Seismic Attenuation for Reservoir Characterization

DE-FC26-01BC15356

October, 2001 to September, 2003

Presented To:

NATIONAL PETROLEUM TECHNOLOGY OFFICE

Tulsa, Oklahoma

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Company Background

THE DISCOVERY BAY COMPANY

Sophisticated architecture for seismic data access and analysis

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Seismic trace attributes and advanced seismic processing algorithms

Spin-off from the Stanford Rock and Borehole Geophysics (SRB) project.
Industry-leading tools for performing petrophysical modeling and analysis.

Currently 30 employees: offices in Houston, Oslo

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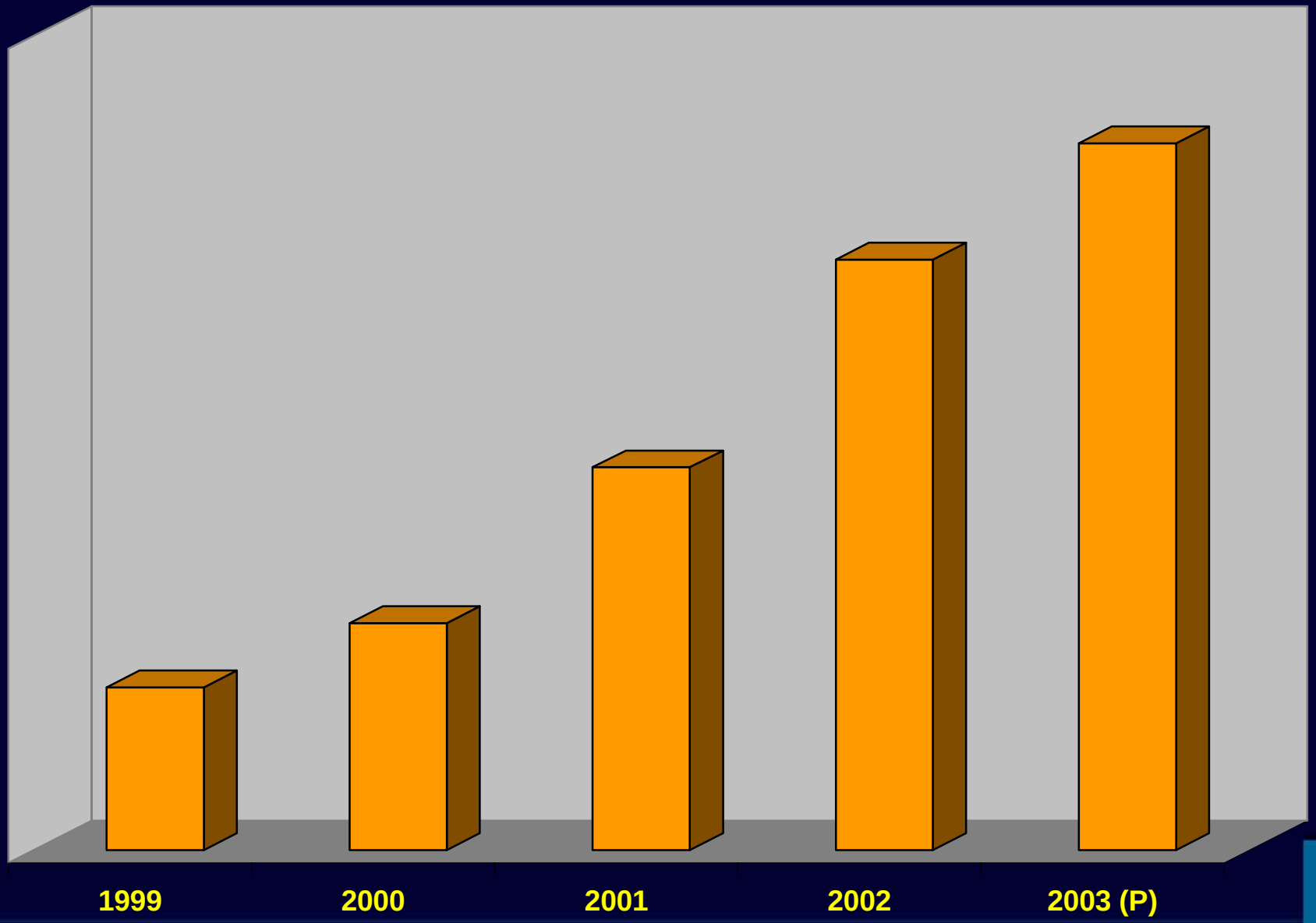

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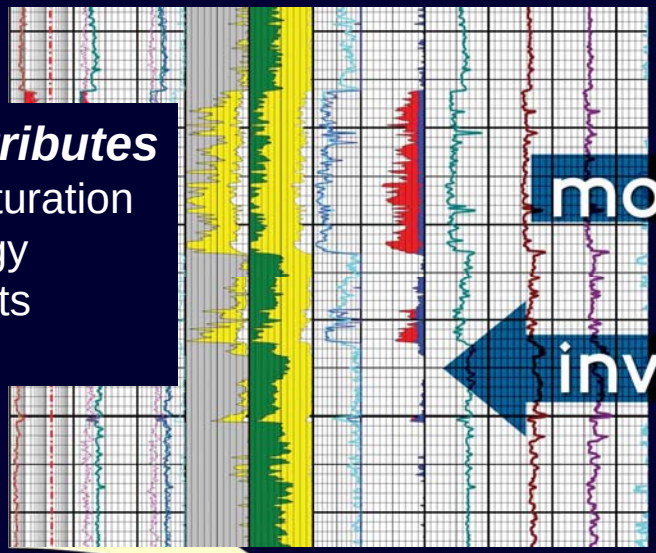
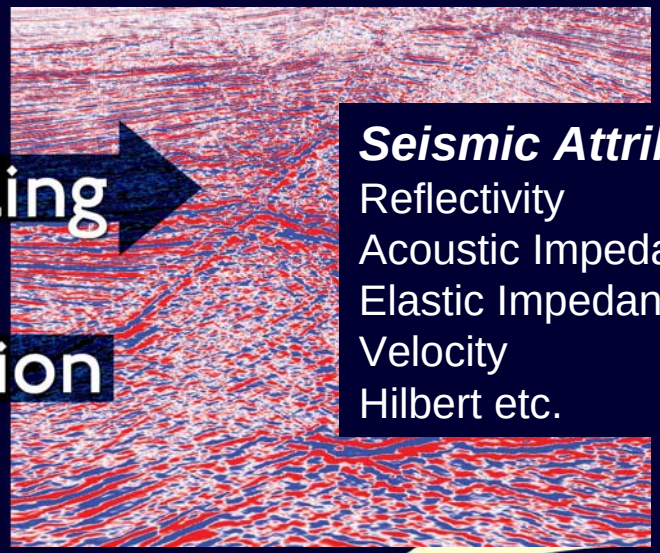
Seismic reservoir characterization



Well Attributes
Water saturation
Mineralogy
Pay counts
Porosity

modeling

inversion

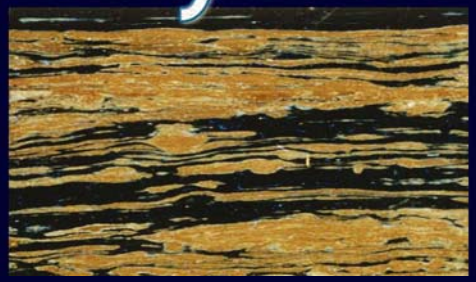


Seismic Attributes:
Reflectivity
Acoustic Impedance
Elastic Impedance
Velocity
Hilbert etc.

Vp, Vs, ρ, Q

Rock Physics

Vp, Vs, ρ, Q



Mechanical Properties
Pressure
Temperature
Fluids
Relative Permeability
Porosity
Net to gross

"Find a reservoir property model which honors both seismic and log data"

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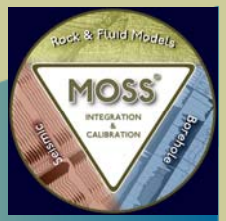
“Model before you invert”

Seismic Attributes

Traveltime
Vnmo
V_p , V_s
Ip , Is
R0 , G
AI , EI
Q
Anisotropy

Acoustic Properties

V_p
V_s
Density
Q



Reservoir Properties

Porosity
Saturation
Pressure
Lithology
Stress
Temperature
Etc.

