A Perspective on 3-D PSDM in Compressive Tectonics

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SUMMARY

3-D Prestack Depth Migration (3-D PSDM) is becoming the ultimate tool for seismic imaging in complex areas. Now generally available, this technique is becoming more efficient and cheaper to use, thanks to the ever growing power of today's massively parallel supercomputers, the availability of large memory storage and very fast I/O capabilities. However, one should bear in mind that 3-D PSDM cannot be used as a black box ; in fact, its success depends on three procedures : 1) deriving and updating an appropriate velocity model, 2) performing careful QC at every step during the imaging process, and 3) using a robust method for computing traveltime tables and other Green function attributes.

In areas such as the Gulf of Mexico, where the velocities are well-known and varying smoothly, 3-D PSDM does not always need to follow these three steps and can be applied with success in almost a blind way with most algorithms. In more structured areas such as the North Sea, where large horizontal heterogeneities exist in the velocity field, one should be more cautious: the main difficulty there is to derive an appropriate layer-based velocity model. Finally, in very complex areas such as compressive zones, the challenge is still ahead. In those areas, if not used carefully, 3-D PSDM can yield very poor results and is not cost-effective. In this case, we propose to use first an alternative, cheaper 3-D imaging method to evaluate the difficulties involved. If 3-D PSDM is then justified, we recommend following very carefully the three steps mentionned above.

INTRODUCTION

2-D prestack depth migration has been used for many years as the ultimate tool for obtaining accurate images of the subsurface. It has completely changed the way interpreters look at seismic data today. Previously, we interpreted time-migrated images representing qualitatively the subsurface structure. Deciding on a well location within the structural interpretation required time to depth conversions involving a good deal of approximations. With the advent of faster computers, 2-D PSDM now allows us to produce images directly in depth, without the need for further corrections, thereby reducing interpretation errors, turn-around time and costs. Algorithms can now be used incorporating the finest imaging and propagator (e.g. : raytracing) techniques available. However, PSDM relies heavily on the use of an appropriate velocity model, much more so than for post-stack or time migration. In 2-D, this problem has been solved by coupling velocity analysis with the migration itself, through techniques such as depth focusing or residual curvature analysis (image gathers). Although computer-intensive, these techniques can be routinely applied today in a number of integrated sofware platforms.

The main challenge for extending PSDM from 2-D to 3-D relies on solving practical management and computation issues. To develop Kirchhoff imaging codes in 3-D with today's massively parallel supercomputers is not a real difficulty. Currently traveltime tables are computed by finite differencing the eikonal equation because it is much faster than conventional raytracing. However finite differencing the eikonal has an inherent problem when first arrivals have weaker energy than later arrivals. Finally coupling velocity analysis with migration in 3-D is still downright impractical in compressive tectonics.

3-D PSDM IN MODERATELY COMPLEX TECTONICS

3-D PSDM algorithms which exist today are all based on Kirchhoff imaging and mostly rely on finite differencing the eikonal equation for computing traveltime tables. In areas such as the Gulf of Mexico, these algorithms generally work well. The reason is that we have good control over the velocities and are thus able to derive appropriate earth models. These velocities tend to be smooth laterally as well as vertically (a vertical linear gradient is the most common rule) and do not require sophisticated raytracing methods.

For good quality data, provided the velocity model is already quite satisfactory, the final image and velocity model can even be refined by using the so-called "Deregowski Loop": during the migration, image gathers are produced at selected locations ; these gathers are converted back to time and standard velocity analyses are performed to correct for residual curvatures. Although approximate, this technique can prove useful in moderately complex tectonics.

THE PROBLEM OF THE VELOCITY MODEL

In more complex areas such as the North Sea, the velocity models tend to be more intricate and are currently described in terms of interfaces. The "Deregowski Loop" approach is unstable and generally breaks down due mostly to the simplifications inherent to the method and the difficulty to pick coherent events on the image gathers. Furthermore depth focusing analysis and migration velocity scans in the target area would have been good alternatives but are prohibitive in term of computer resources. Thus 3-D PSDM in those areas relies very heavily on the construction of a good velocity model by standard techniques. Among them, map migration, stacking velocity inversion and iterative 3-D post-stack depth migration are all of great help. But these post-stack techniques provide velocities not optimal for prestack imaging. For instance, constraining a post-stack derived velocity model to tie with well data is generally inappropriate for prestack depth migration.

THE CHALLENGE OF COMPRESSIVE TECTONICS

The real challenge lies in compressive tectonics areas such as the Andean, the Canadian or the Pyrenees foothills. In those areas, where data quality is usually far below average, and knowledge of velocities quite limited, the approach is to first apply an alternative method to 3-D PSDM. The prefered method is Gardner's 3-D DMO and Prestack Imaging (PSI) technique. This technique conditions a full 3-D prestack dataset in order to make it amenable to 2-D prestack depth migration and velocity analysis. This data conditioning is independent of velocity: velocity analysis, whether before or after migration, is postponed to the very end. This method also allows the derivation of a 3-D velocity model from the actual prestack data at a reasonable computer cost. It also regularizes and interpolates the data which generally has a beneficial effect for 3-D imaging. This approach assumes little velocity variations in the cross-line direction. If this is the case, results obtained may be sufficient. However, if this assumption is not satisfied, depending on data acquisition and quality, then 3-D PSDM using the derived velocity model should be the next step: its high cost can be legitimally assumed.

To perform 3-D PSDM, we emphasize the importance of QC at every step during the migration. Traveltime maps at the surface must be produced in order to optimize the raytracing parameters, check on ray coverage and errors in the ray field interpolation, and discriminate multiple arrivals. The offset range which is used for the migration in a given depth interval must be chosen carefully to reduce the amount of data used and to minimize migration artefacts, especially if image gathers will be used for velocity analysis. Pre- and postprocessing are also crucial, more so than for poststack migration. Oddly enough, for comparative purposes 3-D poststack depth migration used in conjunction with 3-D PSDM at every layer could provide QC information.

CONCLUSION

3-D PSDM appears as the way of the future for proper imaging of the subsurface. Although algorithms now exist, their application is limited to cases of moderate geological complexity, where data quality and velocity control are very good. For more complex areas, care must be taken to construct an appropriate velocity model, for which new methods are emerging. Our strategy in very complex areas such as compressive tectonics is to first evaluate the data set with cheaper, alternative 3-D imaging methods to justify the high cost of 3-D PSDM, and then emphasize methodology and QC during the migration itself.