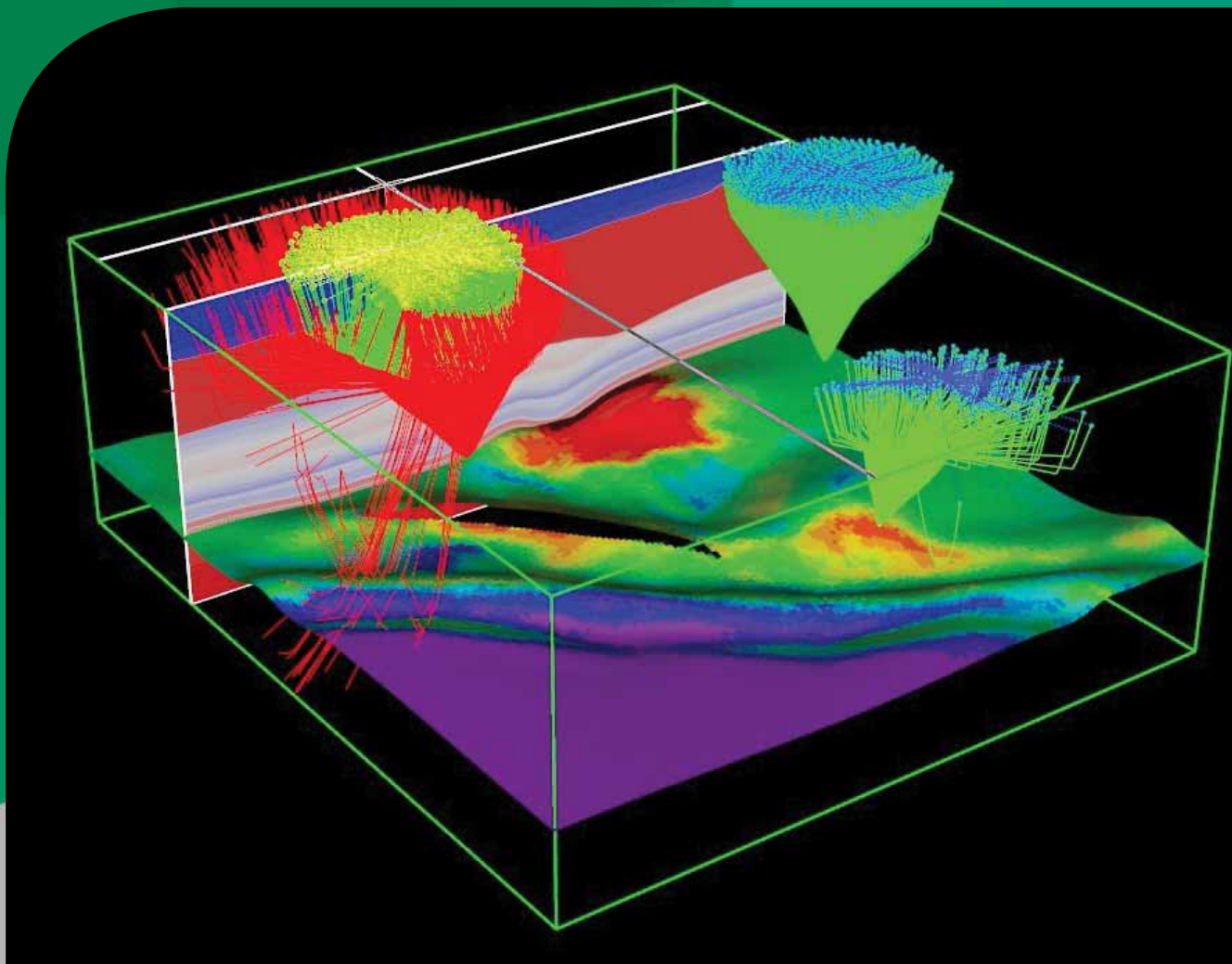
Processing and Imaging

Paradigm®

EarthStudy 360®

Full-Azimuth Angle Domain Imaging and Analysis



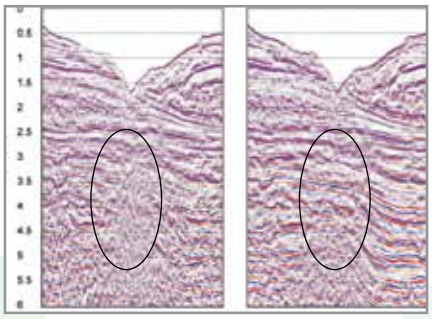
EarthStudy 360

A new world of information for geoscientists

Expanding the Frontiers of Subsurface Exploration

Paradigm™ EarthStudy 360® is an innovative new system designed to deliver to both depth imaging experts and interpretation specialists a complete set of data that enables them to obtain accurate subsurface velocity models, structural attributes, medium properties and reservoir characteristics. The system extracts unprecedented value from all modern and legacy seismic data acquisitions, especially those with wide and rich azimuth and long offset, in both marine and land environments.

