# Advanced Seismic Interpretation and Reservoir Characterization
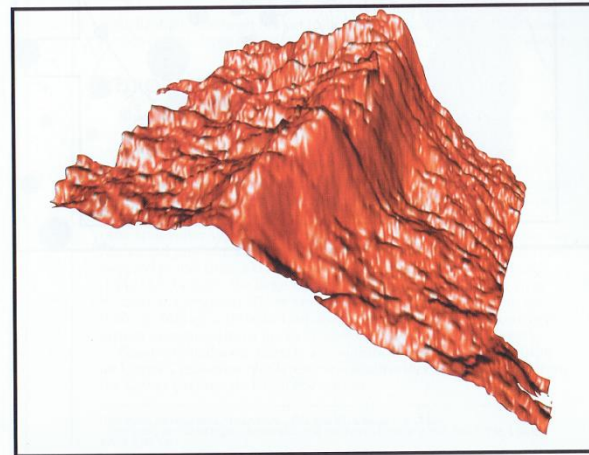
## H. Roice Nelson, Jr.

# Day 3 Session 5

- Reservoir characterization and modeling
  - Lithology prediction
  - Fluid analysis
  - Reservoir geobodies
  - Porosity evaluation
  - Permeability prediction
  - Net Pay
- Advanced Interpretation
- Seismic petrophysics
- Data integration
- Characterization of carbonate reservoirs
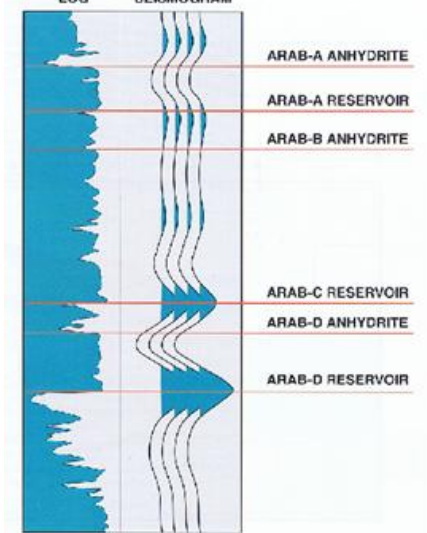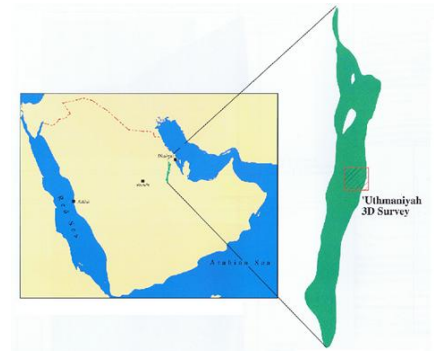
# Reservoir Characterization
## Ghawar Field, Saudi Arabia



ARAB-A ANHYDRITE
ARAB-A RESERVOIR
ARAB-B ANHYDRITE

ARAB-C RESERVOIR
ARAB-D ANHYDRITE
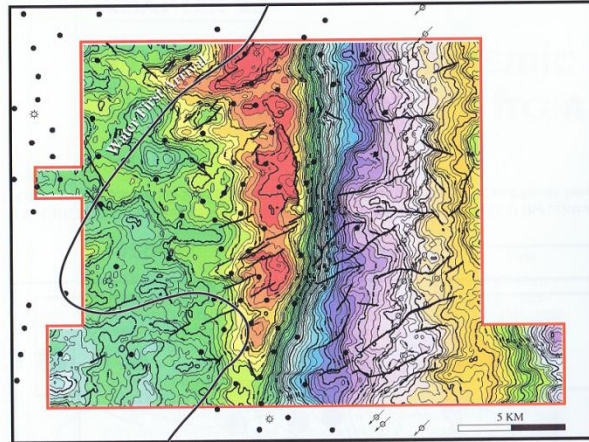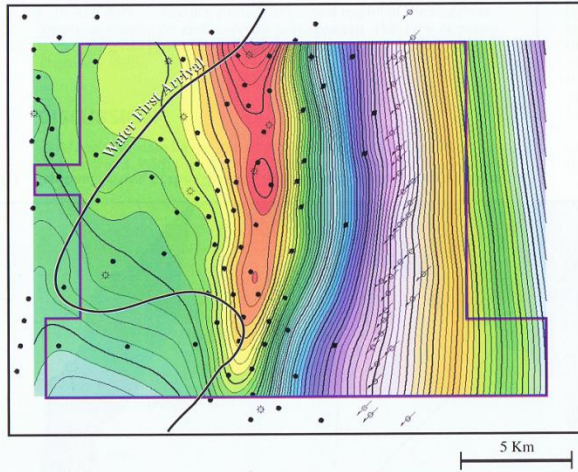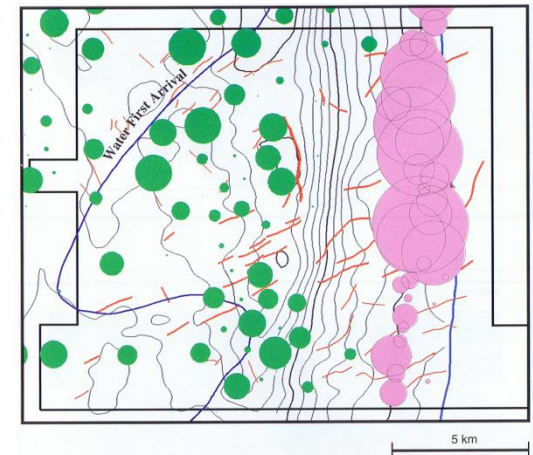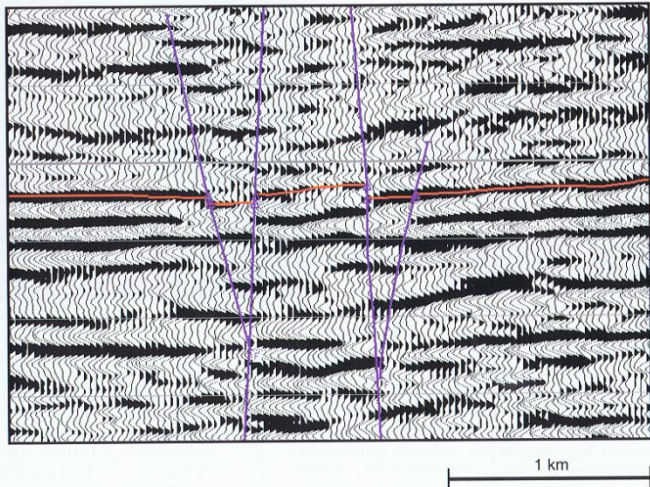
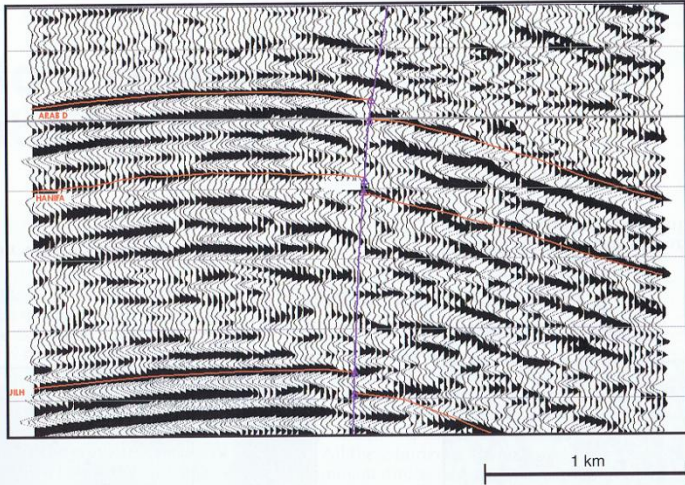ARAB-D RESERVOIR

Log Correlation Structure
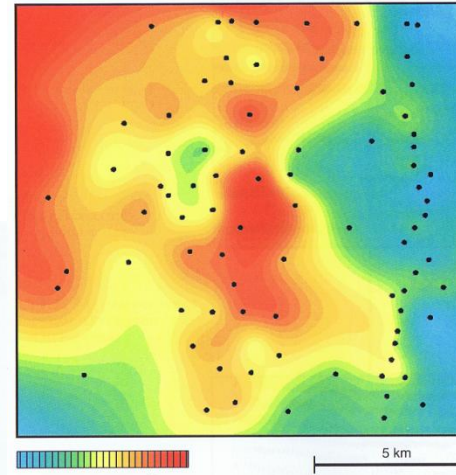
3-D Seismic Structure

David W. Alexander in **Application of 3-D Seismic Data to Exploration and Production**, pages 207-210, data from Aramco.
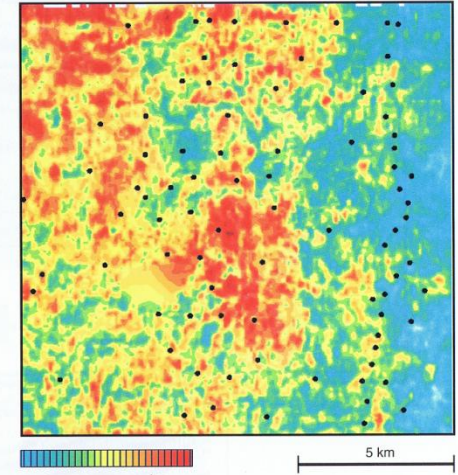
# Reservoir Characterization
## Ghawar Field, Saudi Arabia



Cumulative Production/Injection

5 km

1 km

ARAB-D

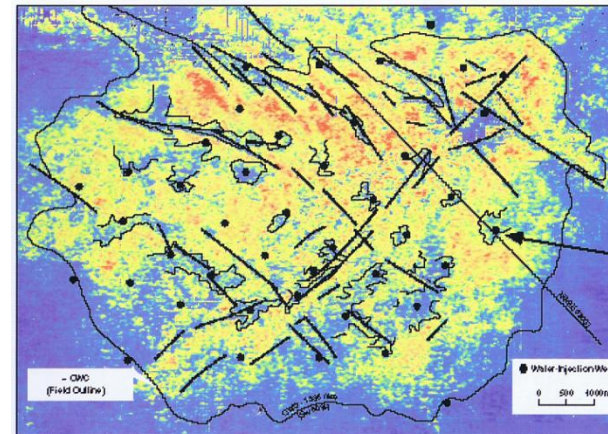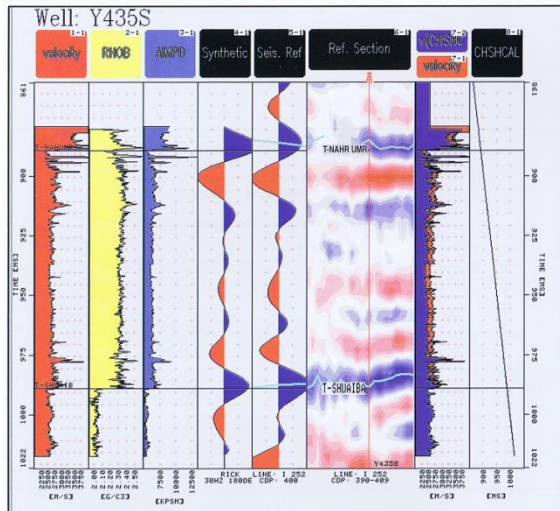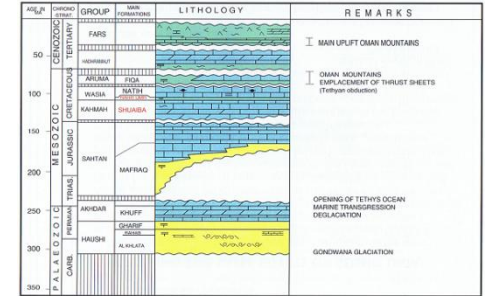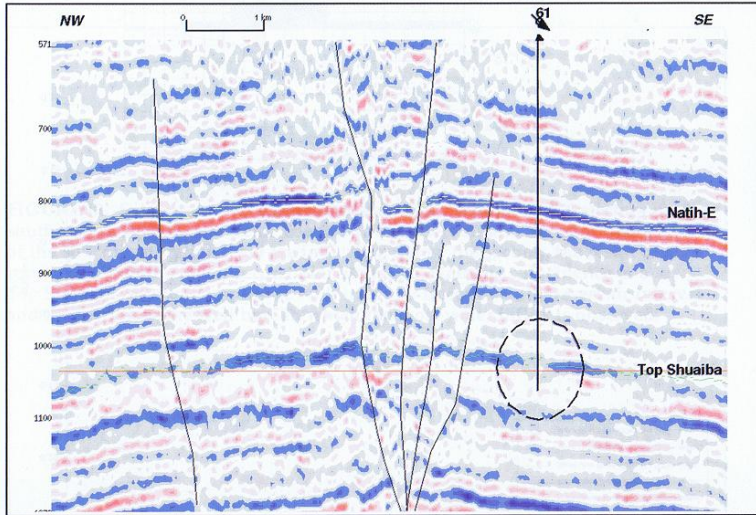1 km



Log Porosity Thickness

INCREASING

5 km



3-D Porosity Thickness

INCREASING

5 km

David W. Alexander in **Application of 3-D Seismic Data to Exploration and Production**, pages 207-210, data from Aramco.

# 3-D to Increase Ultimate Recovery
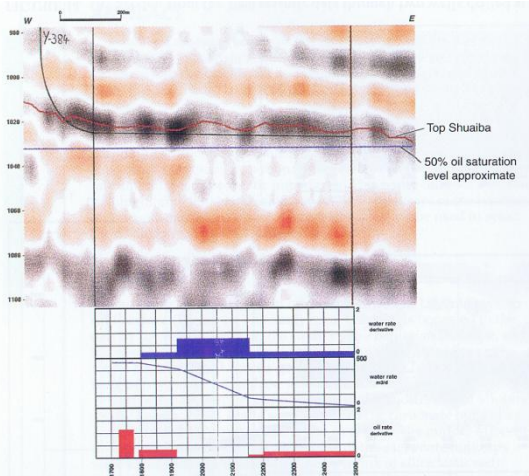## Yibal Shuaiba Reservoir, Oman









Low Amplitude
Around Injectors

Seismic Amplitudes

Dieter K. Skolaud in **Application of 3-D Seismic Data to Exploration and Production**, pages 214-217, data from PDO and Shell on Yibal Shuaiba Reservoir, Oman

3-D Seismic Interpretation - with an emphasis on carbonate terrains
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# 3-D to Increase Ultimate Recovery
## Yibal Shuaiba Reservoir, Oman



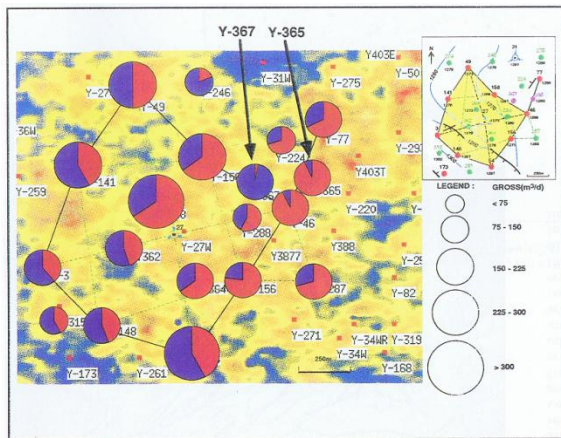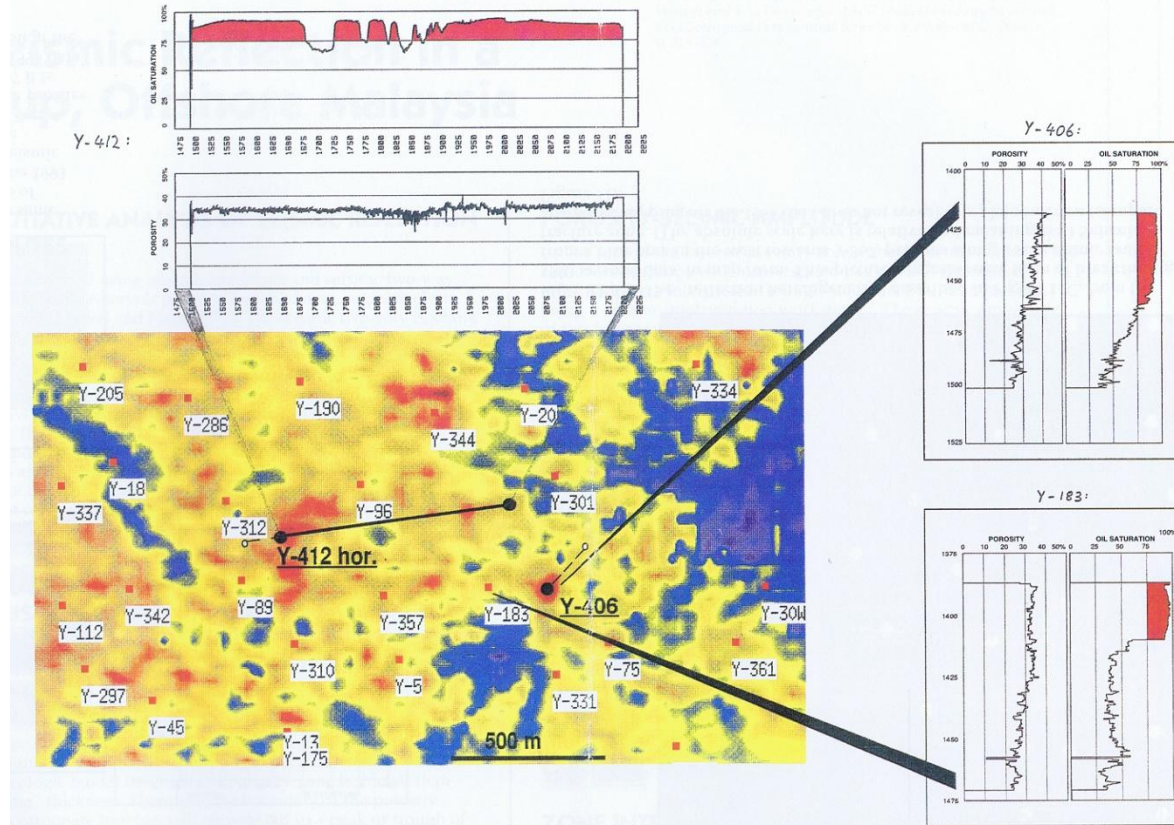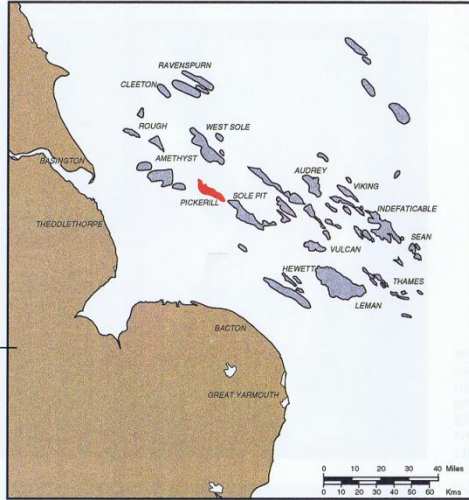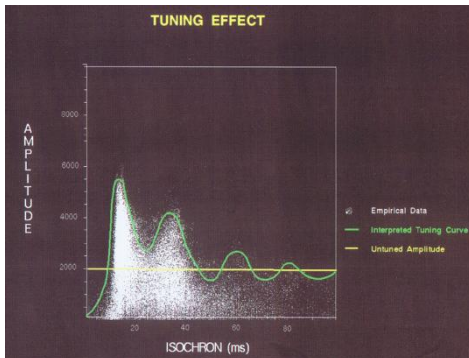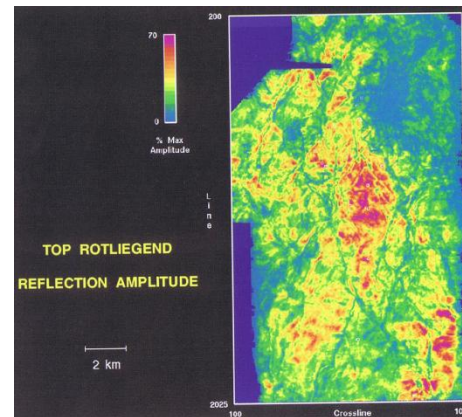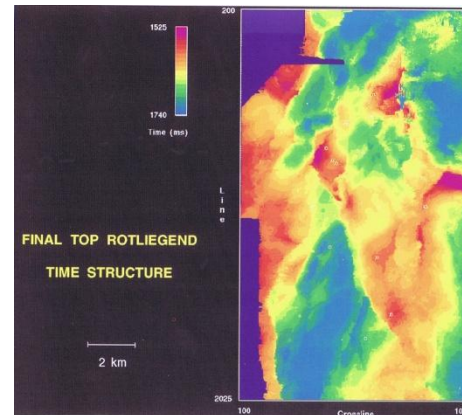Yibal 384 Horizontal Well



