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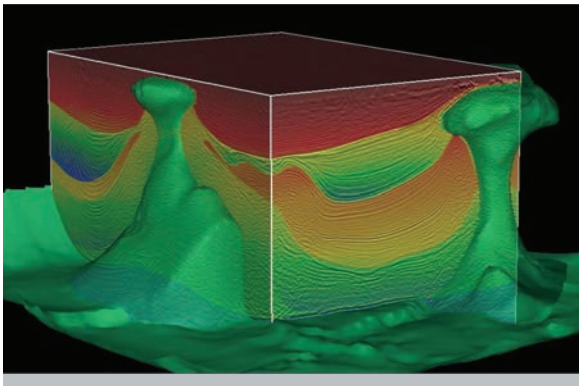
GeoDepth

Velocity Determination, Modeling and Imaging

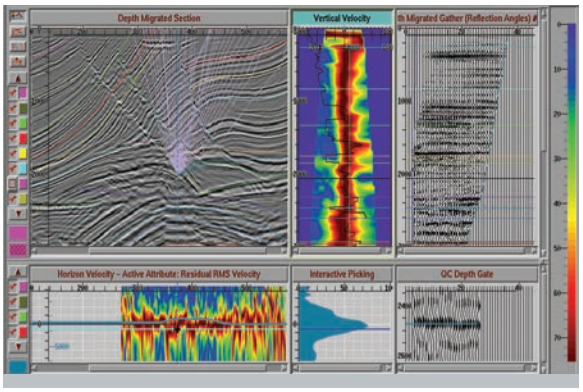


GeoDepth

An Integrated System for Highest Quality Imaging in Depth



▲ Depth image with salt domes



▲ Combined vertical and horizon-based residual moveouts in the GeoDepth Velocity Navigator

A Comprehensive System for Improved Seismic Imaging

Accurate seismic images and depth models are essential in hydrocarbon exploration and production. The GeoDepth™ velocity determination and modeling system offers explorationists a solution for improved seismic imaging in time or depth through the integration of interpretation, velocity analysis, model building, time-to-depth conversion, depth migrations, and model verification and updating. GeoDepth supports the entire range of seismic surveys, including 2D and 3D marine and land surveys, and narrow and wide-azimuth acquisition geometries, covering every type of geological structure in the world.

GeoDepth offers fast access and easy 3D visualization of prestack/poststack seismic data and interpretation data for 2D/3D surveys, as well as well data. The comprehensive 3D view of the data adds new information to the imaging workflow and optimizes quality control.

Solutions that Reduce Drilling Risk

GeoDepth enables users to solve exploration and development problems associated with the imaging and positioning of a wide range of subsurface geological structures, in order to reduce drilling risk. These include fault shadow, subsalt, sub-basalt, salt flanks, reefs, gas plumes, thrust faults and subtle lateral velocity variations.

Enhanced Anisotropy Tools Assure Accurate Positioning of Reservoir Targets

GeoDepth provides full support for transverse isotropy models, including both vertical axis of symmetry (VTI) and tilted axis of symmetry (TTI). Enhanced tools enable the user to define 3D anisotropy parameters (Thompsen's ε and δ parameters and axis symmetry angles) as maps and 3D grids in an accurate and efficient manner. GeoDepth uses the anisotropy models for 3D ray tracing modeling, tomography inversions, ray-based imaging such as Kirchhoff and Common Reflection Angle (CRAM), and Wave Equation Migrations (WEM and RTM [Reverse Time Migrations). The ability to calculate the effect of physical anisotropy on wave propagation (especially in shale and sand sediments) when processing large offset data, results in more accurate models, leading to better positioning of the reservoir targets.