“The rock physics bottleneck”
- Mavko

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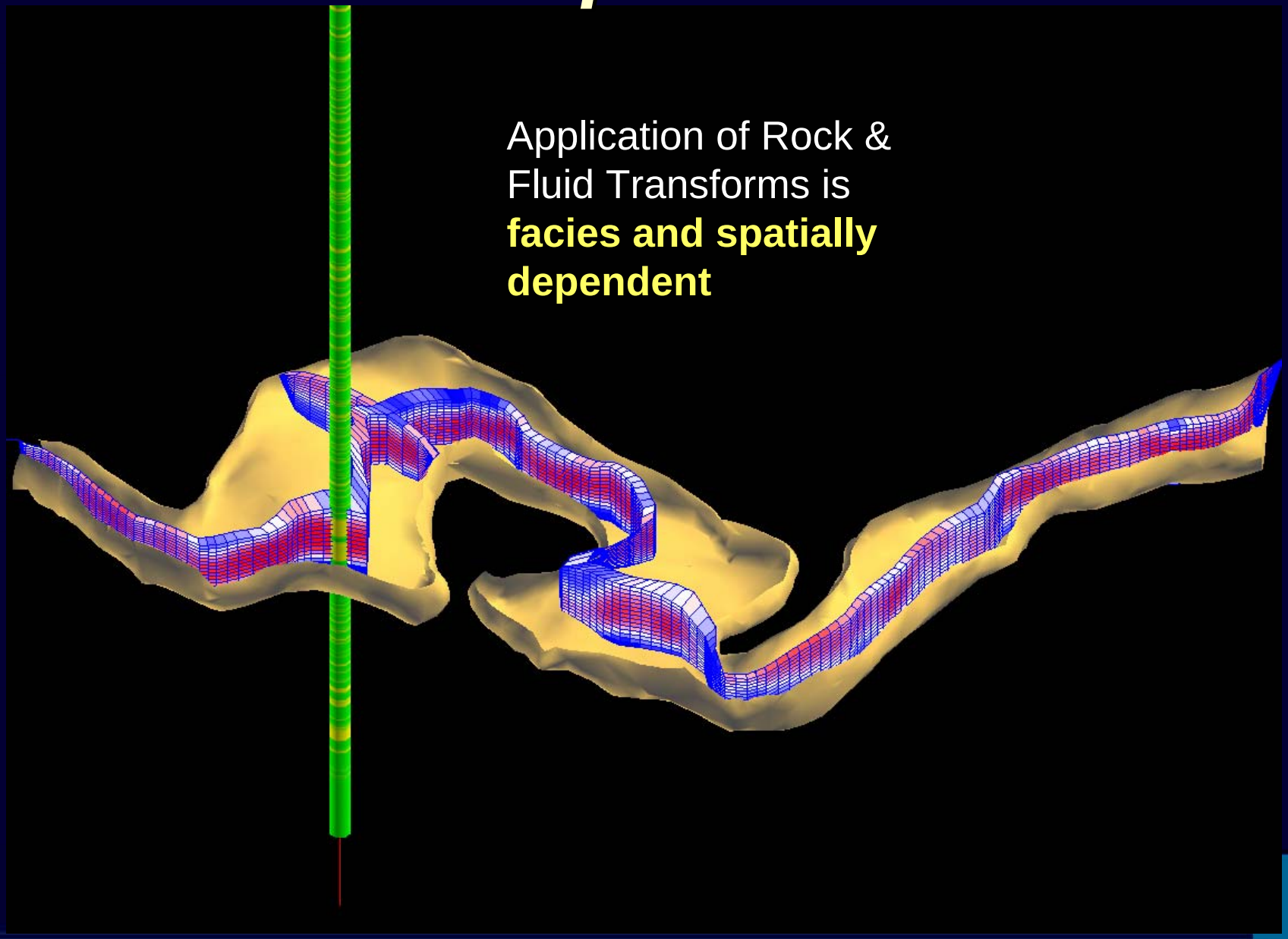
Rock & Fluid Properties Grid



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Why is Seismic Attenuation Important?

Attenuation is independent of reflection amplitudes. It is an inelastic property that is controlled by fluid motion in the pores. It is also affected by solid modulus (lithology) and fluid modulus (saturation).

These relations show critical frequency for some published seismic attenuation mechanisms.

η **Viscosity**
k **Permeability**
K_0 **Moduli Solid**
K_f **Moduli Fluid**
α **Aspect ratio**
l **Patch size**

Biot:

$$f_{biot} = \frac{\phi\eta}{2\pi\rho_f k}$$

V. Hi Freq

squirt:

$$f_{squirt} = \frac{K_0\alpha^3}{\eta}$$

~ Well Log Freq

patchy saturation:

$$f_{visc} = \frac{kK_f}{l^2\eta}$$

Any Freq.

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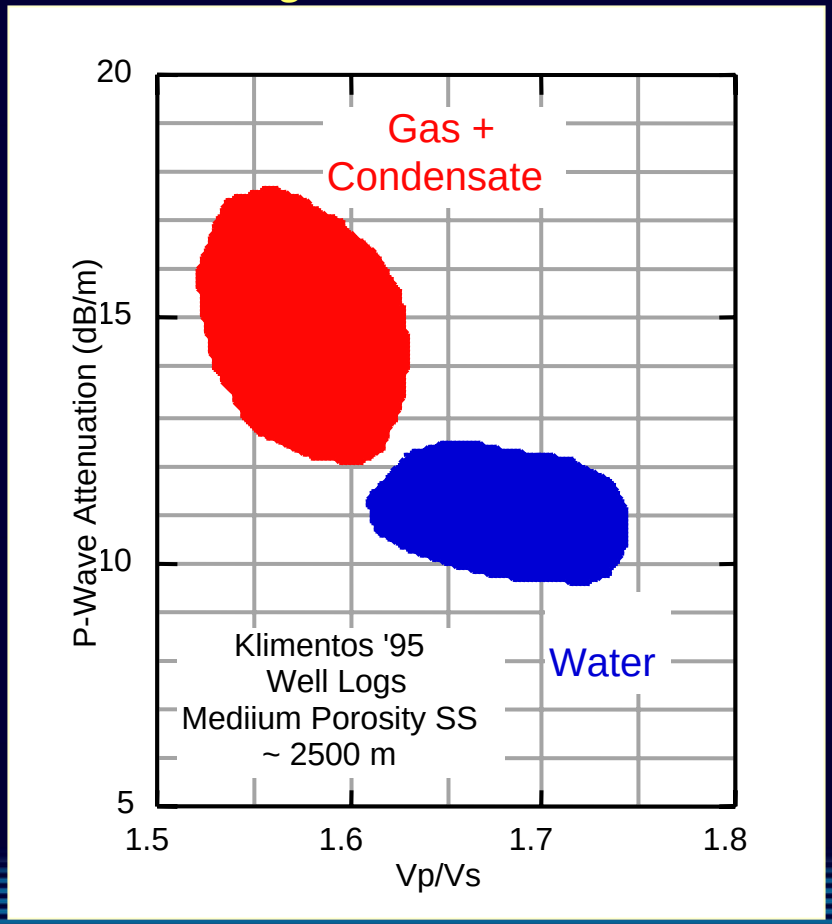
Attenuation in Exploration

Attenuation can be used in reservoir characterization, together with the amplitude. Data show that attenuation reacts to presence of hydrocarbons.

Klimentos used well log data to show that the P-wave attenuation is larger in hydrocarbon bearing sand than in water sand. The difference in the S-wave attenuation between the two was insignificant.



