Implications of 3-D Domain Transformation for Structural and Stratigraphic Interpretation*

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Abstract

The interpretation of depositional systems in a seismic volume is challenging because the effects of geologic structure obscure the depositional systems in the volume. Historically, this problem has been dealt with by one of two methods: Flattening the seismic volume on a horizon, or Proportional or stratal slicing between pairs of horizons.

Flattening produces a volume in which the reflections are flat only near the control horizon. Proportional slicing creates a stratal sub-volume only when there is uniform rate of differential sedimentation or compaction between two horizons. Neither approach handles more complex geologic structure.

A "Domain Transformation" (DT) removes arbitrarily complicated structure from a seismic volume. It is an interpretation guided 3D transform that creates a volume consisting entirely of stratal-slices - all reflection events are flat. This volume is ideal for imaging and interpreting depositional systems because every horizontal slice represents a paleo-depositional surface. Depositional systems are readily recognized from their morphology on these slices. Other stratigraphic details are restored to the approximate position and relationships that they had at the time of deposition.

The structural effects handled by a DT include differential sedimentation/compaction, folds, faults (3D displacement removal), unconformities (including angular), canyons, salt bodies, and carbonate buildups.

A transform may be applied to co-located volumes (e.g., attributes), structural surfaces, well paths, and well logs. Any volume or interpretation created in the stratal domain may be transformed back to the structural domain. Interpreted depositional boundaries and

surfaces may be transformed back to the structural domain. Using transformed attribute volumes, well paths, and logs, seismic facies analysis may be performed in an environment where the complete morphology of the depositional system is imaged.

The transformation also provides a unique means of verifying or refining a structural interpretation. Any problem or inconsistency in the interpreted structure (e.g., missing faults or horizon miss-ties) can readily be identified and corrected in the stratal volume. Consistent application of a DT in structural and stratigraphic interpretation workflows significantly increases the accuracy, consistency, and detail of the interpretation, while reducing interpretation cycle time, particularly for depositional systems.

Implications of 3D Domain Transformation for Structural and Stratigraphic Interpretation

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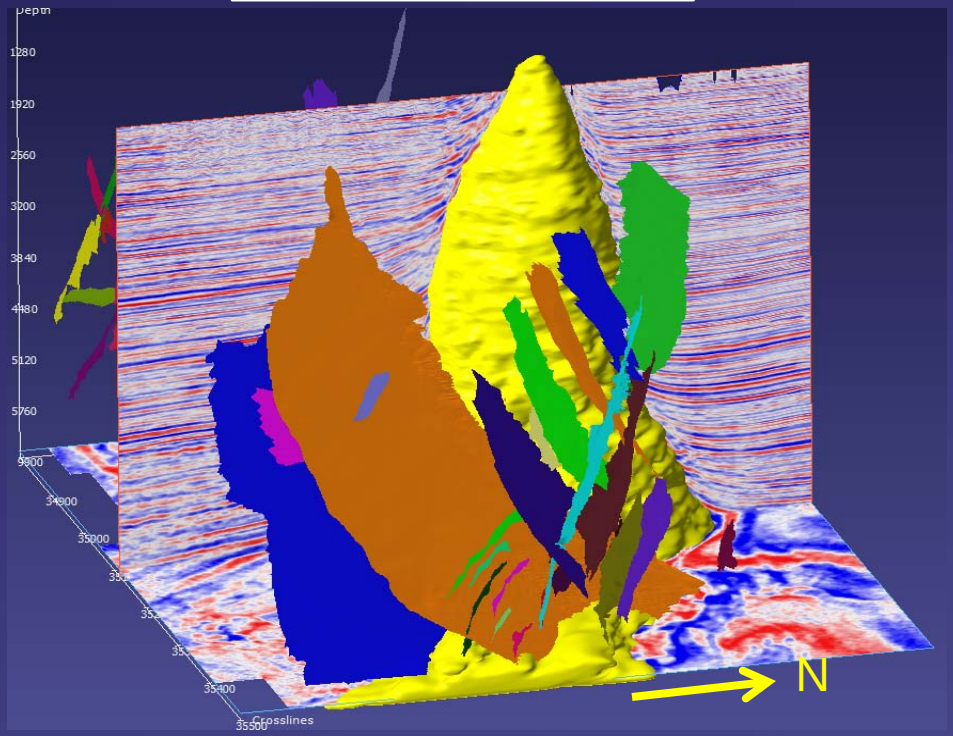
Overview

- The problem with structure
- Defining Domain Transform
- Implications for the interpretation of:
  - Structure,
  - Stratigraphy,
  - Depositional systems, and
  - Seismic facies analysis?

The Problem with Structure

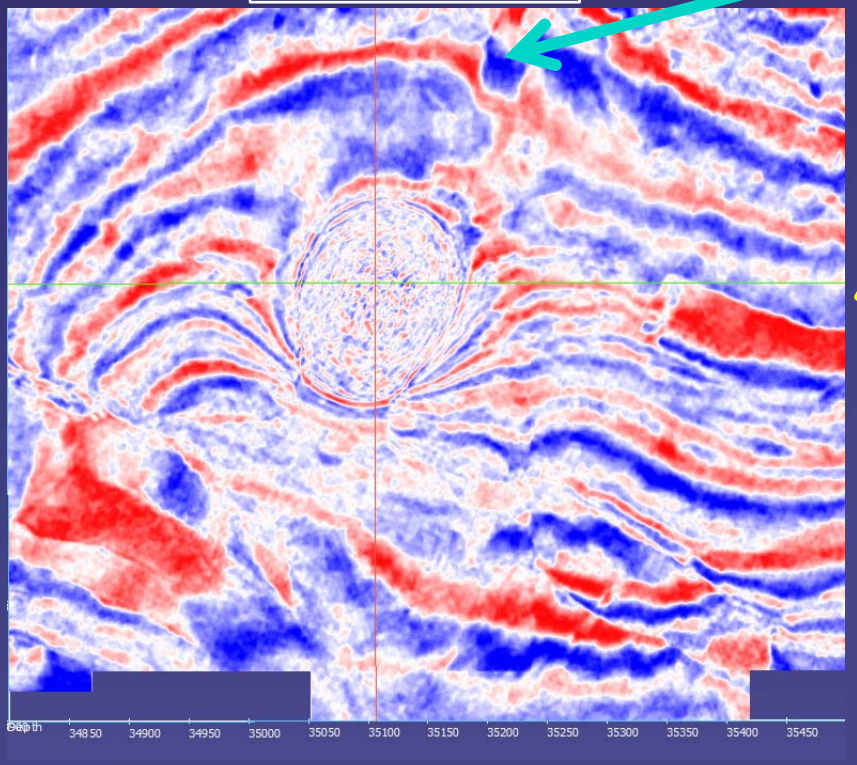
- Stratigraphy and depo systems are imaged as patterns.
- These patterns are obscured by structural effects.

Structural Elements



Depo System

Channel



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3D Domain Transform

- A 3D Domain Transform:
  - Removes all structure from the volume
  - Creates a volume where every horizontal slice is a stratal slice

- Depositional systems and stratigraphy are interpreted in the transformed volume; and
- The interpretation is transformed back to the structural domain.

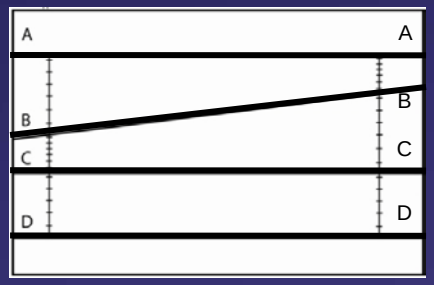
Domain Transform – Removing 3D Structure

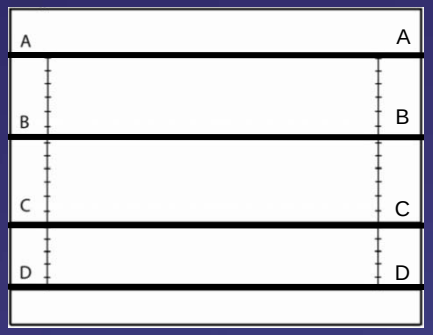
Before

After

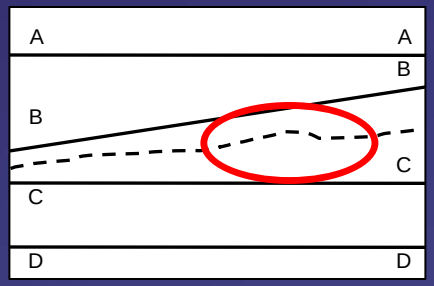
Geologic Intervals

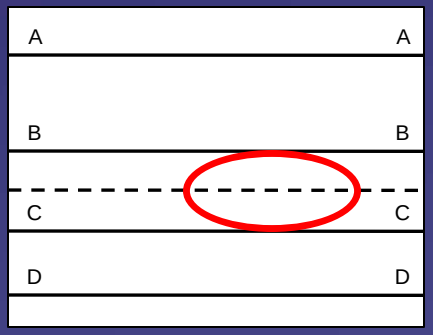
- Differential sedimentation



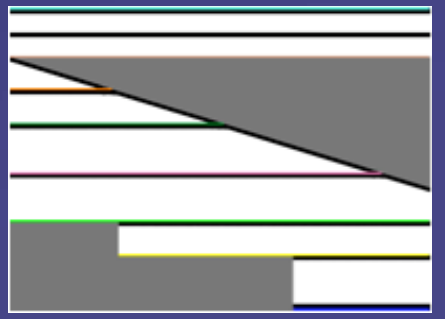


- Differential compaction





- Unconformities



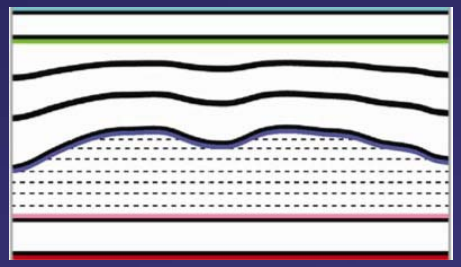
Domain Transform – Removing 3D Structure