EarthStudy 360 is most effective for imaging and analysis in unconventional gas plays within shale formations and in fracture carbonate reservoirs. The system delivers highly accurate images from below complex structures such as shallow low-velocity anomalies like gas pockets, subsalt, sub-basalt and high-velocity carbonate rocks. These result in optimal solutions for anisotropic tomography and for fracture detection and reservoir characterization.



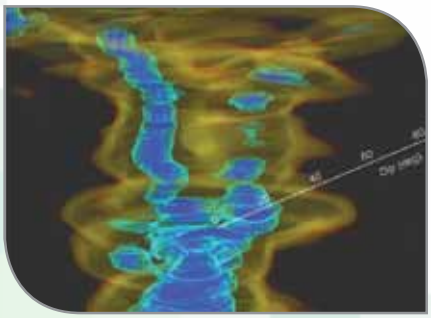
Hidden structure revealed by EarthStudy 360

Added Value for Geoscientists

EarthStudy 360 creates a wealth of seismic image data, decomposed into full-azimuth, angle-dependent reflection and directional (dip and azimuth) data components. These can be selectively sampled, creatively combined, dynamically visualized, and further processed to secure images of the subsurface. The images can reveal the information needed for velocity model determination, as well as provide details regarding the presence of micro-fractures, the orientation of faults and fractures, the influence of anisotropy, the directions of contributing illumination, the elastic properties of target reservoirs, and the boundaries of those reservoirs.

Directional and Reflection Angle Gather Systems

EarthStudy 360 enables geophysicists to use all recorded seismic data in a continuous fashion directly in the subsurface local angle domain. This results in two complementary, full-azimuth, 3D angle gather systems: **Directional** and **reflection**.

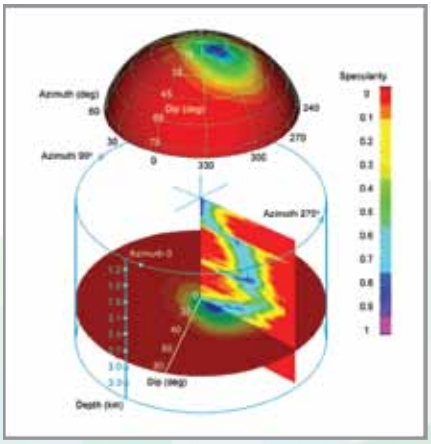


Directional angle gather near geologic pinchout: Two specular signature directions at same location

Directional angle decomposition implements both specular and diffraction imaging with real 3D isotropic/ anisotropic geological models, leading to simultaneous emphasis on both continuous structural surfaces and discontinuous objects such as small faults

New Technologies for a New Age

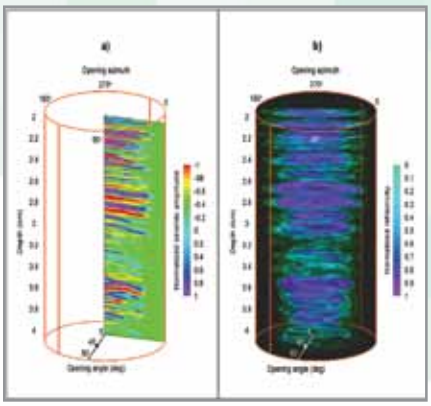
Declining production in mature oil and gas fields is forcing upstream energy companies to explore areas of increasing operational and technical complexity. Existing solutions for extracting information about the subsurface geological model are limited, and there is a need to expand current technologies to include the acquisition of wide and rich azimuth seismic data. Paradigm is the first to meet this need with EarthStudy 360, a new invention designed to image, characterize, visualize and interpret the total seismic wavefield.



3D directional specularity gather

and small-scale fractures. Structural attributes at each subsurface point, such as dip, azimuth and continuity, can be reliably derived directly from the directional angle gathers.

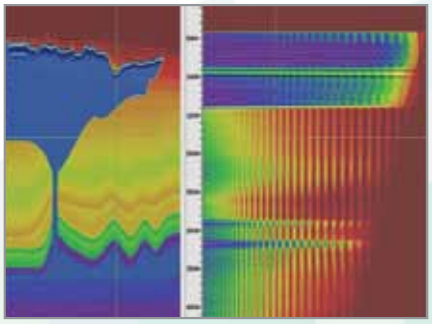
EarthStudy 360 reflection angle gathers provide "true amplitude" reflectivities that substantially increase the information needed to extract residual moveouts (RMO) and amplitude variations. The full-azimuth, angle domain RMO enables accurate velocity model determination (isotropy/anisotropy tomography). Full-azimuth, angle domain amplitude variations result in better reservoir characterization, with high-resolution elastic properties and high-resolution fracture determinations.



