velocities of the near surface permafrost and melt zones were incorporated using a first arrival turning-ray tomography. A slice at a depth of 20 m through the near surface velocity model derived by the tomographic inversion shows the close match to features observed at the surface (Figure 2).

Near Surface Ray Tracing Methodology

The stability of ray tracing through a complex near surface model has always been problematic due to the large velocity varitions. Large velocity contrasts causes the changes in the ray paths to be quite abrupt and may produce shadow zones. One method of avoiding this problem is to convert a smoothed version of the velocity model to statics down to a pseudo-datum assuming an appropriate replacement velocity and then applying these statics to the time gathers before migration. The problem with this is that we lose much of the detail or information that the near surface model would provide as well as losing some focusing of the deeper layers through distortion of the travel time curvature of events.

One method of incorporating these complex near surface velocities is to smooth them only slightly. This smoothing of the near surface model allows ray tracing to be performed while maintaining the important mid- to long wavelength features of the near surface model. The difference between the unsmoothed and smoothed velocity model is incorporated via the application of a surface-consistent residual static that captures the short wavelength details of the near surface. The magnitude of the statics tends to be quite small, on the order of just a few milliseconds, since the velocity is smoothed in the slowness domain in order to preserve the overall travel time.

The incorporation of this near surface tomography (tomo) model improved the quality of the seismic image as seen in the Figure 3. It not only improves the overall coherency of the reflectors, it gives a more realistic image of the structure while at the same time improving the definition of the fault and the images underneath the fault. However there were a few areas where the image was not enhanced by this process. The near surface model in these areas suffered from the ambiguity of the picked first arrivals used in the tomography. The maximum offsets available for the first breaks modelling extended only to 2000 m which limits the turning rays to a depth of penetration less than 250 m. However, from other information the variations in the permafrost are believed to extend down to a depth of about 500 m. The lower parts of the near surface velocity model were adjusted to match the preexisting well log and crystal cable data (Figure 4).

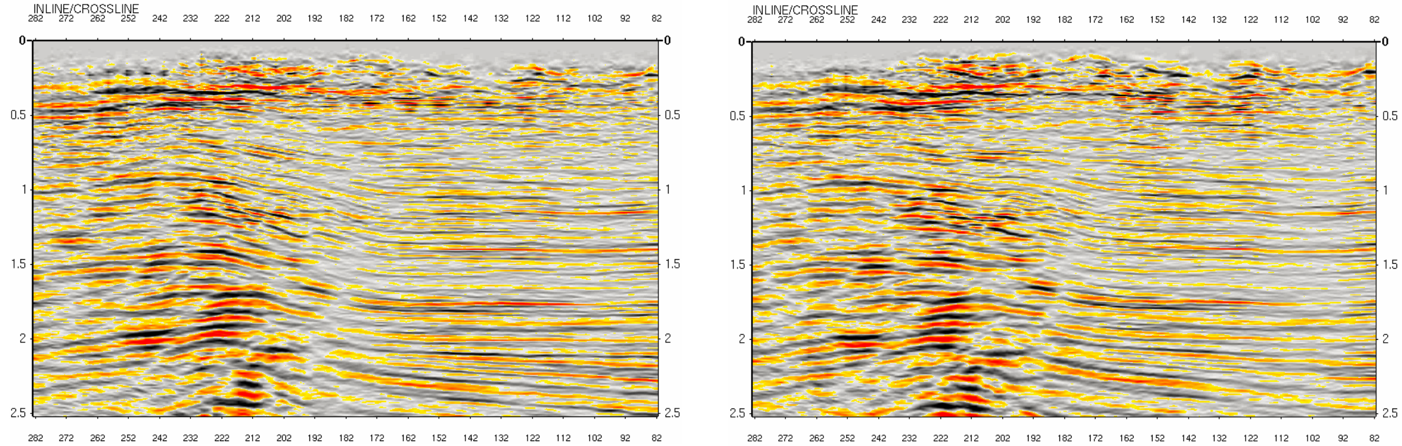
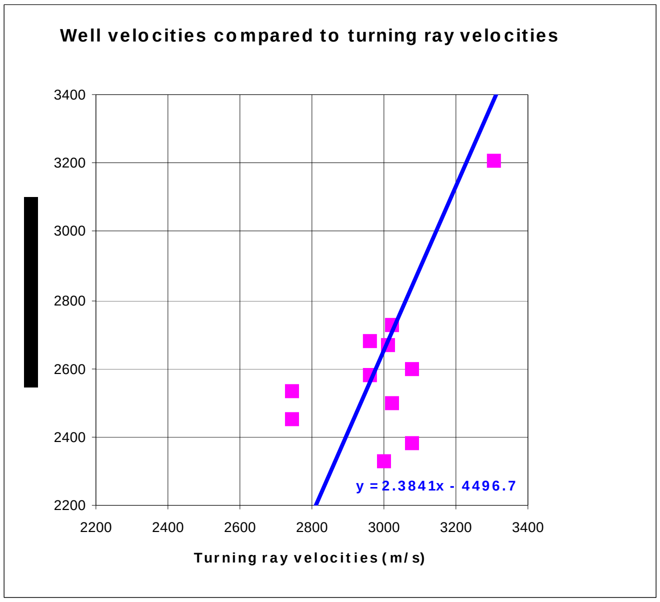