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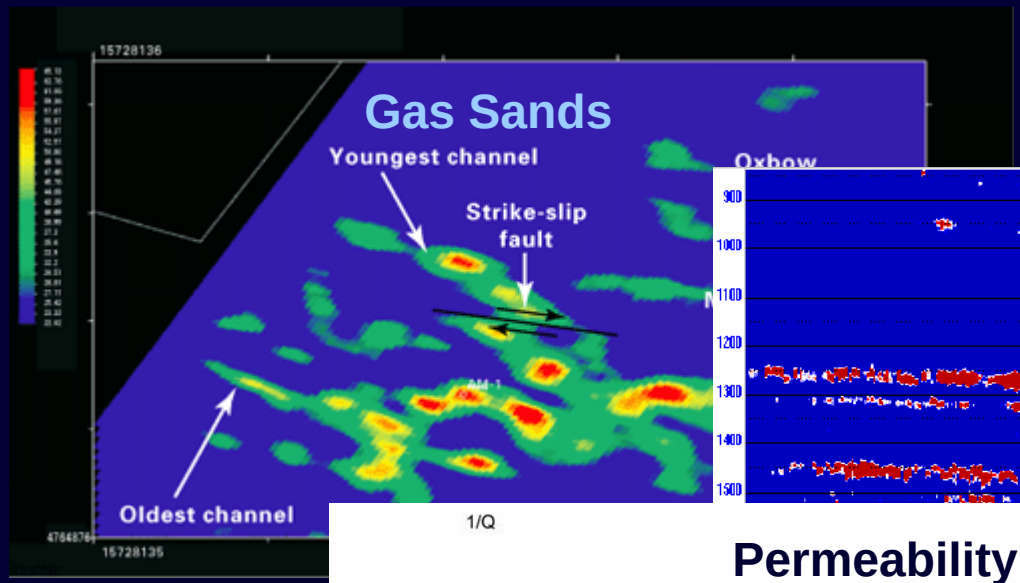
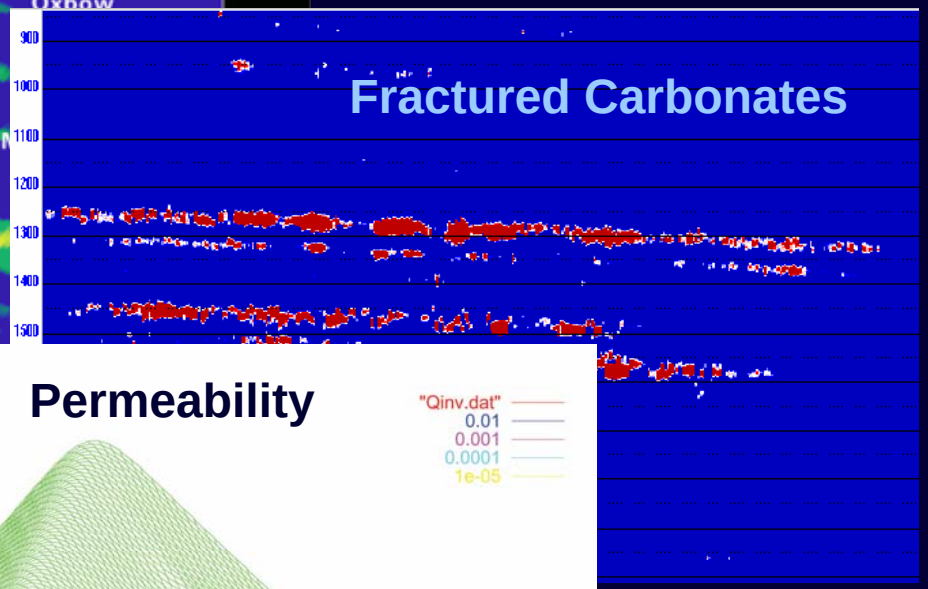
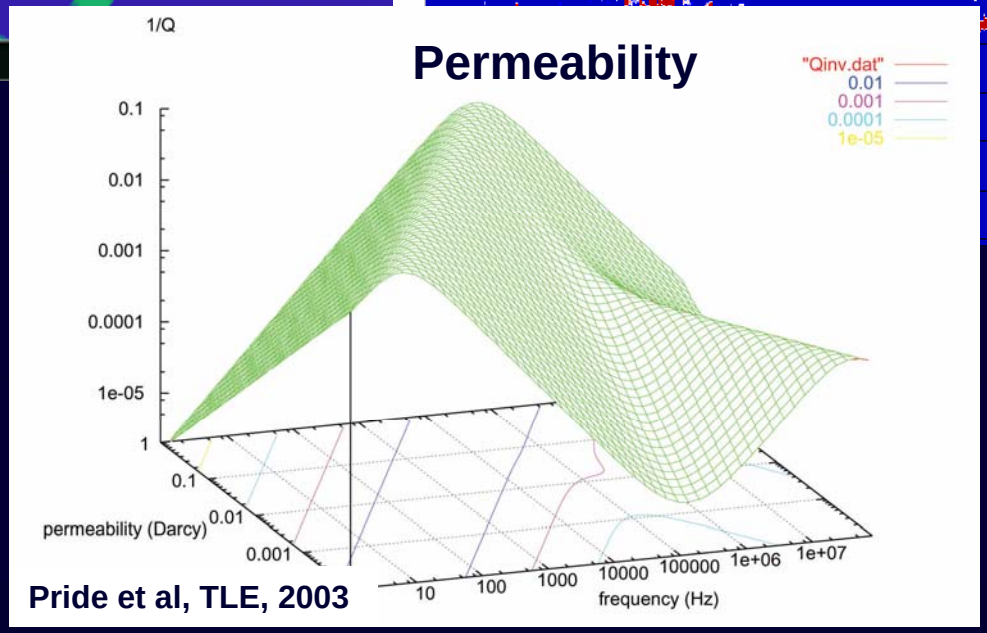
Attenuation in Exploration







Pride et al, TLE, 2003

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DOE Project Tasks

- Task 1 and 2: P and S Wave Q Estimation from Well Logs
- Task 3: Synthetic Seismic Modeling with Q.
- Task 4: Using Multiple Seismic Attributes to Link Q and Dispersion to Well Data
- Task 5: Data Analysis and Reporting

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ROCK PHYSICS MODELING OF ATTENUATION USING WELL LOGS (Tasks 1 and 2)

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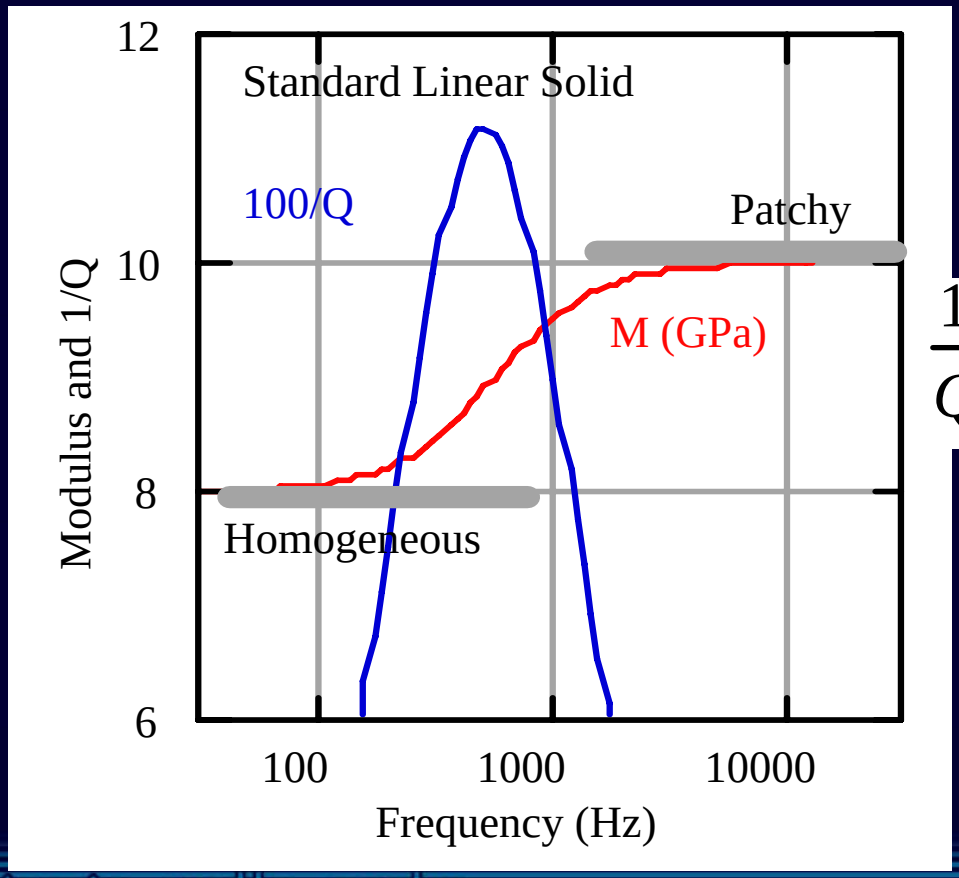
Theoretical Model for Q at Saturation

