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Precision Velocity Determination in the Local Angle Domain

A unified imaging and velocity model-building system aids in velocity model determination, updating, and investigation.

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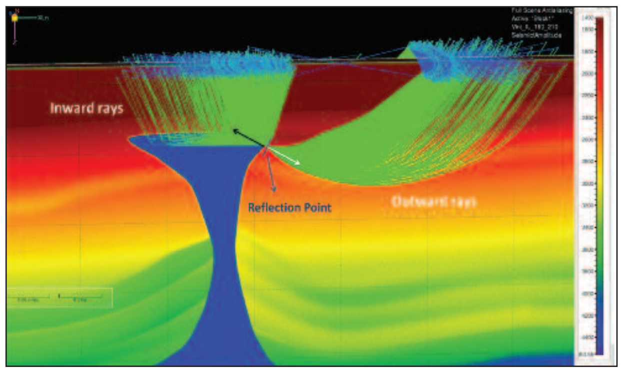
Seismic interpreters work with images in time or depth that are the product of a series of signal processing and imaging transformations. Many of these processes and transformations are driven by an earth model or earth model assumptions that must be rigorously derived from available wellbore data, geological data, and seismic data.

The most important derivation in the seismic method is that of the velocity model. Velocity models not only drive the seismic imaging process but are also used to carry out inversions for rock properties, transformations to pore pressure, and time-to-depth conversions. Interpreters do not always have access to the velocity model but can indirectly benefit from its quality through synthetics correlations, well marker misties, and seismic imaging quality. Poor correlations, systematic misties, and unusual reflector behavior are frequently signs of imaging with the wrong velocity assumptions or poorly derived velocity determinations.

It is challenging to derive velocity models in the presence of anisotropic conditions. When properly constructed, they will model depositional and deformational conditions that control seismic wave propagation in the subsurface, allowing geophysicists to accurately position seismic data and recover amplitude information related to subsurface reflectivity.

Conventional seismic data do not uniquely determine the subsurface geological model (many models can fit the observed seismic recordings). There is a general trend to enrich the seismic data acquisition parameters (higher density, longer offset, wider azimuth, etc.) to reduce this nonuniqueness. These enriched parameters help geophysicists recover anisotropic parameters while reducing the uncertainty of the model. Advanced seismic tomography systems for velocity model updating are able to enhance the accuracy and resolution of all types of velocity models that incorporate both velocity heterogeneity and anisotropy.



The local angle domain separates inward and outward rays from a common image point (BP TTI model). (Image courtesy of Paradigm)

Seismic imaging methods also are critical to the recovery of velocity information. Seismic imaging algorithms generate common image gathers from background velocity models. These gathers are used to estimate residual moveouts, which can be used to compute traveltime errors along energetic rays that propagate through the subsurface. These traveltime errors are minimized through their transformation into velocity model perturbations.

While all seismic imaging methods create common image gathers, few are able to handle the full range of complexities needed to resolve both complex ray pathing and anisotropic velocity behavior. To this end, Paradigm has implemented a unified seismic imaging and velocity modeling system that operates directly in the subsurface local angle domain. The decomposition and construction of common image gathers in the local angle domain has some clear advantages over common image gathers constructed using other traditional imaging methods (e.g. reverse time migration [RTM] or Kirchhoff). Some of these include:

- Local angle domain imaging that can recover full-azimuth reflection data *in situ* and in depth. Residual moveouts from all types of velocity conditions are easy to observe and measure (pick). Because the gather is fully parameterized in three dimensions (depth, angle, and azimuth), automated methods (e.g. Poisson's equation) are used to pick the residual moveouts represented as 3-D surfaces in the azimuth and angle domain;
- Traveltime errors along energetic (specular) rays associated with residual moveouts in the local angle domain that are uniquely obtained without additional transformation or approximation. This is not true for traveltime errors derived from offset-based common image gathers generated from RTM or Kirchhoff imaging methods;
- Using the local angle domain to generate directivity-driven (model-based) angle gathers, where the same specular rays are used for both imaging and tomography. This consistency drives a more convergent and high-quality solution;
- The local angle domain properly handling multipathing by mapping multiple arrivals into independent bin locations parameterized by subsurface image point, angle, and azimuth. Common image gathers produced by Kirchhoff and RTM migrate several events into the same event, creating ambiguity in the assignment of residual moveouts with a specific ray pair. Consequently, the tomographic update process is compromised; and
- A local angle domain that supports the decomposition of inward and outward specular rays originating from the same image point. These conditions frequently arise in areas of steep structure (faults, salts). Conventional imaging methods are not equipped with the internal mechanism to distinguish between the apparent directivities of the ray (wave) pairs. Again, convergence in the tomography solution is accelerated in the local angle domain and compromised with traditional common image gathers.

The unified imaging and velocity model building system afforded by the local angle domain is expected to become a standard for velocity model determination, updating, and investigation. ■