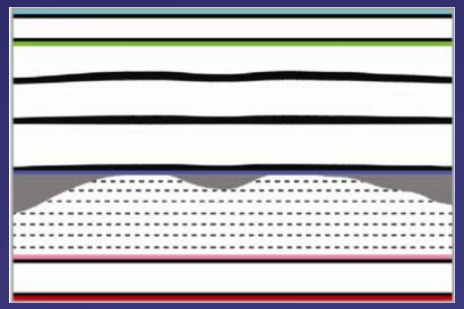
Before

After

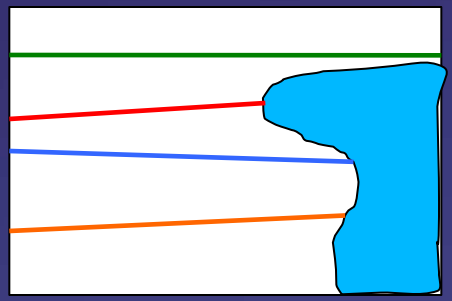
Geologic Intervals

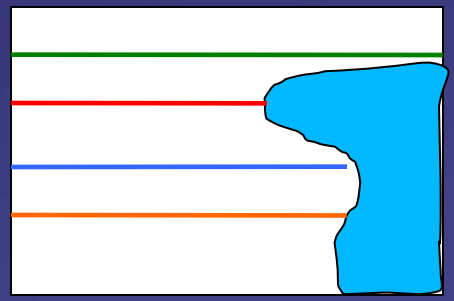
- Carbonate Reef



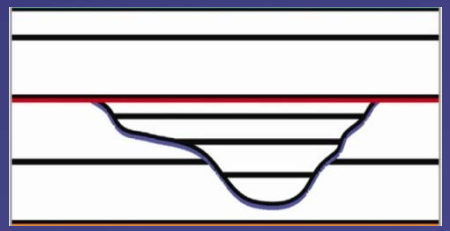


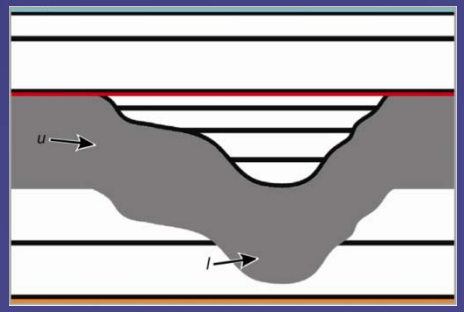
- Salt Body





- Canyon



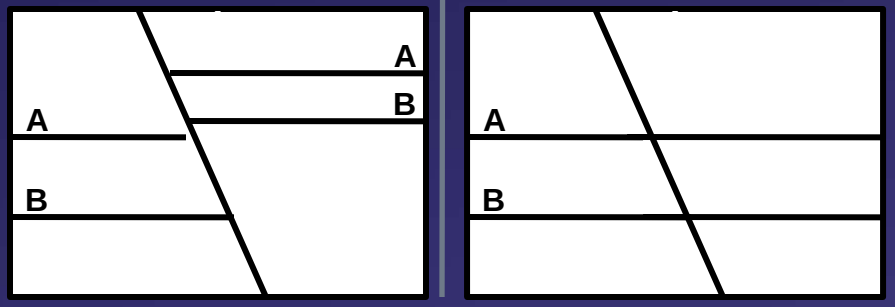


Domain Transform – Removing 3D Structure

Faulted Intervals

Before

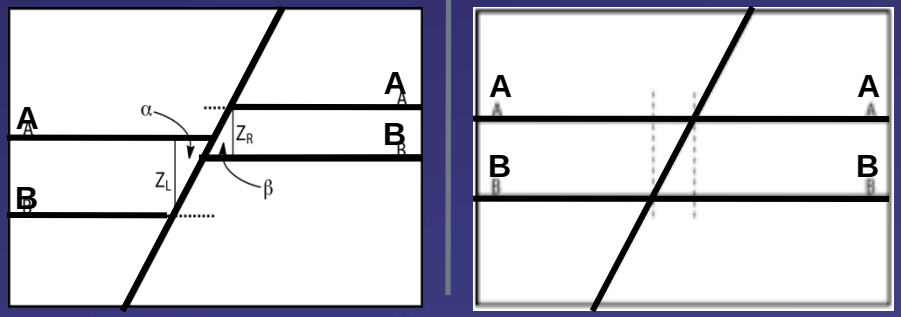
After



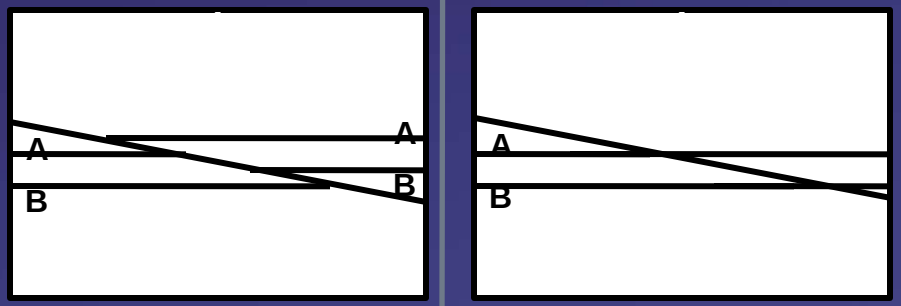
Reverse Fault

Before

After



Normal Fault



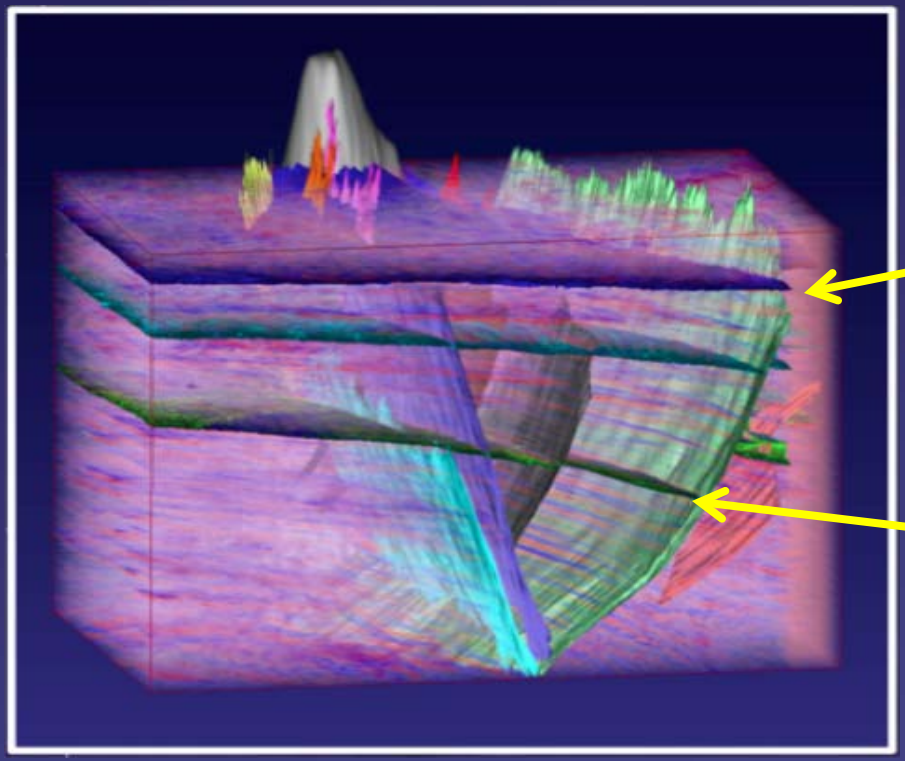
Thrust Fault

Lystric Fault

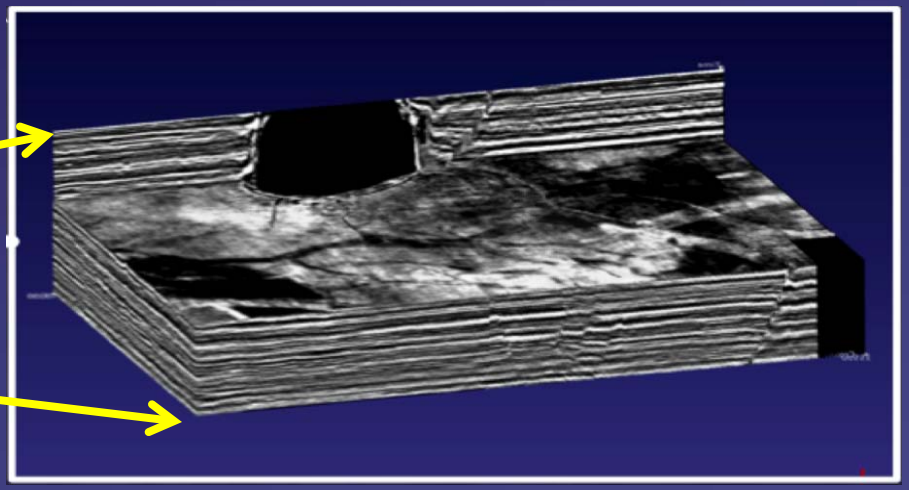
Domain Transform – Removing 3D Structure

