The Case for Depth Imaging All 3D Data

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Summary

Structural complexity in time-imaged seismic data is often due, not to geology, but to lateral-velocity variations that have not been properly addressed. Numerous data examples show the improved imaging and phase stability that depth migration provides when compared with time migration. Gridded cell tomography is the enabling technology that allows the development of geologically-consistent velocity models suitable for use with prestack depth migration. The incorporation of VTI or TTI parameterization in the imaging process can also provide benefits, especially if well calibration is invoked, since this will improve the structural response and form “true-depth” 3-D seismic volumes.

Improving the integrity of seismic data through depth imaging has the potential to reduce the exploration cycle time, allow for improved horizontal well-planning; and reduce the uncertainty involved when fault avoidance is critical.

Introduction

Prestack time migration has been accepted by the industry as a standard 3D seismic processing practice. This has led to improved imaging in many areas and the ability to use 3D seismic data for AVO, prestack inversion, and other advanced prospecting methods. Refinements, such as including diving rays and the incorporation of anisotropic parameters, have provided further improvements in time imaging. Despite these innovations, time migration is inherently incapable of properly handling even subtle lateral velocity variations, limiting its effectiveness for accurate imaging. In most cases, only prestack depth migration can yield the level of accuracy needed to extract the valuable information contained within the seismic data.

Prestack depth migration has been used extensively to resolve imaging problems in areas where strong lateral-velocity contrasts are caused by salt bodies or complex structural geology. However, the method has been under-utilized in areas of lower structural relief, and “simple” velocity regimes where the limitations of time imaging can be less obvious. The combination of high-resolution gridded tomography and prestack depth migration can resolve the local velocity contrasts that distort subtle structural responses and compromise seismic attributes. We illustrate the uplift provided by depth imaging using numerous data examples.

Tomography

In the field data case, only the recorded travel times are known. The velocity field and reflector depths are unknown. This is a familiar problem that, for decades, has mostly been addressed using 1D hyperbolic curve-fitting methods. For prestack depth migration it is important to develop a more exact velocity model as it handles lateral velocity variations correctly. This can be done using gridded-cell tomography.

Gridded-cell tomography is a robust, 3D ray-based inversion method used to refine velocity models for depth imaging. Residual traveltime errors are picked from depth migrated common-image point (CIP) gathers and 3D ray tracing is used to define an updated velocity model. The accuracy of gridded tomography is also improved when a 3D dip field is used in the inversion process. After each tomography loop, a new dip field is calculated. Successive iterations drive the solution to a more highly resolved and more robust velocity update. For most land data, CIP gathers are generated for multiple azimuths. Reflections are picked separately for each azimuth, then the traveltime errors are combined to create a single velocity update, accurately resolving lateral velocity heterogeneities. Finally, gridded tomography differs from the older, layer-stripping approaches in that each update is global, not restricted to particular layers. The application the global approach is illustrated in the following example.

Data Examples

The first example comes from South Texas. In this case, the shallow part of the section contains low to moderate dips. Deeper in the section, rotated fault blocks generate a more complex velocity field and the “fault shadow” effect starts to impact the image quality. The workflow for this project started with three loops of isotropic tomography. Next, well ties were used to estimate vertical transverse isotropy (VTI) parameters. Incorporation of the anisotropic parameters had several benefits: the imaging depths became closer to the vertical depths at the wells, the image gathers were flatter, and there was an improvement in the image quality. Figures 1 and 2 show the evolution of the migration-velocity field. The prestack time migration (Fig. 3) is compared to the final prestack depth migration (Fig. 4) to illustrate the upgrade in image quality.

In an example from the Eastern U.S., where structural relief is low, a shallow velocity anomaly generates apparent faults deeper in the time section (right on Fig. 5). This is complicated by its proximity to a dissolution feature of interest. The depth migration (right on Fig. 6) generated an image where the apparent faults have been largely reduced, and where the dissolution feature is preserved. In addition to improved image integrity below the shallow anomaly, there is improvement in the quality of the lower-amplitude events between the major markers.

