A Regularized Approach to 3-D Prestack Time Migration

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2005 CSEG National Convention

Abstract

The quality of the final image from the usual approach to 3-D prestack time migration is often compromised by the production of migration artifacts due to the irregular distribution of sources and receivers. We control the quality of the prestack migrated image by separately migrating subsets of the full 3-D dataset called common-offset vector (COV) gathers. A COV gather is the natural extension of a 2-D common-offset gather to 3-D by using Cartesian coordinates. Instead of using offset and azimuth to describe the source-to-receiver offset we use inline offset and crossline offset since it leads to a natural subdivision of the data. Issues such as normalization of amplitudes, edge effects and operator aliasing are easily handled in the COV domain. It is especially important to control the impact of the prestack geometry when prestack migrating Canadian plains data since if it is ignored, the subtle improvements expected from prestack migration could be masked by migration artifacts.

Introduction

Getting a reliable image from the prestack migration of 3-D land seismic surveys is difficult because of poor sampling of the prestack data (Canning and Gardner, 1998). 3-D Kirchhoff prestack migration involves the evaluation of a 5-dimensional integral of a highly oscillatory, irregularly-sampled function that is usually aliased in at least 2 out of 4 spatial dimensions. It is difficult to evaluate this integral accurately with discrete summations. With real 3-D data there is not only the issue of irregular acquisiiton geometry to contend with (crooked, missing and irregularly-spaced receiver lines; missing, repeated or skidded shots), but even with perfectly regular sampling, it is not obvious how to treat the data and operator aliasing issues with a typical land geometry of orthogonal shot and receiver lines (Cary, 2001).

The accuracy of 2-D prestack migrations can be controlled with the use of common-offset gathers and sections since in principle each migrated common-offset section can stand alone as a complete image of the subsurface. The COV approach to 3-D prestack migration is along the same lines as the common-offset approach to 2-D prestack migration.

Common-Offset Vector Gathers

The usual way of trying to subdivide a 3-D prestack dataset is by treating the source-to-receiver vector in terms of offset and azimuth (polar coordinates). This inevitably leads to problems. We would like to choose an offset interval and an azimuth interval, and have the prestack traces populate each of these prestack volumes uniformly, without any gaps or large fold variations. But the data have not been acquired on a grid that is defined by polar coordinates, so the data naturally do not subdivide in that manner. Trying to subdivide the data this way is something like trying to fit a round peg into a square hole.

Instead of thinking of the source-to-receiver vector in terms of offset and azimuth (polar coordinates), it is fruitful to think in terms of inline offset and crossline offset (Cartesian coordinates), as illustrated in Figure 1. A common-offset-vector gather is simply a collection of traces that share the same inline offset and crossline offset. The inline offset does not have to equal the crossline offset, but the inline offsets of all traces must be the same, and the crossline offset of all traces must be the same. It turns out that COV gathers can be constructed and analysed in very much the same way as 2-D common-offset gathers.

True COV gathers are normally sparsely sampled in the CMP domain, just like true common-offset gathers are sparsely sampled for a lot of land 2-D geometries. For 2-D data, the spacing between traces in true common-offset gathers is equal to the source interval, which is often several times larger than the receiver interval. For 3-D geometries the inline direction is normally along the receiver lines, and the crossline direction is normally along the source lines. This implies that the spacing between traces in true COV gathers is equal to the source-line spacing in the inline direction and the receiver-line spacing in the crossline direction. In order to obtain a 1-fold volume of traces that fills in every CMP location with similar values of inline-offset and crossline-offset, the inline-offsets and crossline-offsets need to be binned. For an example of how this is done, and for further descriptions of the COV concept, see Cary (1999a, b).