Our new model links Q to velocity dispersion between uniform and patchy saturation -- it calculates the elastic modulus difference from measured velocity, porosity, saturation, and pore fluid properties.



$$\frac{1}{Q} = \frac{(M_\infty - M_0)(f / f_{CR})}{\sqrt{M_0 M_\infty}[1 + (f / f_{CR})^2]}.$$

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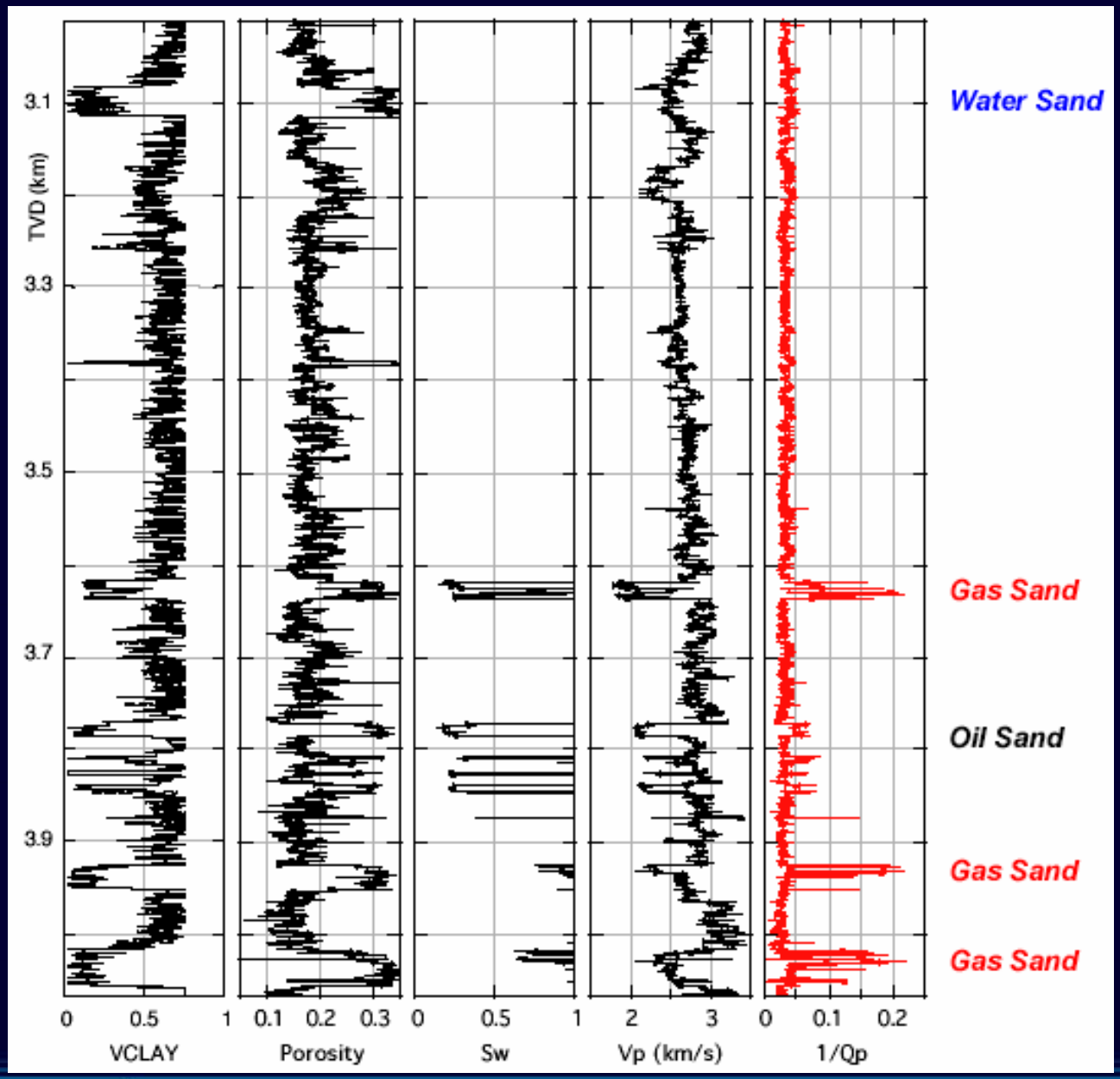
Application to Well Data



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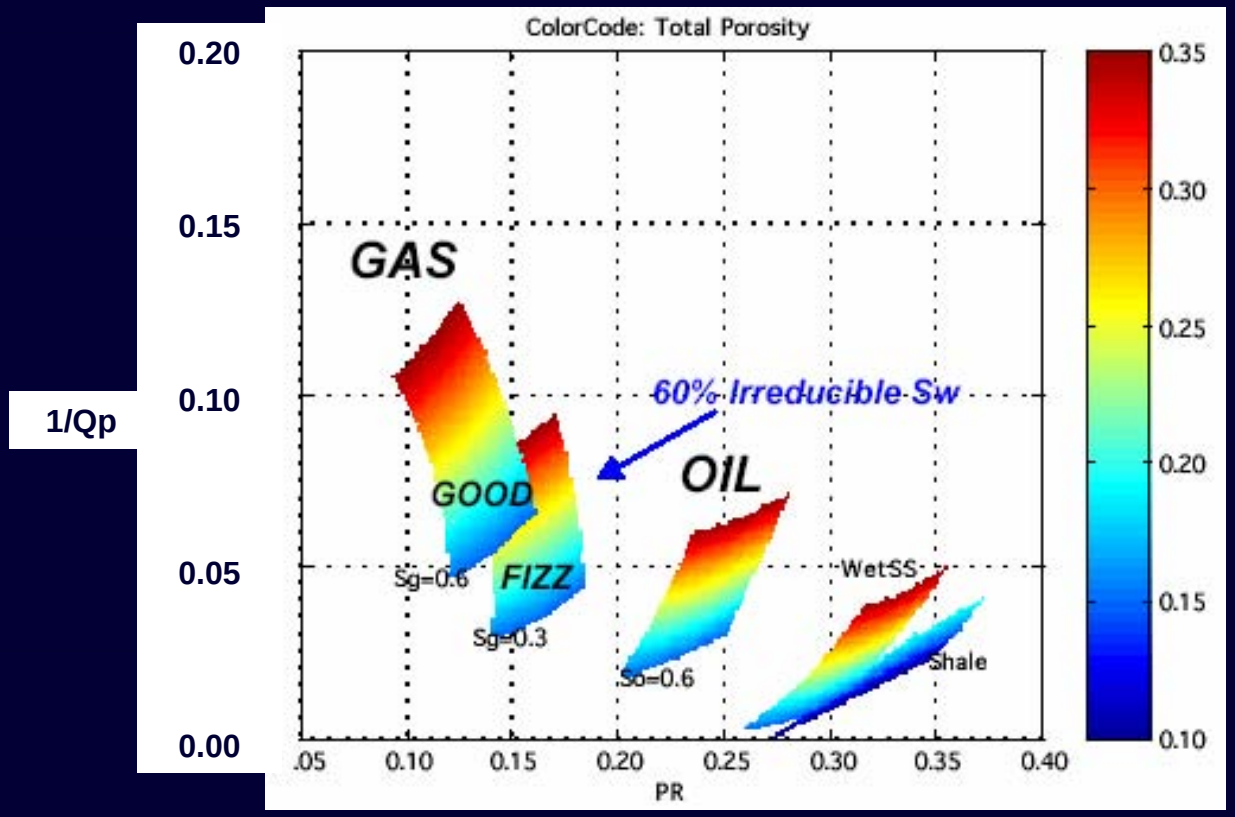
Implications for DHI

The combination of Poisson's ratio (from AVO) and attenuation can be a very powerful tool for discriminating water, oil, gas, fizz.



