Multi-Dimensional Seismic Data Decomposition for Improved Diffraction Imaging and High Resolution Interpretation

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Outline

• Importance of faults analysis
• Challenges
• Seismic interpretation: traditional versus wavefield separation
• Seismic data decomposition in the local angle domain
• Illustration: structural framework interpretation
• Conclusion

Location of the seismic survey in the Eagle Ford oil window

Example of logs behavior (right) and thickness map (left) Lower Eagle Ford

Data Courtesy of SEITEL
Importance of Fault Analysis

• Why is fault analysis important for the industry?
  • Faults are hydrocarbon traps (HC accumulation)
  • Hydrocarbon flow through faults – migration path way from source to reservoir
  • Production flow rates (fault permeability is important for flow rate and pressure gradient)

Predicting across fault- connectivity of reservoir (SGR cut-off values)
Importance of Faults Analysis

• Fractured Reservoir (Tight reservoir)
  • Are fractures the essential contributor to porosity and permeability or
  • Do the fractures actually act as fluid barriers

• Seismic interpretation of small scale discontinuities to understand compartmentalization of heterogeneous reservoirs

• Optimize well placement (location, spacing)

Depth Slice on Reflection volume @ 15000ft
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Data Courtesy of Depth Slice on diffraction volume @ 15000ft. Tectonic induced Faults & fractures
The heterogeneity in the Glen Rose formation is lost in reflection image & appears as a transparent zone. However, the diffraction image shows detail heterogeneity coming from the dolomite/limestone within the formation.
Faults on Outcrop

Outcrop extensional normal fault bands in unconsolidated sand, Jylland, Denmark  © Haakon Fossen
Faults on Outcrop

Outcrop extensional normal fault bands in unconsolidated sand, Jylland, Denmark  © Haakon Fossen
Outcrop Fault Skeleton

The detailed fault pattern at reservoir level which may not be seen on seismic reflection only data.

Fault interpretation on outcrop
Challenges: Recover Diffracted Energy

- Small scale discontinuities, causing diffractions on seismic records, are lost during processing in favor of continuous reflectors.
- Diffracted energy carries high resolution information of small scale discontinuities and subsurface geological features.
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- Small scale discontinuities, causing diffractions on seismic records, are lost during processing in favor of continuous reflectors.
- Diffracted energy carries high resolution information of small scale discontinuities and subsurface geological features.
Larger faults are typically mapped on reflection data.

Small faults have very small displacement: Invisible on regular seismic volume.

Human eye used to seeing layers but not details within the layers.
Diffraction Image Interpretation

The major faults are salt related normal faults, dipping NW-SE.

Data Courtesy of Diffraction Image Interpretation

Navarro Fm.
Eagle Ford Fm.
Glen Rose
Pearsall/Sligo Fm.
Louann Salt

Main bounding Faults
Transfer zone
Relay zone
Traditional Workflow

Traditional Approach

Seismic Interpretation

Major continuous and discontinuous

Reflected (Specular) Energy stack

Coherence Cube®

Curvature

Advanced Structural Analysis

Coherence (above, High Resolution Eigen) depth slice, co-visualized (right) with curvature attribute
Traditional versus Wavefield Separation

Traditional Poststack Approach

Seismic Interpretation

Major continuous and discontinuous features

Reflected (Specular) Energy Migrated stack

Coherence Cube®
Curvature Cube

Advanced Structural Analysis

Wavefield Separation Approach

High Resolution Seismic Interpretation

High resolution delineation of diffraction generators

Full Azimuth Directional Angle Gathers

Wavefield Energy or Structural (Dip/Azimuth) Separation

Advanced Structural Analysis
A point diffraction one-way ray-tracing operator is applied at each sub volume grid point. From this ray fan, ray-pairs are constructed, simulating the reflected/scattered events and organized for separation of specular and diffraction energies.

For each image point, a complete description is stored (Local Angle Domain table), considering all directional dips and azimuths and all of the opening angles and azimuths.
The EarthStudy 360 Migration

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The specular direction carries the most energy.

