Improving the Statics Solution through De-migration: A Canadian Foothills A-PSDM Case History

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Summary

In this Canadian foothills case history, we illustrate how an incorrect static solution (undetected despite careful QC during the processing of this data-set in the time domain) prohibited the convergence of the depth imaging process. The error was only discovered in the middle of the depth imaging phase as the tomography velocity model building iterations were no longer converging. The failure of the conventional statics estimation was due to poor quality pilot traces resulting from both the complexity of the geological structures and a very poor signal to noise ratio in some areas of the data. The de-migration of the PSTM stack volume provided us with greatly improved pilot traces and hence a greatly improved statics solution. The new statics solution definitely improved the convergence of the tomography velocity model building iterations and ultimately helped to derive a better depth image.

Introduction

The Canadian foothills are notorious for the imaging challenges they present: large topographic relief, steep-limbed geological structures, high velocity contrasts, complex near-surface, and low signal to noise ratio. In this example, it was decided after the PSTM phase that depth imaging was necessary to further improve the imaging of the deeper targets. Although the Anisotropic Pre-Stack Depth Migration (APSDM) generated a more focused volume than the PSTM, some complex areas were still poorly imaged. In these areas, the depth imaging iterations were no longer converging. Kinematic inconsistencies, well misties and the nature of the noise pointed us toward a need to revisit the statics solution, both refraction and residual statics.

Topography and near-surface lateral velocity variations generate delays that can be approximated as surface consistent static time shifts. The topography is corrected by a time shift to a flat datum, the long and mid-wavelength velocity variations are corrected by a Tau-P refraction tomography (Ozypov,2000). The residual statics correction method is proprietary and is similar to what was described by Tanner (1974), Wiggins (1976), Kirchheimer (1983), Ronen and Claerbout (1984) amongst others.

A time shift T_{ijk} is a sum of several effects: $T_{ijk} = R_i + S_j + C_k + M_k*(j-i)*(j-i)$

Where R_i = receiver static at i^{th} receiver position, S_j= source static at j^{th} source position, C_k= arbitrary time shift for k^{th} CDP gather, M_k=residual NMO component at k^{th} CDP gather, and (j-i) = source-to-receiver distance.

Under the assumption of surface consistency, shots and receiver statics are derived by maximizing the nonlinear stack power function. This function is subject to numerous local maxima, especially in the presence of ambiguities i.e. cycle-skipping, non-hyperbolic move-out, random and coherent noise.

Rothman (1986) proposed a global optimization method to address the local maxima problem, an approach that is very computationally intensive. Alternatively, to aid the convergence of the stack power maximization, a pilot trace or “model”, that is assumed to be close to the solution, is commonly used. For instance, Side Jin (2006) constructs the pilot trace by a local robust L1-norm inversion at each CDP location followed by a global L1-norm inversion of source and receiver statics from time shifts of all traces in CDP gathers relative to their pilot traces. In this paper we present a different approach to estimate the pilot traces, followed by a global inversion of source and receiver statics relative to their new pilot traces.

A velocity model building issue or an incorrect statics solution?

When all of the aforementioned challenges are encountered in the same project, it makes depth imaging extremely difficult. In particular, this 3D survey was plagued by two serious problems. The first problem is that the acquisition parameters were too coarse to adequately sample the steeply dipping structures close to the surface. The second problem is that there is a large carbonate thrust sheet with fast velocities (above 6000m/s) that lies above much slower overturned clastics formations (3000m/s), the strong fast/slow velocity contrast inducing a shadow zone and an associated poor signal to noise ratio above a potential target (figure 1). In addition, inherent instabilities of the reflection tomography are difficult to dissociate from all of the other potential problems that can be encountered in processing such as geometry errors, improperly conditioned input data and incorrect statics solution.