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Summary: Rock Physics Modeling

A new rock physics model for attenuation in rock allows us to:

- *Calculate attenuation from standard well log curves,*
- *Forward model the effect of saturation, porosity, and lithology changes on attenuation, and*
- *Provide input data for Q synthetics seismogams*

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Effect of Attenuation on Synthetics (Task 3)

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Outline

- Reminder about Causality
- Implementing a Q-filter
- Ray-tracer
- Results

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Ray Tracer; Pros and Cons

Cons: No treatment of:

- 2D, 3D Earth Structure
- 1D, 2D, 3D source characteristics
- Spherical divergence
- Focusing effects
- Multiples
- Anisotropy

Pros:

- Portable (Matlab)
- Lighting Fast

Shortcomings probably comparable to errors in acquisition and processing

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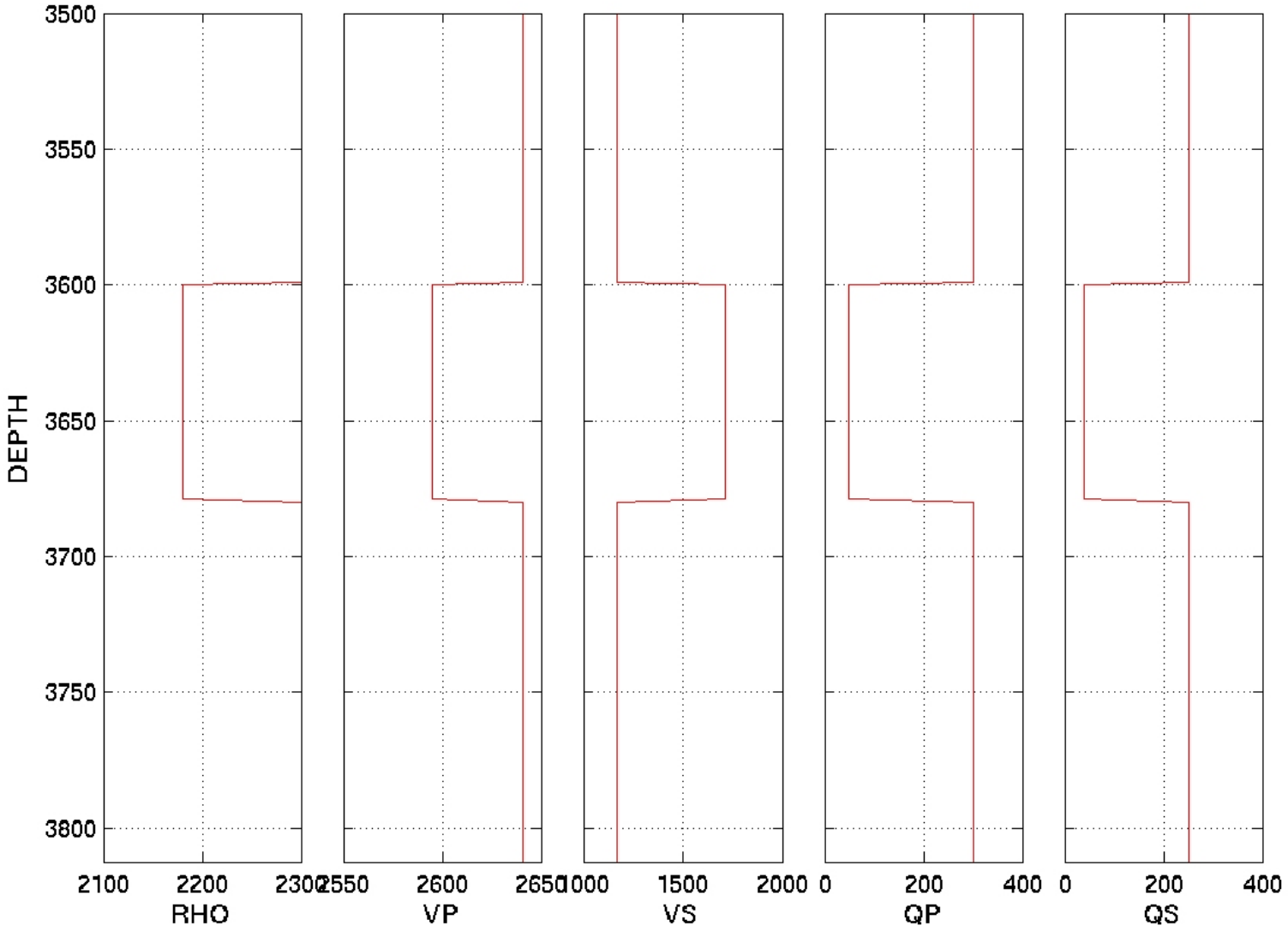
Simple Model - gas sand