A depth migration example by Holt (2008) from the plains of Alberta shows a distinct increase in image resolution visible in the horizontal slices in the time-coherence attributes (Fig. 7) and the depth-coherence attribute at the Gething stratigraphic level (Fig. 8). Note how both sides of the channel features are more symmetrically imaged on the depth slice.

The next example comes from the Williston Basin. This basin has been revitalized recently by horizontal drilling. Velocity anomalies in the shallow section cause the time images (Fig. 9) to be of limited use in mapping the events of interest. The depth migration (Fig. 10) has simplified the structure as well as removed the obvious low-amplitude anomaly to the right of the structure.

The final example comes from a U.S. Land resource play. The apparent fault in the time section (black line in Fig. 11) has been resolved in the depth migration (Fig. 12). The impact of the enhanced resolution and fault validation on horizontal well planning is unambiguous.

Conclusions

Prestack depth migration provides a fundamentally better image than time-imaging methods. The improvements provided by depth imaging include a more stable phase response and enhanced structurally stability due to the proper handling of lateral-velocity variations. It is clear that the use of depth imaging for risk mitigation and well planning should be extended to all geological provinces.

Acknowledgments

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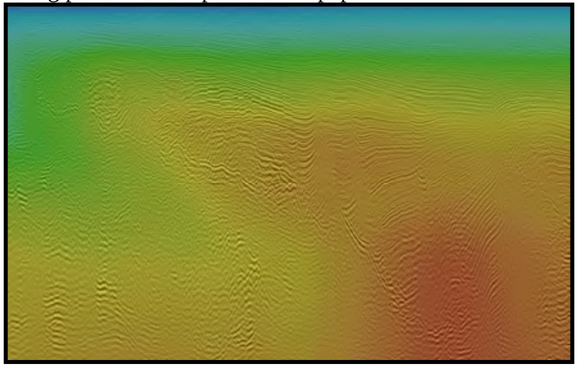

Figure 1: Initial velocity model, South Texas example. Note the low resolution typical of a starting model to avoid introducing details that cannot be resolved by subsequent tomographic solutions.

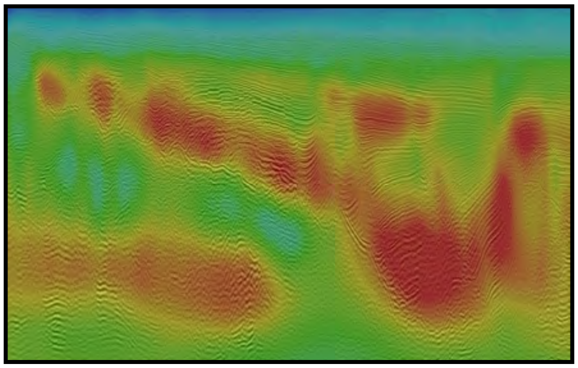

Figure 2: Velocities after five iterations of gridded tomography for the South Texas example. Note the stratigraphically-linked detail provided by the solution.

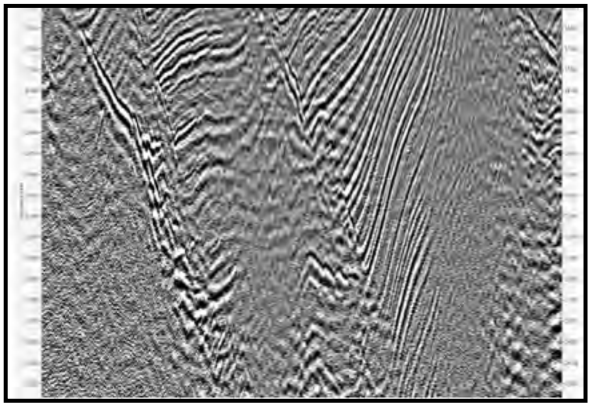

Figure 3: South Texas prestack time migration (pseudo-depth).