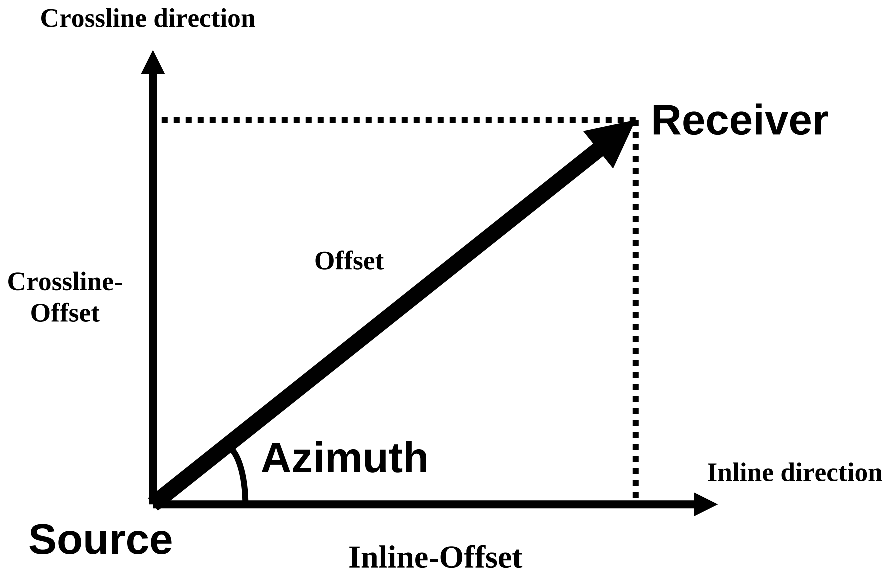

Fig. 1. A common-offset-vector gather is a selection of traces with common inline-offset and common crossline-offset (Cartesian coordinates), instead of common offset and azimuth (polar coordinates).

Results and Conclusions

To illustrate the method we use a typical 3-D dataset from Western Canada. The source line interval is 360m, the receiver line interval is 240m, and the source and receiver intervals are both 60m, as shown in Fig. 2.

A typical 3-D Kirchhoff prestack time migration calculates each output trace by adding in the contribution from all possible input traces. Issues such as how to normalize the summation and how to compensate for boundaries and mute zones around the 3-D is always something of a guess. The result is usually something like the top panel in Fig. 3. This figure compares the results of three different migrated images of one inline through the centre of the 3-D. Notice the noisy appearance of the top panel compared to the other two panels, especially in the shallow section where the mute zone makes the geometry effects extremely irregular. Evidence of migration smiles can be seen emerging from the ends of the stronger reflectors deeper in the section. The overall noisy appearance is due to poor contructive and destructive interference of migration operators.

The middle panel in Fig. 3 shows the 3-D prestack time migration result when COV gathering is used to regularize the geometry before migration. Notice that the image is much less noisy than the top panel. Each COV volume within the total 3-D dataset was migrated separately in order to obtain this result. Since the boundaries and the mute zones of each COV volume are well-defined, it is possible to apply appropriate boundary conditions to each COV volume separately, add together the independent COV images, and know that artifacts are not contaminating the final result.

The bottom panel in Fig.3 shows the 3-D poststack time migrated image. Notice that the poststack result is much more similar to the prestack migration with the COV gathering step than without COV gathering. Since there is little geologic structure in this example, this is exactly the result that we should expect to see. This is the result that we should expect from most plains examples from western Canada. If the prestack migrated image is much different from the poststack migrated image in an area with so little structure, this is reason to suspect that something has gone wrong.

Acknowledgements

We would like to thank Lee Hunt of Ketch Resources for his encouragement and feedback. We also thank Olympic Seismic for their generous permission to show the data.

References

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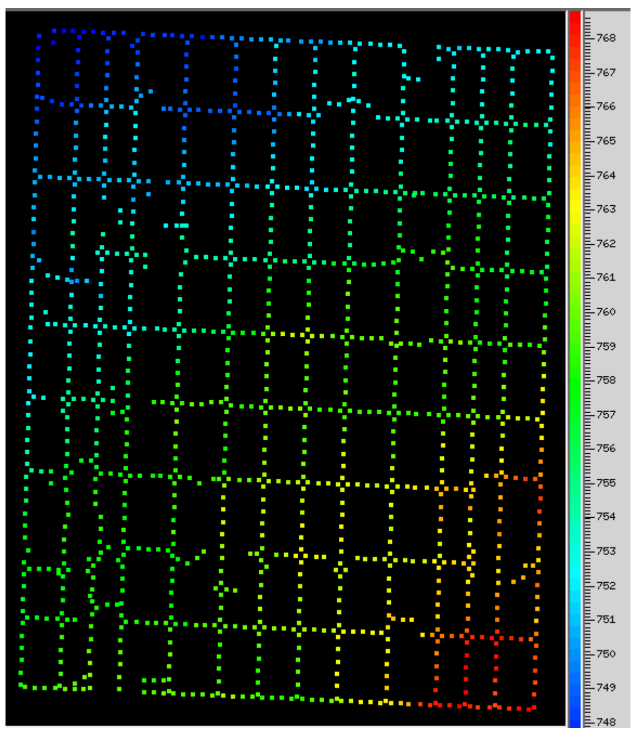

Fig. 2. Elevation map of 3-D survey that illustrates acquisition geometry. This fairly regular 3-D survey has E-W source lines that are 360m apart and N-S receiver lines that are 240m apart. Source and receiver intervals are both 60m.