Bubble Production Data

Dieter K. Skolaud in **Application of 3-D Seismic Data to Exploration and Production**, pages 214-217, data from PDO and Shell on Yibal Shuaiba Reservoir, Oman

3-D Seismic Interpretation - with an emphasis on carbonate terrains
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# Reservoir Characterization Pickerell Field, North Sea









FINAL TOP ROTLIEGEND TIME STRUCTURE

ORIGINAL REFLECTION AMPLITUDE

PHASE CORRECTED REFLECTION AMPLITUDE

TOP ROTLIEGEND REFLECTION AMPLITUDE

TUNING EFFECT

Amplitude Top Rotliegaend vs. Isochron to Top Anhydride
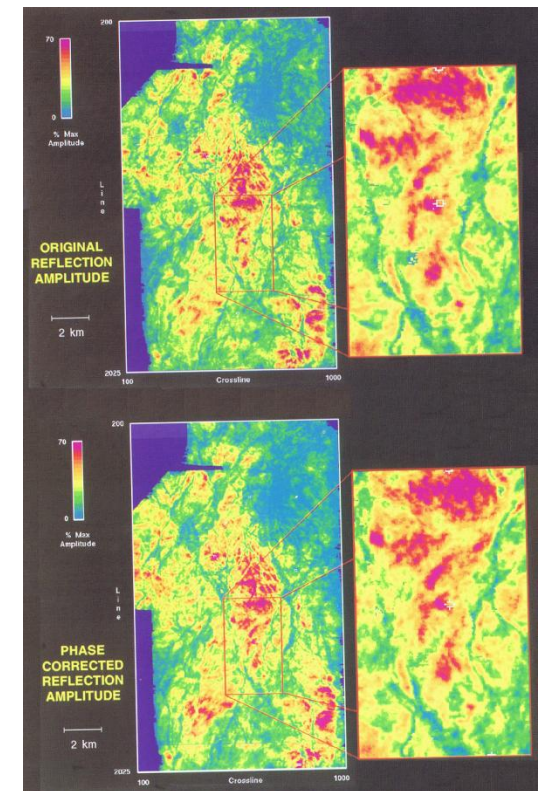
Geoffrey A. Dorn, et. al. in **Application of 3-D Seismic Data to Exploration and Production**, pages 11, 13-16, 19-21.

3-D Seismic Interpretation - with an emphasis on carbonate terrains
Copyright © 2011 Walden 3-D, Inc.

# Reservoir Characterization Pickerell Field, North Sea



Geoffrey A. Dorn, et. al. in **Application of 3-D Seismic Data to Exploration and Production**, pages 11, 13-16, 19-21.

# Reservoir Modeling

- Reservoir characterization and modeling
  - Lithology prediction
  - Fluid analysis
  - Reservoir geobodies
  - Porosity evaluation
  - Permeability prediction
  - Net Pay
- Advanced Interpretation
- Seismic petrophysics
- Data integration
- Characterization of carbonate reservoirs

# Lithology Prediction from Seismic

## A Specific Example from a Fred Hilterman Formula

In the equation:

$$RC(\Theta) = NI_{vel}/\cos^2\Theta + NI_{den} - (2\Delta\mu/\rho\dot\alpha^2)\sin 2\,\Theta$$

$\mu$ = rigidity,
which shows up for $\Theta = 15^\circ\text{-}30^\circ$
and booms for $\Theta = 40^\circ\text{-}50^\circ$.

This has significant implications from a sequence stratigraphy view.

3-D Seismic Interpretation - with an emphasis on carbonate terrains
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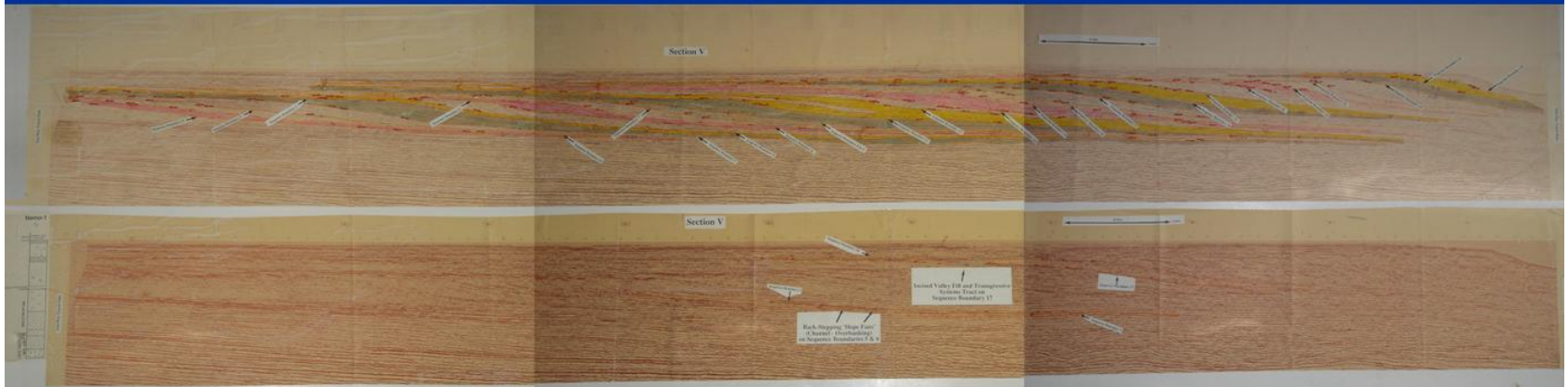
# Lithology Prediction from Seismic

Depositional Weaving insures Sediments on Either Side of an Unconformity have High Rigidity. At Far Offsets, strong reflections come from the Unconformity Surface.

3-D Seismic Interpretation - with an emphasis on carbonate terrains
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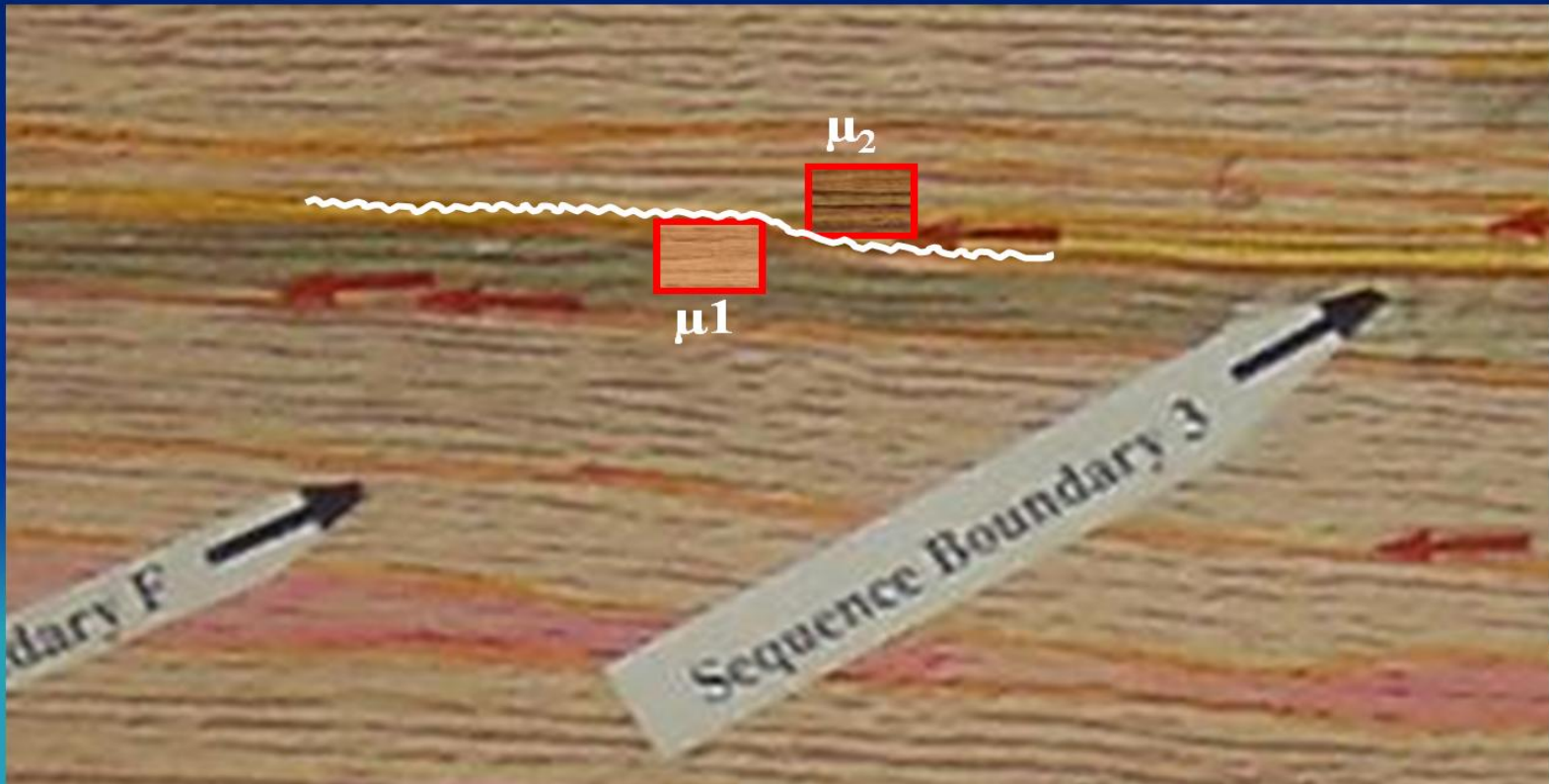
# Lithology Prediction from Seismic

Pete Vail taught seismic reflections come from sequence boundaries. Fred's formula defines why. Depositional weaving and rigidity occurs at sequence boundaries where there is no erosion.

3-D Seismic Interpretation - with an emphasis on carbonate terrains
Copyright © 2011 Walden 3-D, Inc.
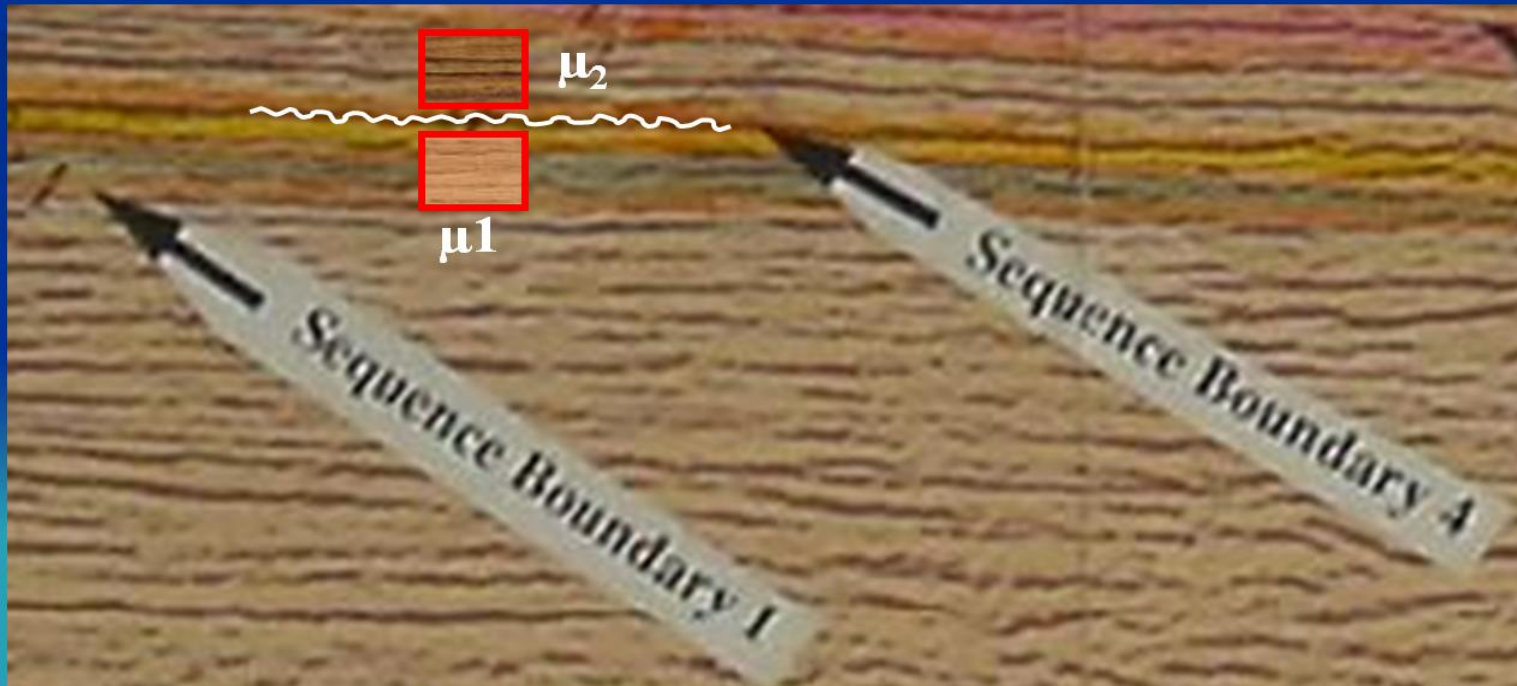
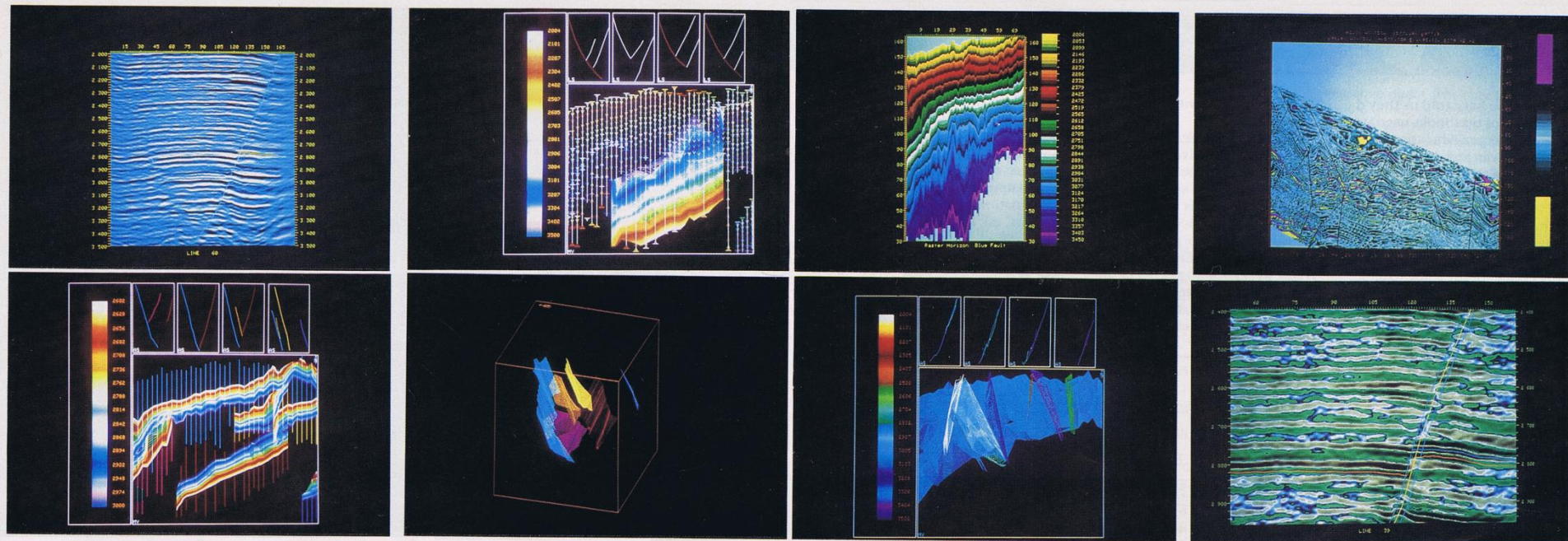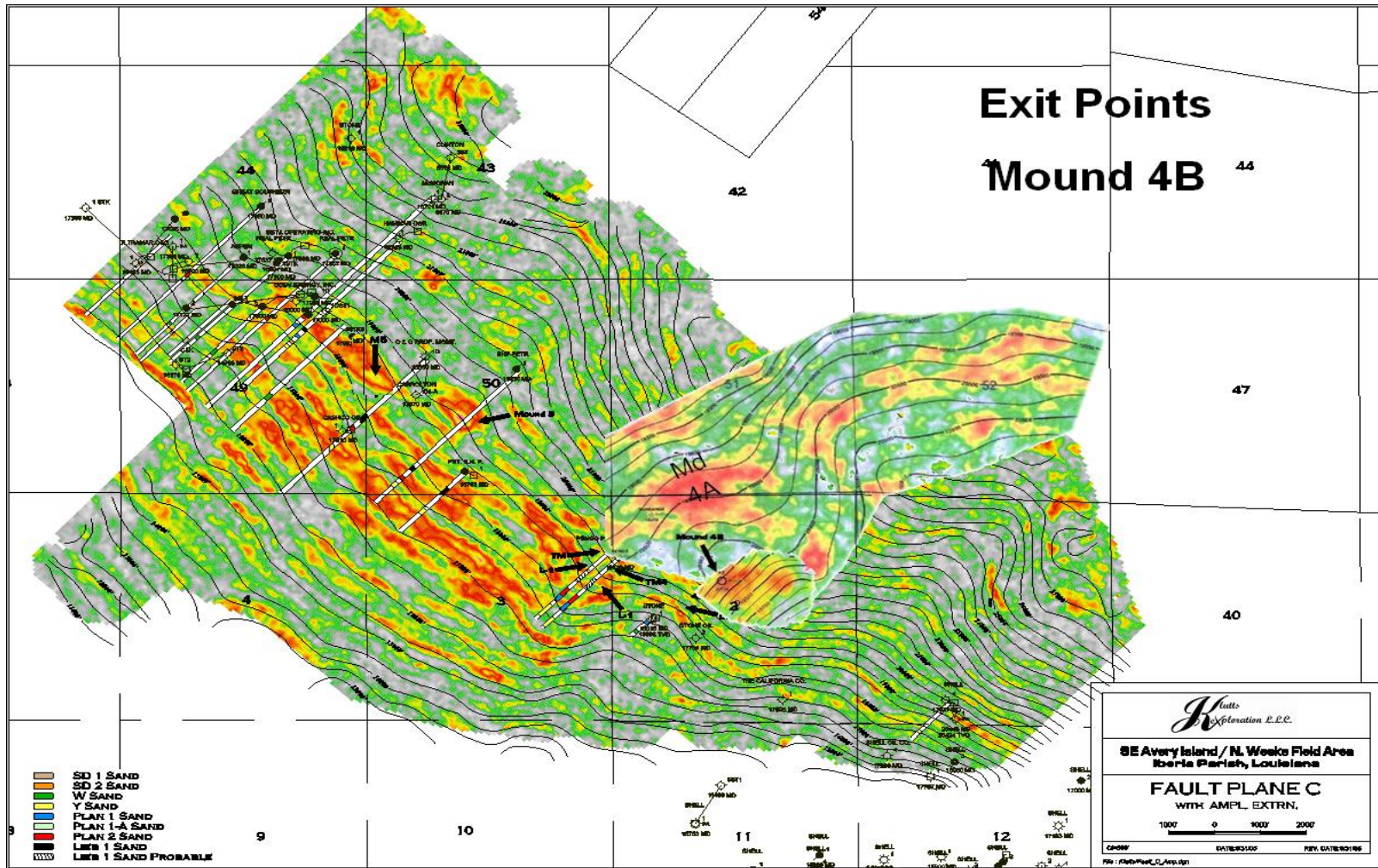# Fault Plane Amplitudes
## Offshore Louisiana