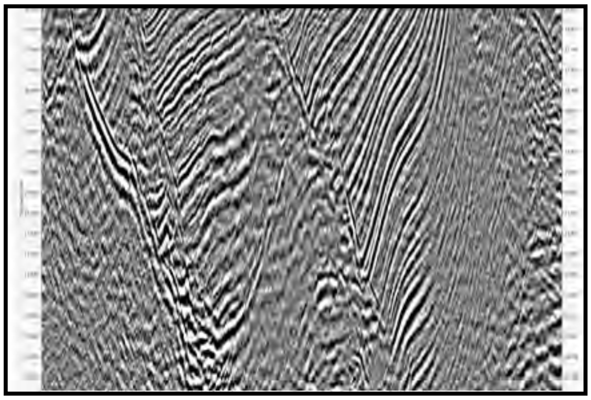

Figure 4: South Texas prestack depth migration (in depth). Note the added resolution to the reflector geometries and the fault clarity.

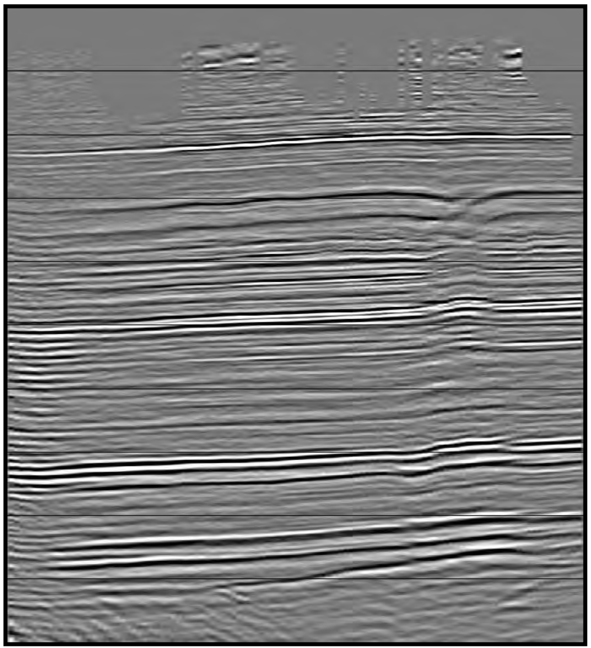

Figure 5: Eastern U.S. time migration (in time). Note the shallow anomaly (right) related to deeper reflector discontinuities possibly indicating faulting.

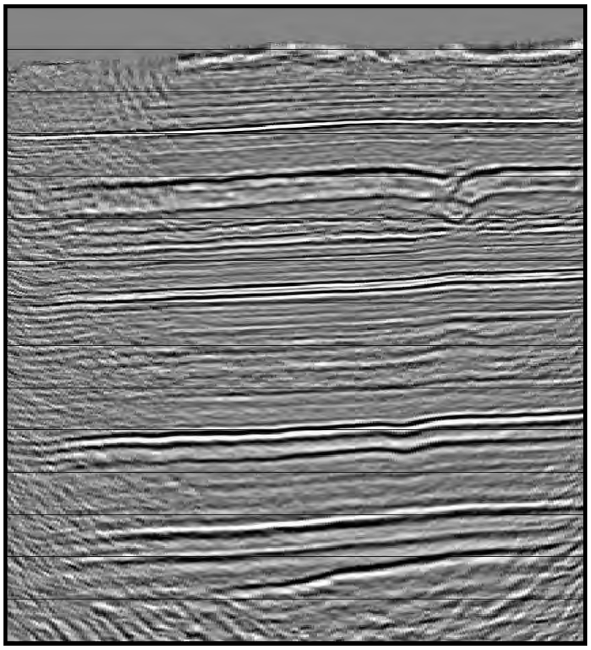

Figure 6: Eastern U.S. depth migration (in depth). Note the healing of the deeper structural response.

Figure 7: Alberta Basin time migration coherence slice. (Holt, 2008).

Figure 8: Alberta Basin depth migration coherence slice. (Holt, 2008). Note the more symmetric channel response.

