Wide offset depth processing of Canadian Foothills seismic data for improved structural images

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Abstract

Acquisition of an extended offset line by Husky Energy Inc. in the Canadian Foothills was followed by novel wide offset (depth) processing approach aimed at using all the seismic signals recorded from short to very large offsets for velocity model building and depth imaging. Velocity analysis was carried out by extensive use of high resolution tomographic tools involving the joint inversion of refracted and reflected data. Imaging was obtained by using a Kirchhoff PSDM scheme. Results show the improvement in the imaging achieved by using offsets up to two times the depth of the target relative to a conventional offset processing approach. The proposed acquisition/processing method can be successfully applied to the exploration of structures characterized by poor seismic response.

Introduction

The foothills tectonic environment is notoriously problematic for seismic exploration due to a variety of causes. These can be primarily identified as: incoherent scattering, difficult energy penetration due to high impedance shallow bodies, rough topography, and sharp lateral velocity variations that make conventional processing methods inaccurate. In such geologic conditions, alternative acquisition and processing strategies should be considered. One of these approaches consists of the acquisition and processing of an extended range of offsets able to widen the range of seismic events available for velocity model building and imaging, such as long-offset refracted and reflected waves respectively.

Long-offset reflected events occur near the critical angle and can provide large S/N ratio signals, as well as undershooting localized high impedance bodies that block the near vertical propagation of the seismic energy. The long-offset refracted waves (either head waves or diving waves) in conjunction with the reflected waves, provide the means for estimating velocities from surface to depth. The properties of long offset seismic waves have been extensively used in crustal seismic exploration and similar concepts can now be transposed to the exploration of industrial targets through appropriate scaling of the problem and by applying novel approaches for the processing and analysis of the data.

In recent years many long-offset seismic lines have been acquired both in land and marine environments, with the intent of undershooting shallow localized complexities. However, uncertainties still remain about the actual use of the long-offset propagated energy due to the lack of confidence about the nature of the recorded signals and because of the lack of commercial software packages (except for some higher-order move-out velocity analysis tools) for the analysis of offsets exceeding the usual 1:1 offset to depth ratio. However, a recent work based on synthetic simulations (Colombo et al., 2003) has demonstrated the feasibility of using long-offset reflected energy for improving the imaging in complex tectonic settings and several applications on real data have been carried out in different geologic environments (Fliedner and White, 2001; Dell'Aversana et al., 2002; Dell'Aversana et al., 2003).

The present paper deals with the application of wide offset depth processing to the exploration of a complex foothill structure in the Canadian Rockies (figure 1).

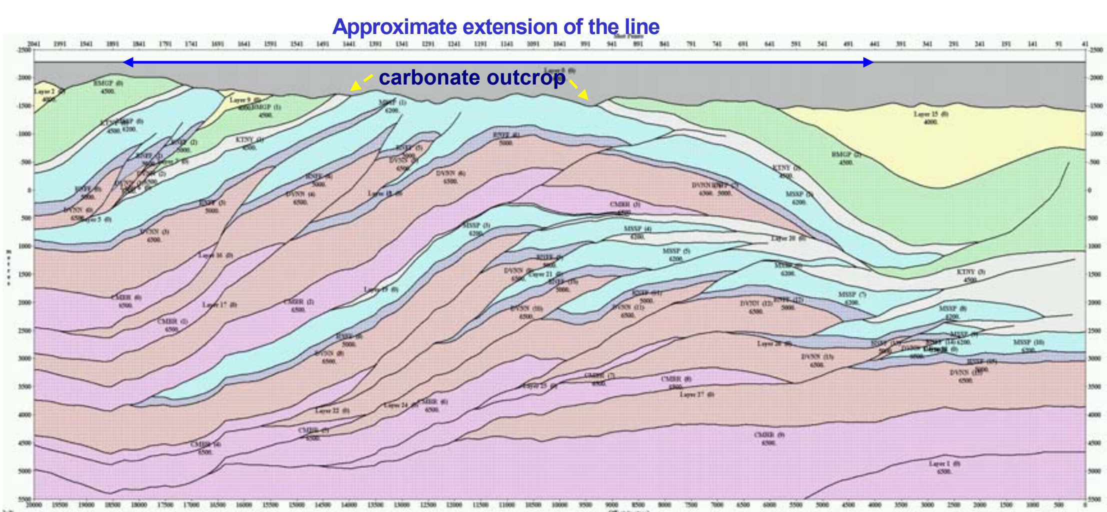

Figure 1. Geologic framework and approximate seismic line location (courtesy of Husky Energy Inc.).