Removing all structure from a volume

Structure Volume

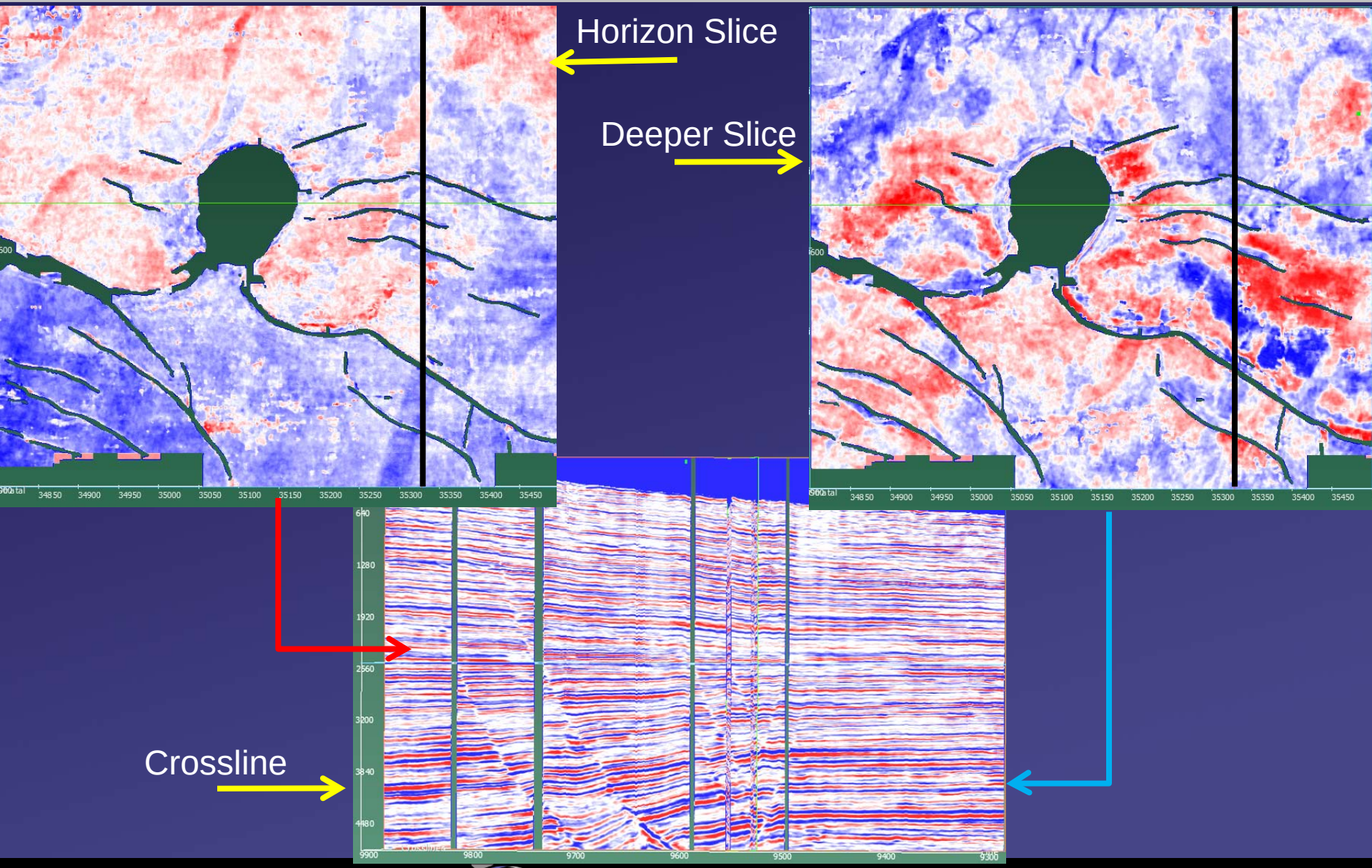


Stratal Volume



Volume between Dark Blue and Green horizons with fault displacements removed.

Horizon (Volume) Flattening



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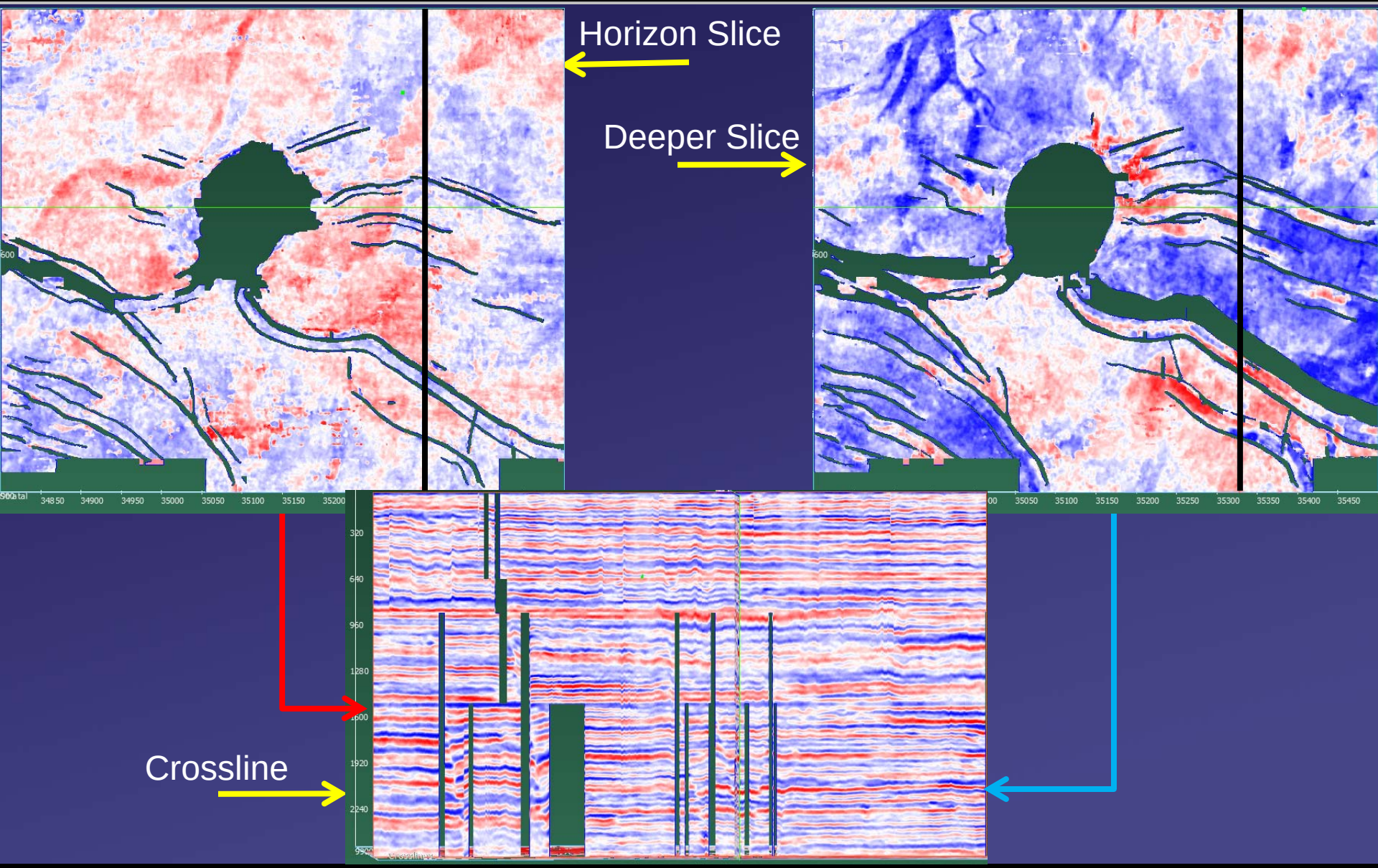
Proportional Slicing