Two views of 3D reflection angle gathers

EarthStudy 360 Imager

The **EarthStudy 360 Imager** is a cluster-based solution that efficiently uses the full recorded wavefield to generate 3D full-azimuth, directional and reflection angle gathers. The Imager can be utilized to provide fast, target-oriented solutions

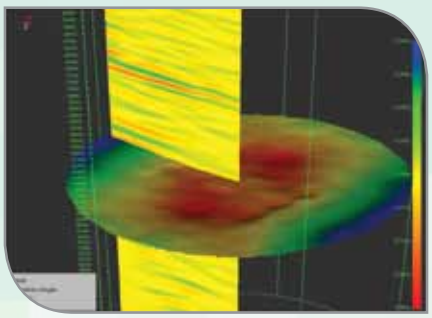


Subsalt imaging and a selected reflection angle azimuth gather overlaid with illumination (Original data courtesy of Devon Energy Corporation)

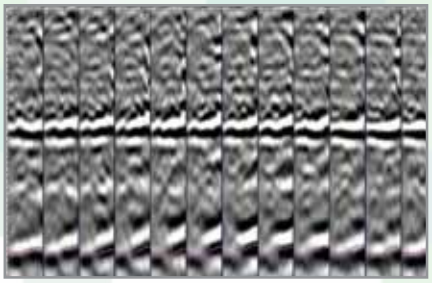
for local analysis, and can also be used for imaging on a regional scale.

EarthStudy 360 Tomography

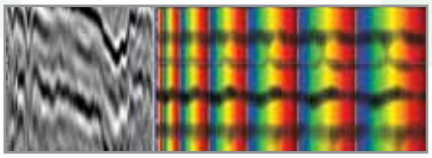
The tomography system uses input data extracted from EarthStudy 360 directional (directivity) and reflection (full-azimuth RMO) gathers to update the velocity model. The substantial increase in information about the subsurface improves accuracy and reduces uncertainty. This is especially important when determining anisotropy model parameters.



Automatic RMO picking along 3D reflection angle gather



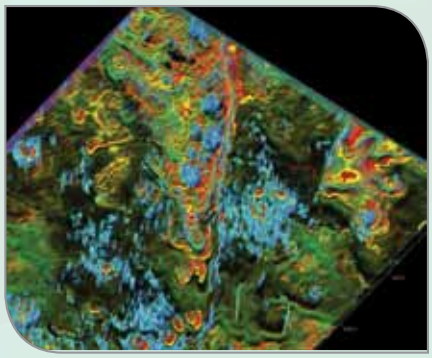
Automatic RMO picking along 12 azimuthal sectors extracted from 3D reflection angle gather



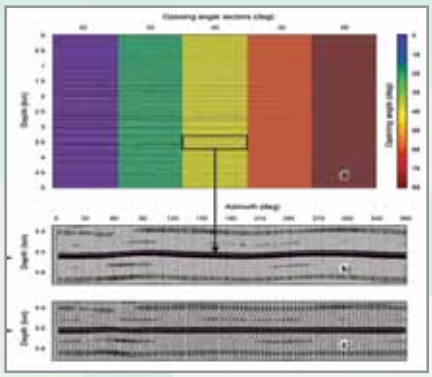
2D display of 3D full-azimuth reflection angle gather (Barnett Shale)

EarthStudy 360 as a Tool for Stress and Fracture Detection

EarthStudy 360 uses both directional and reflection angle gathers to image and detect subsurface local heterogeneities such as small faults and fine fractures. Diffraction weighted stacks applied to directional angle gathers enable high-resolution imaging of the fracture system within the reservoir.

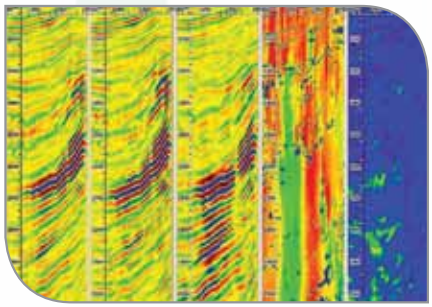


Fracture imaging



Angle sectors of reflection angle gathers: Residual moveouts vary with reflection angles, indicating azimuthal anisotropy effect

Azimuthal-dependent residual moveouts and amplitude variations (AVAZ), which can be automatically extracted from the full-azimuth reflection angle gathers, provide accurate information about the orientation and density of fracture systems.