Data analysis

The acquisition geometry was designed to have all receivers installed and alive, and the shot points moving along the line (Table 1).

Intertrace (m)	**10**
Shot interval (m)	**50/100m**
Maximum offset (m)	**12700**
Line length (m)	**12150**
Number of groups	**1271**

Table 1. Acquisition parameters.

The acquired data are of good quality on the flanks of the structure, showing good seismic response while the quality decreases dramatically in the central portion of the line (figure 2) due to the presence of carbonate outcrops. The overall quality of the first breaks is good for all the gathers allowing realible picking, up to the maximum available offset.

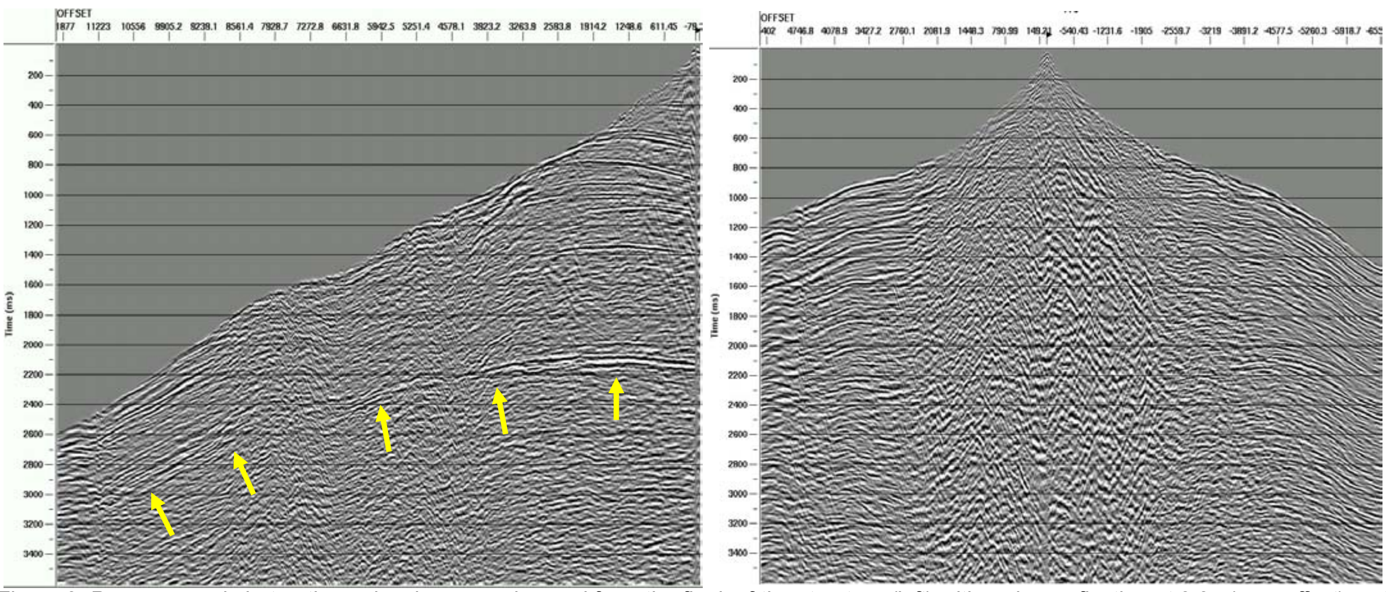

Figure 2. Preprocessed shot gathers showing a good record from the flank of the structure (left) with a clear reflection at 2.2s (zero offset) and its continuation up to the maximum offset; bad seismic record (right) showing the near offset traces (up to 3Km) dominated by noise.

Wide Offset processing results

The approach followed for the processing of the wide offset data consisted of progressive velocity analysis from top to bottom in depth domain by using tomographic techniques and in particular a combination of turning ray and reflection tomography. The tomographic results (figure 3) were in turn used for the calculation of tomostatics that were applied in the pre-stack time domain processing. Reflection tomography was used to derive the macro velocity field distribution at a depth not explored by the turning rays. The refinement of the velocity field was then carried out in the post-migrated domain thrugh the analysis of the residuals on the common image gathers followed by bent-ray tomographic update of the velocity field and/or by performing velocity scans in the areas of low S/N ratio.

