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Resolution Revolution Reaps Results

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and John Weigant

HOUSTON–High resolution 3-D volumes of interpretable data with the proper spatial positioning have long been a goal of the oil and natural gas industry, and many techniques for achieving it have been developed through the years. Everything from newer acquisition techniques to methods for compensating for the absorption and dispersion effects that lower the frequency content of the data have been introduced and are now being used in production environments. This interesting development is part of a broader "resolution revolution," or the ongoing trend toward ever-higher data resolution and imaging clarity.

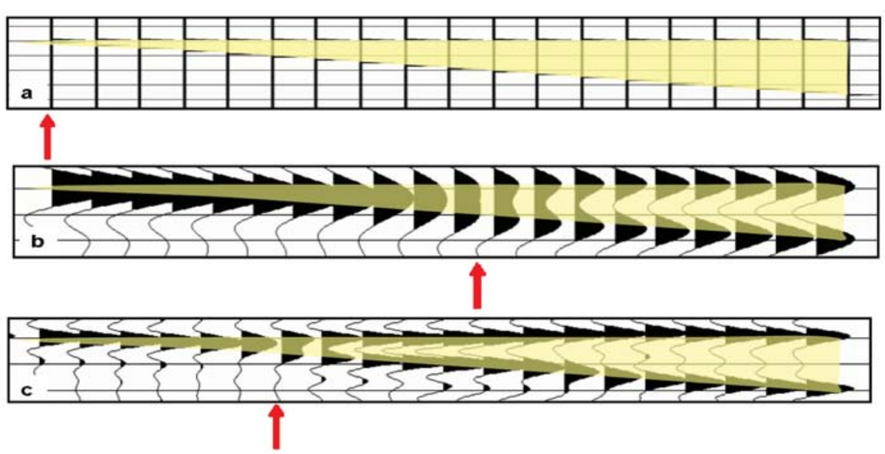
Elevated oil and gas prices have changed the economic viability of many prospects and plays. These favorable economic conditions, combined with enhanced technologies to improve resolution, make discovering and exploiting new and bypassed reserves a realistic possibility. Moreover, the accurate delineation of a fault system or the ability to predict pore pressure and fluid content using amplitude-versus-offset and high-resolution velocity methods can lead to a more productive and safer exploration and exploitation scenario.

One of the most important steps in processing–and one that is most dependent on and potentially damaging to spatial and temporal resolution–is imaging. While much imaging still uses prestack time migration (PreSTM), recent years have seen a significant increase in the amount of prestack depth migration (PreSDM), both Kirchhoff and wave equation methods. PreSDM techniques have improved greatly, and it is now possible to account and correct for acoustic phenomena and elastic energy losses attributable to wave propagation.

Depth imaging techniques have gone from producing kinematically (structural) correct sections to those also featuring correct amplitudes and phases. The advent of accurate high-resolution amplitude-versus-angle (AVA) and AVO techniques have allowed exploration and exploitation professionals to predict fluid content as well as lithology and facies by extracting rock properties from the migrated seismic data. Until recently, these techniques were incapable of "preserving" the high resolution necessary for better stratigraphic, lithological and structural interpretation.

Because of elastic and visco-elastic processes, the very nature of wave propagation in the earth is such that high frequency information is lost as seismic energy propagates through the heterogeneous media. It is paramount to develop data processing techniques that do not aggravate this further, and through other techniques to find mechanisms to restore or enhance the frequency content of the data and allow proper interpretation.

FIGURE 1



In this wedge model seen at different resolutions, the red arrow indicates the tuning distance at which it is impossible to separate the top and base of the formation. Infinite resolution (the effective minimum thickness is zero) is shown in the top, while low resolution is shown at center, and high resolution at bottom.