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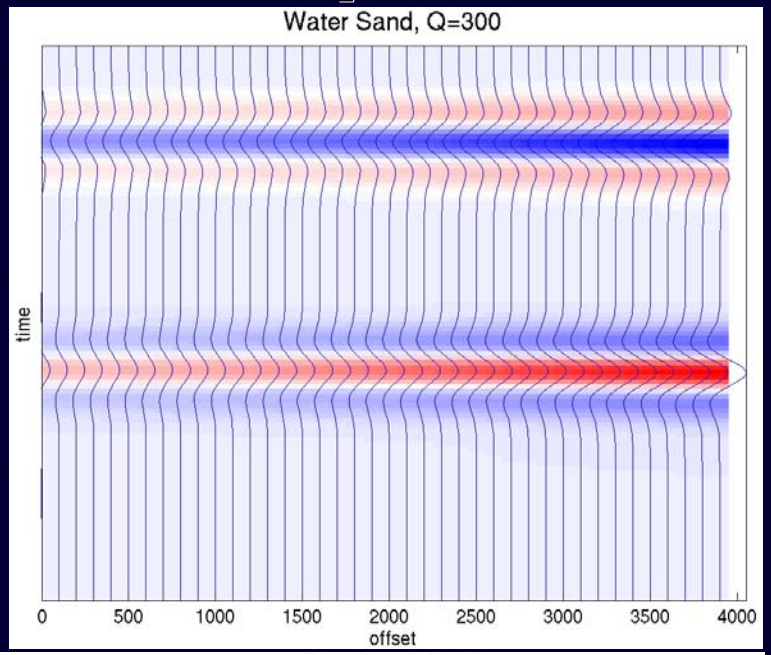
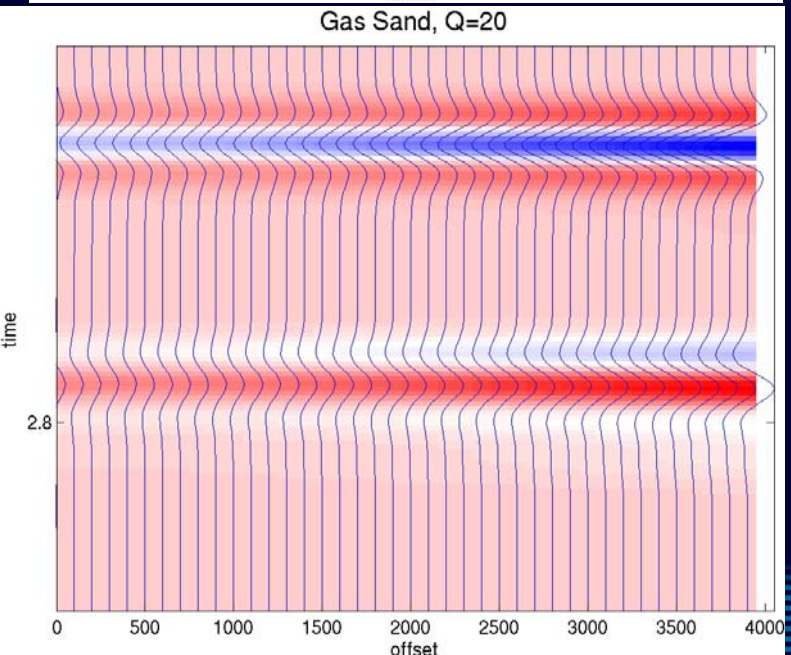
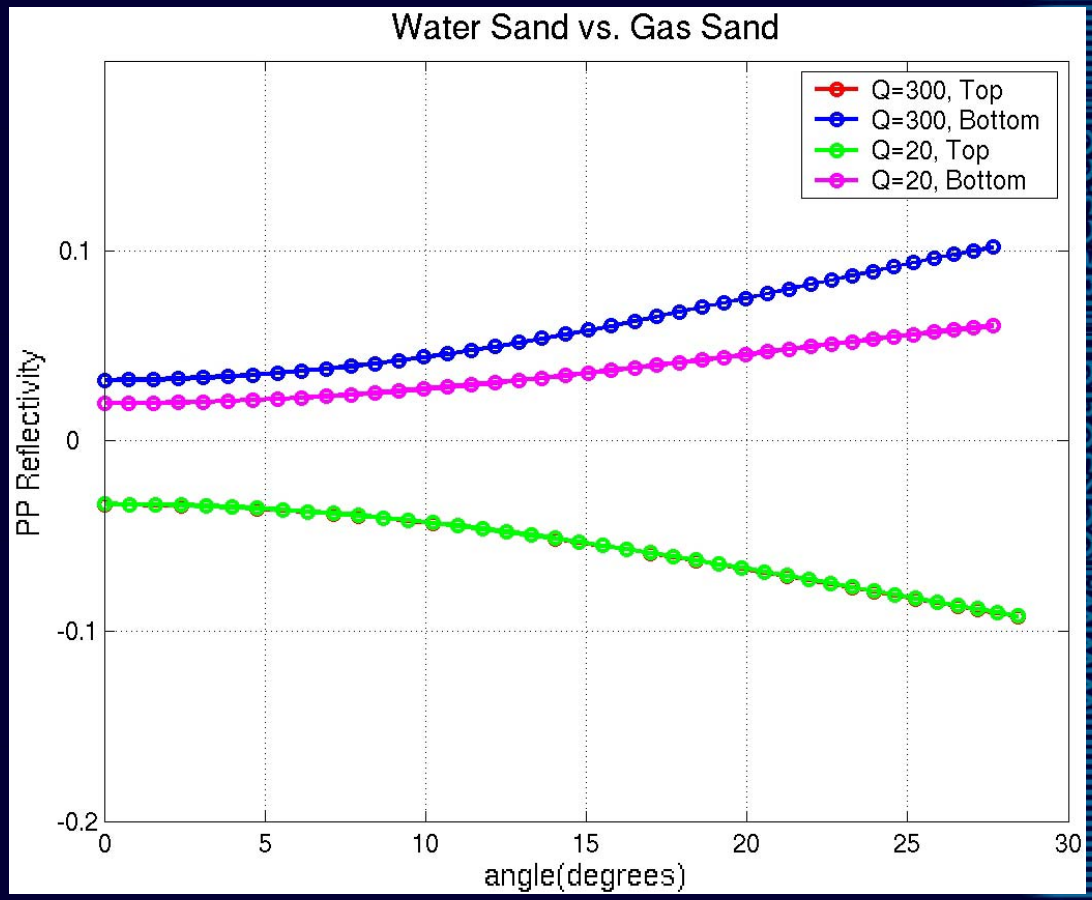
Simple Model - gas sand







Shales, Q=300
Water Sand, Q=300
Gas Sand, Q=20

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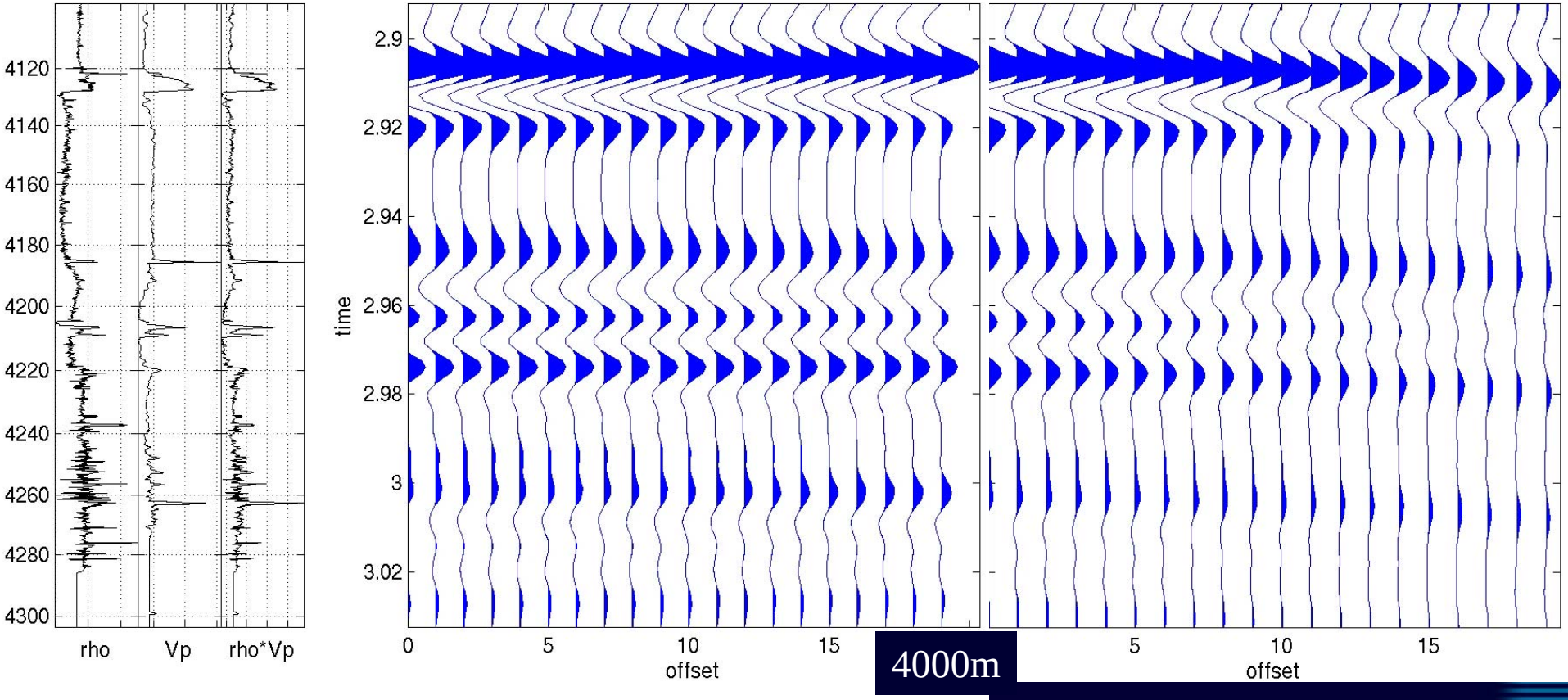
More Complex Model-Turbidite

Elastic Q=50



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Issues for the Future

1. Model Critical Rays and Beyond
2. Incorporate Q-dependent reflectivity
3. Directional recording (vertical component, etc)
4. Focusing, divergence, etc