From left to right, each row: Line 60, Fig. 1; first fault plane, Fig. 3; fault plane map, Fig. 4; fault planes perspective, Fig. 5; blue fault map, Fig. 6; transverse faults, Fig. 7; FMAP transverse faults, Fig. 8; Line 39, Fig. 9.
70 Oil & Gas Journal, Apr 6, 1987

C.J. Nick & H.R. Nelson, Jr., Interactive Fault Interpretation and Seismic Amplitudes, **Oil & Gas Journal**, Apr 6, 1987.
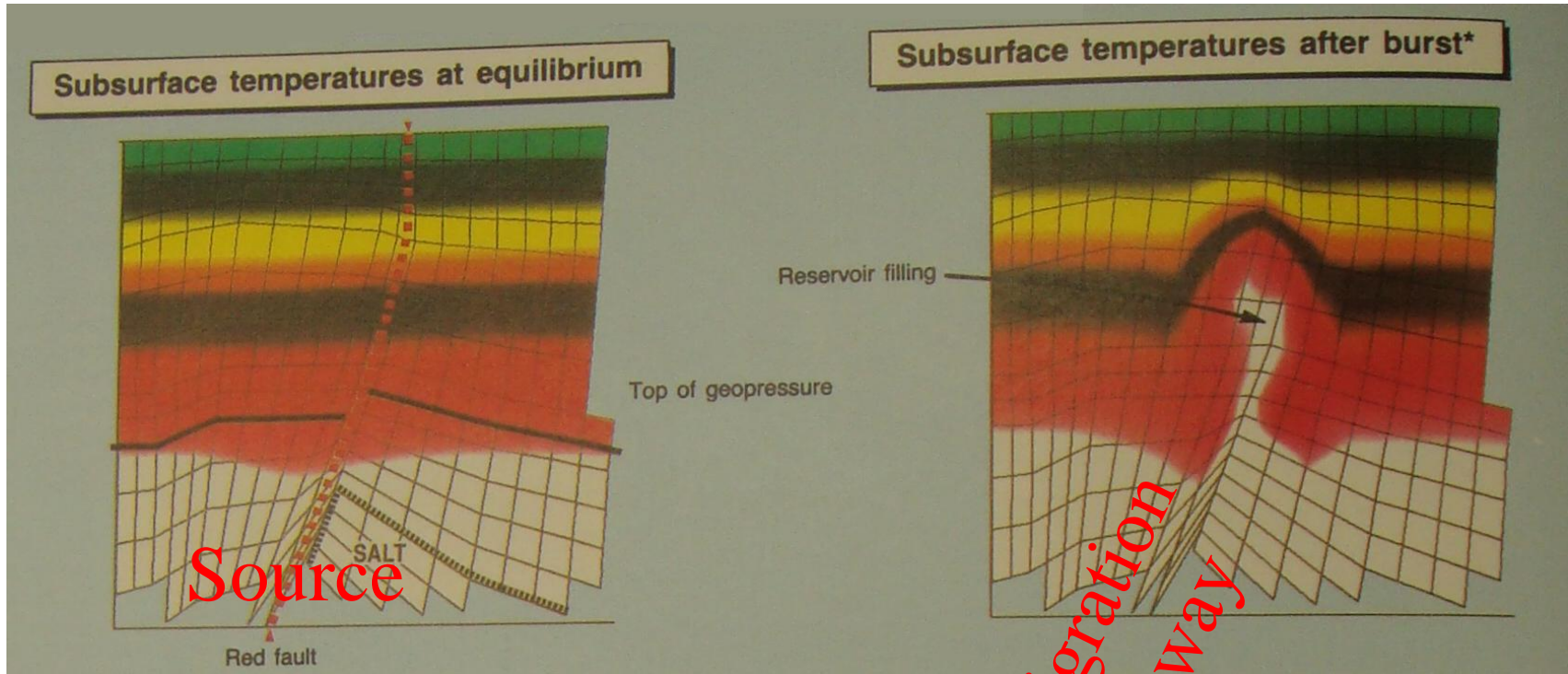
# Fluid Migration
## South Louisiana



Example from Joe Klutts, Personal Communication.
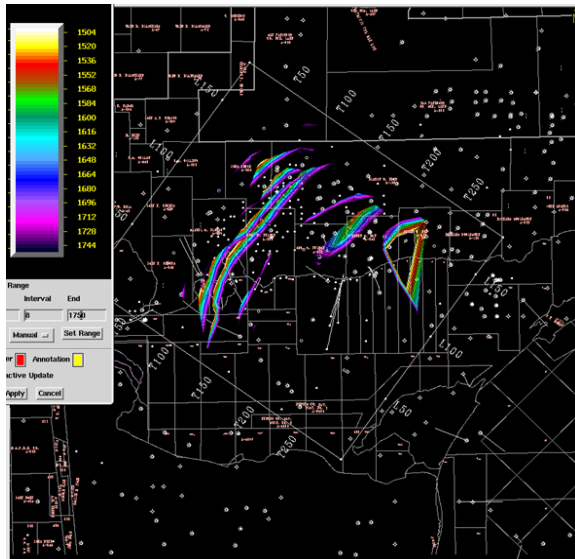
# Fluid Pulses
## EI-330 Offshore Louisiana

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# Location to Possibly Drain Deeper Pay
## South Texas

3-D Seismic Interpretation - with an emphasis on carbonate terrains
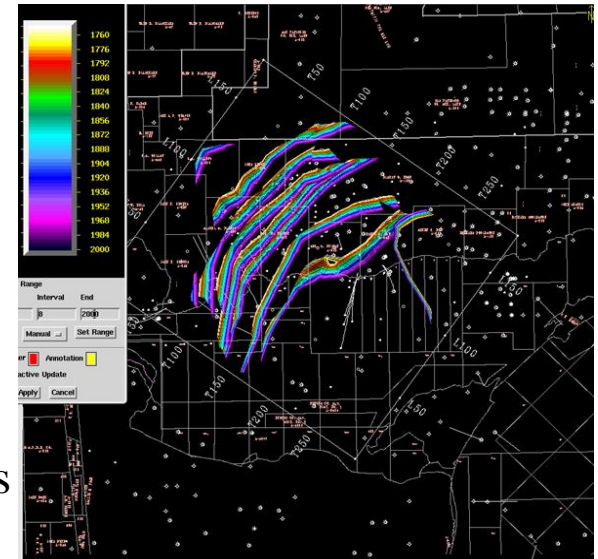Copyright © 2011 Walden 3-D, Inc.
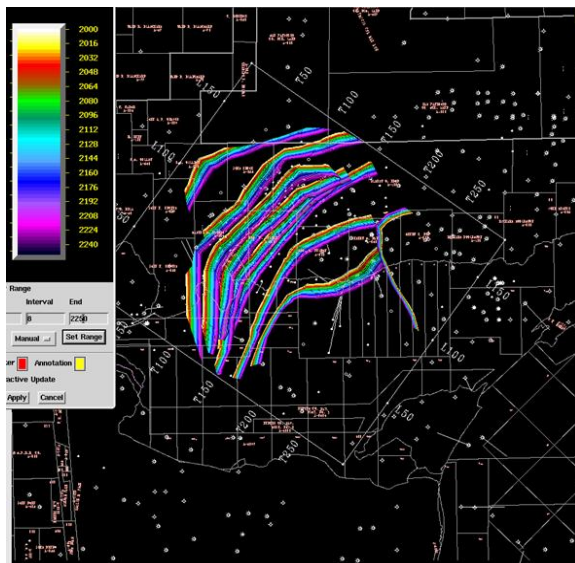
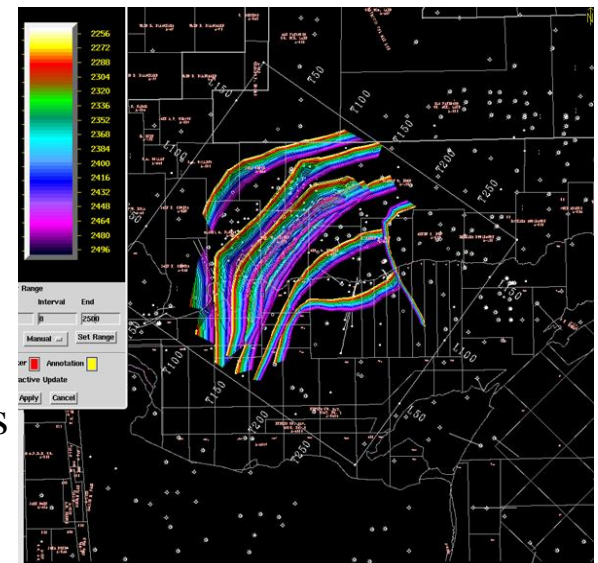# Fault Planes Possibly Draining Deeper Pay
## South Texas



1500-1750 ms
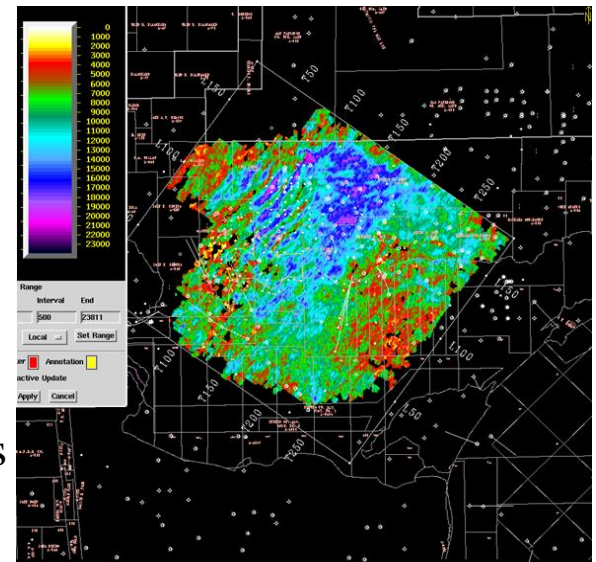
1750-2000 ms

2000-2250 ms

2250-2500 ms
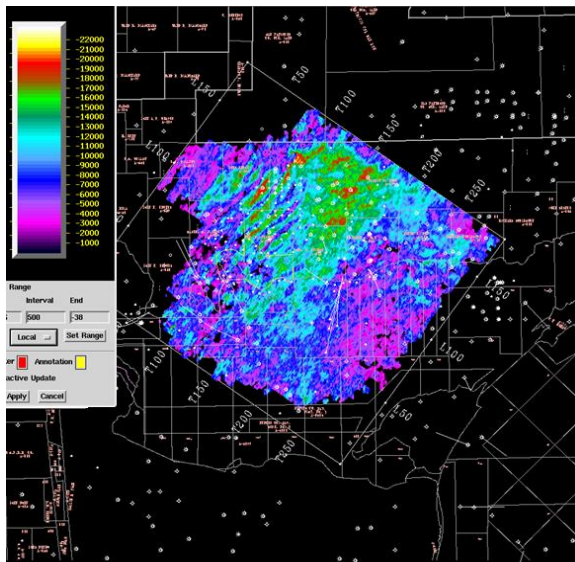
# Key Horizons, Possibly Deeper Pay
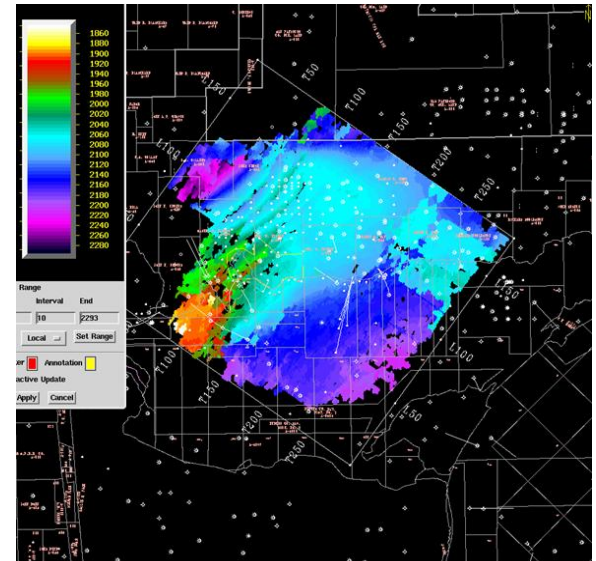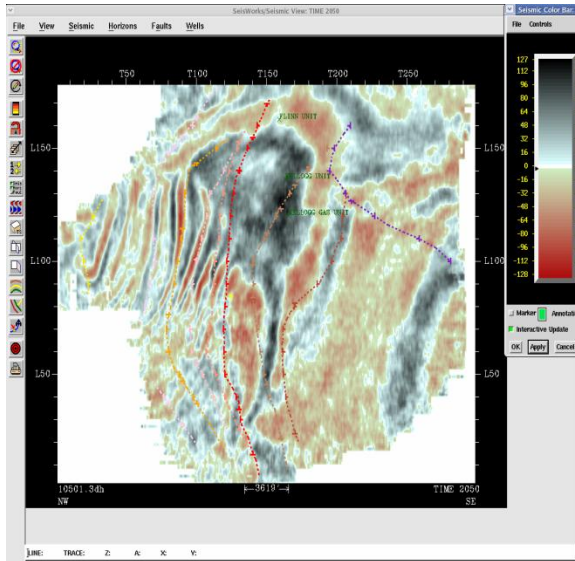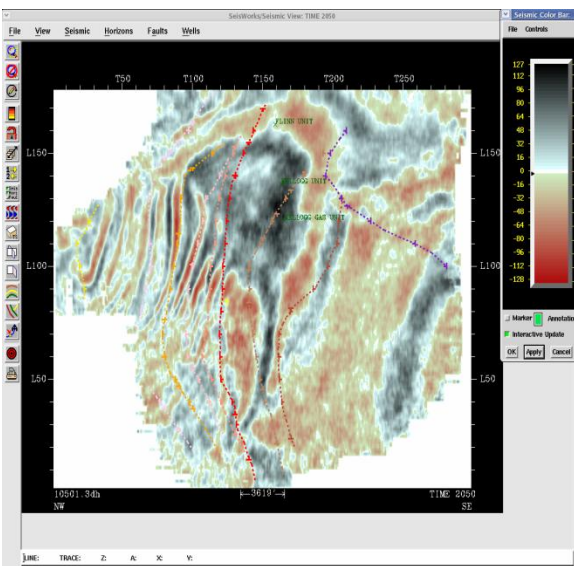## South Texas