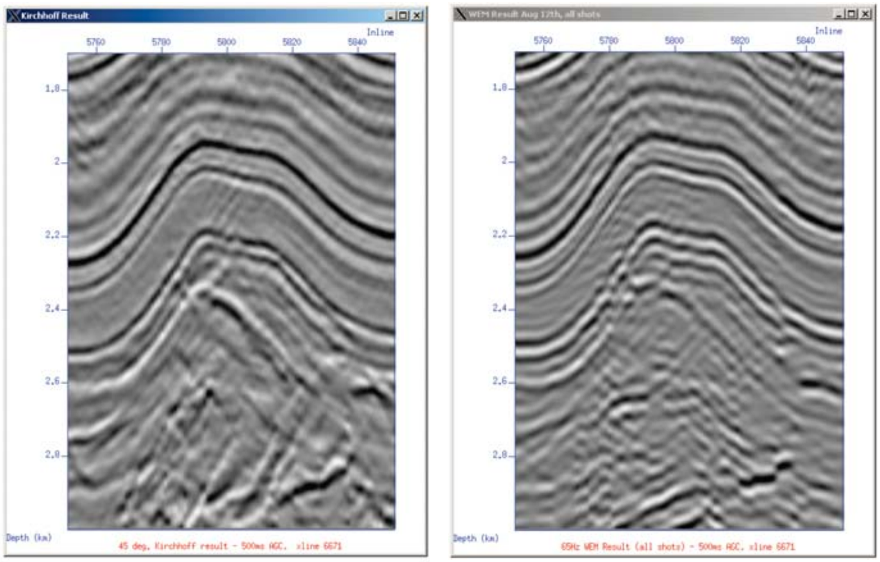
High-Resolution PreSDM

This article focuses on 3-D prestack depth migration and how it has become a high-resolution engine for imaging. 3-D PreSDM requires at least two data sets in the simplest of isotropic earth models and potentially as many as five data sets to properly yield an image of the earth. For the isotropy case, the two data sets are the seismic data and the wave propagation velocity in the subsurface.

The resolution of the final 3-D volume is directly affected by the resolution of these data sets. Many geophysical techniques have been developed to ensure that the seismic data preserves their dynamical range as well as their correct amplitude and phase information while they are being processed and prepared for migration.

While seismic data are directly acquired in the field, the seismic velocity must be determined from that seismic data. In some sense, the velocity has been "encoded" into the seismic data and

FIGURE 2



In this example from the North Sea, the image on the left was obtained by performing prestack depth migration on a 3-D volume that has a maximum frequency of 45 Hz. The figure on the right uses the same velocity model, but the input data has a maximum frequency of 65 Hz. Note the higher frequency content of the depth volume on the right, along with the improved imaging of fault blocks at the deep prospect level.

needs to be separated and refined for use in the imaging step. Modern migration algorithms self-determine the correct velocities to optimize the imaging. A symbiotic relationship between seismic data and velocity data plays a crucial role in the ability to produce accurate images.

The industry has employed various techniques to derive these velocity models, and most combine PreSDM technology with some type of "velocity updating" techniques. However, all such techniques deliver relatively low-resolution velocity information.

A new 3-D tomographic updating technique is now being introduced based on a multiscale representation of the 3-D velocity model that yields high-resolution velocity models. These models, when combined with high-resolution seismic data, can produce superior results and give life to old prospects and help discover new ones.

The resolution revolution continues with advanced land and marine data processing algorithms, 3-D PreSDM and velocity model building tools that utilize proprietary multiscale simultaneous tomography technology for true high-resolution velocity analysis and depth-velocity model building.

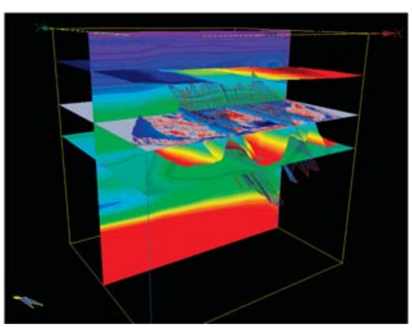
What is Resolution?