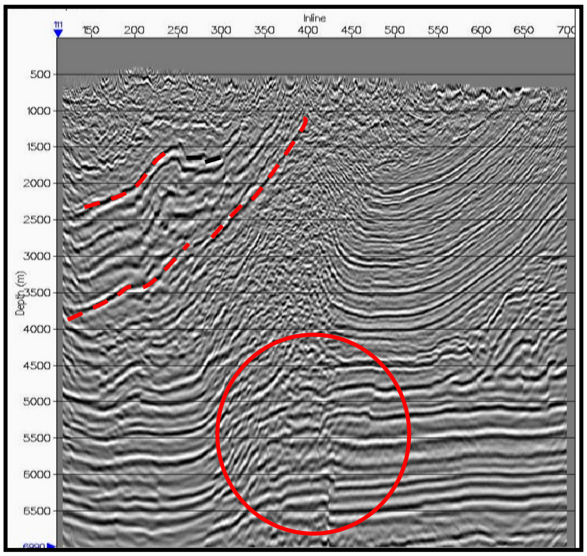

Figure 1. PSDM inline showing distortions on base carbonate layers (in red circle). The dashed lines outline the carbonate thrust sheet.

A generally focused APSDM volume was obtained after a series of velocity model updates using a hybrid tomography velocity model building approach (Charles et al, 2008). However, the image was out of focus in some areas showing conflicting dips and discontinuous events.

Figure 1 shows an inline section that has the problem area circled in red. The events were expected to have similar continuity on the left of the circle as on the right. The poor imaging within the circle could be caused by unresolved short wavelength lateral velocity variations that are not included in the velocity model or by any of the aforementioned problems.

After a careful review of the velocity model and the well ties; several unsuccessful tomography velocity updates; a review of the input and output gathers of the APSDM, we concluded that the residual statics solution was locally incorrect. The statics failure was not detected during the PSTM phase because PSTM cannot image these deeper structures in this area due to the complexity of the velocity model.

New statics approach

Accurate statics corrections are critical to the success of any land seismic data processing project. In this case, the original statics solution was calculated using the best structure (un-migrated) stack as a model (pilot) during the iterations of statics calculations. The quality of the estimated statics typically depends on the quality of cross-correlations between the input data and the pilot traces. Since the quality of our cross-correlations was very poor in some areas, we needed a better model. For a better model, we used a de-migrated PSTM stack volume. This stack was gene-

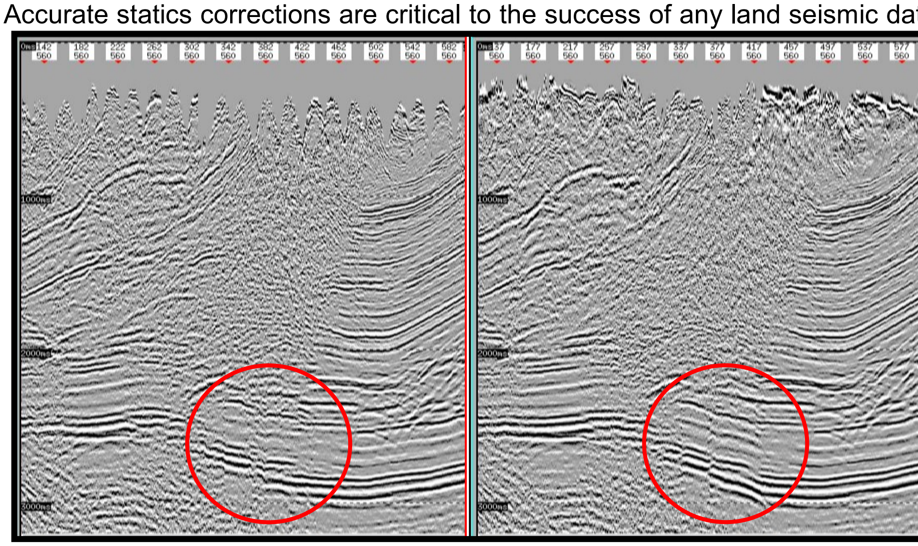

Figure 2. Structure stack of the same line as in Figure 1 shows a comparison of stacks with conventional statics calculation (left) and new de-migration statics calculation (right).

rated from a migration/de-migration loop: the data were pre-stack time migrated, additional noise attenuation applied, and de-migrated using the same velocity field. Particular care was taken during the noise attenuation to avoid introducing false structures. The new statics solution improved the resulting imaging.