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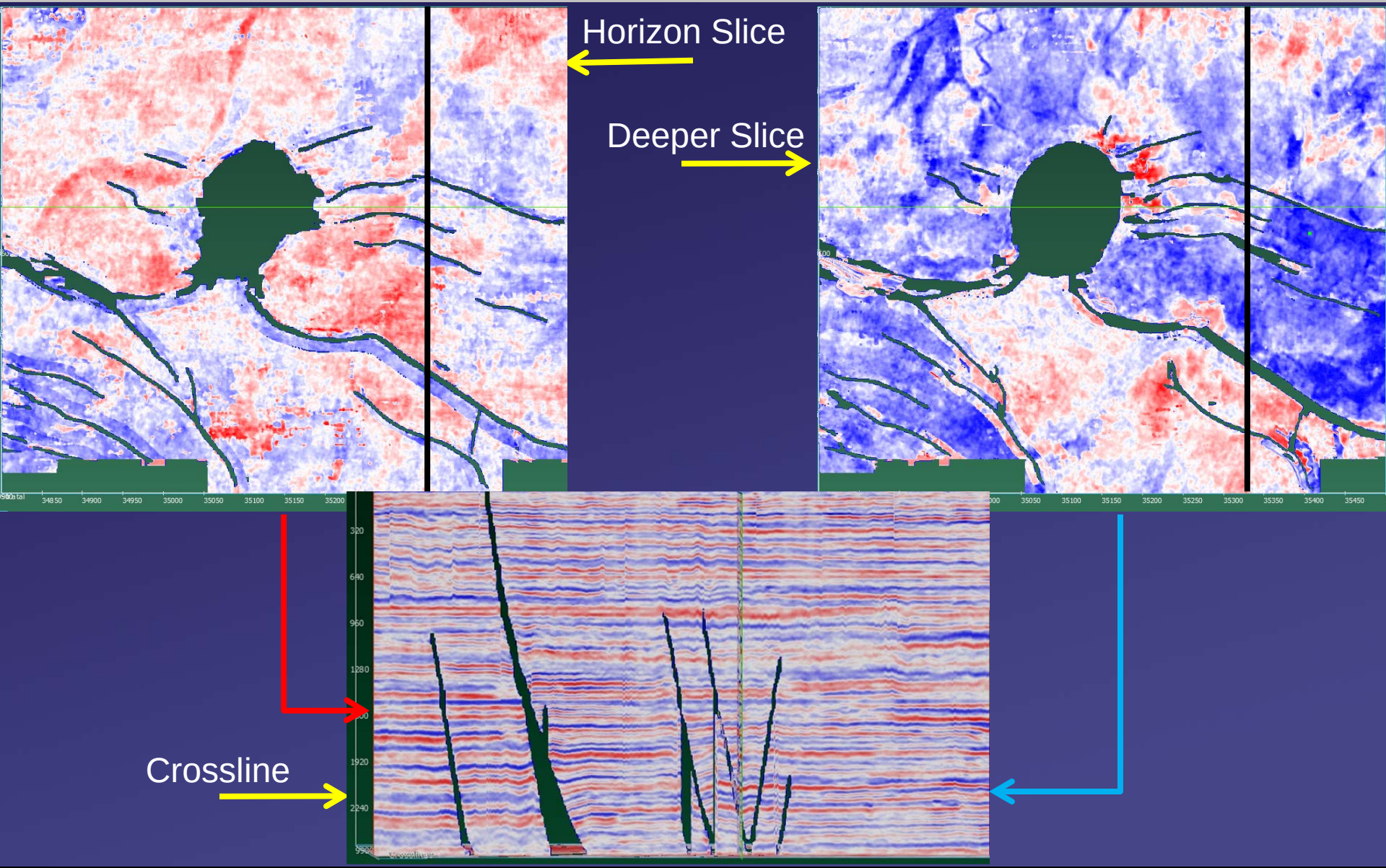
Domain Transform – Vertical Fault Displacement



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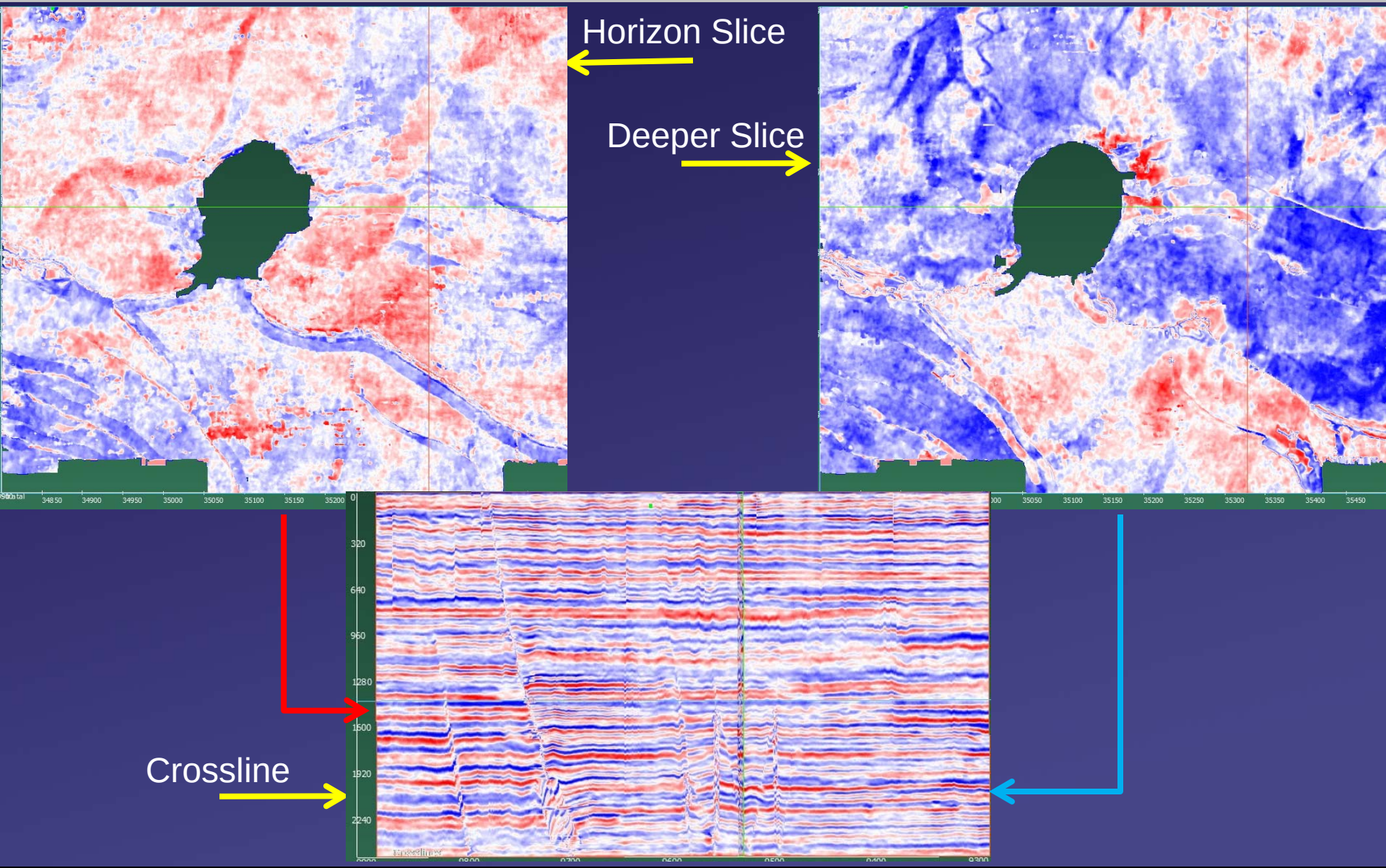
Domain Transform – 3D Fault Displacement



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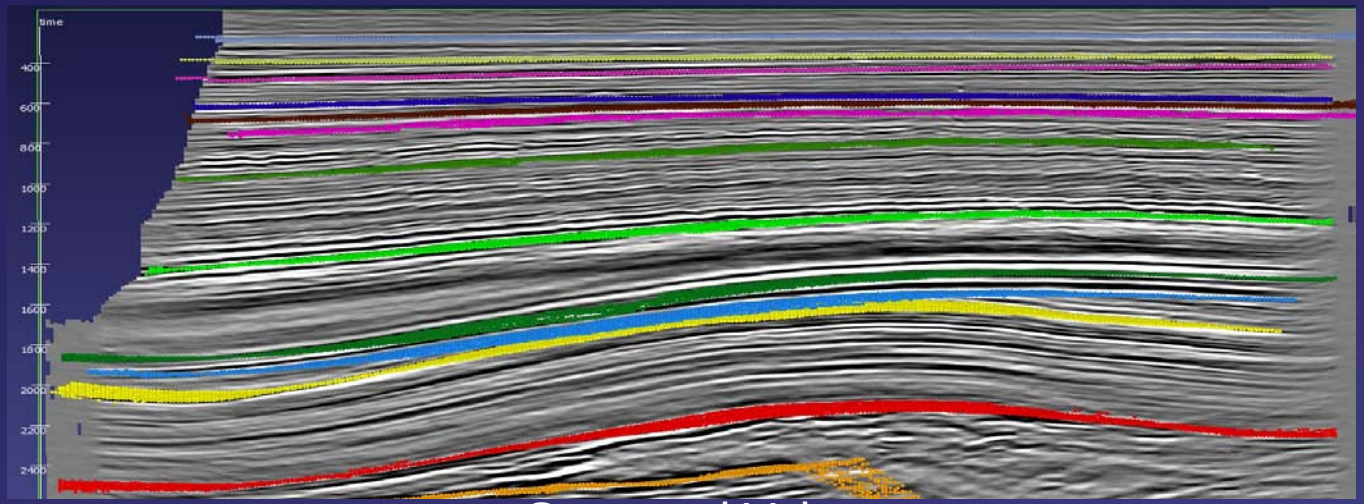
Domain Transform – Angular Unconformities

Horizon Relationships

H1 – N/A, C
H2 – C, D
H3 – C, C
H4 – D, C
H5 – D, C
H6 – C, D
H7 – C, D
H8 – C, C
H9 – D, C
H10 – C, D
H11 – C, C
H12 – C, N/A