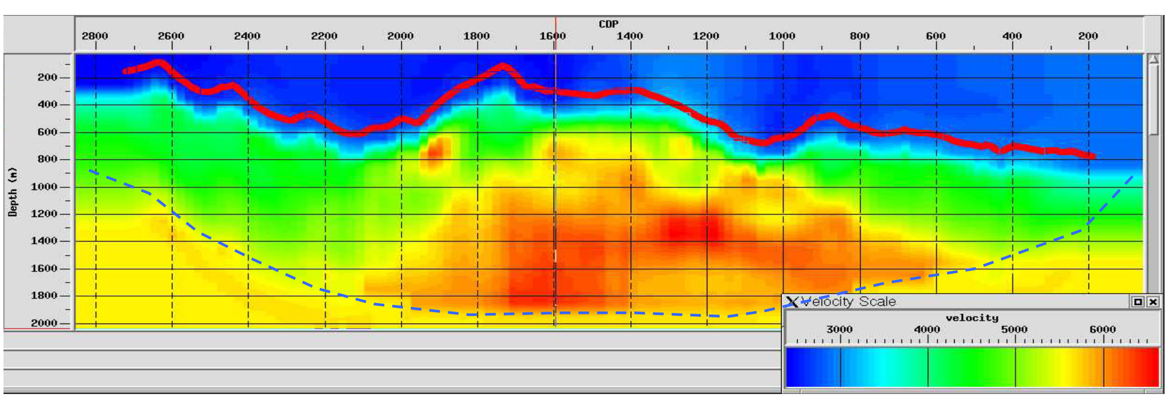

Figure 3. Turning ray tomography results. The dotted line indicates the area sampled by the rays.

A Kirchhoff pre-stack depth migration algorithm was used for depth imaging and a maximum amplitude travel time calculation scheme was used for the generation of the travel time tables for migration. The contribution of the long offset reflected energy to the image is clearly visible in the centre of the line where the short offsets are dominated by noise. This effect is better shown by comparing the results of two PSDM which used the same final velocity model but where the offset was limited in one of the two to a conventional 3+3Km maximum offset (figure 4).