Initial Picking Grid



ZAP Horizon Grid



Seismic Amplitudes



Cepstrum Amplitudes

# Flatspot at Deeper Pay



Time-Slice at Flatspot
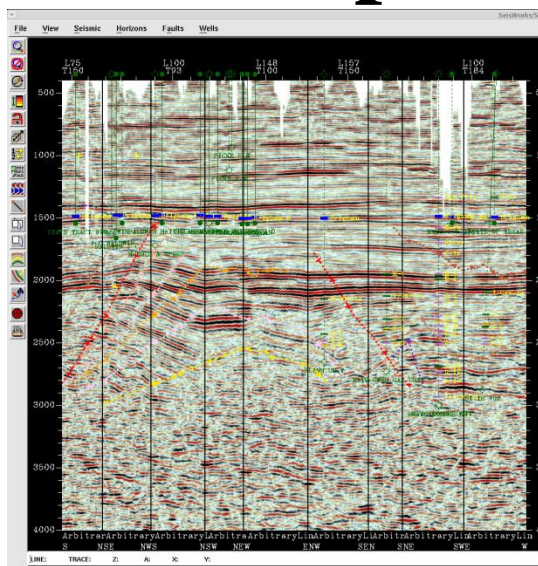


Sections Around Flatspot Boundary
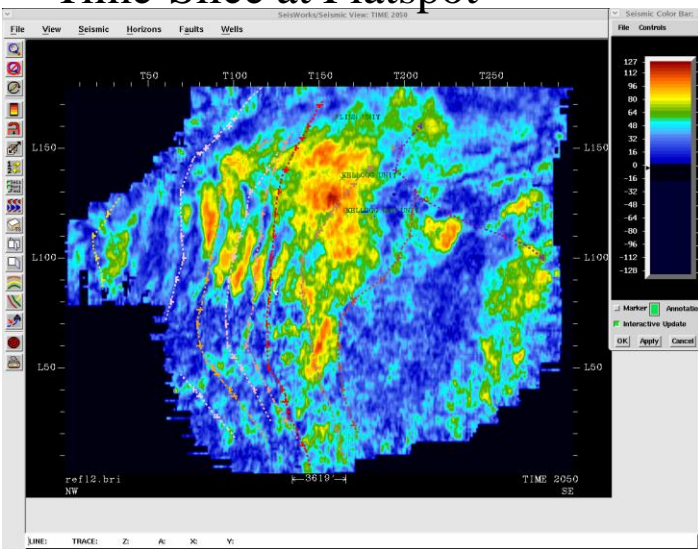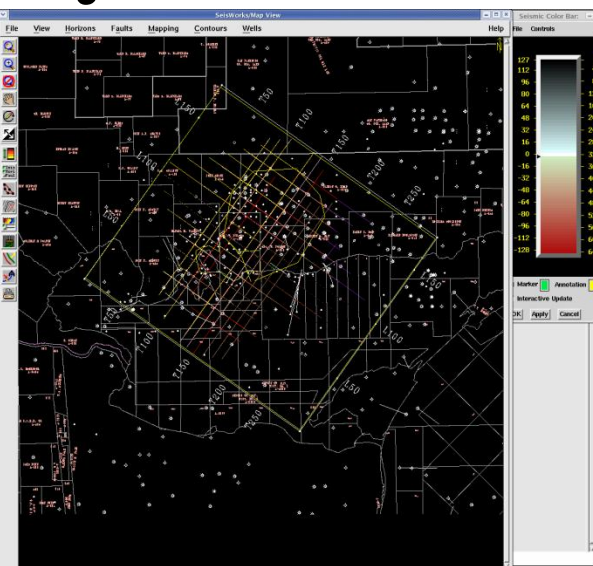


Ceptstrum
Time-Slice at
Flatspot

Ceptstrum
Time-Slice at
Top of Amplitude
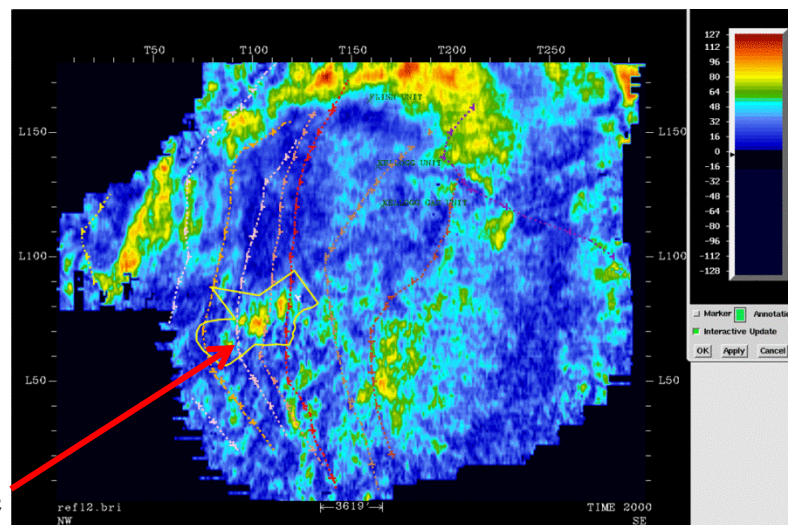
# Wavelet Genotype to Reservoir Geobodies
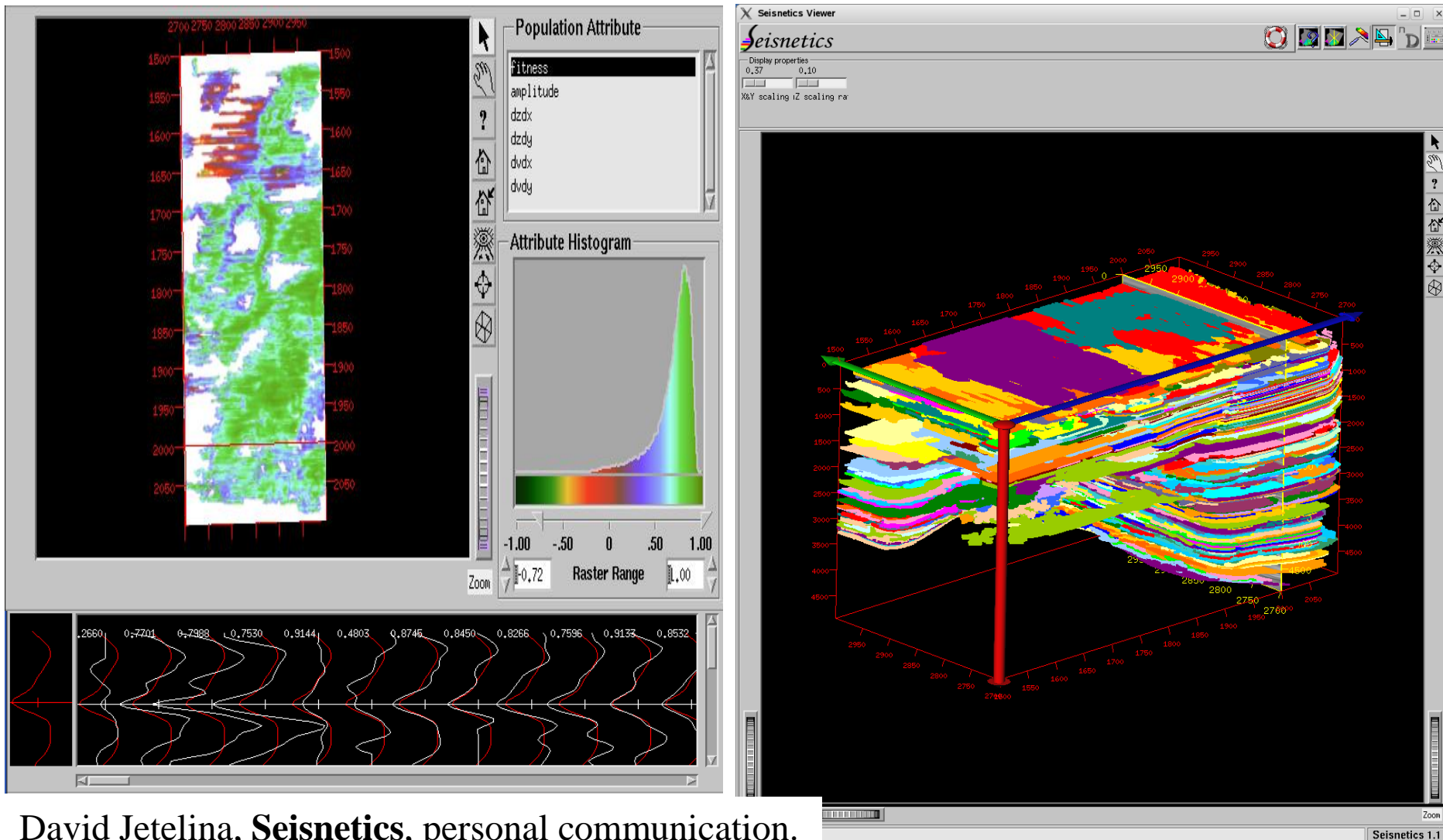


David Jetelina, **Seisnetics**, personal communication.

# Common Contour Binning (*CCB) Example



Jan Gabe van der Weide and Andries Wever ideas, *Intellectual Property of **Wintershall Noordzee BV**, presentation from Open-dTect, www.dgb-group.com.

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# Interpret the Top Reservoir
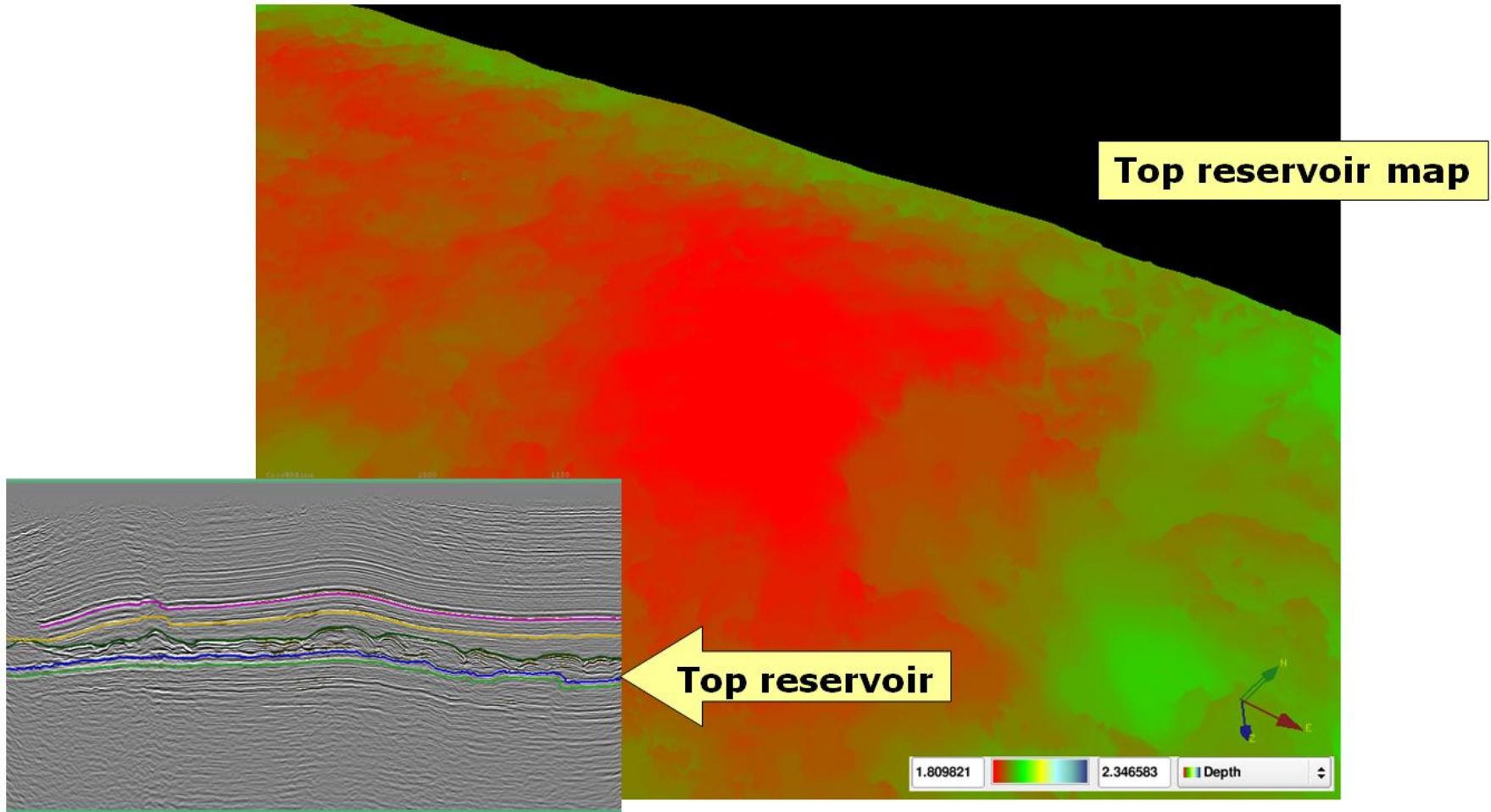


Top reservoir map

Top reservoir

Jan Gabe van der Weide and Andries Wever ideas, *Intellectual Property of
**Wintershall Noordzee BV**, presentation from Open-dTect, www.dgb-group.com.

# Extract Amplitudes at Top Reservoir Horizon



Jan Gabe van der Weide and Andries Wever ideas, *Intellectual Property of **Wintershall Noordzee BV**, presentation from Open-dTect, www.dgb-group.com.

# Extract Seismic Traces Along Contours



Jan Gabe van der Weide and Andries Wever ideas, *Intellectual Property of **Wintershall Noordzee BV**, presentation from Open-dTect, www.dgb-group.com.

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# Redistribute Stacked Traces Along Contour Lines



Jan Gabe van der Weide and Andries Wever ideas, *Intellectual Property of **Wintershall Noordzee BV**, presentation from Open-dTect, www.dgb-group.com.