Figure 3. The left panel shows Subline 300 migrated using the old method of statics and a replacement velocity from the surface to a pseudo-datum of 500 m. The right panel shows Subline 300 migrated using the slightly smoothed near surface velocity model after application of small magnitude surface-consistent residual statics.



Graph 1. Comparison of checkshot velocities computed at various well locations versus turning ray velocities obtained.

On close examination of the near surface velocity model, it was found that the tomographic velocities were typically somewhat faster than the velocities as determined by the check shots. One major difference between the turning ray velocities and the check shot velocities is the direction in which the rays travel (Graph 1). The turning rays predominantly travel in the horizontal direction while the check shots predominantly travel in the vertical direction. This implies that the permafrost is not necessarily isotropic but rather may exhibit TI anisotropy. In order to account for this, we slowed down the slow velocities and only slightliy changed the fast velocities by essentially adjusting the dynamic range of the near surface velocities from tomography to match the well data (Figure 4). The anisotropy parameters epsilon and delta were set to 12 % and 5 %, respectively. This had the effect increasing the structural correctness of the depth image. When migrated with out including anisotropy we find that the structure of the layers underneath this have structural undulations that are not expected (Figure 5). When anisotropy is incorporated into the depth model, this medium wavelength stuctural trend disappears (Figure 6).