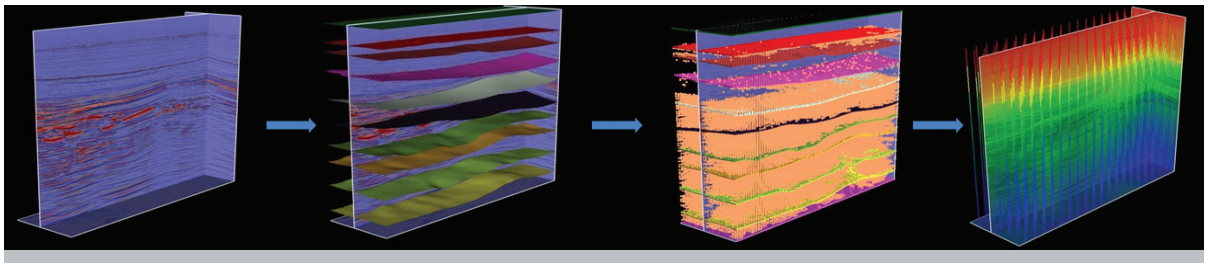
Velocity Estimation Techniques for Accurate Model Determination

Layer velocities may vary with depth of burial, age, lithology or a combination of all these factors. In building a velocity/depth model, the appropriate tool must be selected to model these factors. Through the state-of-the-art Velocity Navigator user interface, GeoDepth supports a wide range of tools designed especially for each of these conditions. These include a model-based velocity analysis method for structure-dependent regimes, and a grid-based approach for a structure-independent environment, or a combination of both.

Velocity Model Building

GeoDepth performs velocity model determination in two stages – building an initial background model that is consistent with the short-to-medium offset traces of the input seismic gathers, and refining it to obtain an improved model that is fully consistent with the entire range of offset traces.

"GeoDepth offers a wide variety of velocity model determination and imaging techniques suitable for our most critical seismic assets in every geological environment. Its advanced QC and visualization tools deliver highest-quality results that enhance our understanding of depth uncertainty. Furthermore, the efficiency of the product has enabled our asset teams to dramatically increase their productivity."



▲ Imaging and 3D visualization of various attributes, e.g. RMO, dip and azimuth, illumination, main and interlayer horizons, uniquely stored in a Pencil database

Building a proper initial background velocity model is essential, and GeoDepth does this efficiently and in a geologically constrained manner, using advanced proprietary techniques. Among these are GeoDepth coherency and stacking velocity inversions, which successfully perform ray-based layer stripping in areas of complex geology, and a constrained Dix-based method (CVI) for sedimentary basins with moderate lateral velocity variation.

Efficient Analysis of Errors in the Velocity Depth Model

Once the initial background velocity depth model is built, GeoDepth provides a wide range of tools and workflows for refining the velocity model. The main workflow includes depth migration to create both an image and common image gathers (offset or angle domain). This is followed by interactive and/or automatic picking of main reflection events in the image domain, and residual moveouts (RMO) along the common image gathers. The RMO indicate the non-flatness of the reflection events, and provide information about traveltime errors along rays travelling through the subsurface, which is the core information needed to refine the velocity model.

GeoDepth's dedicated Velocity Navigator application window optimizes RMO extraction accuracy, ensuring the reliability of the updated velocity model. Gather processing and conditioning with RMO extraction may be performed on clusters comprising massive amounts of nodes, enhancing productivity in today's large-scale projects in both marine and land environments.

GeoDepth offers a number of proprietary methods for RMO extraction. Parabolic and higher order RMO parameters may be extracted either by using semblance profiles, or through the use of AVO attributes (the FastVel™ add-on application). In addition, vector-based, trace-by-trace, automatic RMO picking is provided.

Velocity model updating may be performed using either GeoDepth Constrained Velocity Inversion (CVI) or GeoDepth Tomography.

GeoDepth Constrained Velocity Inversion (CVI)

GeoDepth CVI offers a rapid, straightforward and robust method for updating the velocity model. It uses a constrained least square solution to convert either velocity or residual vertical functions, sampled irregularly and sparsely (laterally and vertically) into a regular, fine, geologically constrained interval velocity. Unlike tomography, CVI assumes a locally varying 1D model for the updating process.