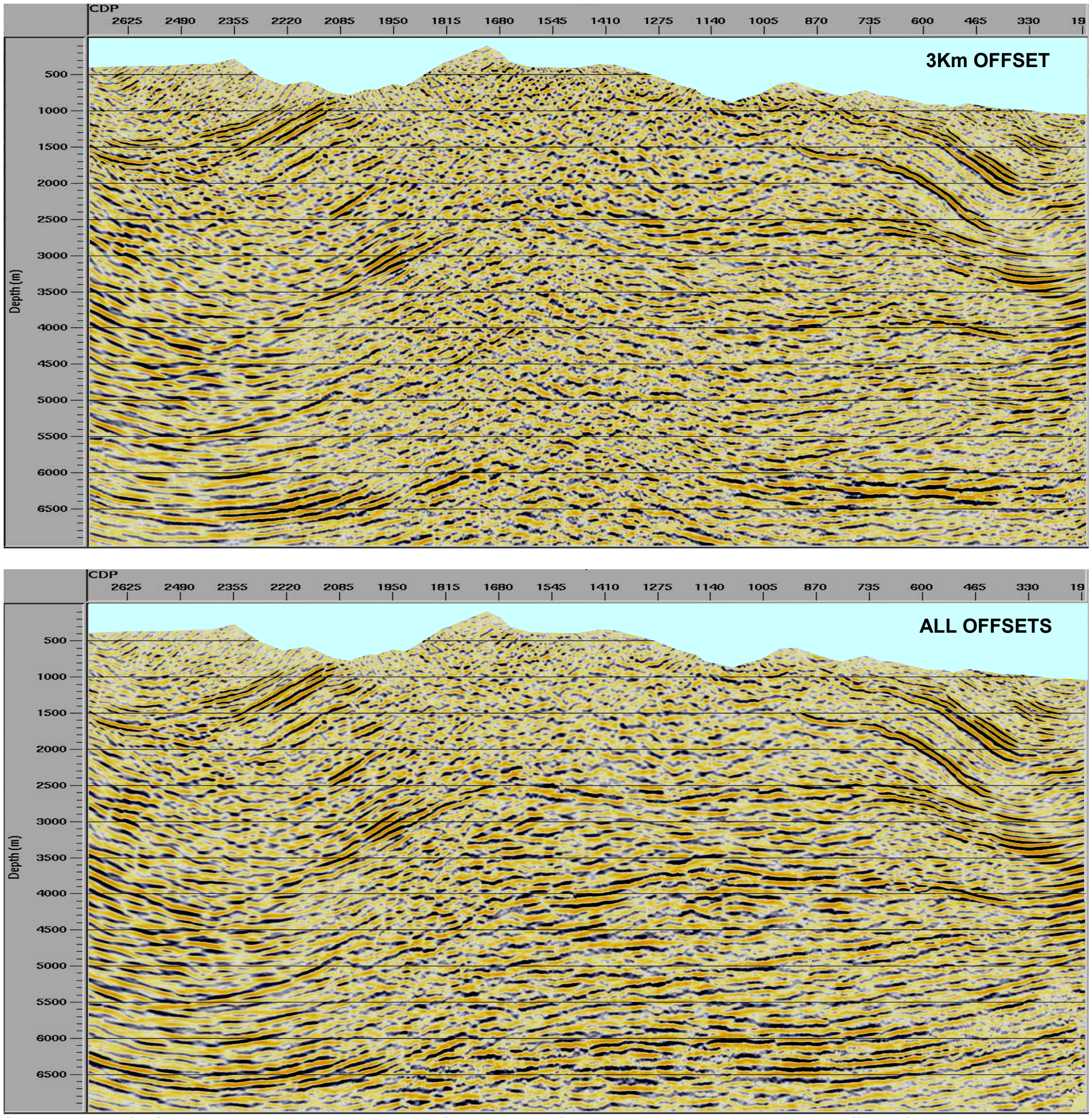

Figure 4. Comparison of PSDM results by using the same final velocity field and limiting the maximum offset of the input data to 3Km (top) or by allowing all the available offsets to be migrated (bottom).

The maximum contribution of the long offsets to the image building is in the central section of the line and starting from an approximate depth of 2500m (in model coordinates). The analysis of the common image gathers (figure 5) indicates that the flanks of the anticline structure are well imaged by conventional short offset data while the central portion of the line receives most of the signal from events having an offset larger than 3000m

The central section of the line for the portion shallower than 2500m does not improve with the use of long offset and this can be attributed to the ratio between the carbonate outcrop size (about 5000m), where the seismic response is poor, and the depth of imaging. The offset that is possible to use for imaging is controlled by the stretching after migration that is in turn influenced by the velocity values (large velocities produce more stretching with offset). For the processed line and for the velocities involved, we can state that effective undershooting of the outcropping carbonate sequence is obtained for offsets up to two times the depth of imaging. However, offsets larger than this ratio were extremely useful for velocity model building obtained by means of tomographic analysis.