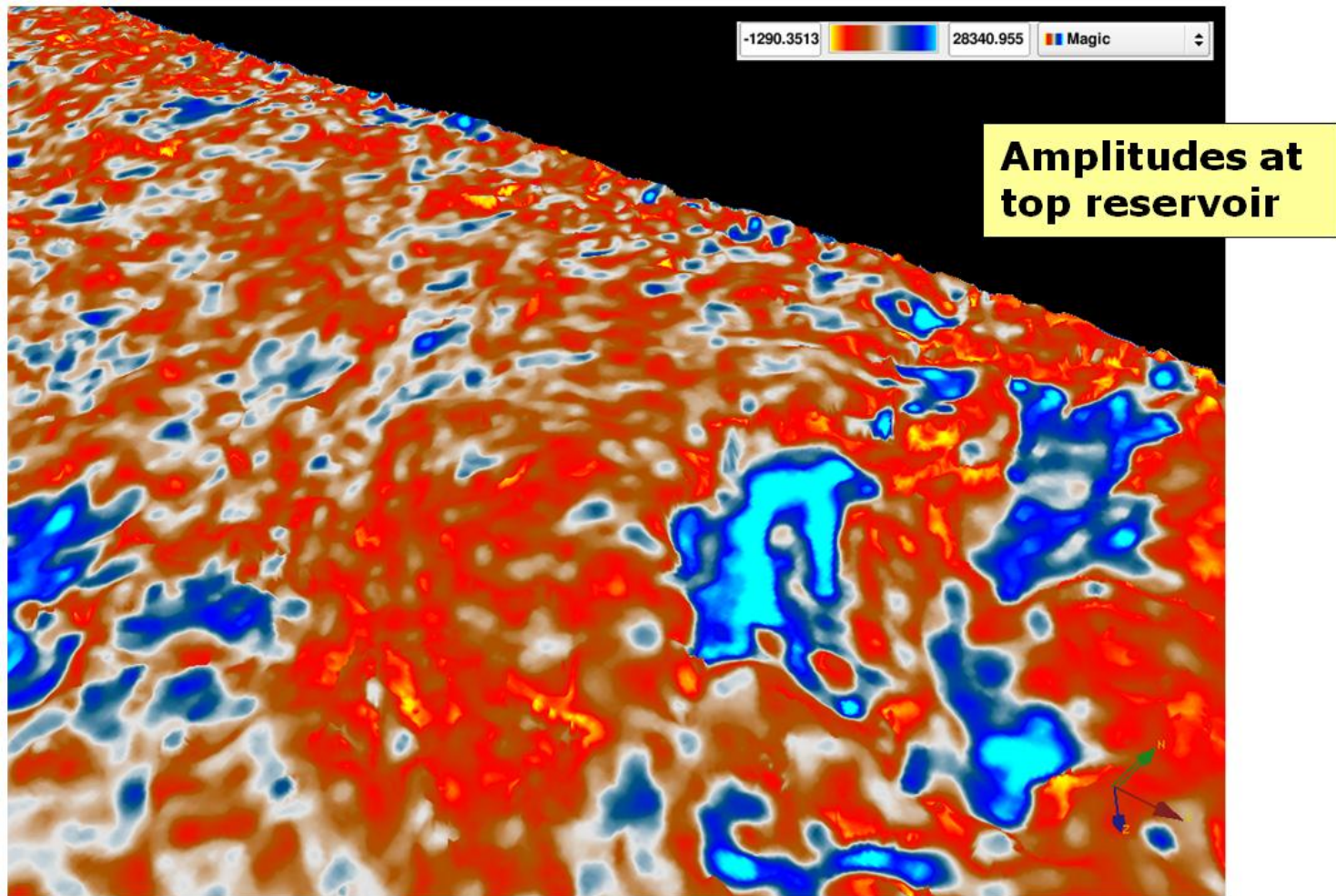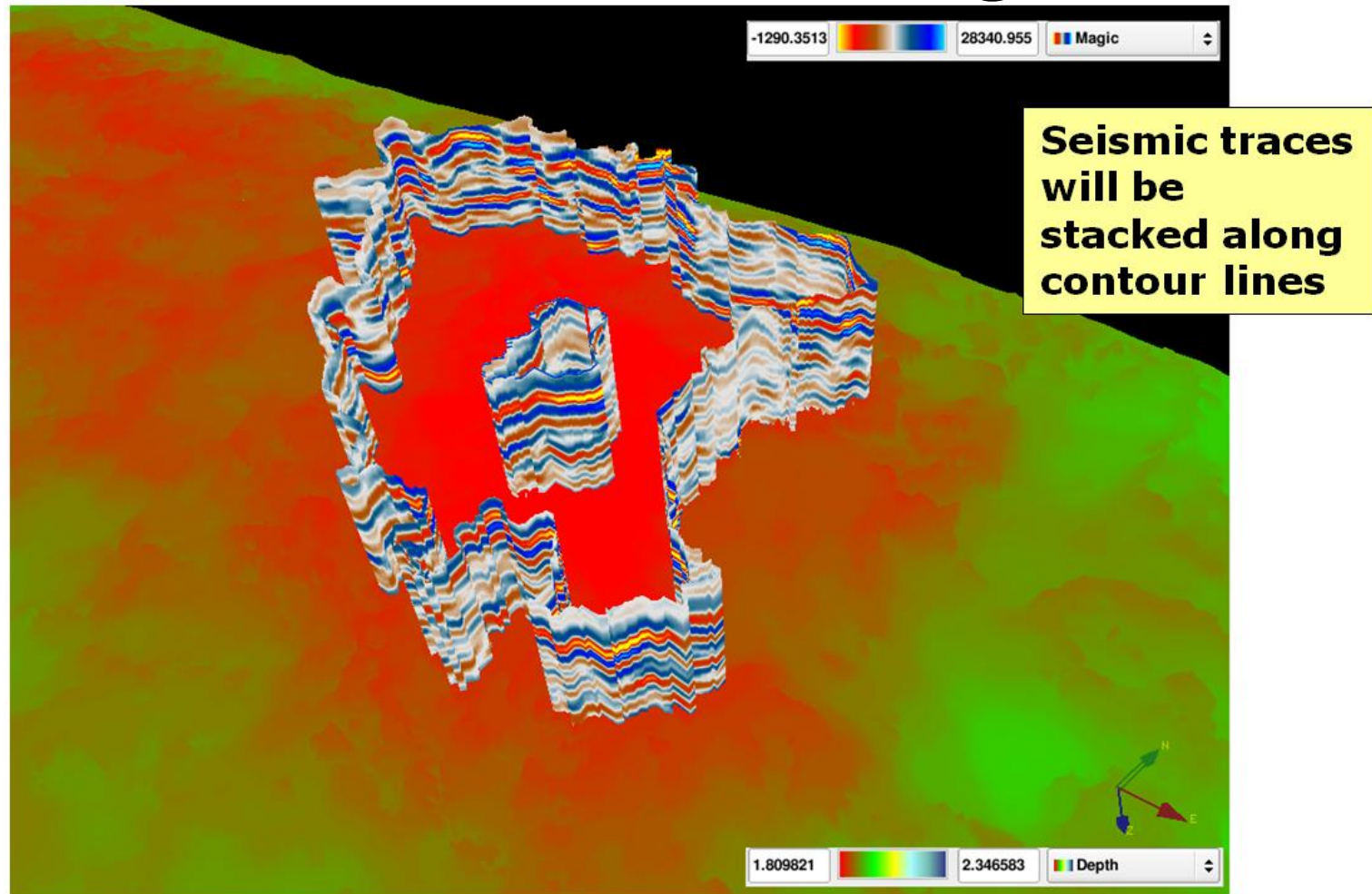# Re-extract Amplitudes After CCP Stacking



Jan Gabe van der Weide and Andries Wever ideas, *Intellectual Property of **Wintershall Noordzee BV**, presentation from Open-dTect, www.dgb-group.com.

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# New Extracted Amplitude Map



Amplitude change at the depth of the expected spill point

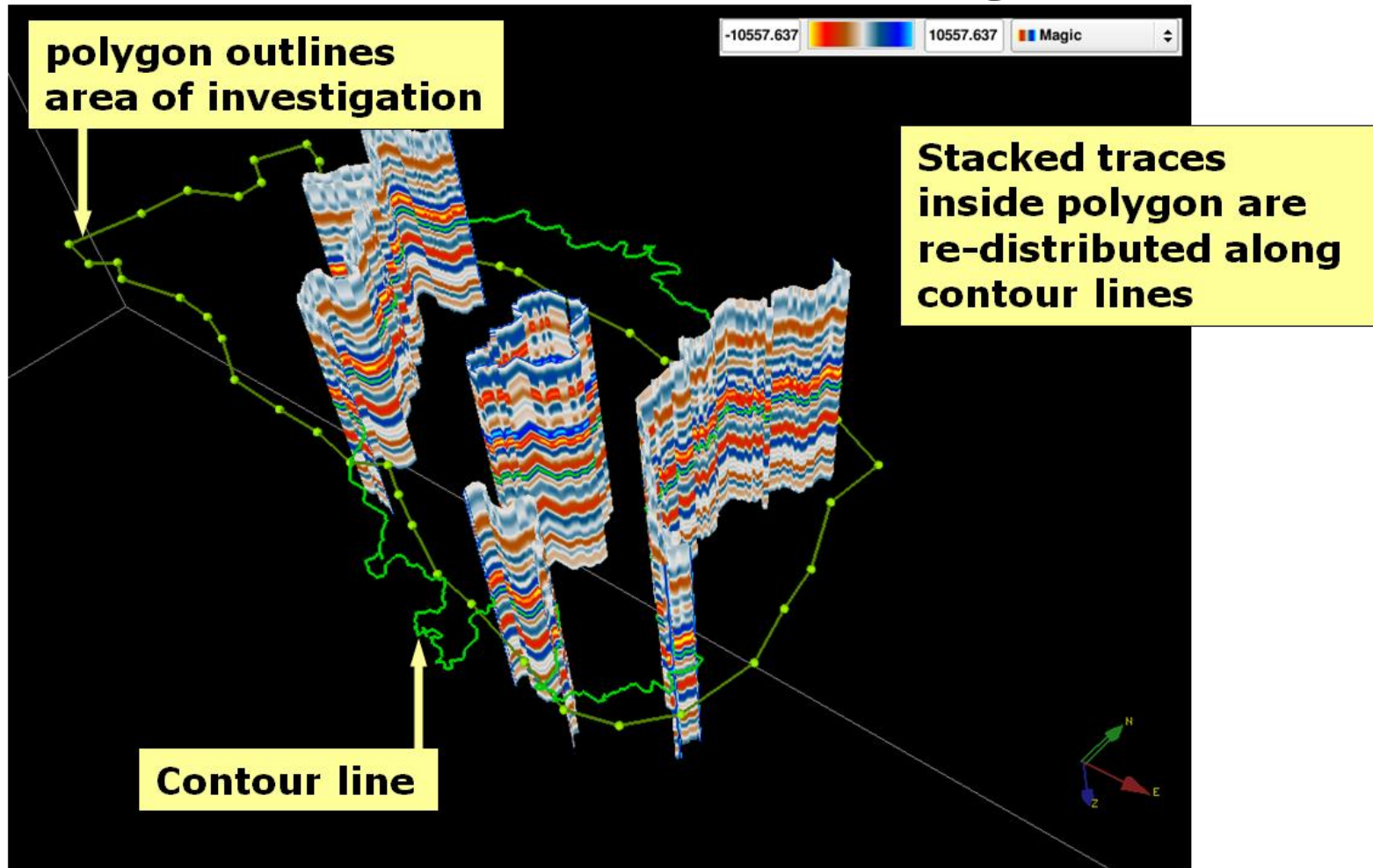Restricted low amplitude anomaly at the top of the structure

Jan Gabe van der Weide and Andries Wever ideas, *Intellectual Property of **Wintershall Noordzee BV**, presentation from Open-dTect, www.dgb-group.com.

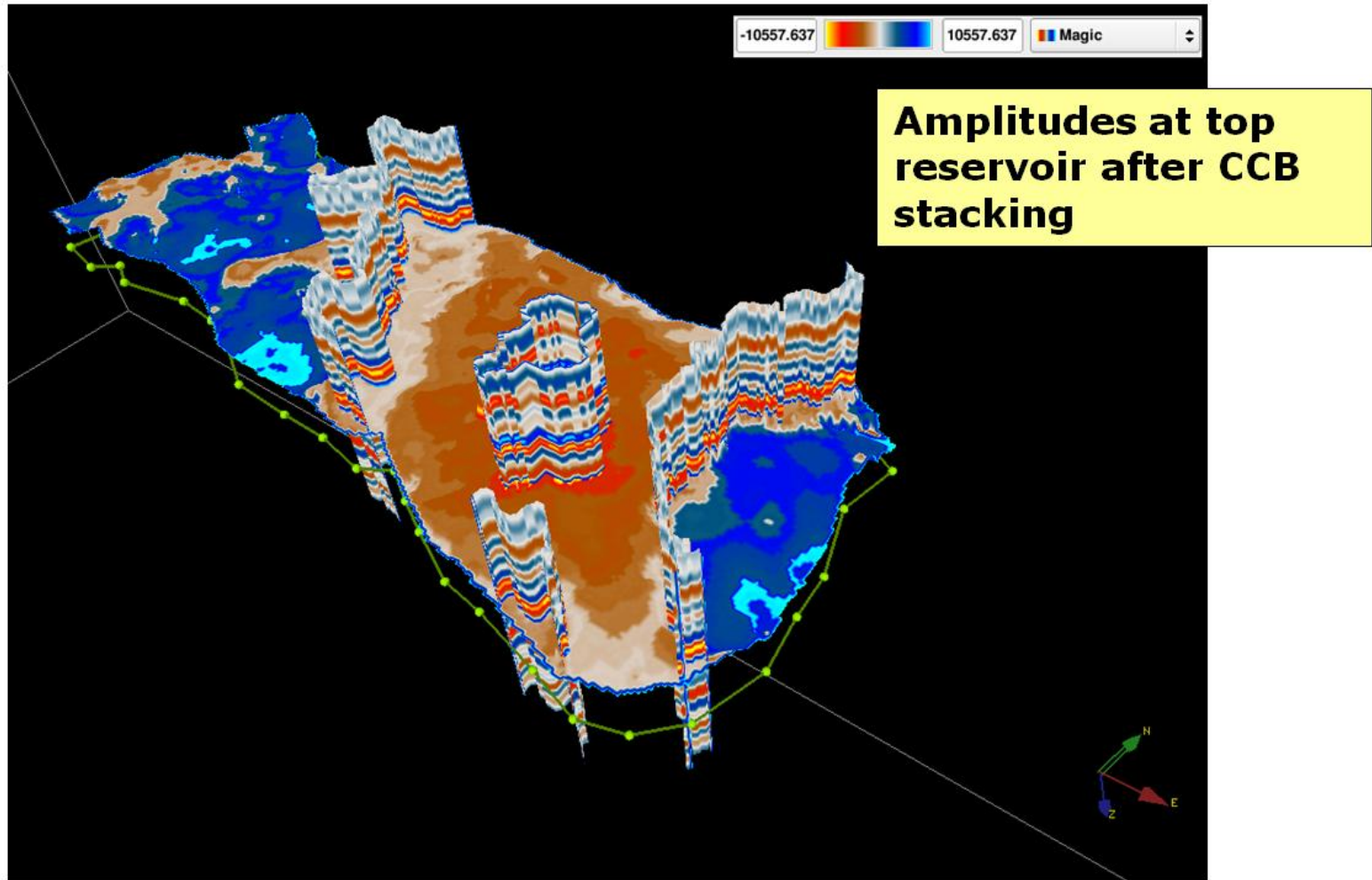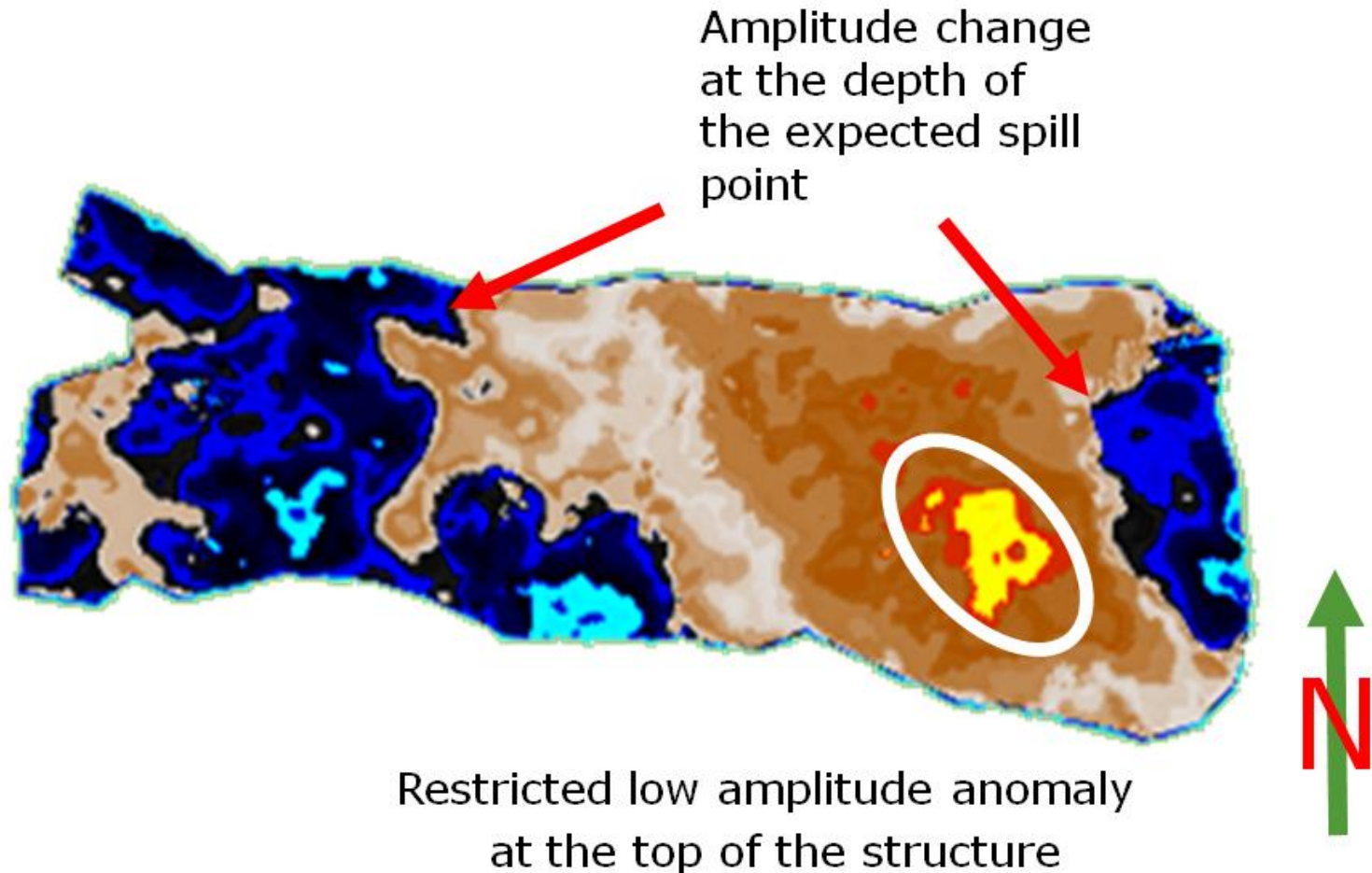# Wavelet Near Top Reservoir After CCB Stacking



Jan Gabe van der Weide and Andries Wever ideas, *Intellectual Property of **Wintershall Noordzee BV**, presentation from Open-dTect, www.dgb-group.com.

