CONSTRUCTION OF 3D VELOCITY-DEPTH MODELS

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Introduction

Three-dimensional velocity-depth models are playing an increasingly important role in our seismic data processing and interpretation. In addition to being critical input for 3D depth migrations, the models are becoming an integral part of our structural interpretations of complex prospects. Even when working with 2D seismic data, a 3D model enforces consistency across interpretations of individual lines. This talk presents our methods of constructing and refining velocity models for a series of examples ranging in complexity from a simple four-layer model for West Africa, to a more intricate faulted model for West Africa, to a complex Thrust Belt model. All of these examples begin with 2D analysis and then advance to fully 3D model building.

These varied examples carry one dominant theme: that model building is an iterative, interpretive process. The iterative nature of model building stems from both technical and business needs. The technical causes are well known: after performing a 3D depth migration we have new information about layer boundaries that can greatly improve a subsequent migration. The business needs may also demand iterations, because a preliminary, approximate result may be required at an early phase of the project, to be followed later by a more accurate answer..

Velocity Information

Because we draw upon several kinds of information to construct our models, methods for blending this information are important. In the first example, the velocity boundary is initially derived from well control, then later modified using the results of a 3D depth migration. This modification is done in such a way that we rigorously honor the well control, honor the 3D interpretation as much as possible, and yet still retain a smooth surface. The mixing of the well-control with seismic results was achieved using the DSI algorithm of GOCAD (Mallet, 1989). In the second example, the initial model was built by combining a series of 2D models, which had been constructed in an iterative 2D depth migration process. At later stages of the model building, we combined this initial model with surfaces interpreted from 3D depth migrations of small output targets.

We must also blend different kinds of information about the velocities within layers. In the examples shown here, we mix checkshot-

derived velocities with interval velocities derived from stacking velocities. In some cases, we bring in hand interpreted velocities extrapolated along trend. In a limited number of cases we have used velocity information derived through 2D prestack depth migration. The interpretive judgements used in these examples emphasize the iterative nature of 3D model building. This part of our effort is closely related to our routine velocity and depth analysis.

Model Representation

Our interpretation methods depend on a robust and flexible 3D model representation that can be clearly visualized with 3D graphics. We use layered models. Though sometimes artificial, subdivision into macro layers results in a sparsely parameterized model that can be manipulated by geologist and geophysicist as a natural part of the interpretation process. Triangulated surfaces represent layer boundaries within our models, and simple gradient functions usually represent velocities within layers.

The method of joining together the layers of the model is a critical aspect of 3D model building. Although we can sometime use simple models with boundaries that cross the entire model, for complex structures we must employ the power and flexibility offered by general layer topologies. The work shown here is based on the GOCAD model, with our own extensions to accommodate the 3D topology proposed by Weiler(1989). Each of the examples shown here addresses this issue of 3D topology, showing some of the experiences we have had in taking a set of boundaries and creating closed 3D regions.

3D Raytracing and Depth Migration

The ability to efficiently construct and modify complex models provides a basis for the 3D raytracing that is an essential part of our structural interpretations. By combining this earth modeling facility with raytracing and seismic display tools, we can quickly raytrace through a provisional velocity model, superimpose ray travel times on the seismic data, and modify the velocity model with trials that are based on mismatches between the ray travel times and the recorded seismic events. By iteration of this modeling process, along with frequent dip bar migrations, we can rapidly refine the velocity model.

Iterative 3D depth migration is clearly an important component of our velocity model refinement. As discussed above, we use interpretations taken from the depth migrations to directly update the velocity model. Furthermore, judgements of depth and dip ties to wells and overall judgements of image quality lead to updates to the interval velocity parameters. The central role of 3D depth migration in this iterative model

building process places a different set of constraints on the depth migration than would be present if the migration were simply a one-time process. Basically, the depth migration is asked to provide whatever amount of information it can calculate on the modeler's timetable. That is, the size and style of 3D migration targets is driven by the varying timescales: immediately, over lunch, overnight, over the weekend. Our present 3D migration algorithm, using a cluster of about 6 workstations, can do a few output lines overnight, or a significant volume target over the weekend.

The complex nature of 3D model building imposes a further constraint on the migration program: that it not require its own specialized model building effort. Although we often smooth our models because of structural uncertainty, our depth migration programs perform well with the blocky layered models that are often the direct products of our model-building tools.

Future Directions

We see two major areas for future work. First, the routine use of 3D prestack velocity information. Few of the tools that make up a 2D structural toolbox (prestack migration, image gather analysis, tomographic analysis of depth residuals) have made their way into our standard analysis procedures. Second, because the model building procedure stands in the inner loop of our iterations, we must continue to automate and simplify this procedure. Based on the progress made in the last couple of years, we expect to see rapid further developments in these areas.

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