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Q from Seismic Data (Task 4)

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Review of Attenuation Attributes

- Energy Absorption Analysis (EAA)
  - “Caravel” method using spectral ratio
- Anamolous Absorption (AA)
  - Compares background Q to local variation
- Relative Acoustic Impedance and Q (RAIQ)
  - Hybrid attribute responds to low acoustic impedance and high attenuation

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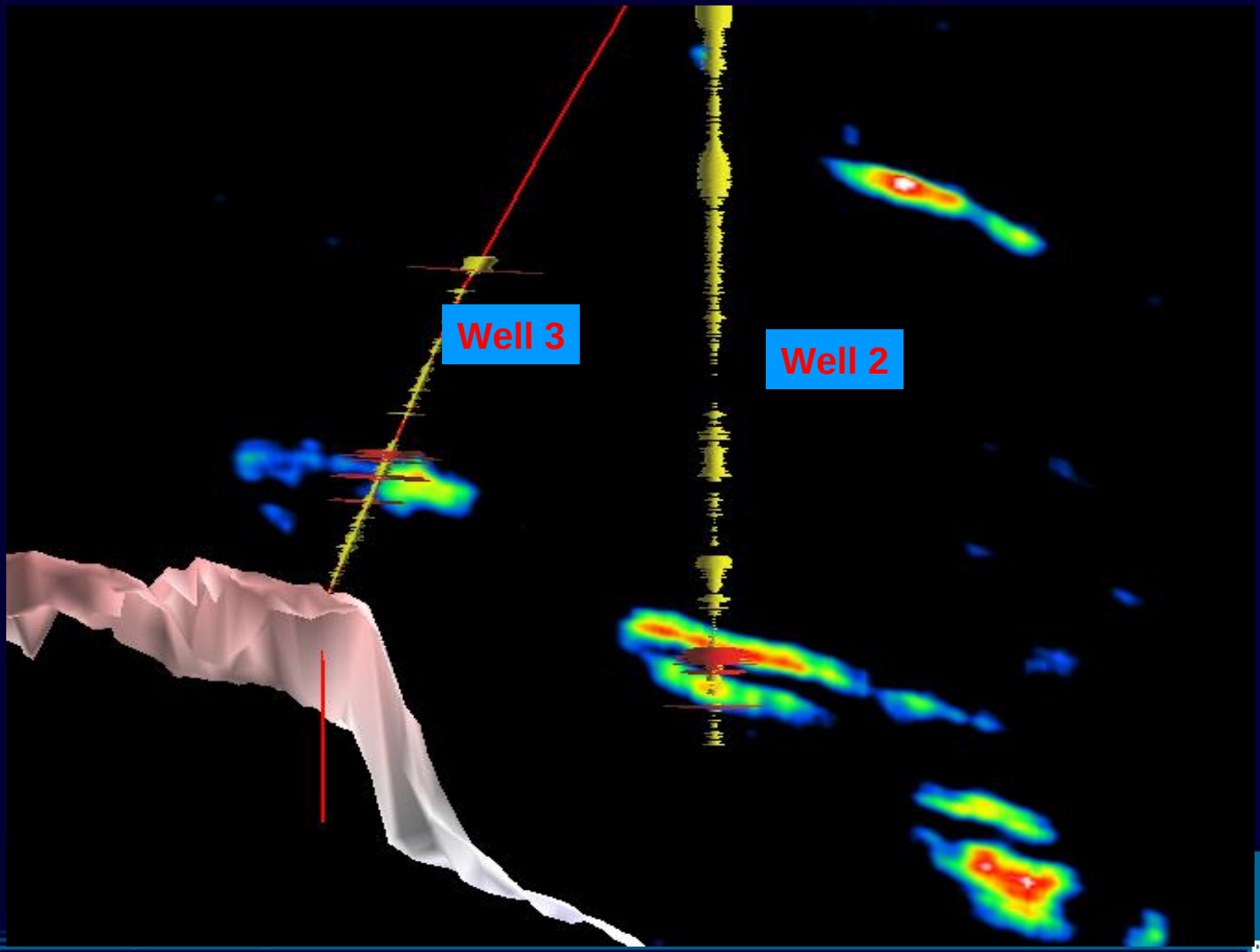
Energy Absorption Analysis (EAA), Deep Water GOM



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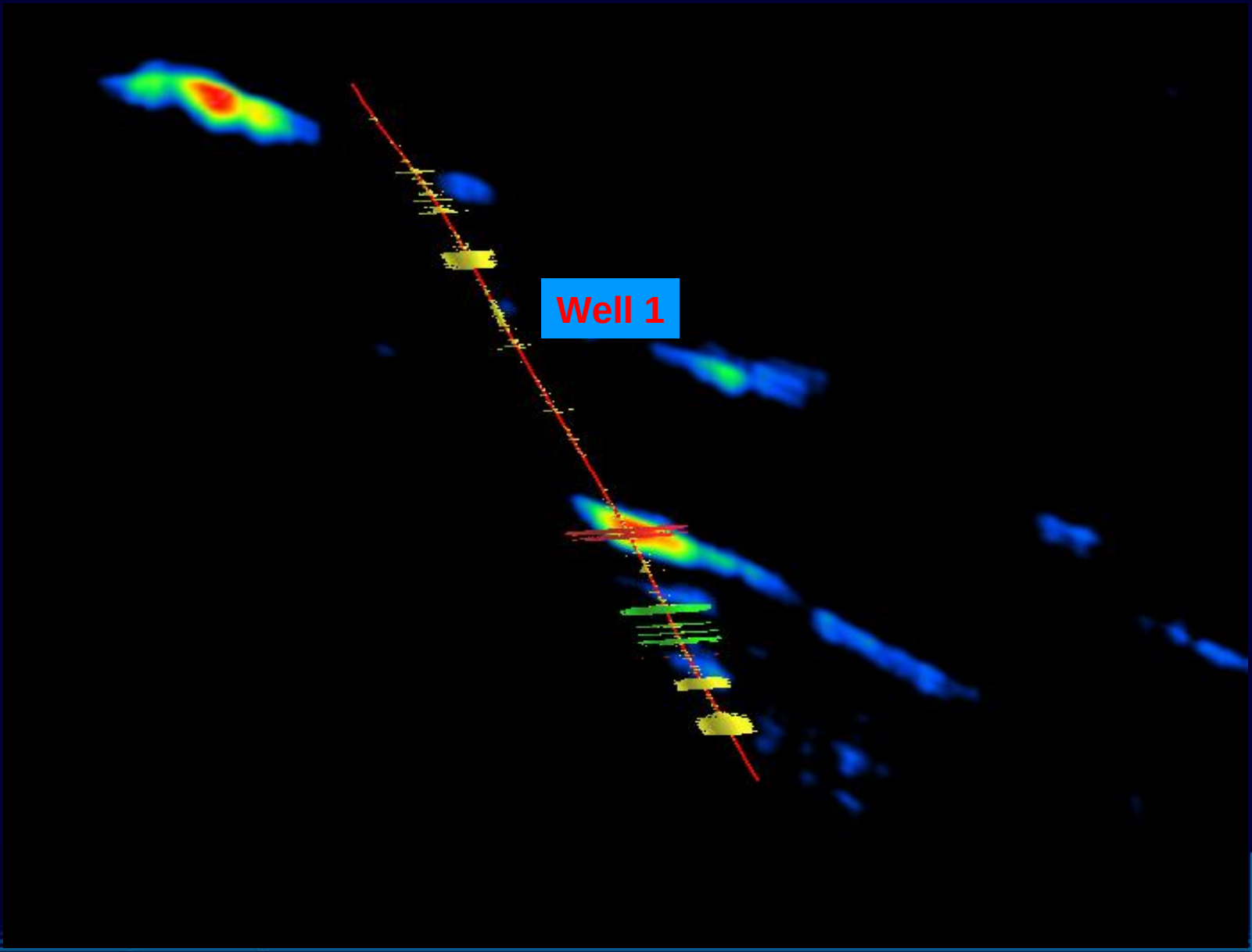
Energy Absorption Analysis (EAA), Deep Water GOM