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Stacking Options – Pre-stack Domain

Energy Separation

- Specular Energy Stack (High Energy Enhancement)
- Diffraction Energy Stack (Low Energy Enhancement)

Structural Dip Separation

- Dip-based angle mute (Highlight Faults or discontinuities)
- Azimuth-based angle mute (Remove Inter-bed multiples)
Stacking Options – Pre-stack Domain

Energy Separation

- Application of specular attenuation filters as a post-processing step in order to remove the specular energy

Specularity (left) & diffraction (right) filters

Specular energy stack amplitude range

Diffraction energy stack amplitude range
Wavefield Separation Approach

- Wavefield Separation Approach
- High Resolution Interpretation
- Delineation of smaller diffraction generators
- Full Azimuth Directional Angle Gathers
- Wavefield energy or Structural (Dip/Azimuth) Separation
- Advanced Structural Analysis

Diffraction Energy stack co-visualized with fault Likelihood
Wavefield Separation Approach

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Co-visualization of coherence and diffracted weighted image along the Buda structural interpretation
Objective: Improve fault interpretation for accurate structural framework

Fault Enhanced and high-resolution Eigen coherence co-visualization

Fault network and diffraction energy stack
Karsts delineation

Marble Falls

Ellenburger

Full Wavefield Stack
Inline 880

Full Wavefield Stack
Depth slice 4500 ft.
Diffraction Energy vs. Full Wavefield

Diffracted Energy Stack
Depth slice 4500 ft.

Full Wavefield Stack
Depth slice 4500 ft.
Structural Dip Partial Stacks

Structural Dip Partial Stack (0-15 degrees)
Depth slice 4500 ft.

Full Wavefield Stack
Depth slice 4500 ft.
Structural Dip Partial Stacks

- Structural Dip Partial Stack (0-15 degrees)
  Depth slice 4500 ft.
- Structural Dip Partial Stack (15-30 degrees)
  Depth slice 4500 ft.
Structural Dip Partial Stacks

Structural Dip Partial Stack (30-45 degrees)
Depth slice 4500 ft.

Structural Dip Partial Stack (15-30 degrees)
Depth slice 4500 ft.
Conclusion

- Improve fault interpretation
- Fault seal analysis (thickness, SGR, sealing, transmissibility)
- Reservoir scale fault compartmentalization, internal faults which maybe laterally discontinuous
- Explore upside potential of geologically complex field
- Quantify lateral fault location uncertainties
- Fault geometry
- Petrophysical properties of fractures within reservoir (porosity, permeability)
- Salt weld (thickness, faulted or not)
- Understanding impact of geologic structure on fluid flow
Licensing Paradigm 16

• EarthStudy 360 Directional Imaging
  − This package includes the imaging part and the tools for interpretation, QC and validation
  − Targeted for operators or services companies which will carry out the imaging part and interpretation

• EarthStudy 360 Analysis
  − This package includes visualization, processing and QC tools of ES360 deliverables
  − Targeted for:
    • Paradigm geoscience service customers who want to be more involved in the creation of final deliverables or ongoing deliverables
    • Customers who carry out EarthStudy 360 projects that want to make the deliverables more accessible inside the company
    • Customers of other service providers that utilize EarthStudy 360 technology
Components

• Data loading and management capabilities

• EarthStudy 360 Imager with only directional gathers output enabled
  – No velocity updating, or VVAZ/AVAZ analysis capabilities
  – Only available in EarthStudy 360 Directional Imaging (Linux OS)

• Post-processing of directional angle gathers (2D/3D Canvas):
  – Stacking by dip
  – Weighted stacks
  – Correlation stacks (New Paradigm 16 implementation)
  – Interactive and batch functionality

• 2D/3D Canvas and Basemap

• 3D Gather Viewer
Broad Portfolio of Geoscience Services

Focus on business outcome rather than process

“Embedded” customer involvement

Integration of geophysical and geological models

Full field studies with industry partners

Example Engagements

- **Eagle Ford Shale** - Establish a repeatable, best-practice full-azimuth depth imaging and characterization workflow to optimize well placement and horizontal drilling.

- **Cantarell Field** – Build a unified, validated and regional stratigraphic-structural velocity from a rich multi-survey seismic interpretation and hundreds of wells to better understand field compartmentalization.

- **Offshore Nigeria** – Locate new reservoirs and validate the use of ocean bottom seismic data in the highly faulted West Africa Field.
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References


Thank You