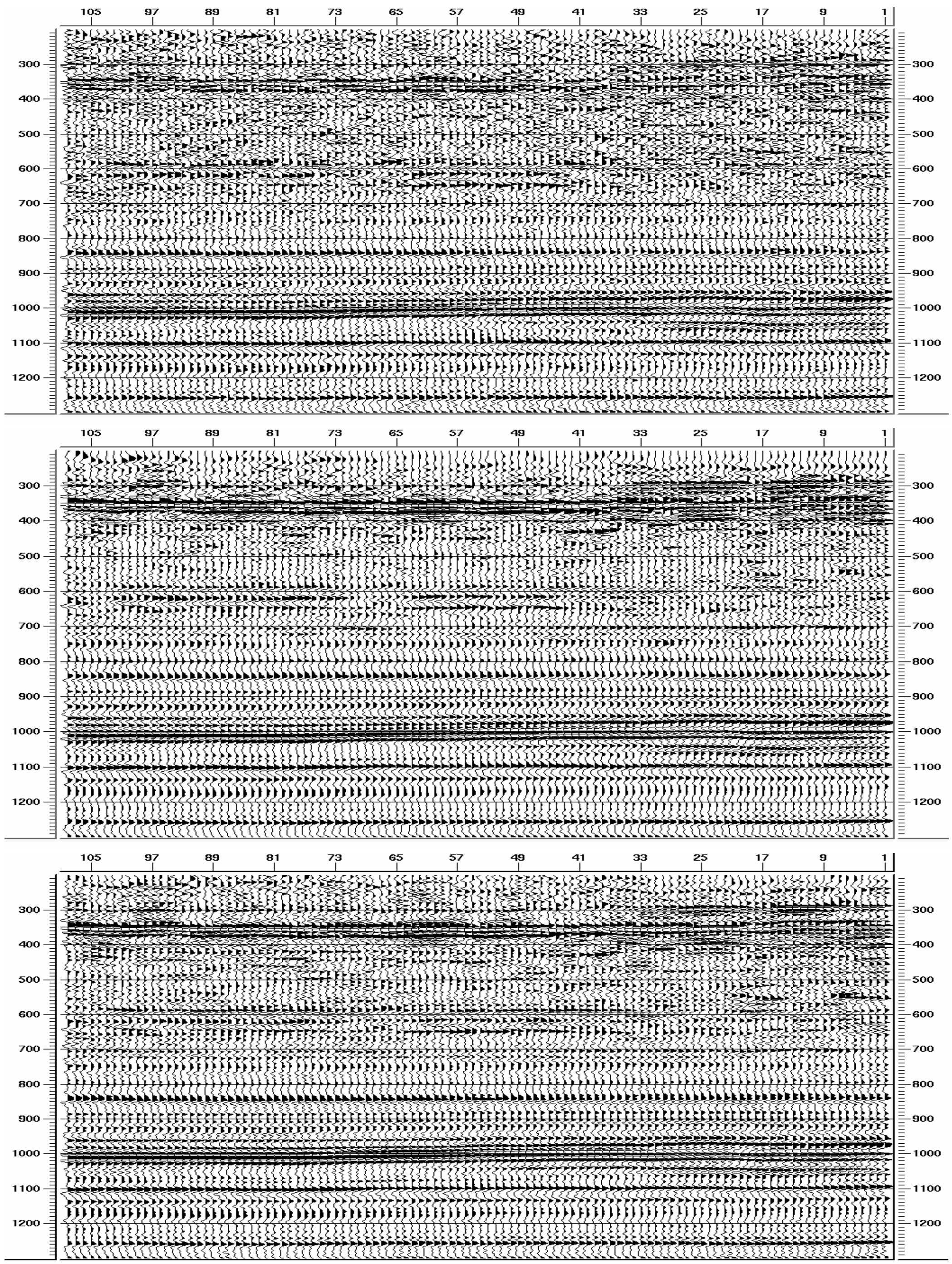

Fig. 3. Top Panel: 3-D prestack time migration without COV gathering. Middle Panel: 3-D prestack time migration with COV gathering. Bottom Panel: Poststack time migration. Notice the noisy appearance of the prestack migration result without COV gathering compared to the other two results.