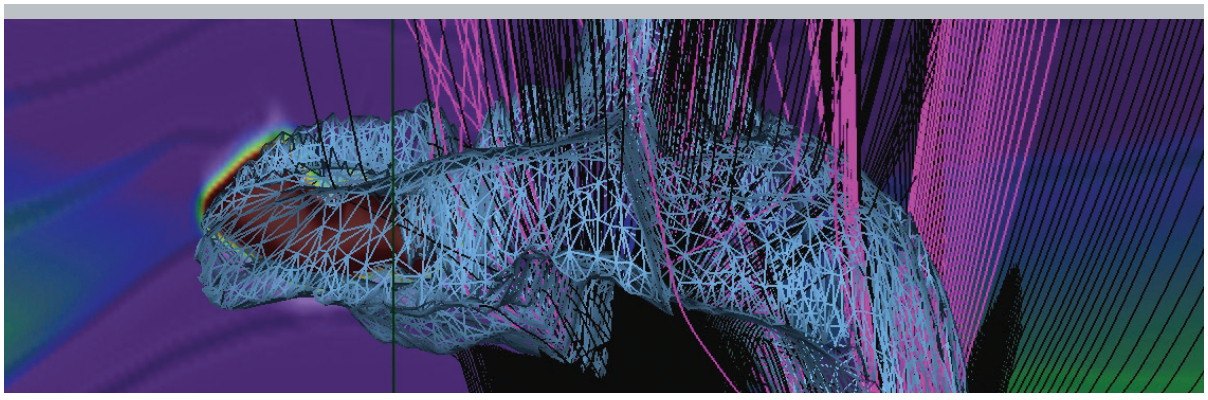
GeoDepth Tomography

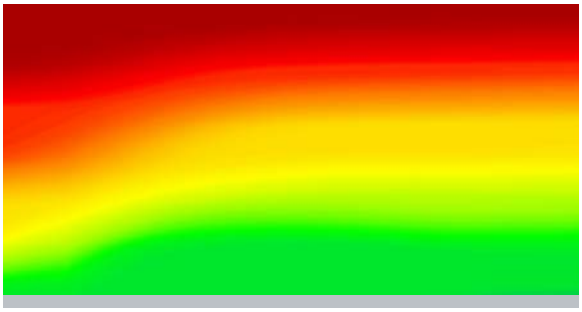
GeoDepth Tomography is a state-of-the-art velocity model updating system designed to handle all velocity environments, including extremely difficult scenarios (anisotropy, topology, size) and model complexity. It enables conversion of isotropic models to VTI/TTI anisotropic models and their update, ensuring the best positioning for reservoir targets. High-resolution calculation grids provide accurate velocity models in surveys of any size, especially in shallow areas.

GeoDepth Tomography supports 2D multi-line grid-based, 3D grid-based, 3D model-based, and hybrid tomographic methodologies, customized to the problem at hand. Grid-based 2D and 3D tomography share the same workflow, user interface and parameters, making them easier to both learn and use. 2D grid tomography provides a multi-line capability that enables work on a large number of lines (from a few dozen up to several hundred) with minimal user intervention.

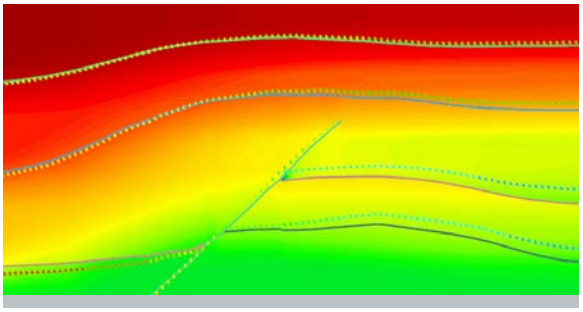
GeoDepth Tomography offers a powerful combination of high-performance cluster computing, rich bottom-up specular ray tracing in all azimuths and angles, automatic reflection patch picking (poststack) and residual moveout picking (prestack), and anisotropic model parameter picking. Supported prestack data includes 2D offset/angle gathers, 3D full-azimuth angle gathers, and sectored offset/angle gathers.

▼ Ray tracing and illumination in GeoDepth





▲ Smoothed background model used as input to structural model-based tomography



▲ In GeoDepth structural model-based tomography, faults are correctly taken into account, resulting in an updated, geologically consistent velocity model

GeoDepth combines the explorationist's regional knowledge of subsurface geology with seismic imaging and velocity model building tools, to efficiently create an accurate earth model.

The 3D Canvas window provides a comprehensive visualization and interpretation system to analyze, QC and edit the automated RMO picked data. The rich 3D environment enables the display of RMO curves along a massive amount of gathers, together with the ability to filter out outliers according to predefined QC attributes.