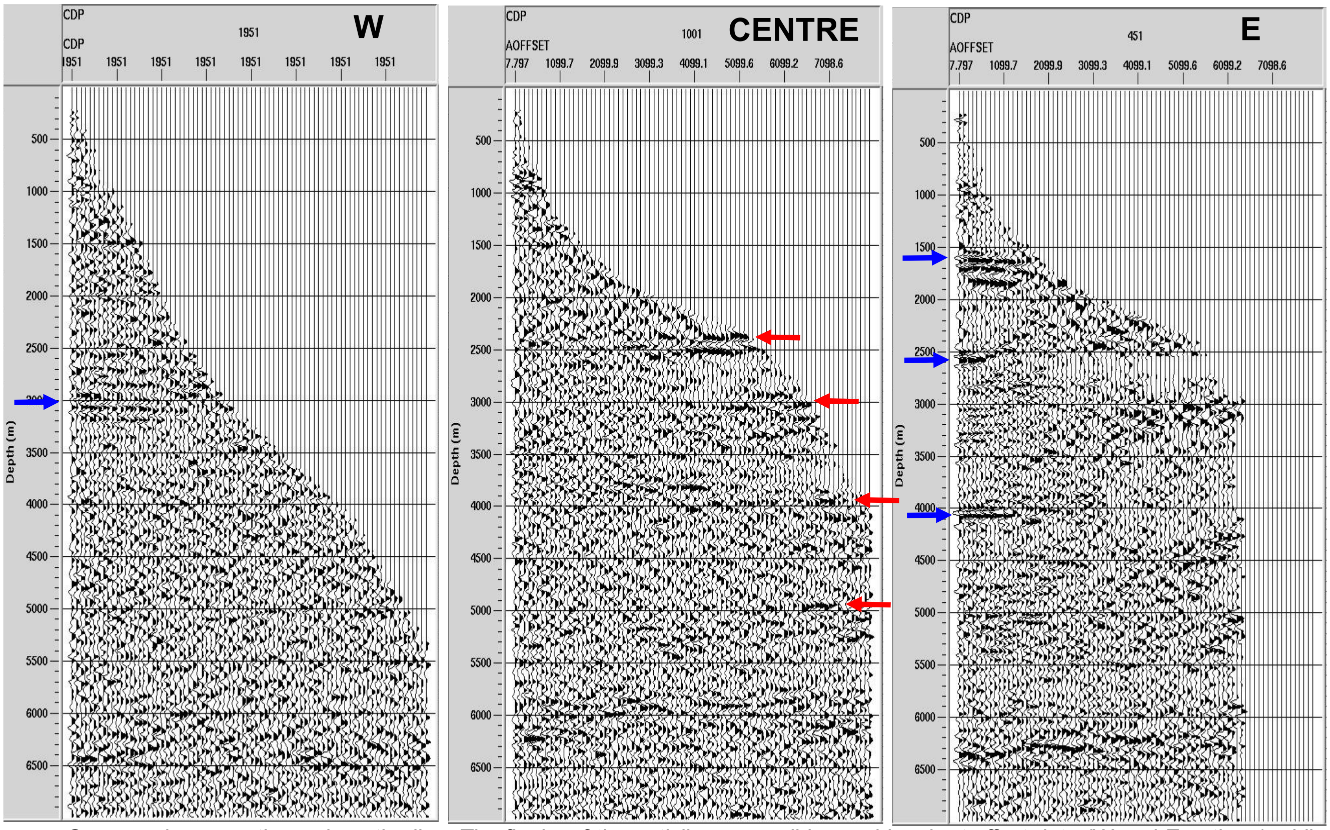

Figure 5. Common image gathers along the line. The flanks of the anticline are well imaged by short offset data (W and E gathers) while the centre of the structure is imaged by offsets larger than 3000m.

Conclusions

A wide offset depth imaging workflow has been successfully applied to seismic data acquired in the Canadian Foothills over a complex anticline structure known to represent a challenging environment for seismic imaging. The obtained results indicate that even in complex structural settings and with high velocities, imaging can be improved by using source-receiver offsets up to two times the depth of the target. Offsets larger than this ratio are, however, important for velocity analysis since they allow deep penetrating turning waves and wide angle reflections to be included in the velocity model building procedure.

Extended offsets are able to overcome the problems related to near-vertical propagation of the seismic energy through high impedance bodies by undershooting them and by taking advantage of a larger S/N ratio near the critical reflection angle. The effectiveness of wide offset imaging is strongly dependent on the ability to perform reliable and accurate velocity analysis in depth domain which can be achieved by means of high resolution tomographic techniques using a variety of seismic phases including at least refracted and reflected waves.

The wide offset workflow can be considered as a viable solution to improve seismic imaging in complex tectonic settings including thrust belt, sub-salt and sub-basalt imaging since it provides extended analysis capabilities while preserving the characteristics of conventional seismic reflection profiling.

Acknowledgments

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References

Colombo, D., Wilkes, M., Villani, L., and Mantovani, M., 2003, Feasibility study for long offset seismic acquisition in a thrust-belt, SEG 73rd Annual Meeting, Dallas, **ACQ2**, 51-54.

Dell'Aversana, P., Morandi, S., Colombo, D., and Buia, M., 2002, Time-Depth Processing of Global-Offset Data: a New Perspective for Seismic Imaging in Thrust Belt, 64th Ann. Internat. Mtg., Europ. Ass. of Geosc. & Eng., (**E035**).

Dell'Aversana, P., Colombo, D., Buia, M., and Morandi, S., 2003, Velocity/interface model building in a thrust belt by tomographic inversion of global offset seismic data, Geoph. Prospecting, **51**, 23-35.

Fliedner, M.M., and White, R.S., 2001, Sub-basalt imaging in the Faeroe-Shetland Basin with large offset data, First Break, **19.5**, 247-252.