Figure 2 is a comparison of structure stacks using the original statics and the improved statics solution. The new stack has more continuous reflectors in the problem area (circled in red). Note that both stack images used the same NMO velocity field for a true comparison of the statics effects, although these velocities are not necessarily appropriate for the new statics solution (degradation in the shallow part of the section).

Improved APSDM 3D Image

The velocity model was refined via additional tomography velocity model building iterations using the new statics solution. The additional iterations benefited from the improved signal to noise ratio on the Common Image Point (CIP) gathers and converged to a final velocity model faster (Figure 3).

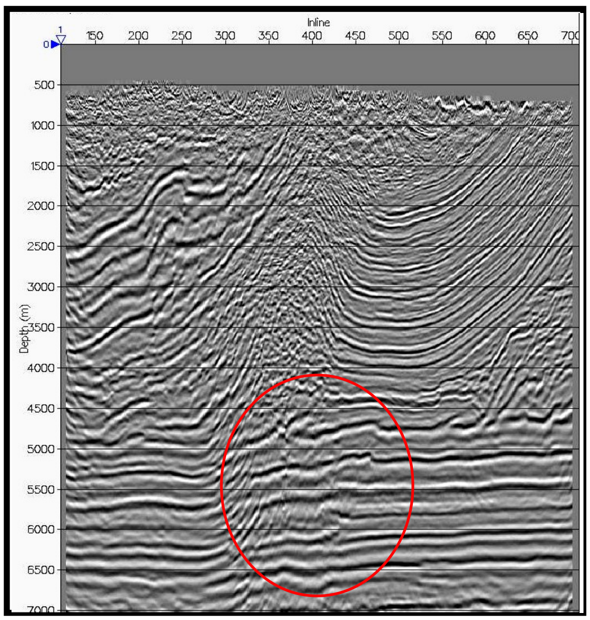

Figure 3. The final depth image shows improved reflector continuity and clearer fault.

With the new statics solution, the new depth image (Figure 3) clearly shows improvements over the previous results shown in figure 1. The reflector continuity and fault definition in the regional carbonate formations are improved.

Despite this improvement, the quality of the image below the large carbonate thrust sheet still exhibits some imaging artifacts. Those are the results of

- a lack of illumination due to the shadow zone (fast carbonate sheet over slow clastic sediments)
- a seismic survey that is coarse and too short, especially on the left part of the image.
- and the well-known limitations of the migration engine (Kirchhoff).

Conclusions

In this paper we have presented a new approach to surface-consistent residual statics estimation. We used a de-migrated PSTM stack volume as model to guide the surface-consistent residual statics estimation. This approach was successful in improving the convergence of the tomography velocity model building iterations and therefore successful in improving the resulting depth image. A natural extension of this work would be to replace the de-migration of a PSTM stack volume by the de-migration (or zero-offset modeling) of the APSDM stack volume.

We have shown that the conventional derivation of residual statics solutions can be insufficient. The residual statics solution and the stacking velocity model used to compute the statics solution are coupled and can fail in areas of complex structure and poor signal to noise ratio. Standard QC methods may not detect this failure in time domain imaging. Although detected in the depth phase of the processing, the problem was corrected by going backwards to the time domain. In this example time and depth processing were not independent processes, and these two processes should maybe be more intertwined in areas of complex structures and poor data quality.

Acknowledgements

We would like to thank the following people and organizations:

- Talisman-Energy Inc for permission to present the information contained in this paper.
- CGGVeritas Library (Canada) Ltd for permission to show the seismic data.
- Rob Holt and all of those at WesternGeco who helped with this project.
- Eileen Charles for a careful review of this abstract.

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