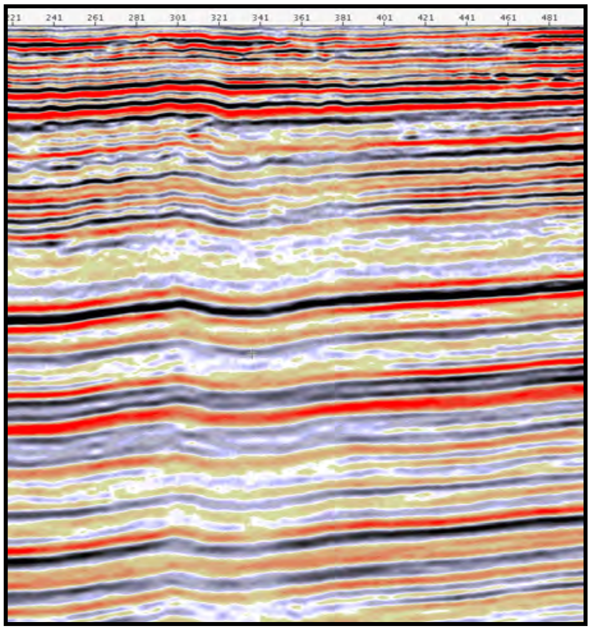

Figure 9: Time migration (in pseudo-depth). Note local structuring (left) and low-amplitude response just to the right.

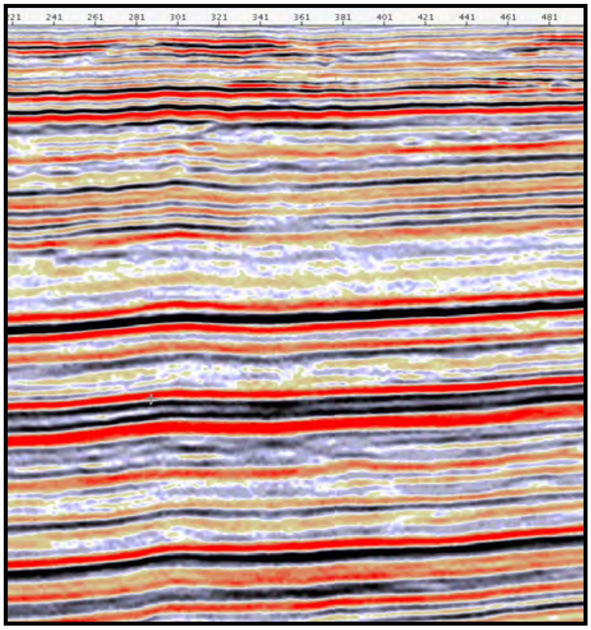

Figure 10: Depth migration (in depth). Note simplicity of structural response (left) due to resolution of shallow velocity variations and the healing of the associated amplitude distortion.

Figure 11: U.S. Resource Play, time migration (in time). An apparent fault is highlighted.

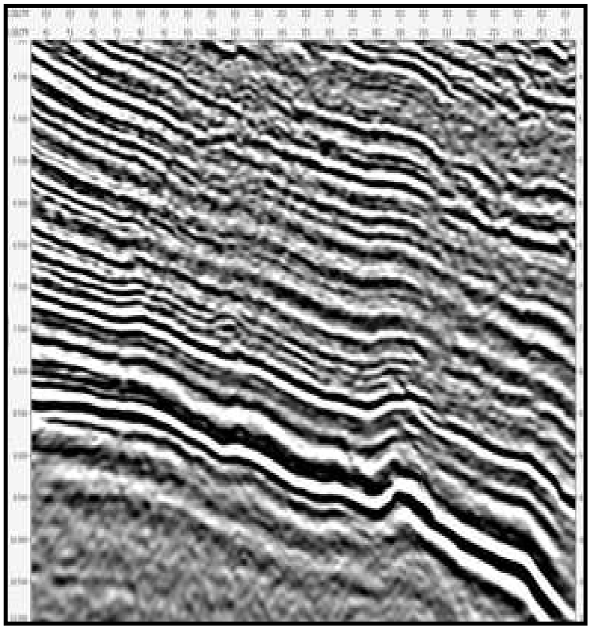

Figure 12: U.S. Resource Play, depth migration (in depth). Note the impact of solving for the shallow velocity anomalies eliminating false faulting.

EDITED REFERENCES

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REFERENCES

Holt, R., 2008, How to increase the bandwidth of your plains data: Joint Annual Convention, CSPG CSEG CWLS.