All information, including picks and associated attributes such as dip, azimuth and continuity of reflecting surfaces, surface ID, residual velocity and others, is stored in a Pencil Database. The information can be extracted using either volume-based (ImageDAC) or reflector-based (ImagePICK) operations. The extraction procedure is parallelized, for added efficiency.

GeoDepth tomography enables the performance of multiple inversions to solve the tomography matrix, with different geological constraints applied independently to each geological layer or model creation of complex geology.

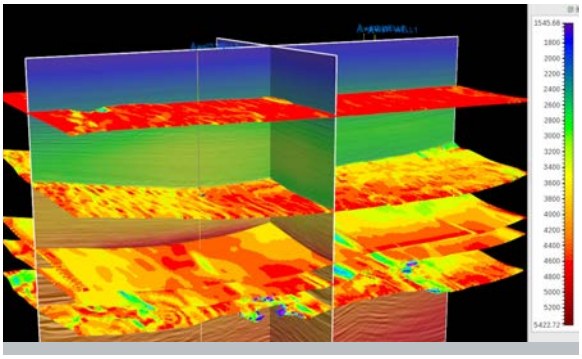
As a result of enhanced integration between GeoDepth and the SKUA™ structural and stratigraphic modeling solution, it is possible to run model-based tomography on complex SKUA-generated models (via pencils), including faults and multi-value surfaces, for structural and stratigraphically constrained velocity models. Three component displacements from model-based tomography can be used to generate updated depth T-surfaces for horizons/faults,and then used in SKUA to rebuild the model. The geologically-consistent updated velocity model fully honors the structural complexity of the subsurface.

GeoDepth is uniquely able to integrate well information (check shots, VSP data, and well markers) into tomography equations for solving and controlling anisotropic inverted parameters. Integrating VSP data reduces uncertainty in the model building process, resulting in fewer iterations and quicker delivery of the final model.

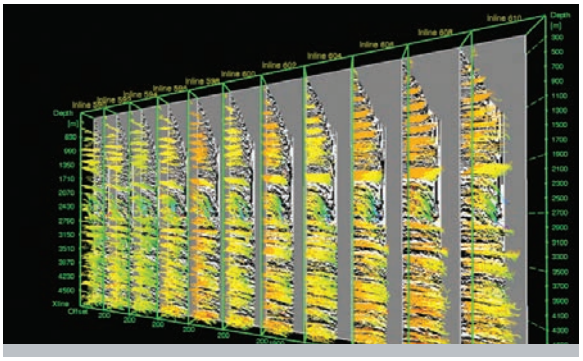
Tying the horizons interpreted on the seismic image to well markers plays a critical role in the velocity model building workflow, especially in the presence of anisotropy. The aim is to find a velocity model that yields flat gathers after depth migration, and ties to the well markers. Subsurface velocities cannot be uniquely determined by the surface recorded seismic data alone; in such cases, it's possible to find a velocity that will flatten the gathers but not tie to the wells. Well information is used to reduce this ambiguity.

Mis-ties between seismic horizons and well markers are calculated and used as input to well tie tomography to update the velocity/anisotropic parameters, resulting in a velocity model that minimizes the input mis-ties.

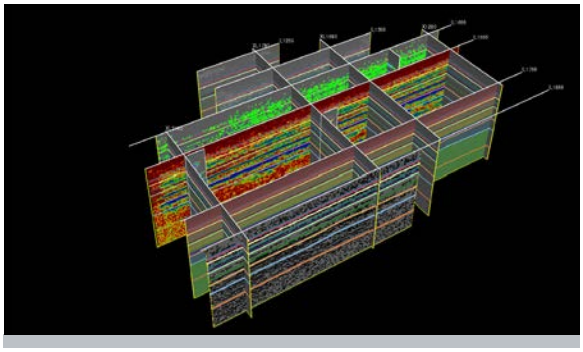
GeoDepth also offers time-preserving tomography, an efficient and accurate application for simulating different scenarios of isotropic/anisotropic velocity-depth models which are consistent with a given background model. Re-depthing using time-preserving tomography systematically reduces depth seismic-to-well marker mis-ties.