There are hard (scientific and quantitative) and soft (qualitative and intuitive) definitions of resolution. We will leave aside the hard definition and instead use the more traditional and intuitive definition of resolution. A geoscientist requires both temporal and spatial resolution in seismic exploration to truly "see" small structures.

In seismic data processing, temporal resolution is understood as the ability to distinguish thin beds. Although spatial resolution is harder to define, it can be understood as the ability to quantify the lateral extent of a reservoir or formation. One good example that combines both ideas is imaging beneath a fault, where the challenge lies in resolving small structures in the fault shadow.

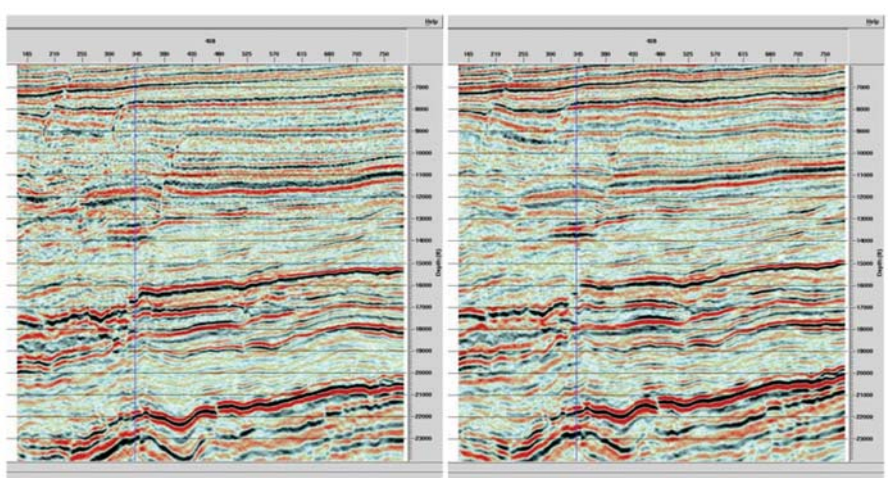
It is important to remember that seismic data do not show the actual reflective boundaries associated with the lithology, but instead a fuzzy version of them because of the existence of a wavelet. This is the consequence of acquisition technology. The earth is probed with acoustic pulses or waves that have a finite frequency range, or dynamic range. When two reflectors that form a wedge or thin bed are imaged, there exists a

FIGURE 3



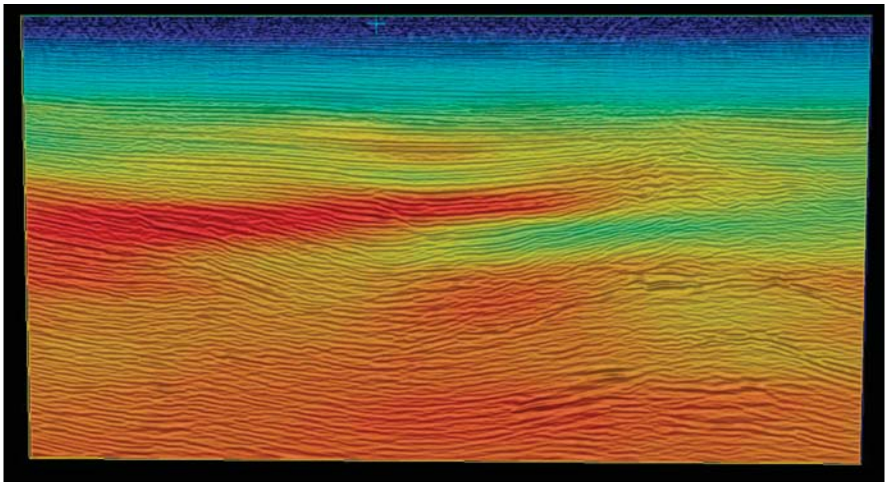
Faults and horizons are picked or imported in the model building software to be used as constraints in the tomographic inversion and model building workflow.