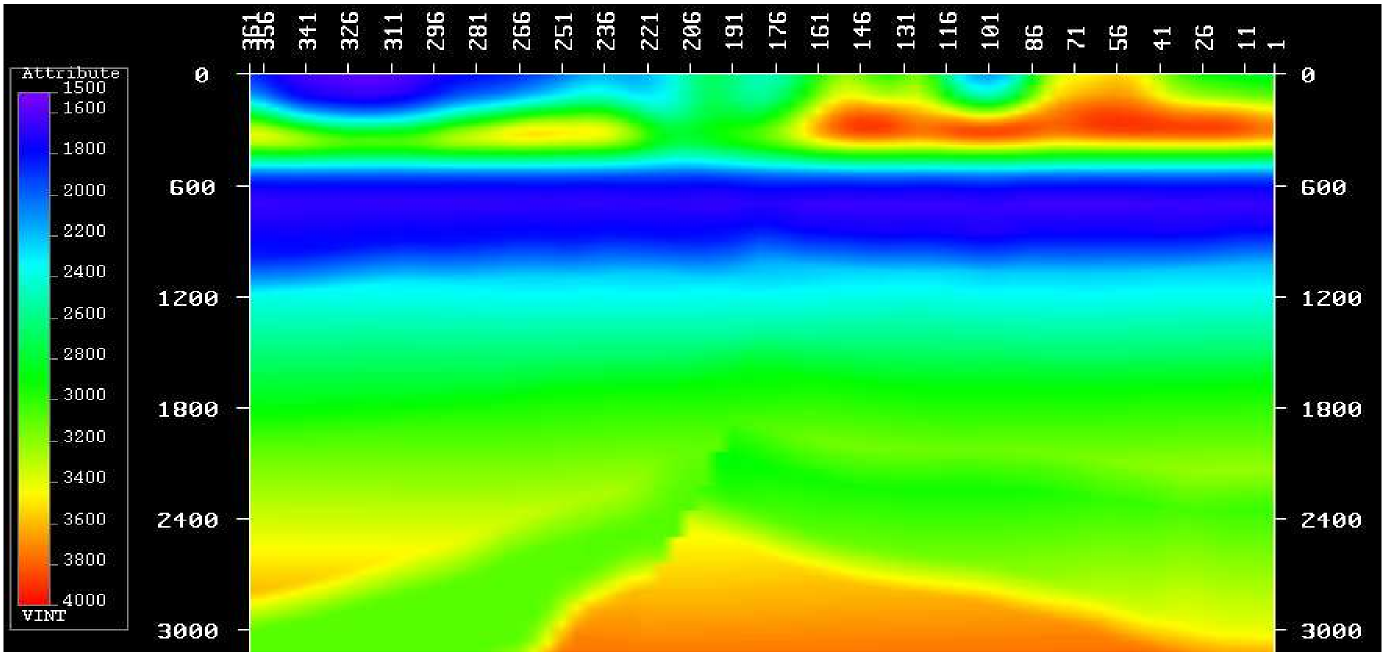


Figure 4. Slice of the velocity model at Subline 300 adjusted to match preexisting well log and check shot information. The vertical axis is in metres and the colour bar denotes velocities in m/s.

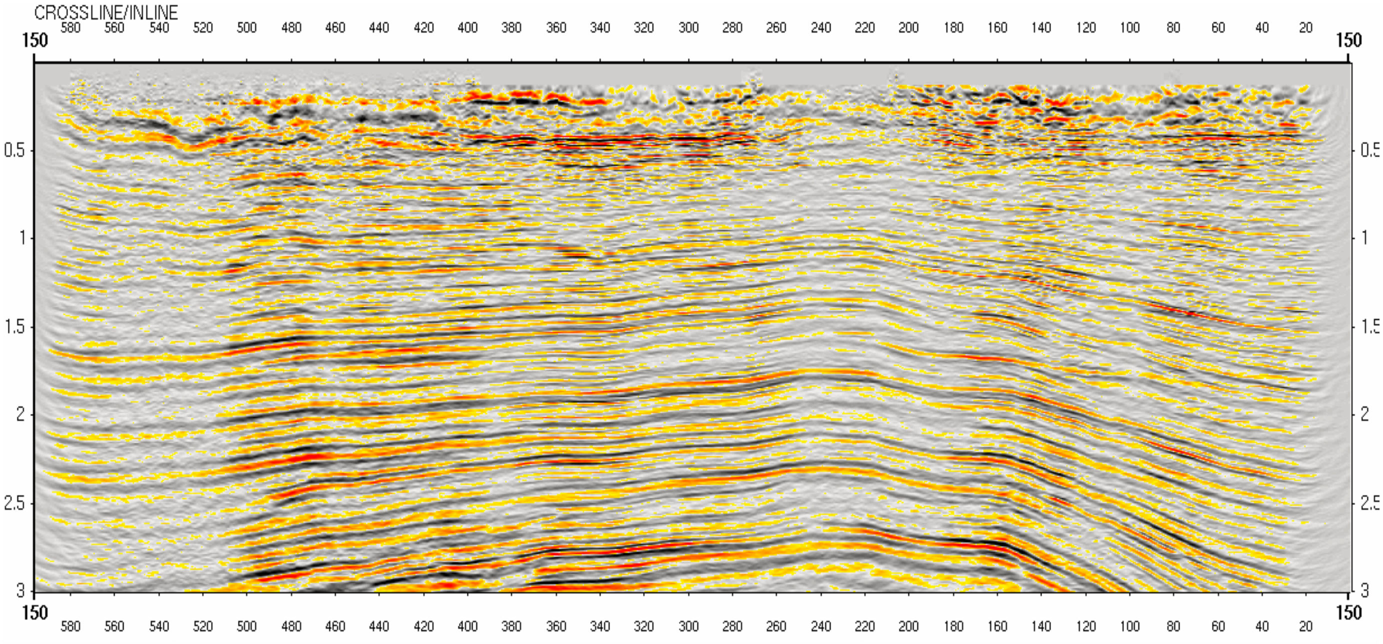


Figure 5. Depth slice of Crossline 150 with isotropic permafrost.