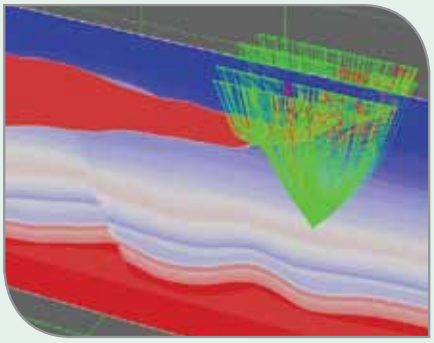


Full-azimuth reflection data (AVAZ attributes)

Illumination for Seismic Data Mining

The **EarthStudy 360 Illuminator** is an advanced seismic data mining tool that provides a previously unattainable breadth of knowledge about ray propagation in complex areas.

The Illuminator uses an enhanced, interactive ray tracing technology that both quantifies and qualifies the relationship between the surface acquisition geometry and the subsurface angles in targeted areas. Launched from the Paradigm SeisEarth® or GeoDepth® 3D Canvas, input for the Illuminator includes isotropic/anisotropic velocity models and optionally, data acquisition geometry. Interpreters can generate ray attributes, illumination and reliability maps to gain knowledge about the quality and integrity of the seismic image. A user who wants to know more about why certain areas have low reliability, has access to an extensive set of tools which deliver



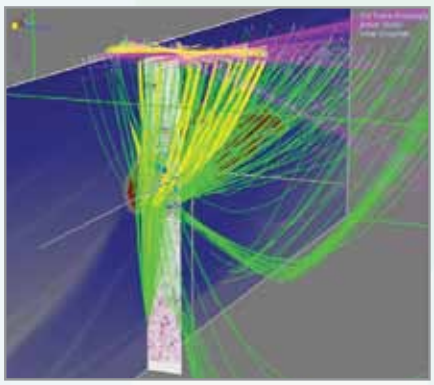
Two-point ray tracing in complex subsurface

that knowledge. The results are displayed in a clear visual manner, simplifying even the most complex set of imaging characteristics.

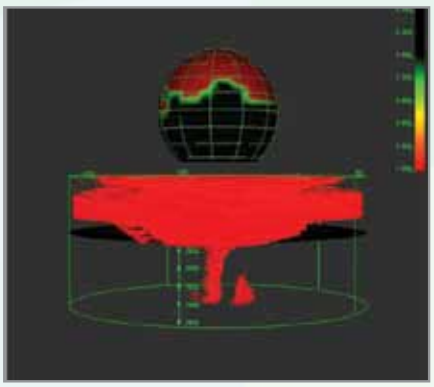
In addition to all the functionalities of the Illuminator, **EarthStudy 360 Illuminator Plus** can perform ray tracing in batch mode along fine 3D grids for the generation of full-azimuth illumination and ray attribute gathers, volumes and maps. Grid-based ray tracing is supported by Paradigm's HPC functionality and can run on multi-node clusters. Illuminator Plus is aimed at depth imaging specialists who seek additional knowledge about imaging reliability.

Enhancing Velocity Modeling and Amplitude Inversion

EarthStudy 360 significantly extends the velocity modeling capabilities of Paradigm's industry-leading GeoDepth imaging and velocity determination system. The information gained from the 3D angle gathers provides the seismic imaging specialist with additional knowledge about the subsurface, enabling a more accurate and reliable velocity model. Similarly, for the geoscientist using the Probe® AVO/AVA system to analyze amplitude variation with angle and azimuth (AVAZ), the rich information obtained from all angles and azimuths enhances accuracy and reduces uncertainty in hydrocarbon detection, fracture detection, and other reservoir properties that are vital to the exploration and production work cycle.



Interactive ray tracing as a tool for understanding quality of common image gather events



3D illumination angle gather

Interoperability

All Epos-based applications enable interoperability with third-party data stores, including:

- OpenWorks® 2003.12, R-5000
- GeoFrame® 4.5
- OpenSpirit® 3

System specifications

- All 64-bit, for x64 architecture processors
- Red Hat® Enterprise Linux® 5.3 and above, 6.0 and above

The Paradigm Advantage

+ Full-azimuth angle domain imaging and analysis maximizes knowledge from seismic data.
+ Maximized ROI for deep water, unconventional shale resource plays and fractured carbonate reservoirs.
+ Extracts unprecedented value from all modern and legacy seismic data acquisitions, notably those with wide and rich azimuth and long offset.
+ Delivers highly accurate isotropic/anisotropic velocity models, especially in complex subsurface areas.
+ Delivers high-resolution information about principal reservoir properties.
+ Extends the capabilities of leading Paradigm processing, imaging and analysis systems.