# Relationship of Gas Chimneys and Structure



**Observations:**

1. No chimneys above the structure -> good top seal
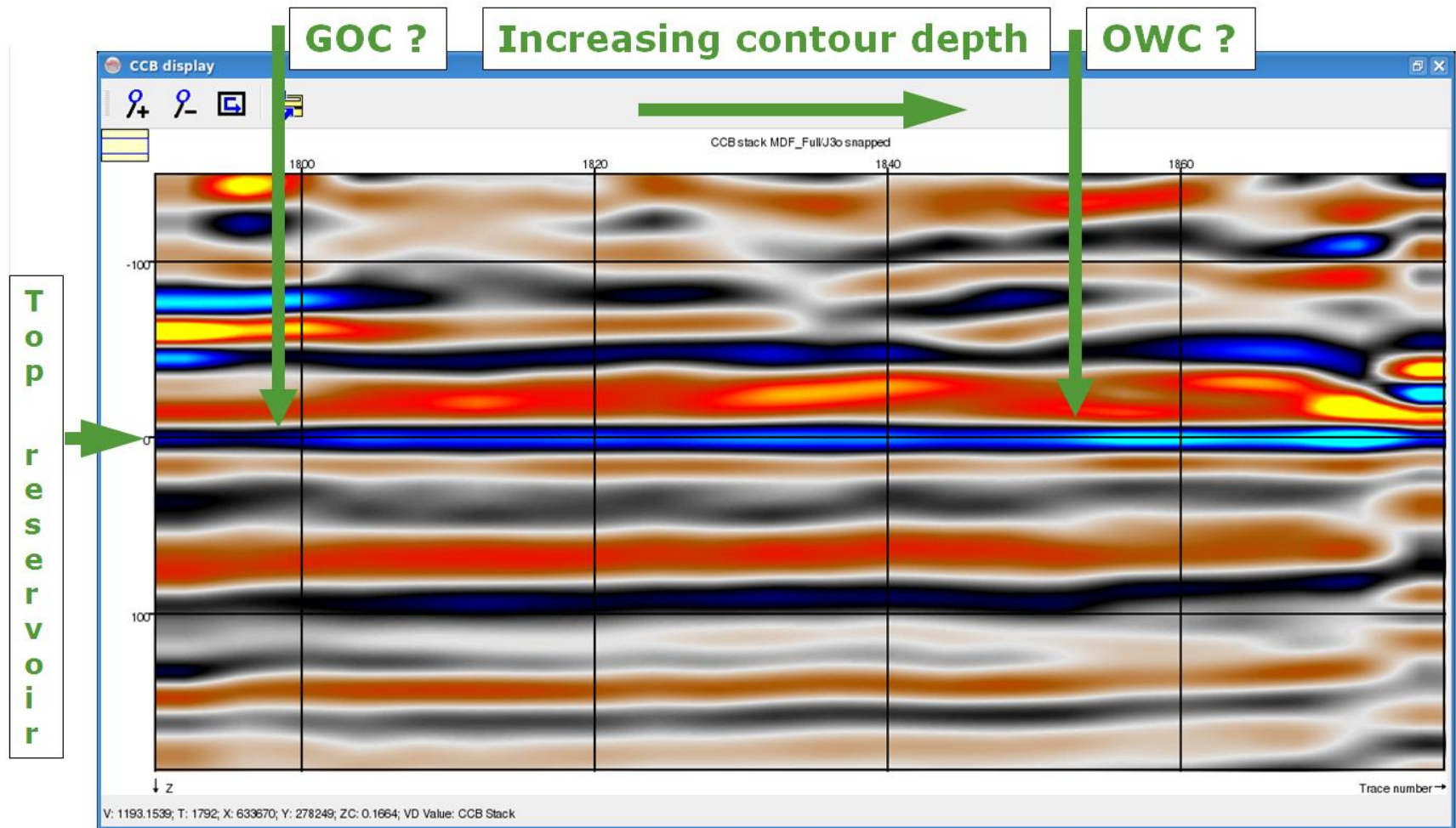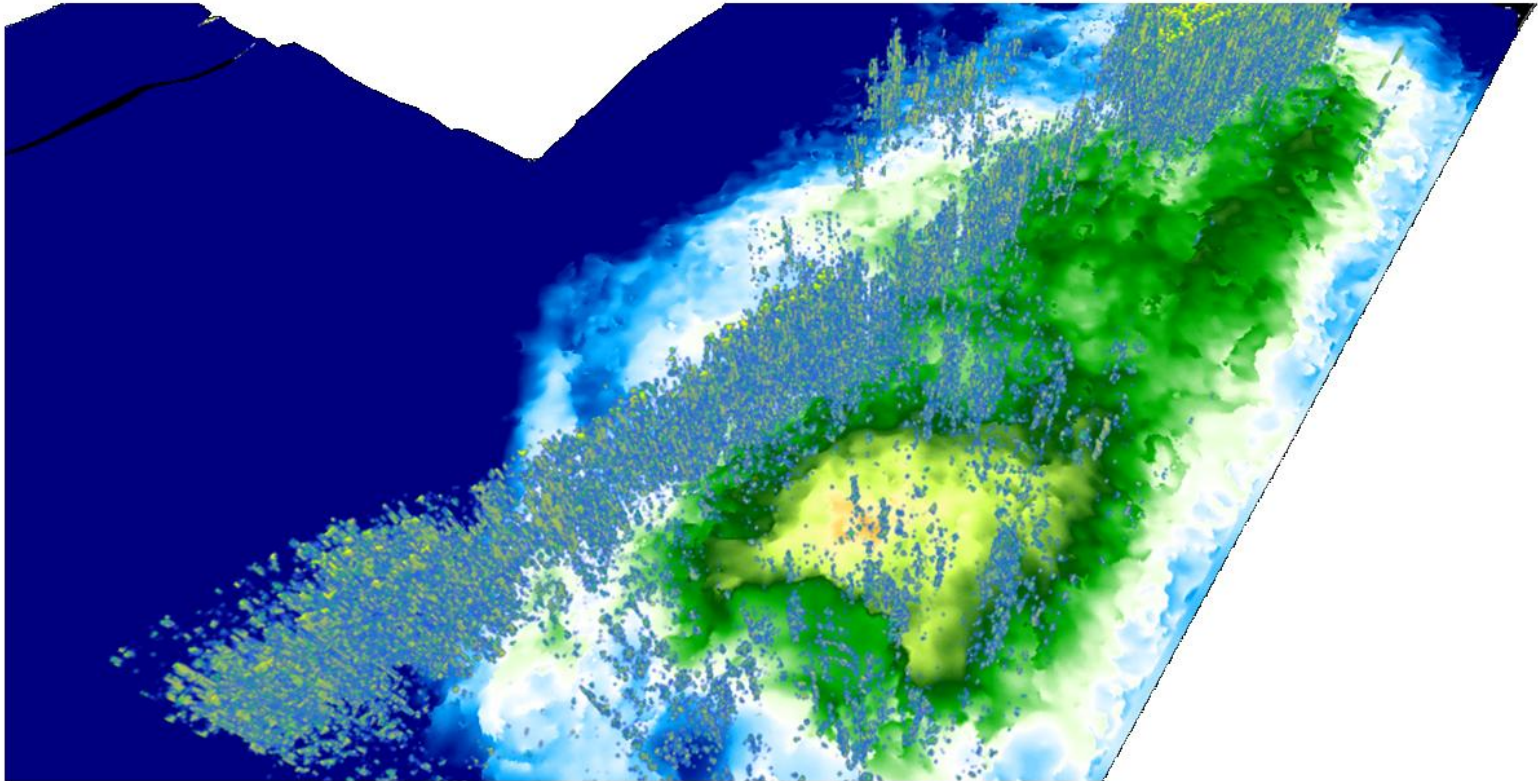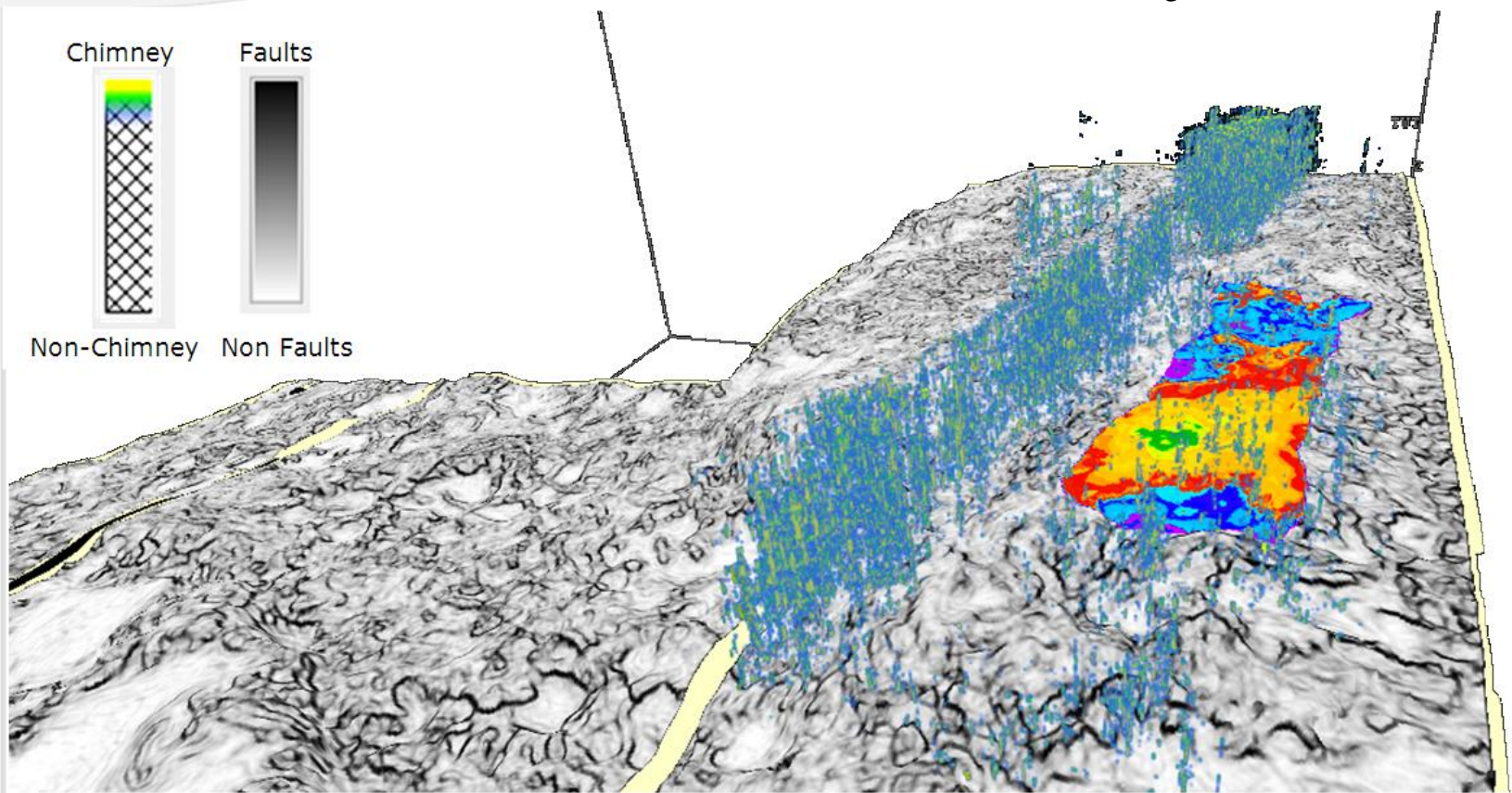2. Leakage occurs along the fault down-dip of the structure

Jan Gabe van der Weide and Andries Wever ideas, *Intellectual Property of **Wintershall Noordzee BV**, presentation from Open-dTect, www.dgb-group.com.

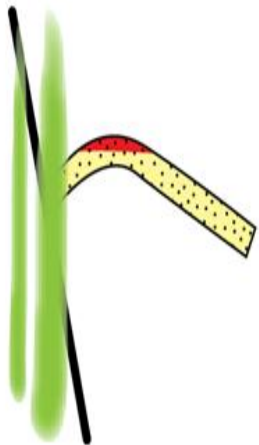# Faults Tie To Gas Chimneys



## Observation:

### 1.  Anomaly coincides with onset of chimneys along the fault

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# Gas Chimney Classification



**Non-fault Seal Trap (HIT)** — 94% Discoveries, n=18

**Fault Seal Trap (HIT)** — 93% Discoveries, n=30 — Seal

**Gas Cloud Trap (Oil prone MIT)** — 97% Discoveries, n=42
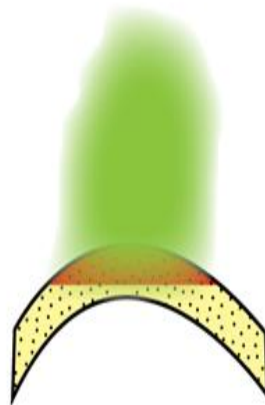
**Fault Leak Trap (LIT)** — 27% Discoveries, n=19

**Non Chimney Trap** — 57% Discoveries, n=14

HIT, MIT, LIT: High, Medium, Low Integrity Trap

Jan Gabe van der Weide and Andries Wever ideas, *Intellectual Property of **Wintershall Noordzee BV**, presentation from Open-dTect, www.dgb-group.com.
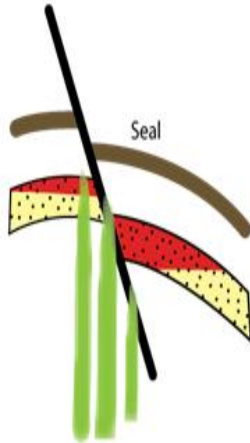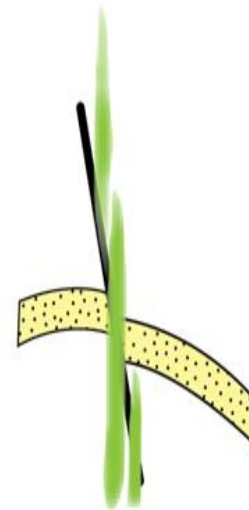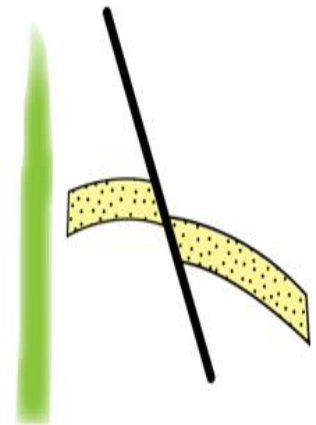
# Data Integration

- Most Geoscience and Engineering Data is:
  - A Point $(x,y,z,a)$: e.g. top, perforation, fault cut, sample location, lightning strike location, etc.
  - A Line $([x_1,y_1,z_1],a_1; [x_2,y_2,z_2],a_2; \ldots;[x_n,y_n,z_n],a_n)$: e.g. outcrop transverse, well path, log, seismic trace, dynamic data from a reservoir, etc.
  - A Section $([x_1,y_1],z_1,a_1; [x_2,y_2],z_2a_2; \ldots;[x_n,y_n]z_n,a_n)$: e.g. 2-D seismic section, geologic cross-section, etc.
  - A Volume $(x_1,y_1,z_1,a_1; x_2,y_2,z_2a_2; \ldots;x_n,y_n,z_n,a_n)$: e.g. 3-D geologic model, seismic volume, reservoir model, etc.
  - A Time-Lapse Volume $(x_1,y_1,z_1,t_1,a_1; x_2,y_2,z_2,t_2,a_2; \ldots;x_n,y_n,z_n,t_n,a_n)$: e.g. palinspastic or geochronostratigraphic geologic model reconstruction, 4-D seismic volume, reservoir modeling run, etc.

- Integration is the process of reducing different data sets to a common coordinate system and merging the different data sets into one project, where the different data sets can be turned on and off.
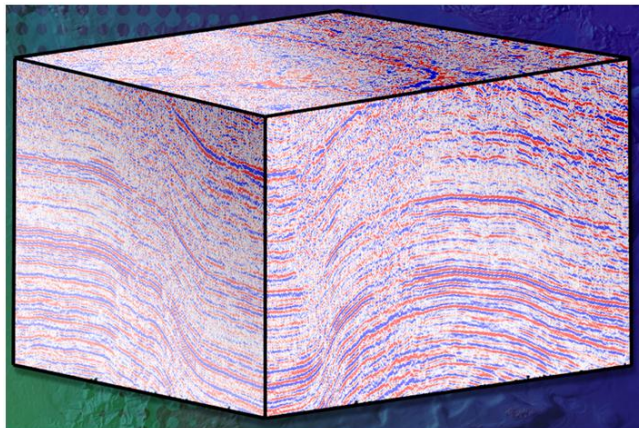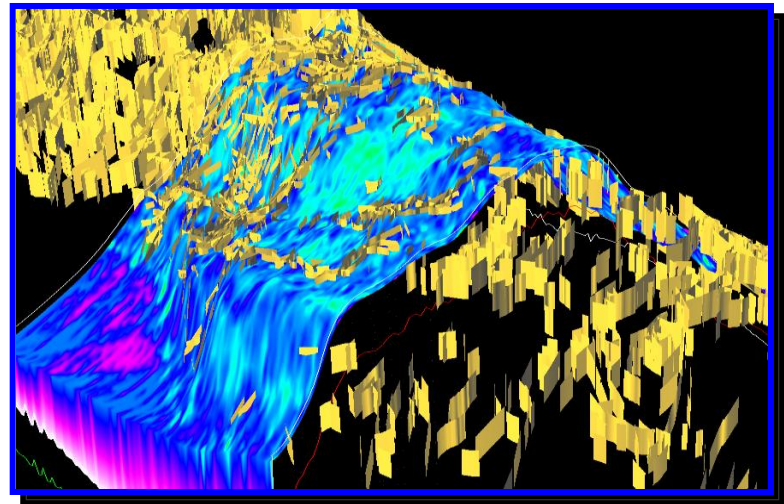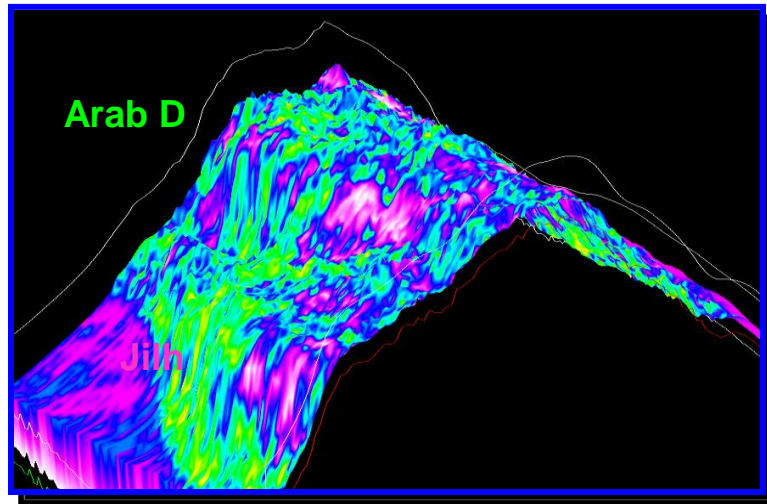
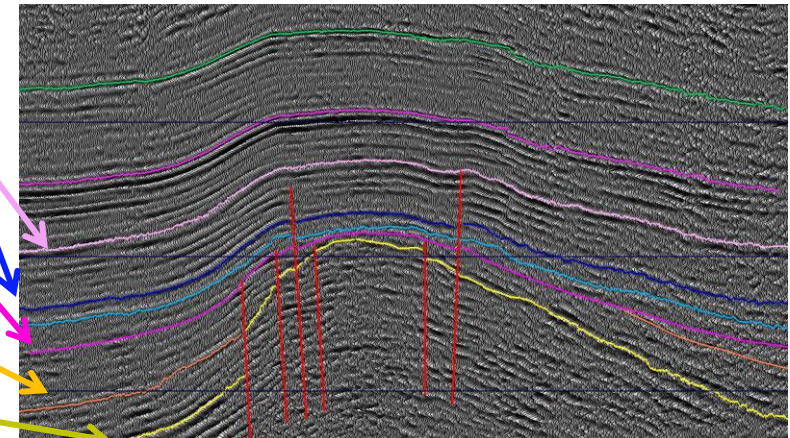# Display Concepts
## University of Louisiana at Lafayette LITE