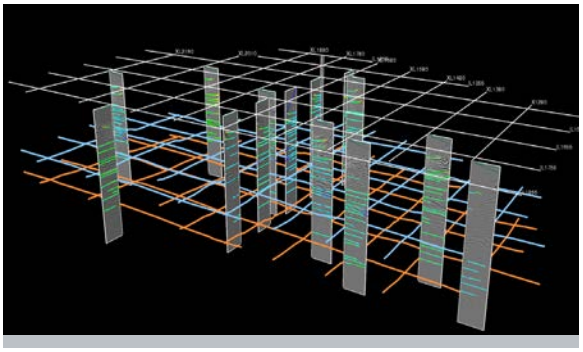
▲ Pencils extracted from model maps colored by Dip



▲ Automatic picking of RMO along common image gathers in 3D Canvas



▲ 3D Canvas visualization plays a central role in the multi-2D velocity building workflow, from multi-2D line interpretation to visualization of prestack, poststack, RMO curves, and RMO attributes, for efficient multi-2D line QC.



▲ Visualization of prestack gathers and picks in 3D Canvas along multiple 2D lines

Flexible Technologies for Mapping and Modeling

Emerson offers a wide range of geomodeling capabilities covering all the model-building needs of today's geoscientist, from simple, map-based solutions through more complex, surface-based applications, up to true 3D modeling capabilities in the SKUA-GOCAD™ suite of products. Together, these provide the flexibility needed to create the appropriate model quickly and easily from horizon and fault surfaces described by grids, triangulated meshes or picks.

Using a comprehensive set of mapping tools, it is possible to create horizon, fault and slice maps, as well as velocity attribute maps. By supporting multi-Z valued surfaces and picks, such as vertical faults, salt overhangs and fault overthrust, the most complex structures can be easily and accurately represented.

Connectivity to SKUA Structural and Velocity Modeling

GeoDepth works seamlessly with the state-of-the-art SKUA structural and velocity modeling application. Using SKUA, it is possible to build complex structures and create volumes that are available to GeoDepth for analysis and imaging.

SKUA offers a wide range of powerful yet easy-to-use technologies for the accurate, efficient and productive construction of subsurface models. Unlike other, map-based solutions, where structural complexity is quickly a limiting factor and where the approach incorporates simple layering, SKUA enables accurate modeling in salt and other structurally complex environments, making use of 3D operations that honor the stratigraphy and faults. GeoDepth velocity maps and vertical functions may be accessed by SKUA to create velocity volumes.

Advanced Migrations Assure Highest Quality Imaging

GeoDepth is supported by a full range of 2D and 3D prestack depth migration add-on modules, including flexible, target-oriented Kirchhoff migrations with high-end imaging options (Wavefront Reconstruction and Common Reflection Angle Migrations [CRAM]) and Common Shot Wave Equation Migrations (WEM). Reverse Time Migration (RTM) is available within the Echos™ seismic data processing and analysis system. Collectively, these migrations can be applied to solve a broad range of imaging objectives, such as thrust fault, subsalt and rugged terrain imaging, and accommodate a variety of imaging acquisitions, including wide angle, OBC and other multi-component recordings.

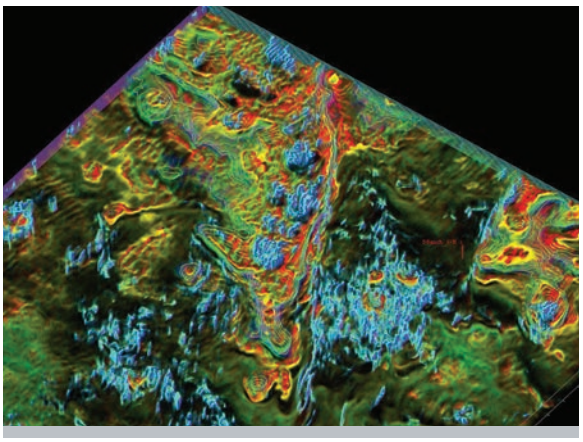
EarthStudy 360 – A New World of Information for Geoscientists

EarthStudy 360™, the next-generation extension of GeoDepth, is an innovative system that generates three-dimensional angle gathers which are then uniquely processed and analyzed. The result is a complete set of data that provides accurate isotropic/anisotropic 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.