C: Concordant
D: Discordant

1st – Interval Above
2nd – Interval Below



Structural Volume

Stratal Volume

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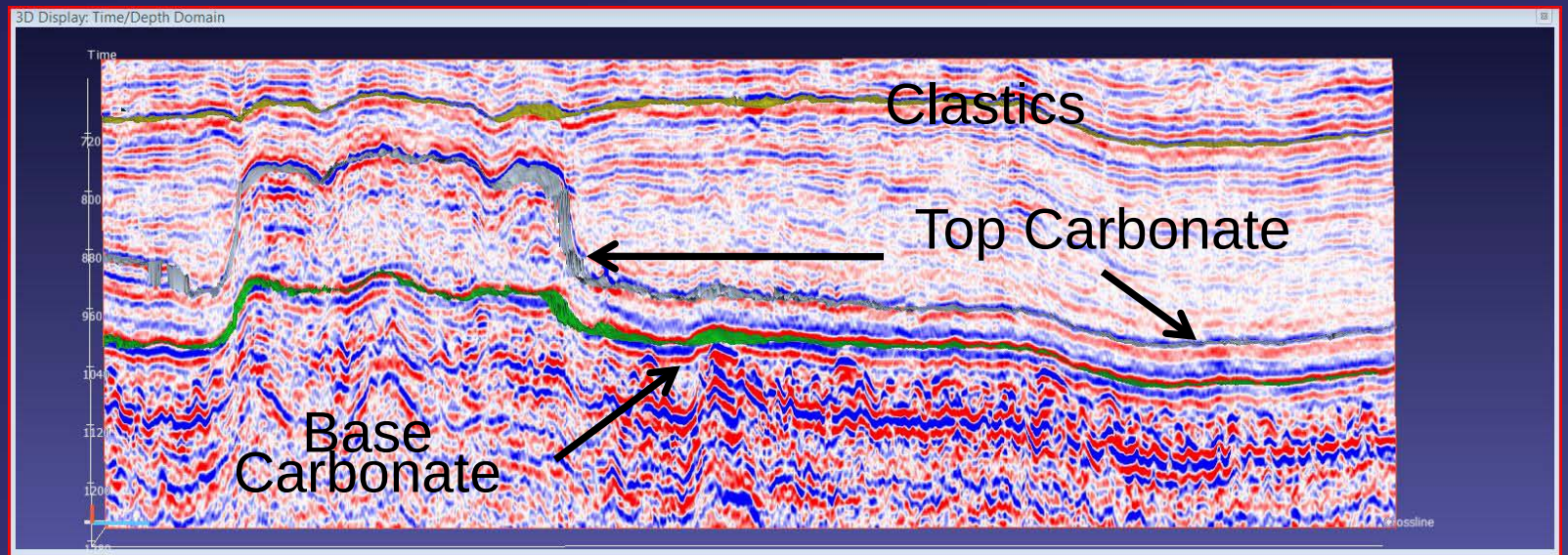
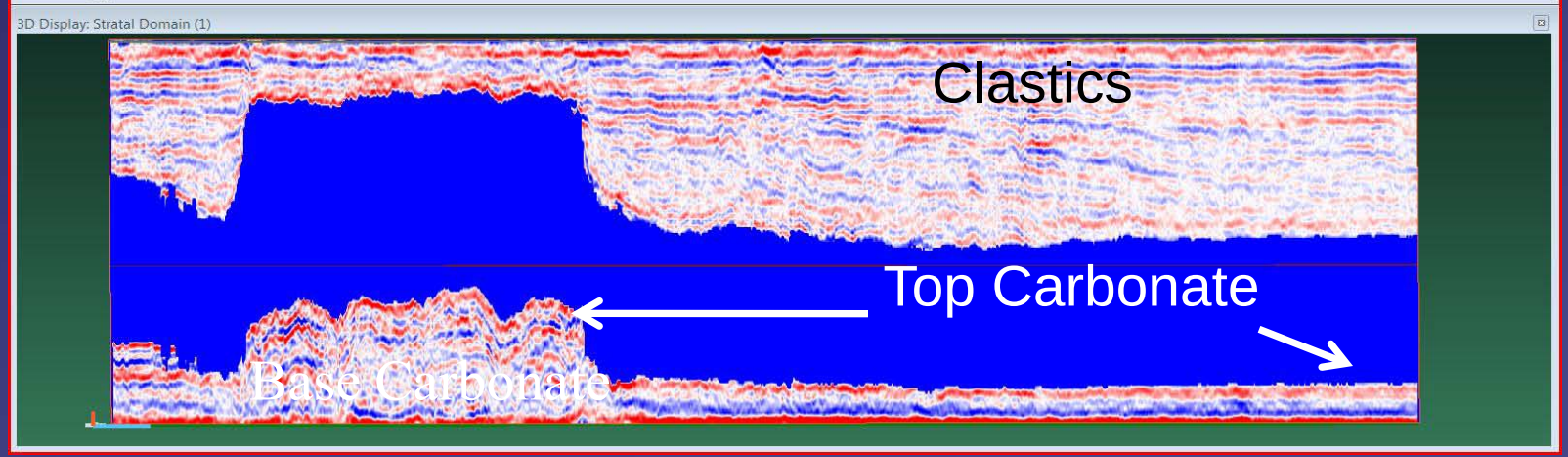
Domain Transform – Carbonate Reefs

Reef Example

Structure



Stratal

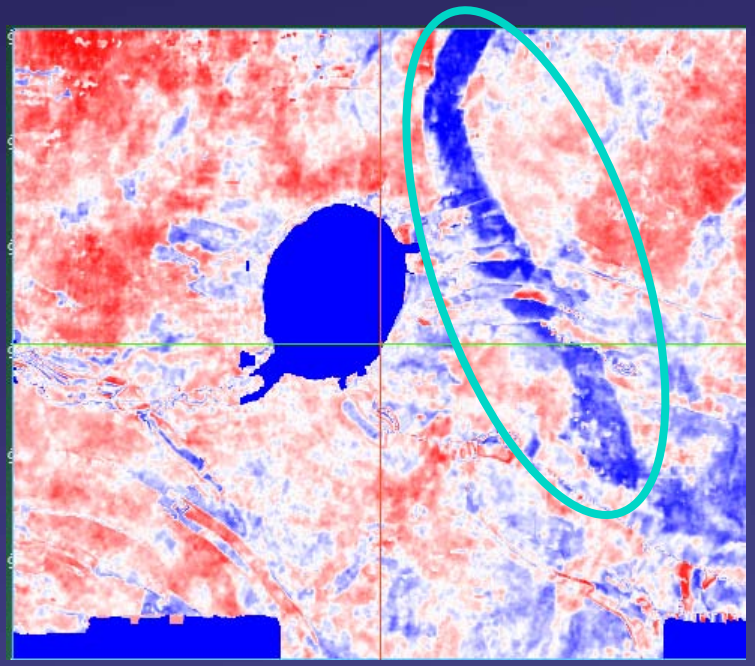


Domain Transform – Applications

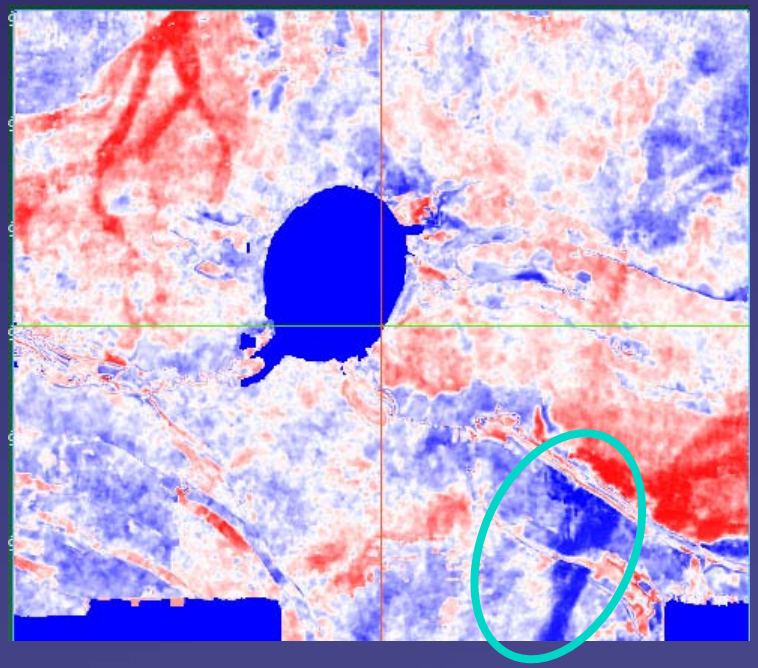
- Structural Interpretation
  - Q/C and correction
  - Rapid infill of Horizons
- Stratigraphic/Depo System Interpretation
  - Explore the volume for depositional systems
  - Interpret Depositional system boundaries (the container)
  - Interpret Other stratigraphic features (progrades, onlap, …)

Applications – Structural Interpretation Q/C

- Missing structural elements (e.g., a fault)
- Identify and fix a horizon miss-tie across a fault