# Porosity and Fault Mapping
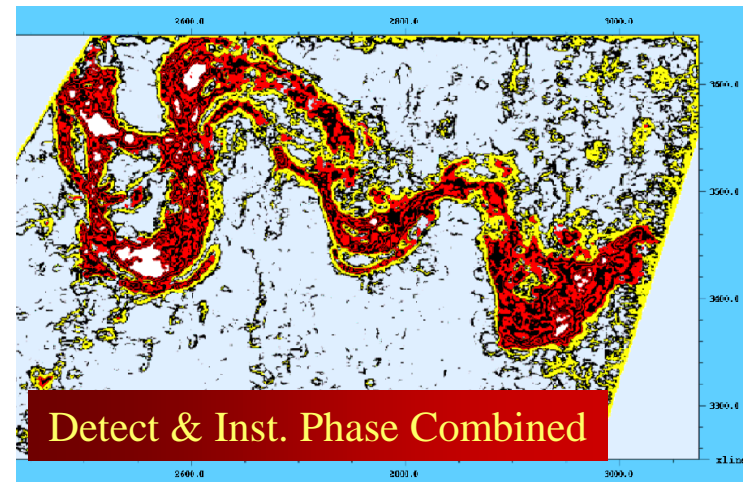## Example of Characterization of a Carbonate Reservoir
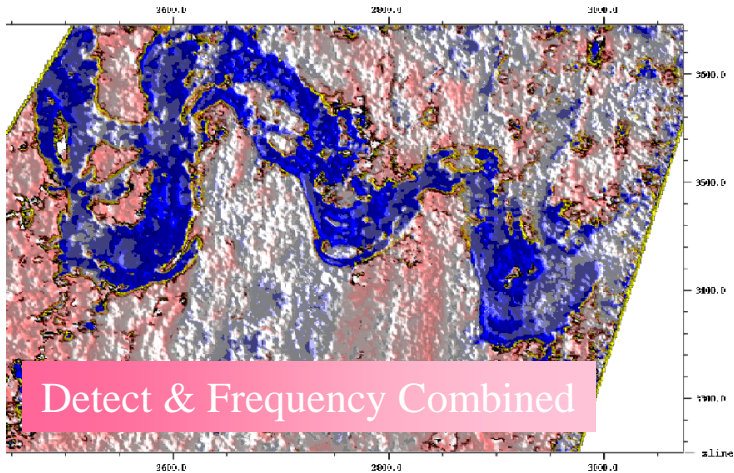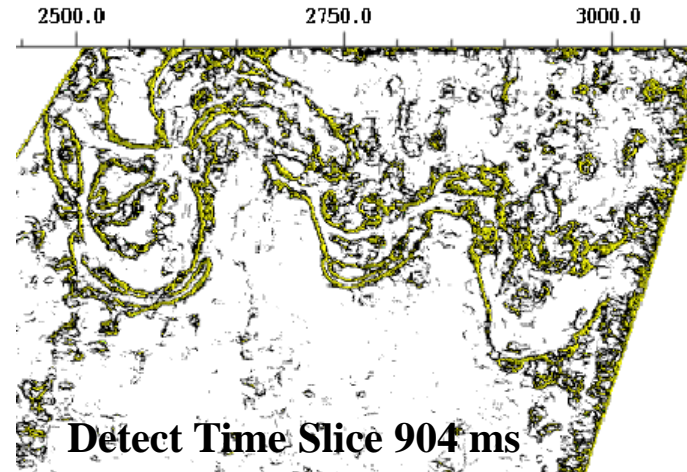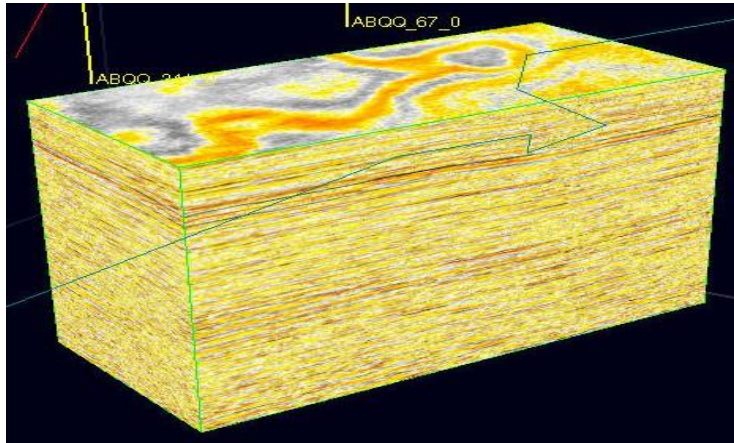## Haradh Field Saudi Arabia



Shiv Dasgupta, formerly at Aramco, personal communication.
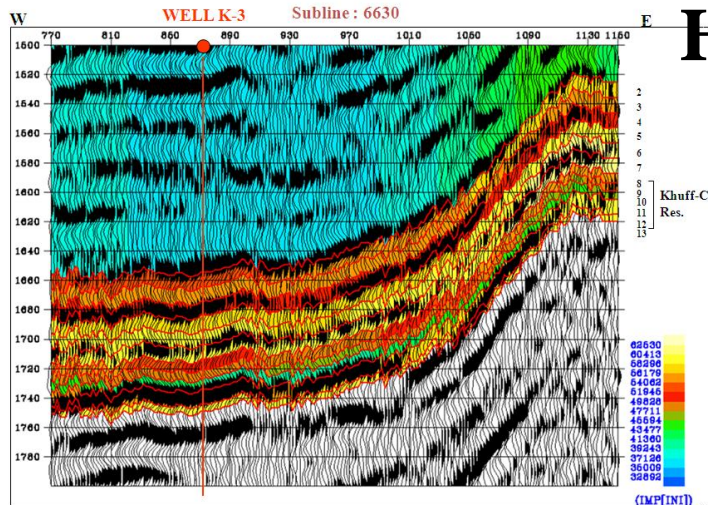
# Paleozoic Clastics

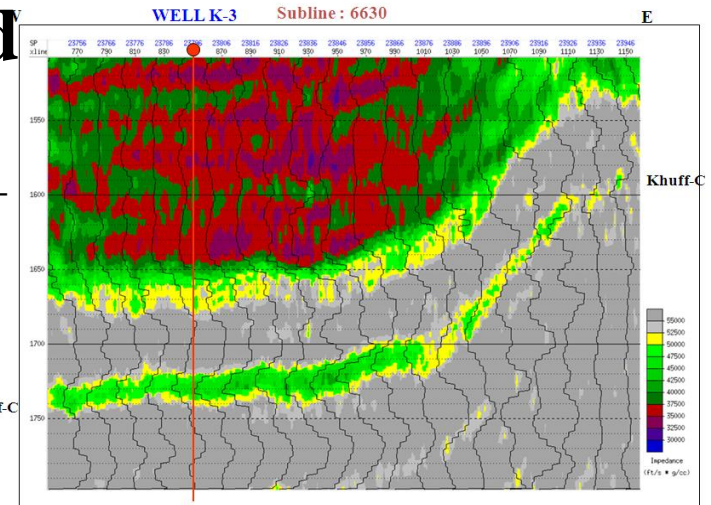## Showing Meandering Channels, Haradh Field, Saudi



Shiv Dasgupta, formerly at Aramco, personal communication.

# Amplitudes, Acoustic Impedance, & Inversion
## Haradh Field



Seismic Amplitude + Initial Model

Acoustic Impedance – Amplitude Inversion



WELL K-3

206 ft

Top Khuff-C (12134 ft)

Porosity 12-15%

B. Khuff-C (12340 ft)
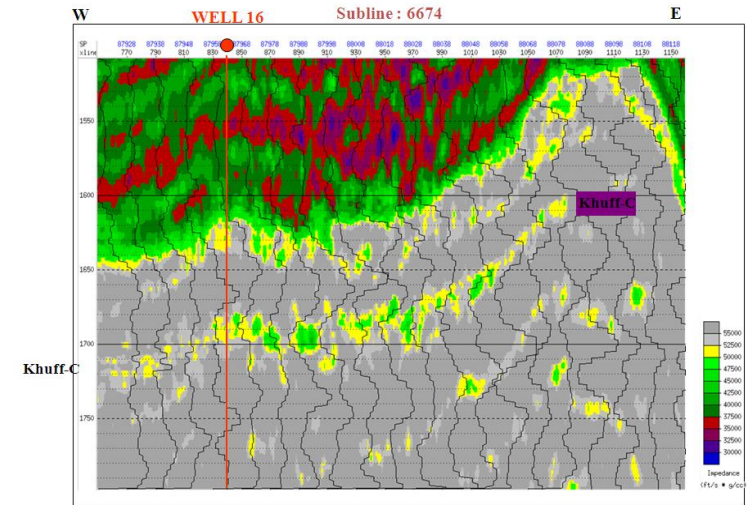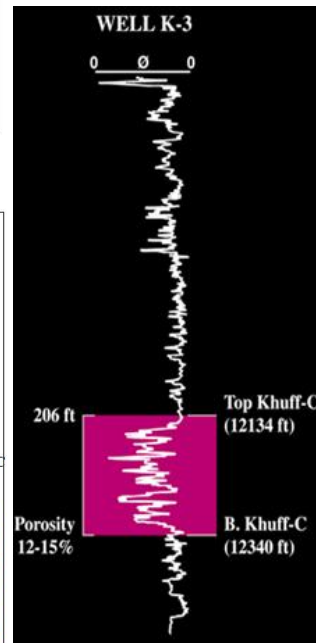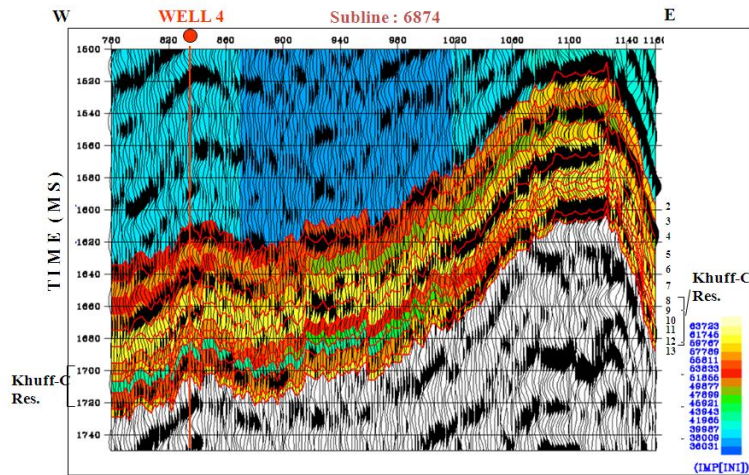
Seismic Amplitude + Initial Impedance

Acoustic Impedance – Amplitude Inversion

Shiv Dasgupta, formerly at Aramco, personal communication.

# Porosity Determination
## from 3-D Inversion, Haradh Field, Saudi Arabia



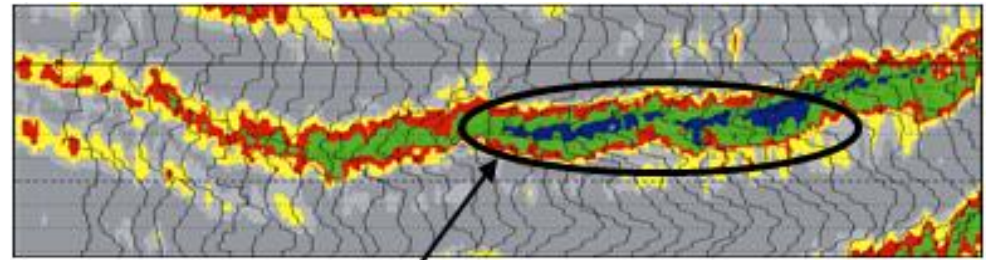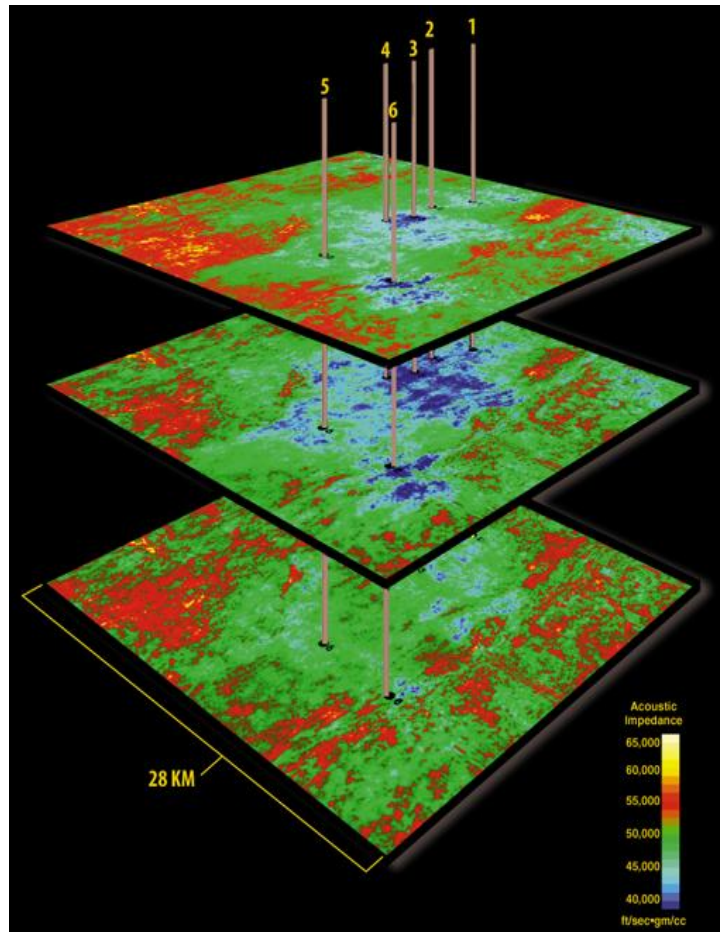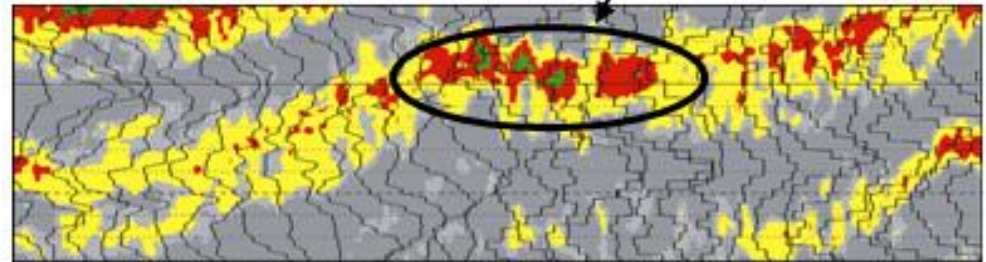Good Porosity

Poor Porosity

**Porosity Development**
**Khuff C Inverted Impedance**

'Uthmaniyah Khuff-C Layers

Shiv Dasgupta, formerly at Aramco, personal communication.