FIGURE 4



The image on the left is from a 3-D PreSDM volume created using a velocity model that was built using traditional non-high-resolution tools. The image on the right is the same line from a 3-D PreSDM volume generated using a high-resolution velocity model built using multiscale simultaneous tomography and appropriate geological constraints. Wells in the fault block of interest verify the accuracy of the depths and dips in the image on the right.

FIGURE 5



Depth imaging and accurate tomographic model building can accurately image below velocity inversions caused by significant overpressure.

point at which it becomes impossible to distinguish the top and the base because the wavelets have effectively fused into one (Figure 1). The minimum distance at which this happens is called the "tuning distance."

Data resolution increases as the tuning distance decreases, although it is important to note that the physical distance between the formation's top and base remains fixed. The actual change takes place in the apparent thickness because of the existence of a wavelet.

Careful preprocessing is required to preserve the frequencies, amplitudes, and phases of the data. There are many steps in the processing sequence where these attributes can be adversely affected to reduce the resolving power of the data. Care must be taken when selecting deconvolution operators, applying filters, and removing noise by the many available methods, which include high-resolution radon transforms, wavelet filter transform, and surface related multiple attenuation. With conscientious data preparation, resolution can be preserved and high frequency depth products are achievable (Figure 2).

Multiscale Simultaneous Tomography

As previously mentioned, velocity model accuracy is a key factor in resolving any PreSDM algorithm's capability. This includes vertical resolution–the ability to accurately define thin layers and other subtle stratigraphic traps–and spatial resolution–the ability to accurately resolve small structures that come and go over a relatively short lateral distance. Constructing these high-resolution models requires a dense collection of velocity analysis control points combined with a highly stable and well constrained tomographic inversion algorithm.

Fortunately, the latest development in high-resolution modeling is a comprehensive velocity analysis and model building software package that enables multiscale tomographic inversion as well as the ability to incorporate geological-based constraints into the model building process (Figure 3). These constraints can include horizons and faults, and are used to guide the tomographic inversion process as well as any subsequent velocity interpolation, extrapolation, or smoothing that may be required.

One of the more significant problems with high-resolution velocity model building is the stability of the tomographic inversion. Implementing the new multiscale inversion algorithm makes it possible to incorporate much denser input data into the inversion process and use significantly smaller grid cell sizes in the inversion. This leads to the most accurate depth-velocity models possible as input to advanced depth imaging algorithms. The key to this high-resolution velocity model derives from an ability to represent such a model by many length scales chosen automatically in an adaptive manner.

Multiscale simultaneous tomography combines with other technologies such as a new tool that automatically picks dense volumes of horizons for dip field calculations, to create a true high-resolution velocity model-building package to enhance well productivity. Combining innovative technologies like these with advanced autopicking and quality control techniques ensures that accurate velocity models can be produced to meet the most demanding time frames.

By applying these leading edge high-resolution velocity model building techniques, it is possible to construct models capable of yielding improved results from depth imaging (Figure 4).

Conclusion

High-resolution techniques for preprocessing data have matured enough to prop-

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erly prepare the data for the complicated and costly imaging (PreSTM and PreSDM) step. This high resolution is obtained without compromising the data's true amplitude and phase response.

Prestack depth imaging continues to be a very important component of the exploration and production process. As depth-imaging technology has advanced, issues such as migration algorithms and the accuracy of velocity models have been proven to be primary factors affecting the resolving capabilities of the PreSDM process. Accurate imaging technologies like amplitude-preserving Kirchhoff PreSDM and wave-equation PreSDM, combined with high-resolution model building techniques, can provide more accurate models and seismic images.

Whether the imaging problem at hand involves small fault blocks in South Texas, faulting below anomalous velocities in the North Sea, or deep inversions caused by overpressure on the Outer Continental Shelf (Figure 5), depth velocity analysis and multiscale simultaneous tomography tools can provide the most accurate images available today. ❐