Stratal Slice 301

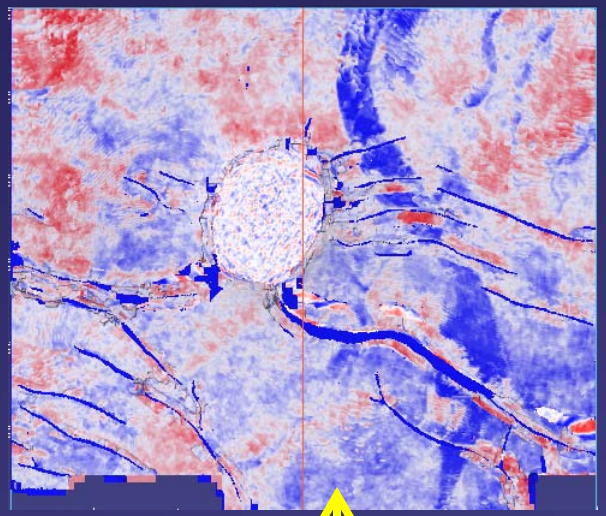


Stratal Slice 309

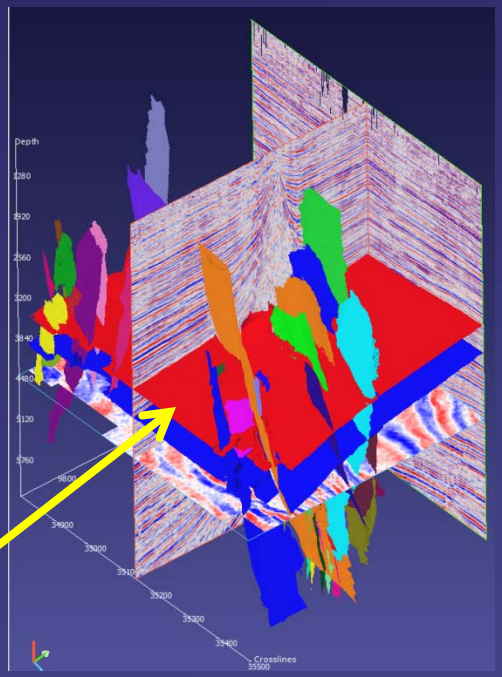
Applications – Structural Interpretation Q/C

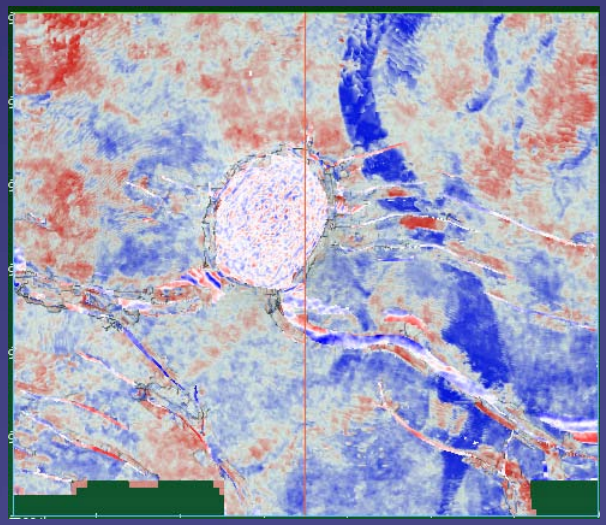
- Inverse transform stratal slices to create two horizons
- Merge two horizons along the miss-tie
- Include in next forward Domain Transform

Amplitude Extraction



New Horizon



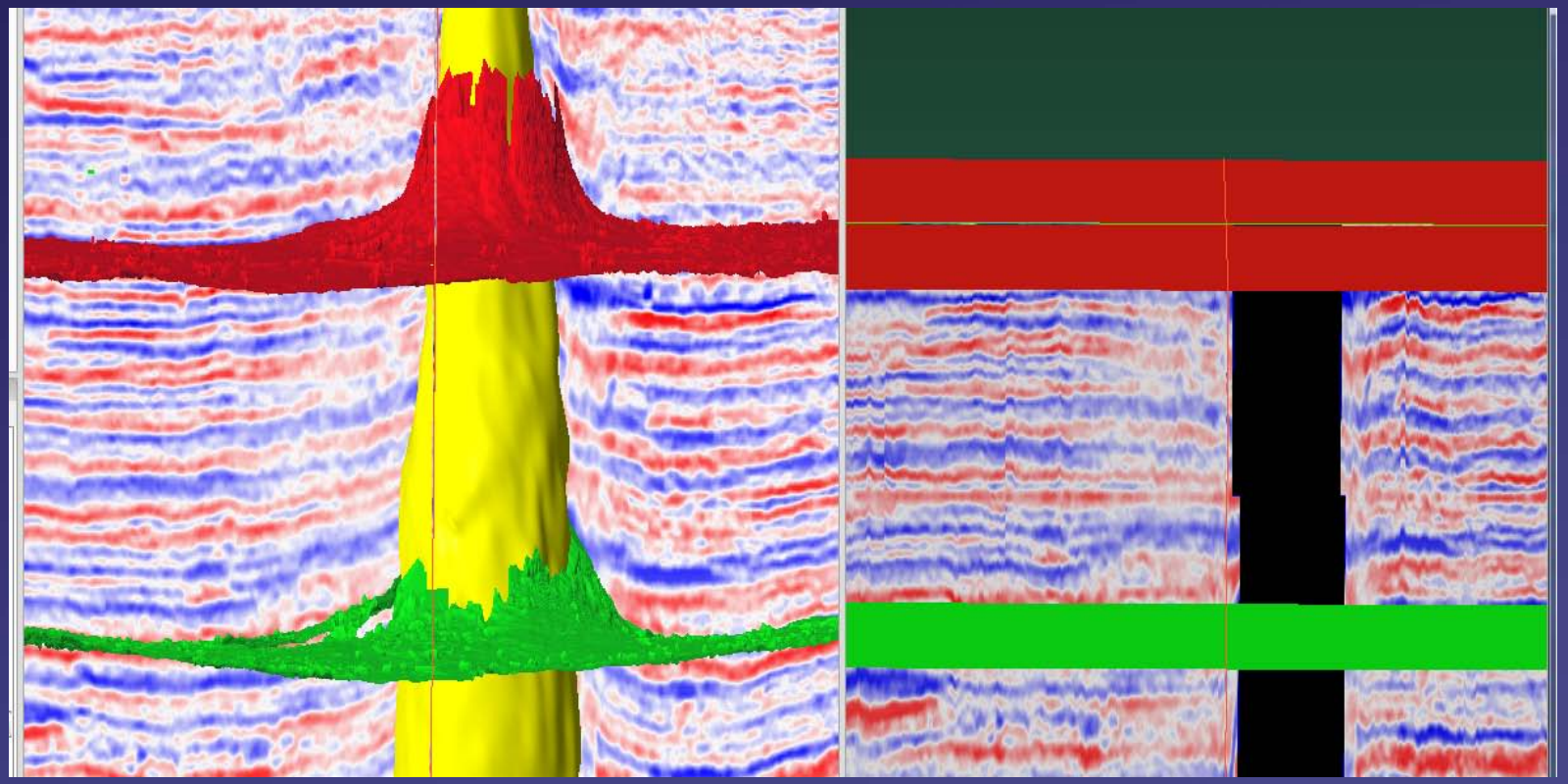


New Stratal Slice 305

Applications – Rapid Infill

- Autotrack and inverse transform “stratal” horizons
- Inverse transform and snap stratal slices