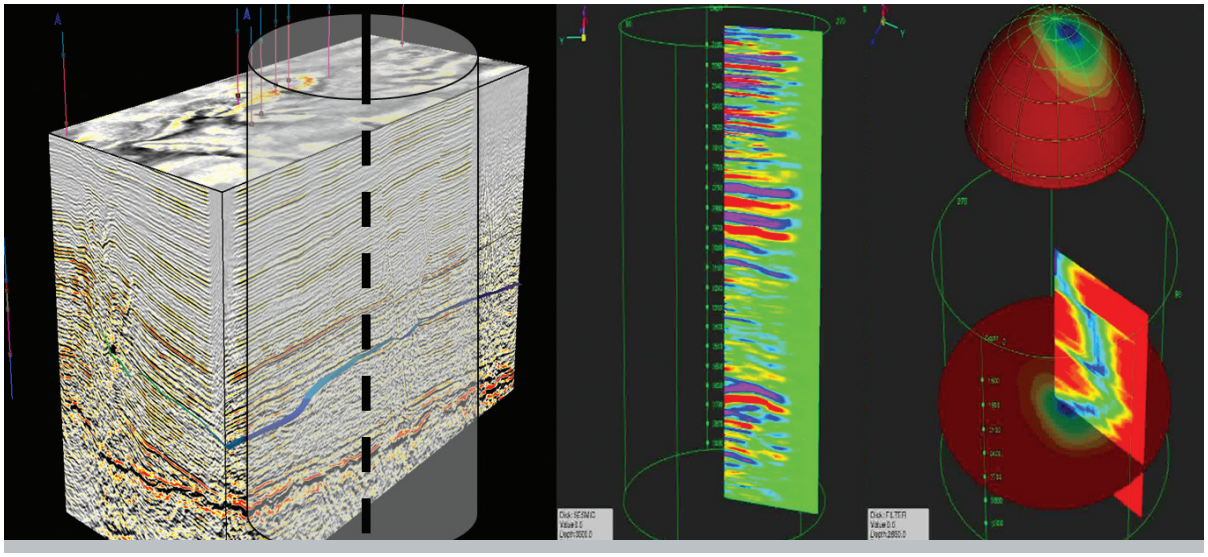
EarthStudy 360 is most effective for imaging and analysis in unconventional gas plays within shale formations and in fracture carbonate reservoirs. The system delivers highly accurate images from below complex structures such as shallow low-velocity anomalies like gas pockets, subsalt, sub-basalt and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

A Fully Integrated Product Suite Offers Seamless Workflows

GeoDepth is fully integrated with all other Emerson E&P software products running on the Epos™ infrastructure and data management platform. Furthermore, due to the system's comprehensive interoperability capabilities, datasets



▲ Fracture imaging in EarthStudy 360



▲ Reflection and directional angle gathers in EarthStudy 360 at a given location along the depth model

in existing multi-vendor databases can be accessed and processed smoothly and quickly, with no reformatting needed.

Integration with the Echos Seismic Processing System

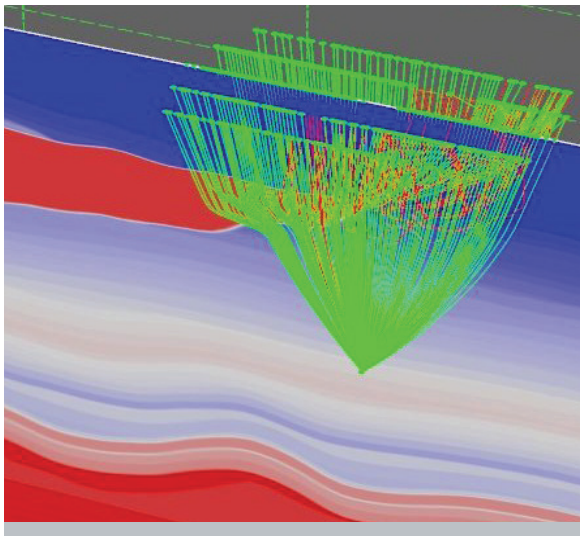
GeoDepth shares a file system, project data and core computational libraries with Echos. The seismic images produced by GeoDepth benefit from Echos pre-processing and post-processing capabilities. Together, they produce the highest quality images of the subsurface.