# Deep Multi-Lateral Gas Well in Clastics
## Haradh Field, Saudi Arabia



Ghazal-7

Ghazal-9

14000'

Unayzah
Section

Base
Khuff

**E-W Impedance Traverse**
Low impedances (yellow-red) indicate
better reservoir development

Reservoir Contact: 9,000'

Gas Rate: 50 MMSCFD

100% increase over Vertical
well with frac (MM$ 30/year)
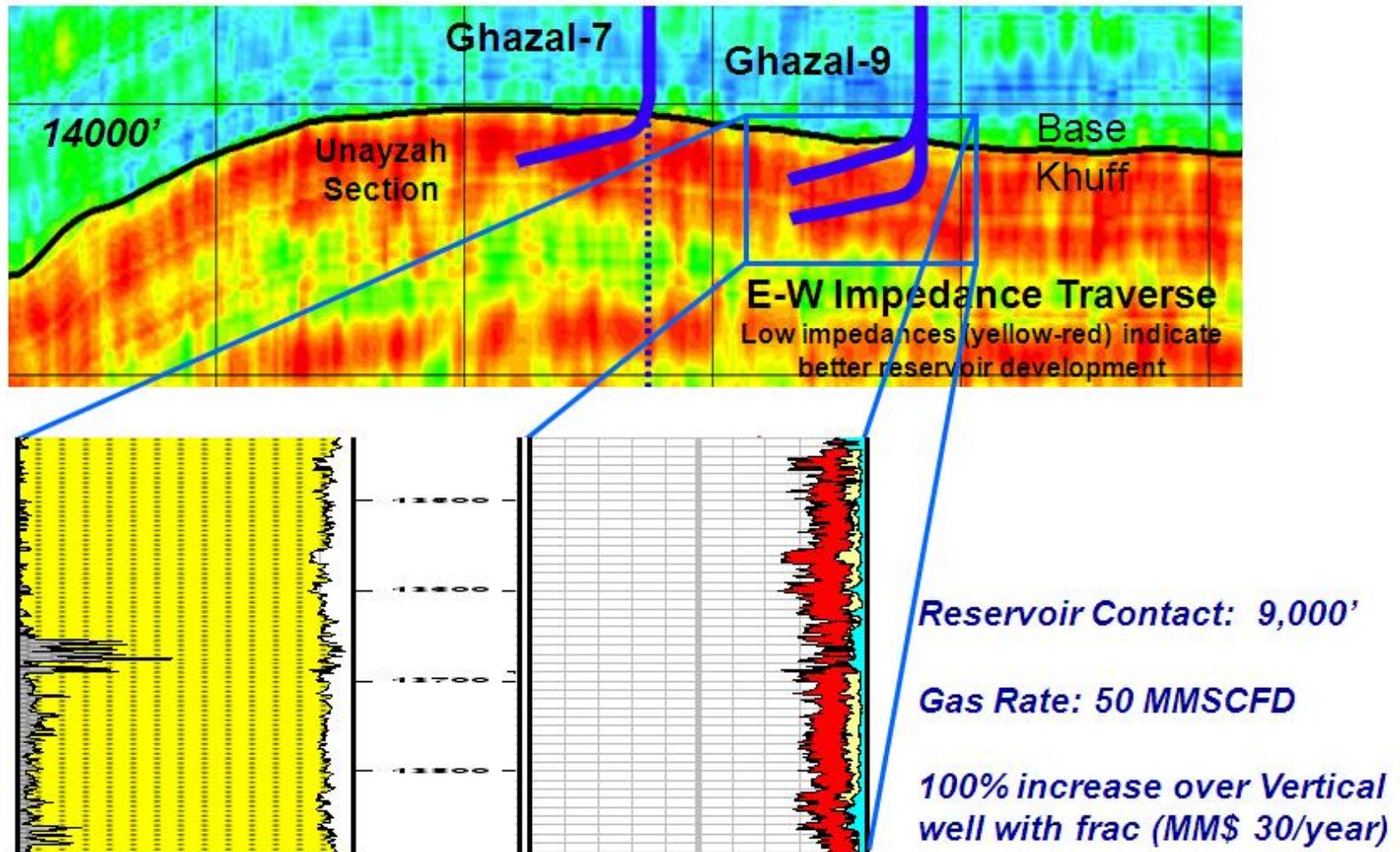
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# G & G Integration
## Saudi Aramco



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# Predicted Well Body before Drilling
## Haradh Field, Saudi Arabia



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3-D Seismic Interpretation - with an emphasis on carbonate terrains
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# Well Planning
## Saudi Arabia
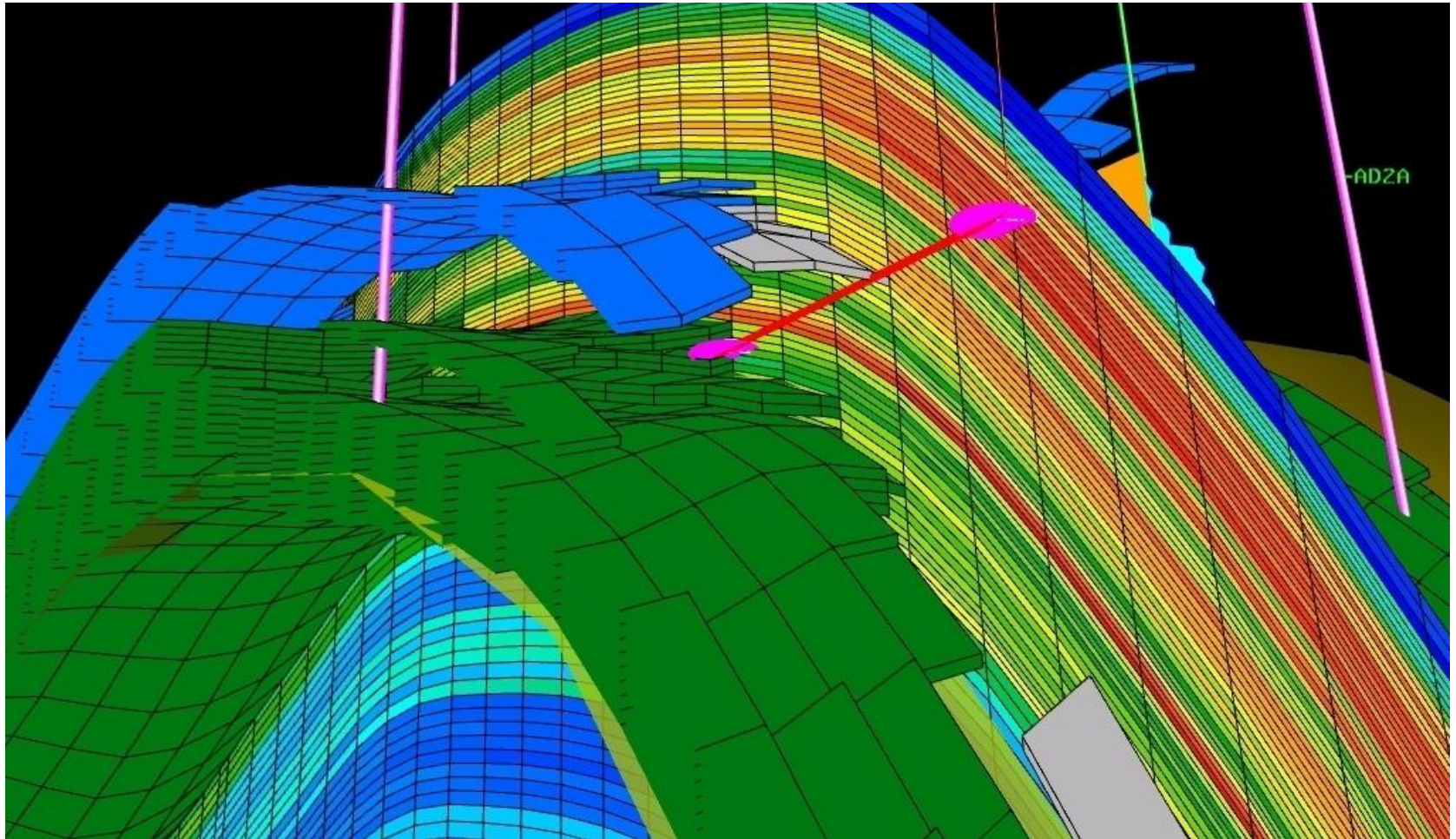


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# Geobody Extraction of Reservoir
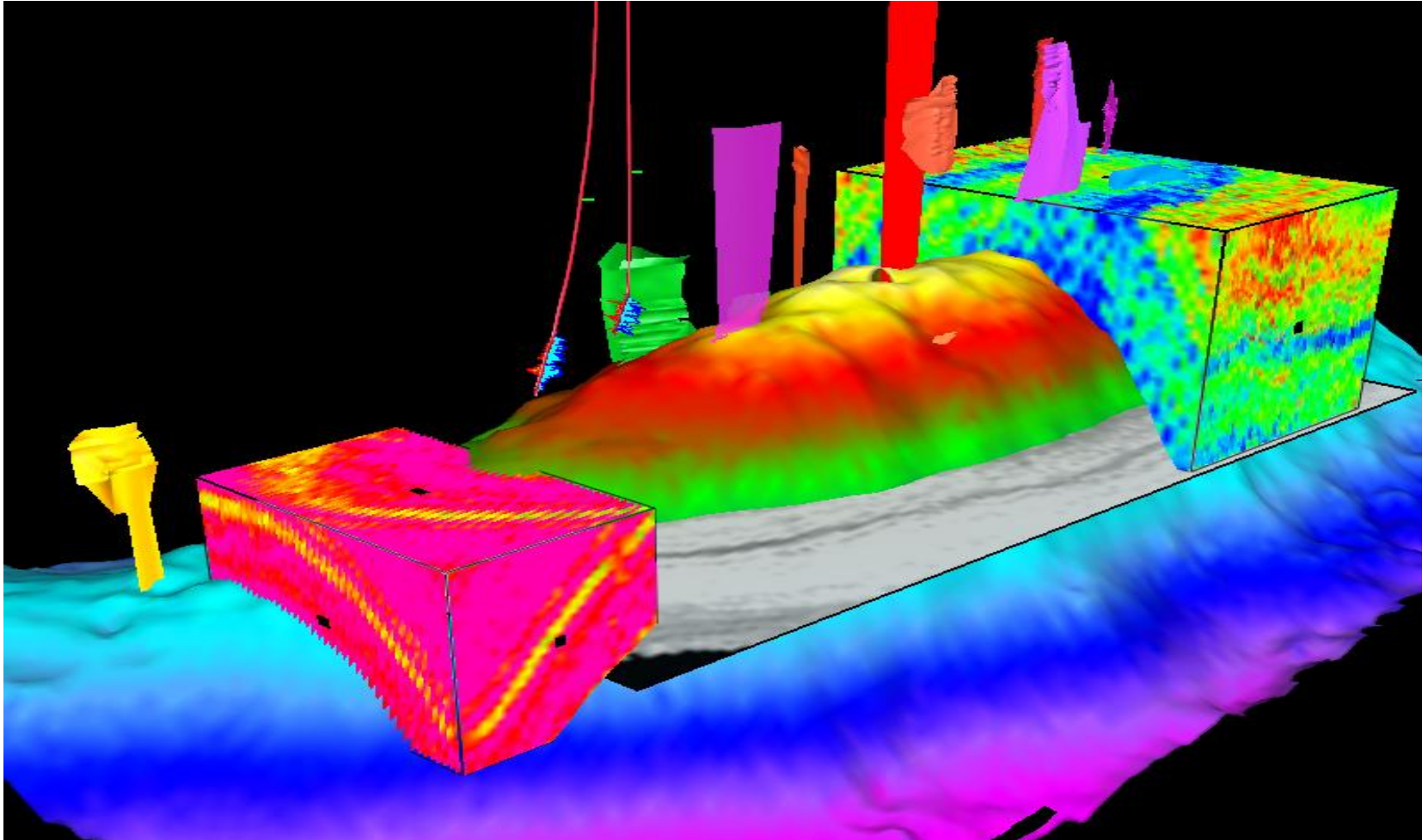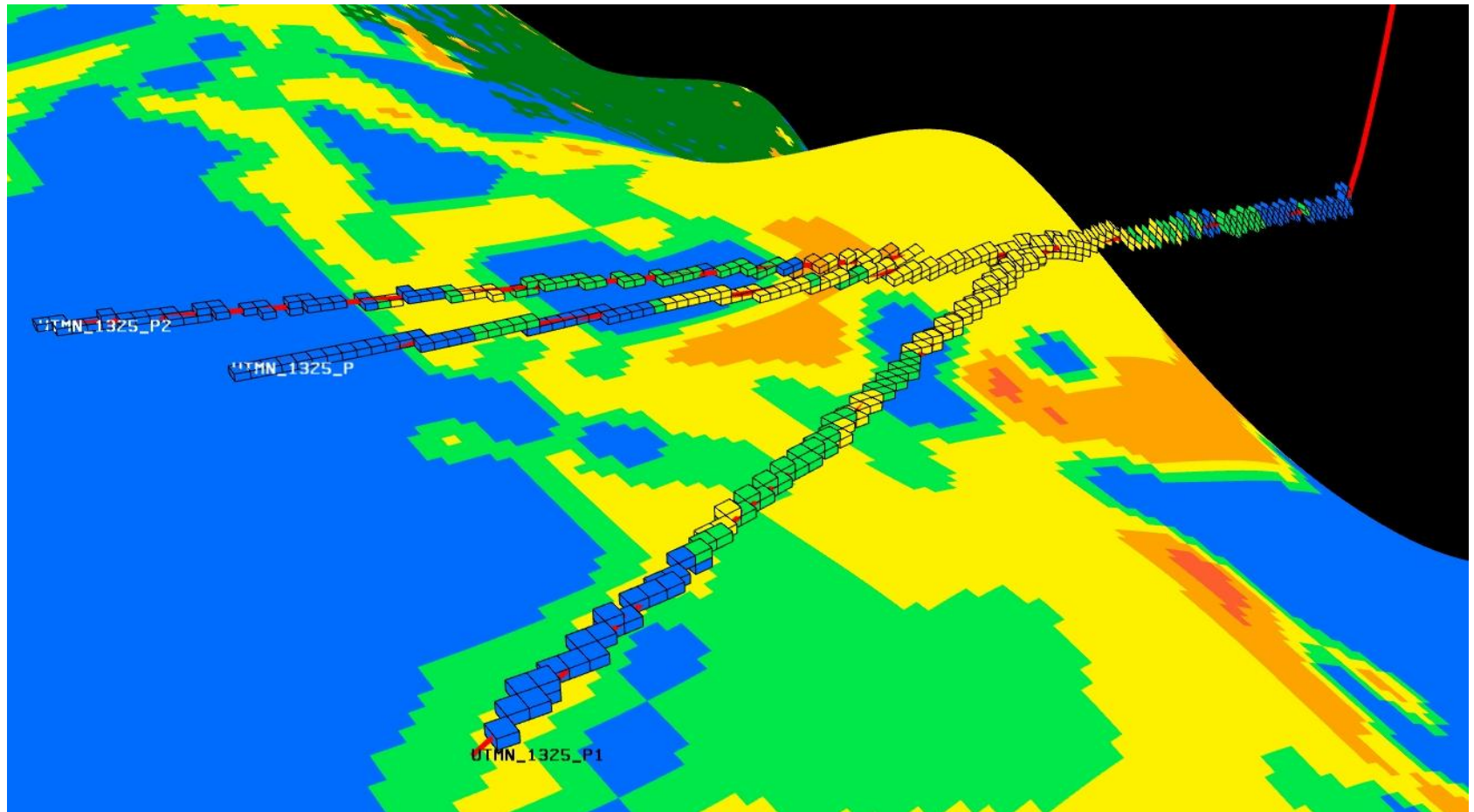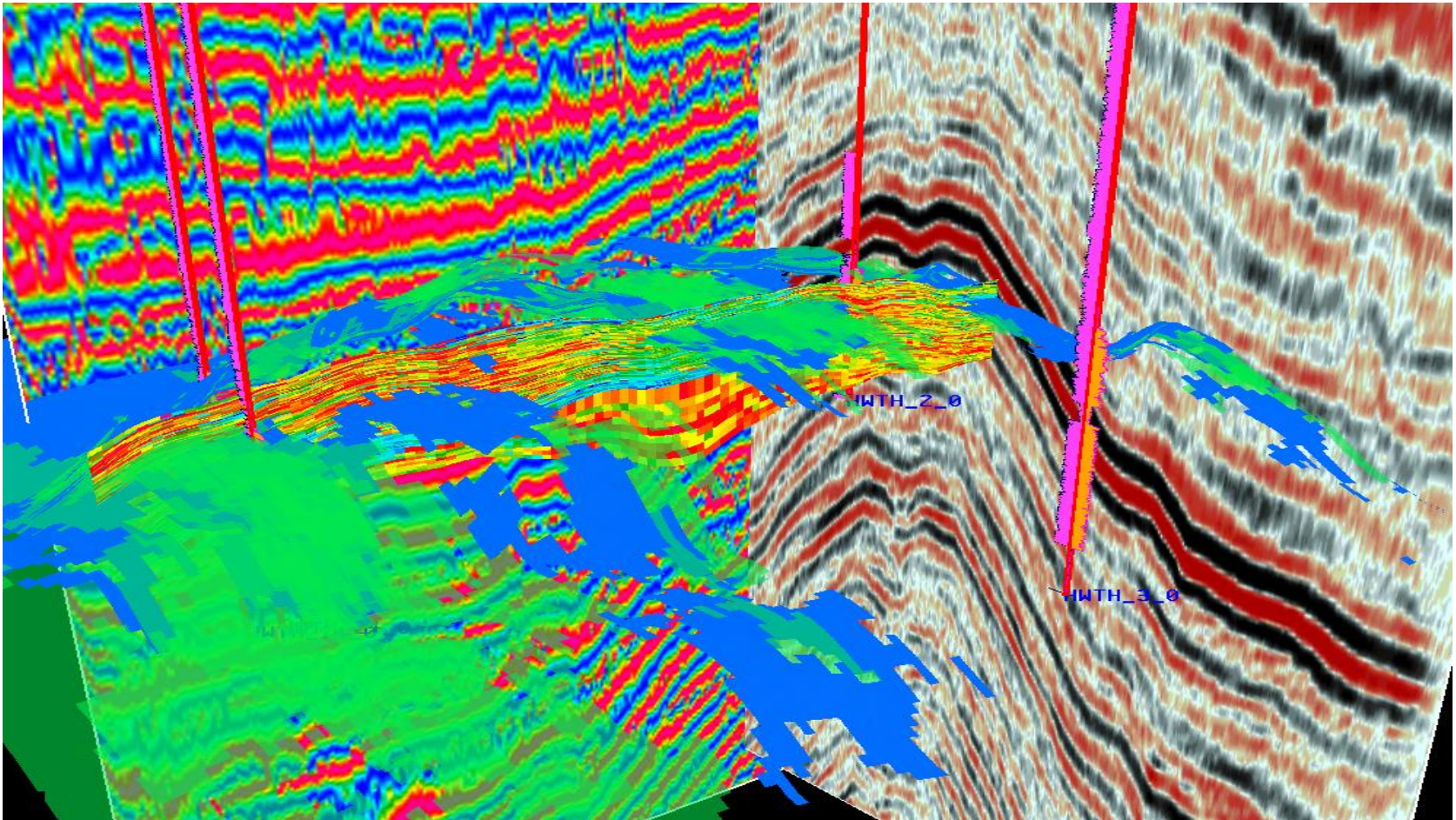## Haradh Field NW Development, Saudi Arabia



Good Porosity and Good Permeability

Shiv Dasgupta, formerly at Aramco, personal communication.

# Review of Discussion

- Reservoir characterization and modeling
  - Lithology prediction
  - Fluid analysis
  - Reservoir geobodies
  - Porosity evaluation
  - Permeability prediction
  - Net Pay
- Advanced Interpretation
- Seismic petrophysics
- Data integration
- Characterization of carbonate reservoirs

3-D Seismic Interpretation - with an emphasis on carbonate terrains
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