Domain Transform

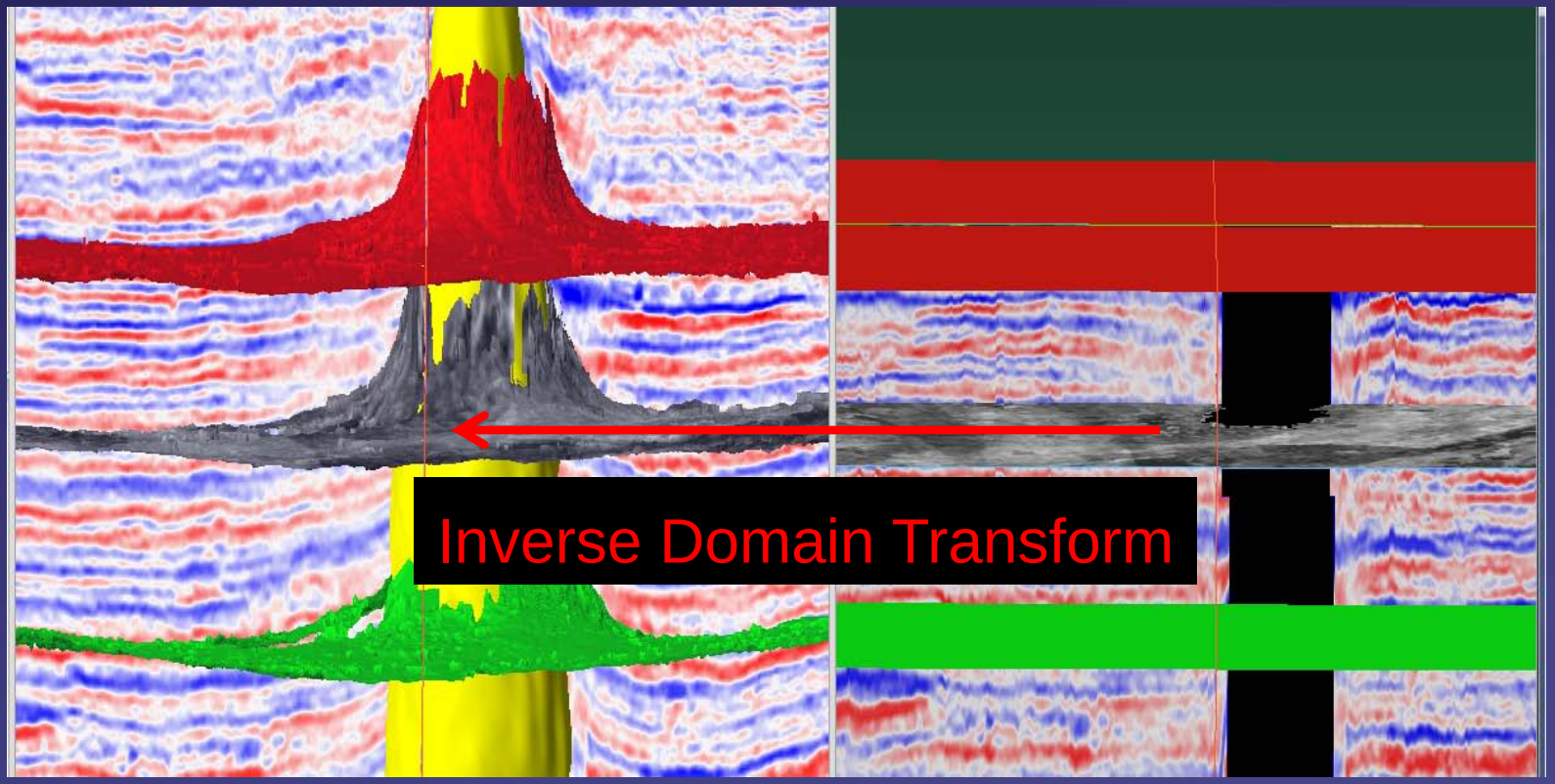


Structural Domain

Stratigraphic Domain

Applications – Rapid Infill

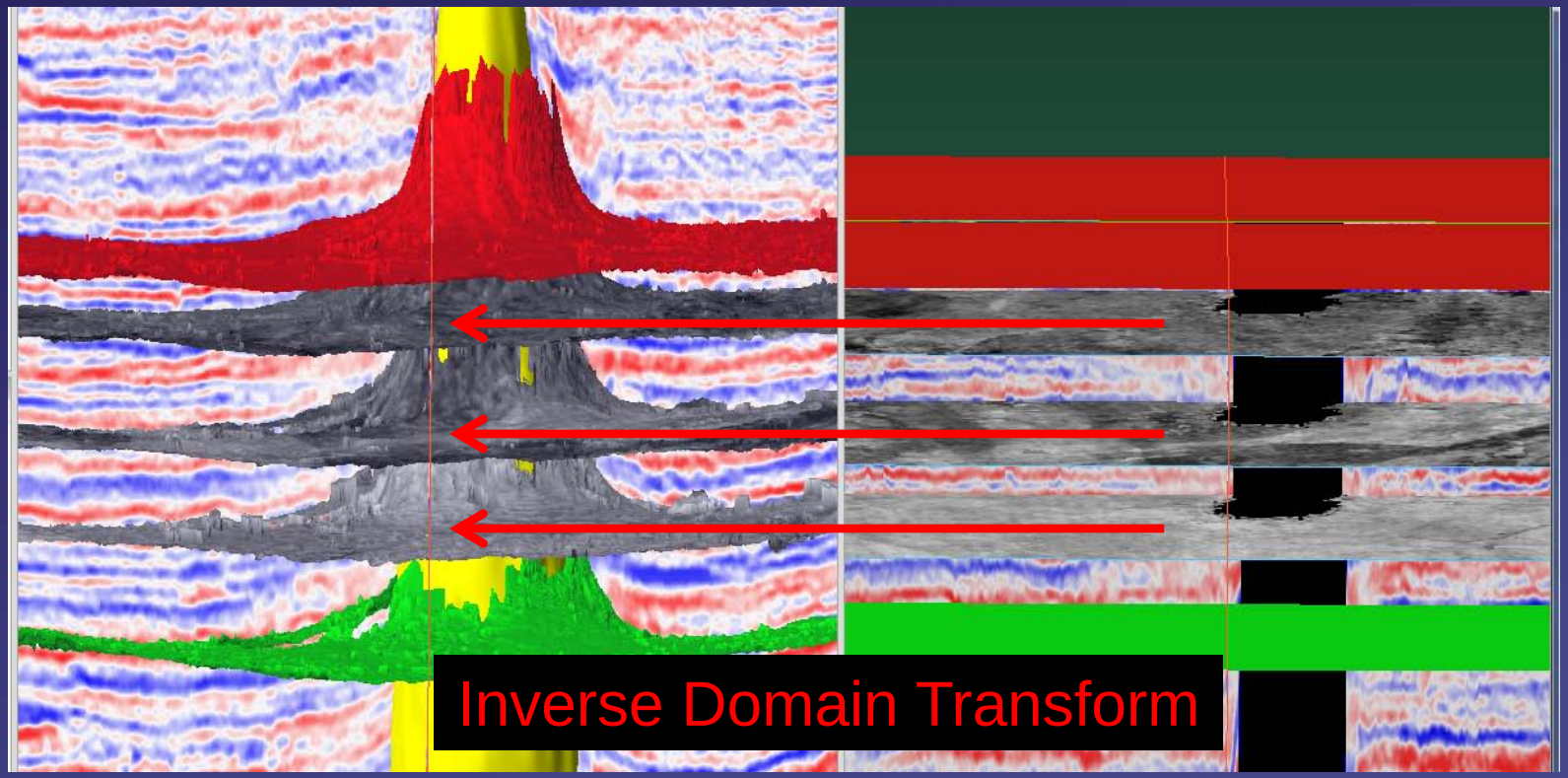
- Autotrack and inverse transform “flat” horizons
- Inverse transform and snap stratal slices



Structural Domain Stratigraphic Domain

Applications – Rapid Infill

- Autotrack and inverse transform “flat” horizons
- Inverse transform and snap stratal slices

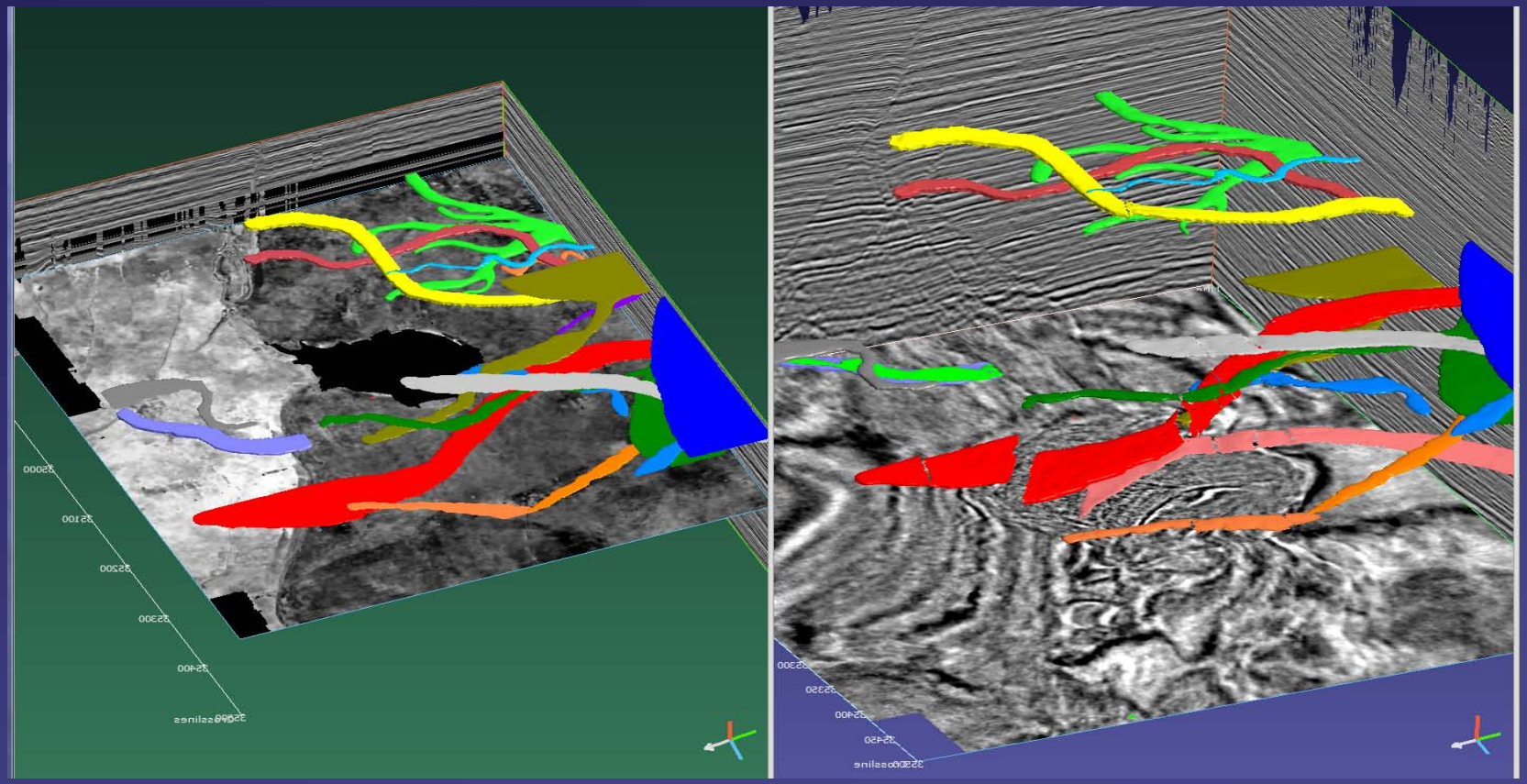


Structural Domain Stratigraphic Domain

Applications – Depo System Boundaries

- Channels:

Inverse Domain Transform

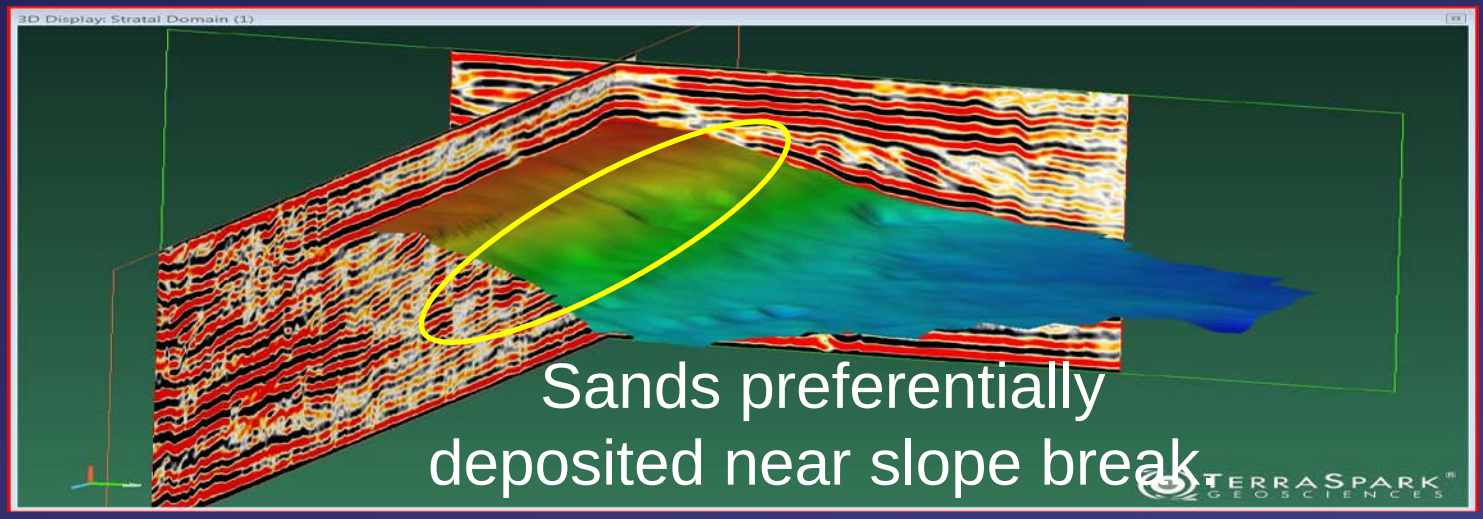


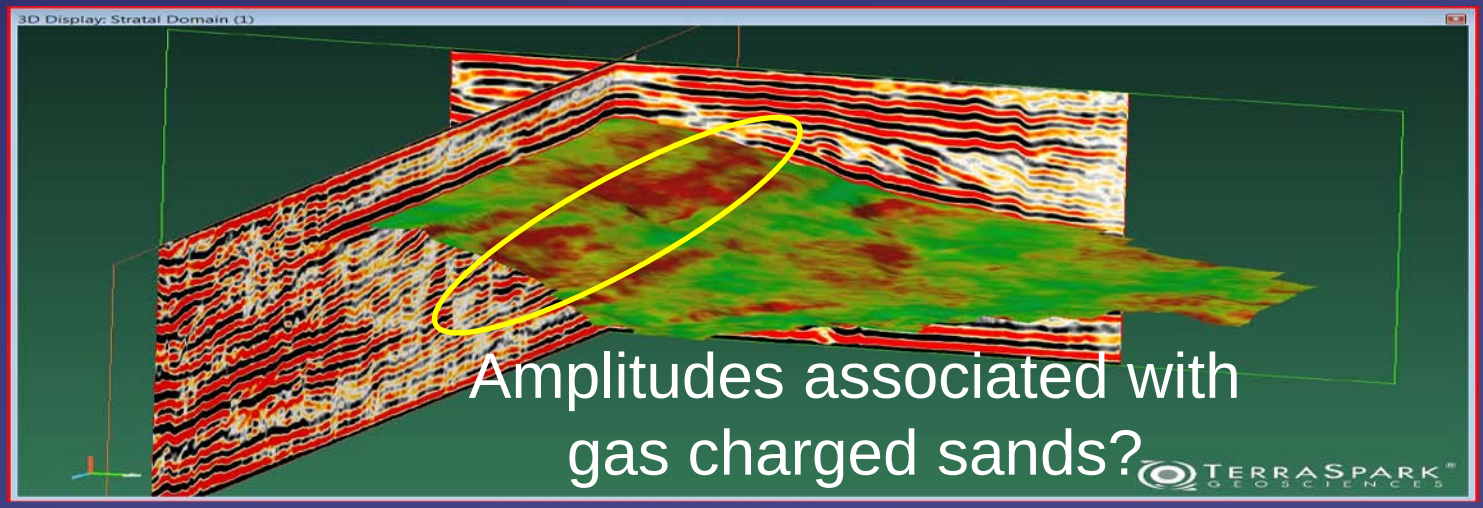
Stratigraphic Domain

Structural Domain

Applications – Other Stratigraphic Features

Stratal Slicing Prograding Fans





Domain Transform – Additional Applications

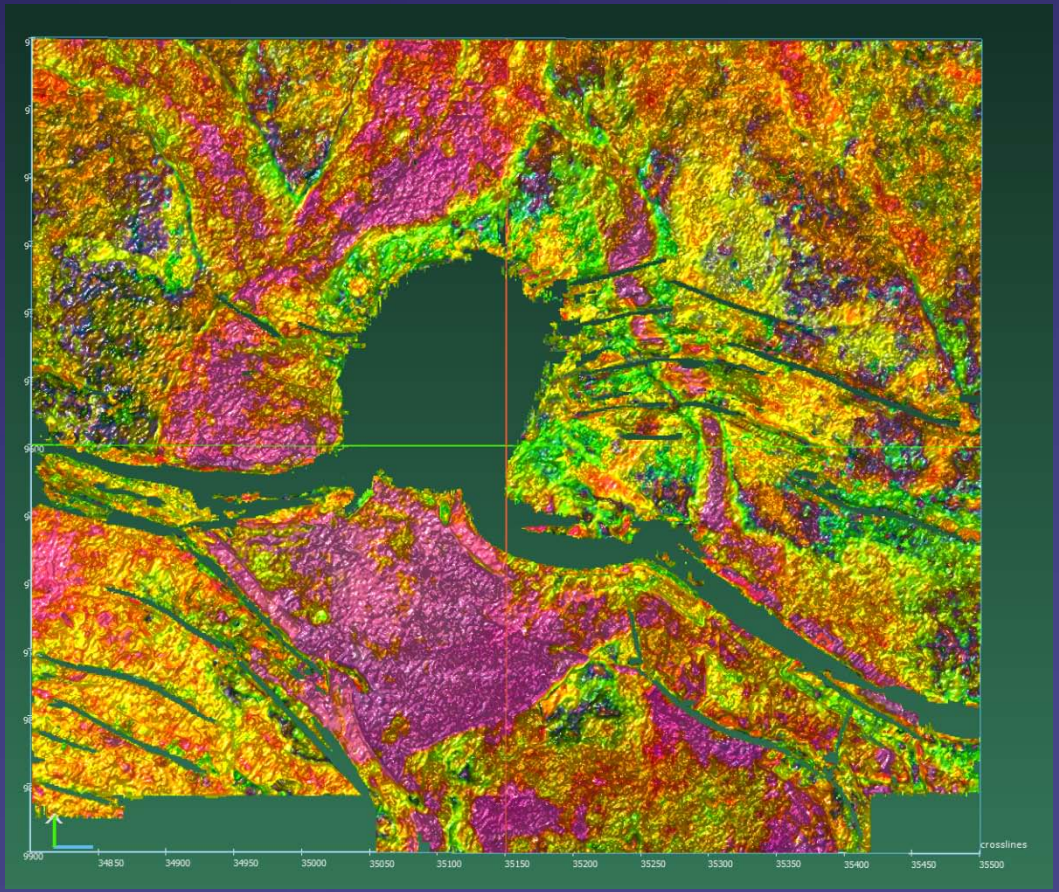
- Stratigraphic/Depo System Interpretation
  - Seismic facies analysis within the morphology of the depo system
- 4-D seismic registration, interpretation, and analysis
- Quantitative information from the Transformation Matrix
  - Fault displacement field
  - Differential compaction/sedimentation rates

Applications – Seismic Facies Analysis

- Seismic Facies Analysis where the full morphology of the depositional system is visible.

A stratal slice displayed in co-rendered attribute stratal volumes:

- Inst. Amplitude (red)
- Inst. Frequency (green)
- Inst. Phase (blue)
- Edge Stack (lighting)



Summary:

- Domain Transformation is a powerful new technique that removes of all structural effects from a 3D volume enabling a number of new interpretation and analysis workflows.

- Structural Applications
  - Q/C of structural interpretation
  - Rapid addition of horizons to the interpretation
  - Horizon verification by matching stratigraphic/depositional features
  - Extract 3D fault displacement field from transform

Summary:

- Stratigraphic Applications
  - Rapidly explore a volume for stratigraphic/depositional features
  - Interpret the boundaries of depositional systems
  - Image and interpret systems/stratigraphic features from a paleo depositional view
  - Perform Seismic facies analysis where you can see the morphology of the depo systems
- 4D seismic volume sample-sample registration

Acknowledgements

The following companies have supported the development of this technology through the GIVC Consortium since 2003:

- Anadarko
- BHP Billiton
- BP
- Chevron
- ConocoPhillips
- ExxonMobil
- Repsol
- Shell
- Stone Energy
- Paradigm

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