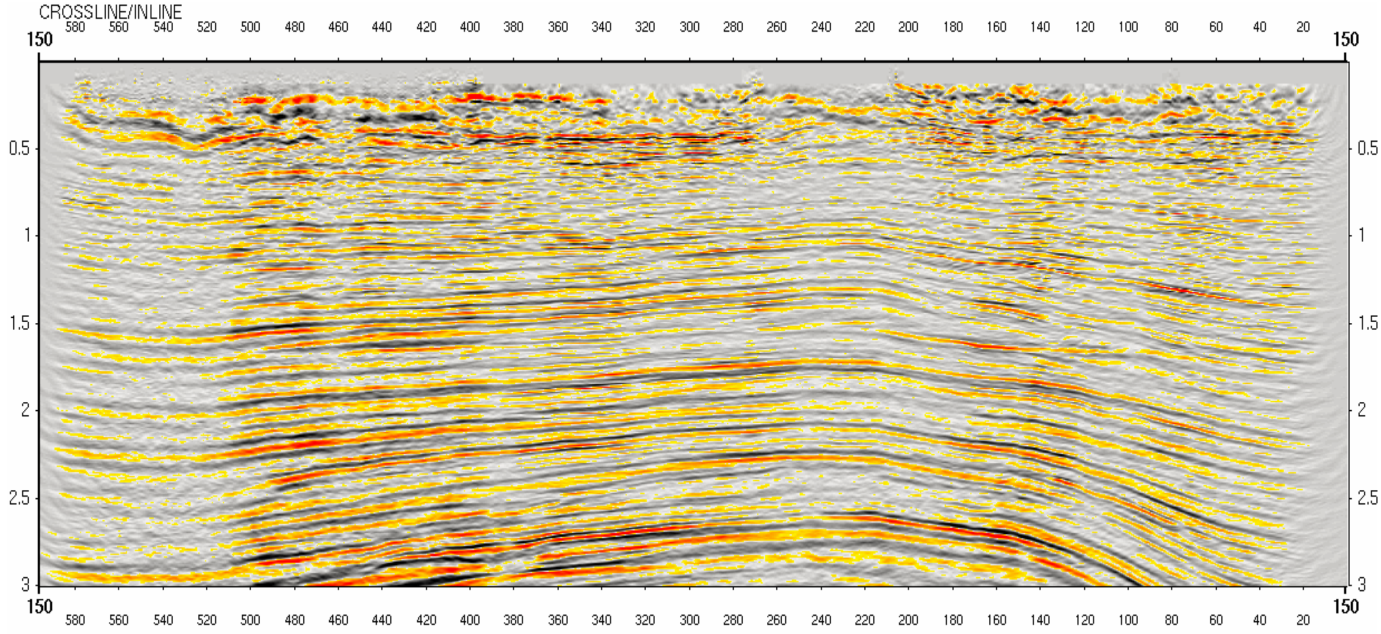


Figure 6. Depth slice of Crossline 150 with anisotropic permafrost.

Conclusions

An anisotropic prestack depth imaging workflow has been described for data recorded over the Taglu Field. Due to the complexity of the near surface velocities in a permafrost environment it was necessary to utilize several customized processing procedures. First-arrival turning ray tomography was used to establish a near surface velocity model with spatial variations that closely matched observed surface features. Mild smoothing of near surface model derived by tomography enabled a separation of the velocity variations into a short wavelength residual static applied to the data gathers and a medium to longwavelength velocity layer for raytracing. This improved the structure and continuity of the underlying seismic data. The velocities in near surface model were calibrated to better match preexisting information from well logs, crystal cable, and checkshots. It was also necessary to introduce anisotropy into the near surface model as well as deeper clastic layers in order to improve structural correctness of the final depth image. The resulting migrated image closely ties the available well tops, providing higher confidence for the ongoing interpretation of the seismic data from the Taglu Field.

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