Integration with Quantitative Seismic Interpretation

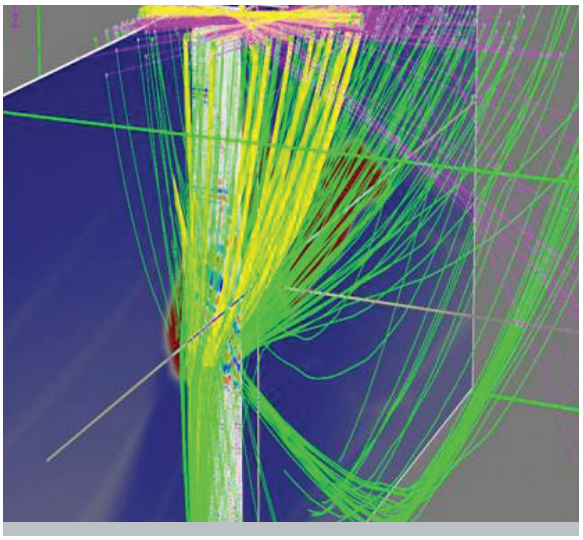
Quantitative Seismic Interpretation (QSI) AVO inversion is based on the velocity model and amplitude-preserved migrated image gathers generated in GeoDepth, and uses some of its core computational libraries, such as ray tracing modeling and residual moveouts. GeoDepth amplitude preserved migrations, especially in the angle domain, determine the quality of the AVO inversion. The 3D velocity models and seismic images generated by GeoDepth migrations are the input for the QSI inversions, and determine the quality of the results.

Integration with Emerson E&P Interpretation Software

GeoDepth capabilities are heavily embedded in the SeisEarth™ multi-survey, regional to prospect interpretation product suite. The SeisEarth 3D Canvas supports the simultaneous display and use of prestack and poststack seismic data in a common interpretation environment. It enables efficient and accurate three-dimensional picking, editing and QC of the main reflectors used for velocity model determination and amplitude inversion. In particular, massive amounts of residual moveout curves can be visualized and edited, enhancing reliability and productivity. A new 2D visualization window allows the simultaneous display of prestack and poststack data, including multiple displays and panel management.



▲ Two-point ray tracing



▲ Prestack gather in the post-stack domain (Data courtesy of AWE)

Illumination

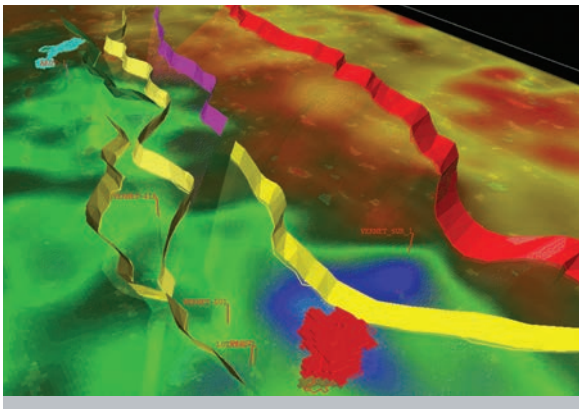
GeoDepth offers an advanced illumination add-on module that provides a previously unattainable breadth of knowledge about ray propagation in complex areas.

The Illuminator uses an enhanced, interactive ray tracing technology that quantifies the relationship between the surface acquisition geometry and the subsurface angles in targeted areas. Launched from SeisEarth 3D Canvas, input for the Illuminator includes isotropic and VTI, TTI and orthorhombic/anisotropic velocity models, converted waves, and optionally, data acquisition geometry. Ray tracing is fully parallelized, for increased productivity.

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

For depth imaging specialists who seek additional knowledge about imaging reliability, the Illuminator can perform ray tracing in batch mode along fine 3D grids for the generation of full-azimuth illumination gathers, volumes and maps.

Grid-based ray tracing is supported by Emerson's HPC functionality and can run on multi-node clusters.



▲ Pore pressure prediction

Pore Pressure Prediction

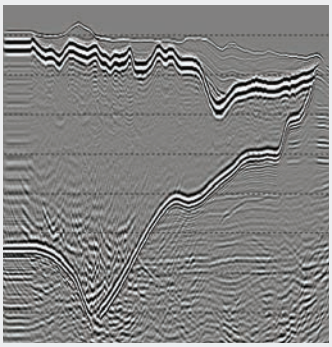
Pore Pressure Prediction procedures that use seismic velocity information have had a huge impact on drilling safety and the economics of drilling design and well construction. As pore pressure prediction is a multi-disciplinary procedure, it is more effectively carried out with a technology base and common infrastructure that include seismic data processing, velocity model building, high-resolution tomography and depth imaging. The detailed velocity models provided by GeoDepth, and the ability to identify velocity anomalies, enable geoscientists to accurately predict pore pressure.

Kirchhoff Migrations

Prestack Time Migrations: 2nd and 4th order, and anisotropic curved rays.

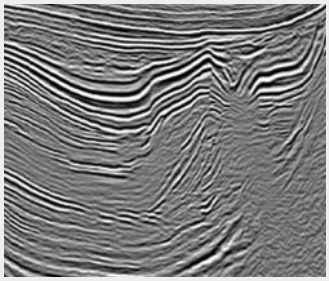
Prestack Depth Migrations: Computation of traveltimes for waves propagating from sources to subsurface image points using the Wavefront Reconstruction, Fermat or Eikonal method. Wavefront Reconstruction is the most accurate solver and supports VTI/TTI anisotropic models, using the most energetic arrivals.

Kirchhoff is a fast, target-oriented process which enables efficient velocity model building and updating and is particularly adaptable to irregular acquisition geometries. It accurately handles anisotropic and converted wave velocity models and surface topography. In 2D surveys, users can easily and efficiently run migrations for tens to hundreds of 2D lines.



Local Angle Domain Imaging

Advanced Local Angle Domain imaging is performed in the EarthStudy 360 Imager. The GeoDepth Common Reflection Angle Migration (CRAM) is a major component of this offering. CRAM generates subsurface, amplitude preserved, reflection angle gathers, using all arrivals within the full recorded data. These are the optimal gathers for accurate determination of the velocity depth model as well as for amplitude inversion (AVA). CRAM can be utilized to provide fast, target-oriented solutions for local analysis, and can also be used for imaging on a regional scale. CRAM supports anisotropic VTI and TTI models, as well as Q compensation.



Features

- Dedicated application interface (Velocity Navigator) for grid-based and model-based velocity analysis
- Efficient, cluster-based gather processing
- Anisotropic multi-azimuth global tomography
- Flexible, accurate mapping and geomodeling (SKUA)
- Full support for ray- and wave equation-based isotropic/anisotropic modeling, imaging and velocity determination
- Automatic RMO analysis using the SWAN method (FastVel)
- Broad range of illumination analyses
- Full integration and seamless operation with the Echos seismic processing system
- Full integration with the Epos-based SeisEarth interpretation and visualization product suite

Interoperability

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

- RESQML 2.0.1
- OpenWorks® R5000.10
- GeoFrame® 2012
- Petrel* 2019 & 2018
- Recall™ 5.4.2

(a mark of Schlumberger)*

System Specifications

- 64-bit Red Hat® Enterprise Linux® 6.8 and subsequent minor releases, and 7.1 and subsequent minor releases

The Emerson E&P Software Advantage

- A complete suite of interactive and batch velocity analysis tools handles a full range of seismic imaging problems.
- Continuity in the velocity model building process prevents data loss and honors geological constraints.
- Easy construction of 2D and 3D models, regardless of the complexity of the structural geology.
- A complete 2D/3D ray tracing modeling library, comprising isotropy and anisotropy models, enables accurate
- Simulation of wave propagation in complex subsurface areas.
- An intuitive, wizard-driven user interface, assuring a short learning curve and full control over the velocity analysis process.

www.emerson.com/EPSoftware

Cover image data and Kirchhoff migration data courtesy of Devon Energy Corporation.

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