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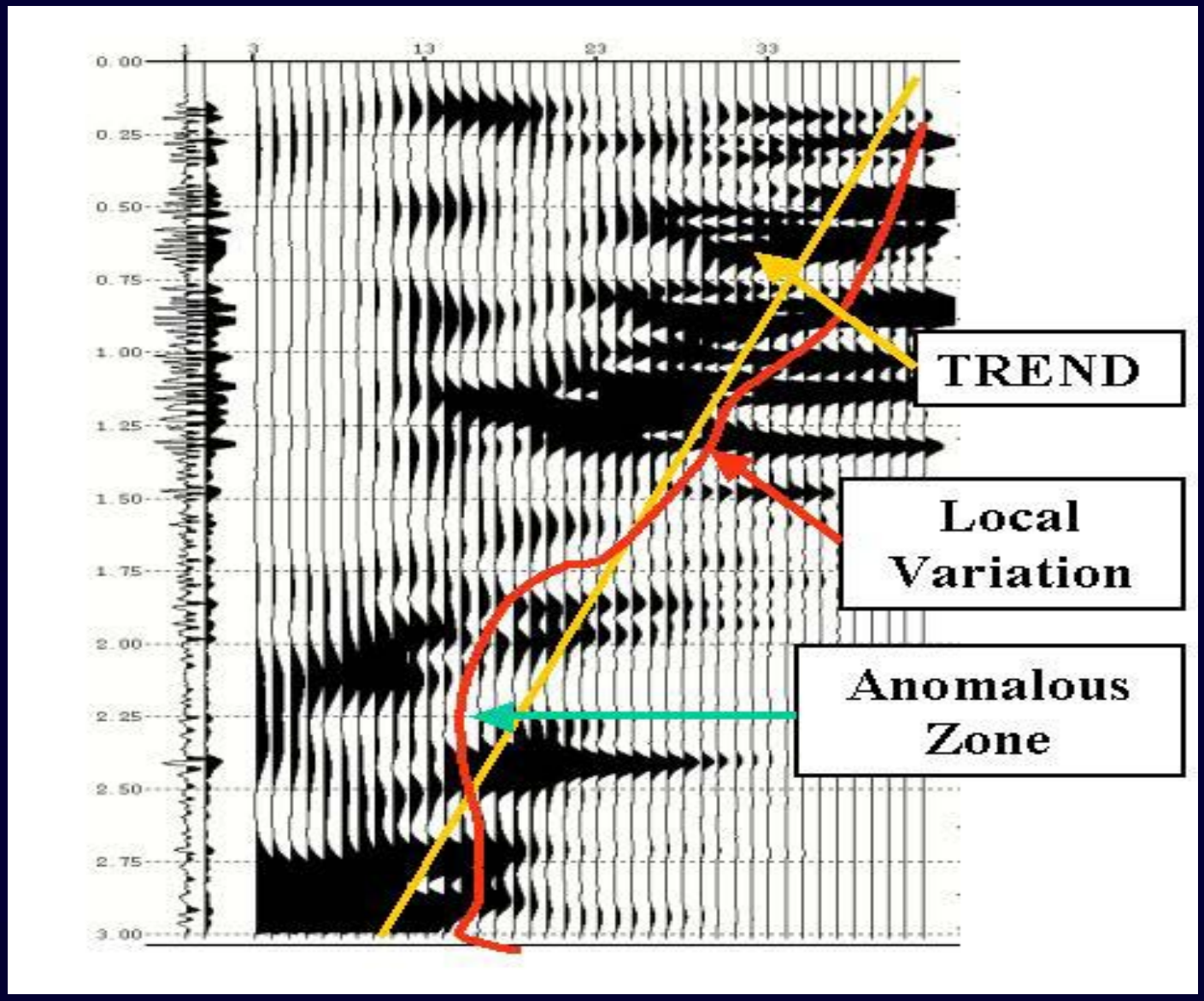
Anomalous Absorption (AA)



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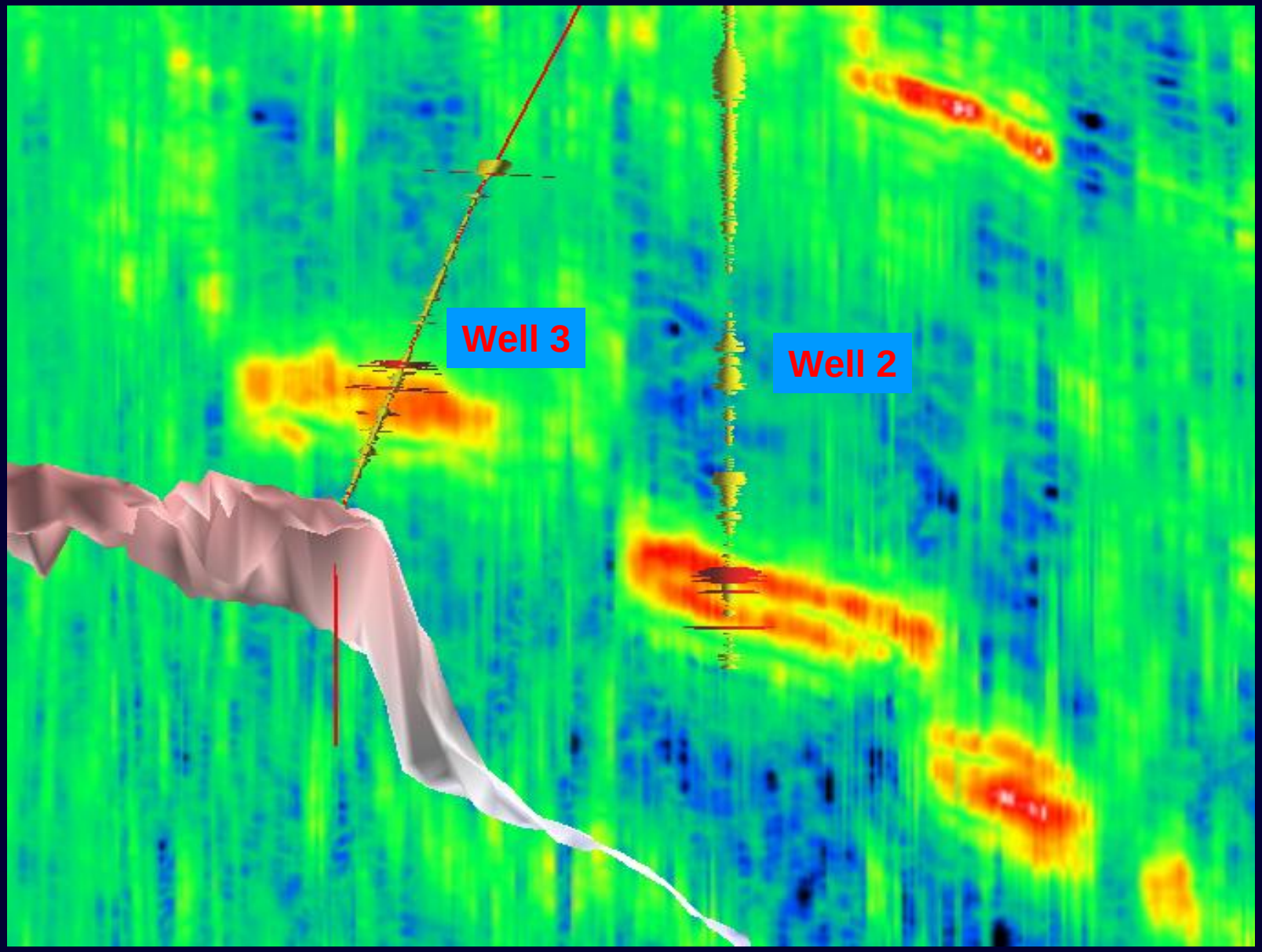
Anomalous Absorption (patent #1), Deep Water GOM



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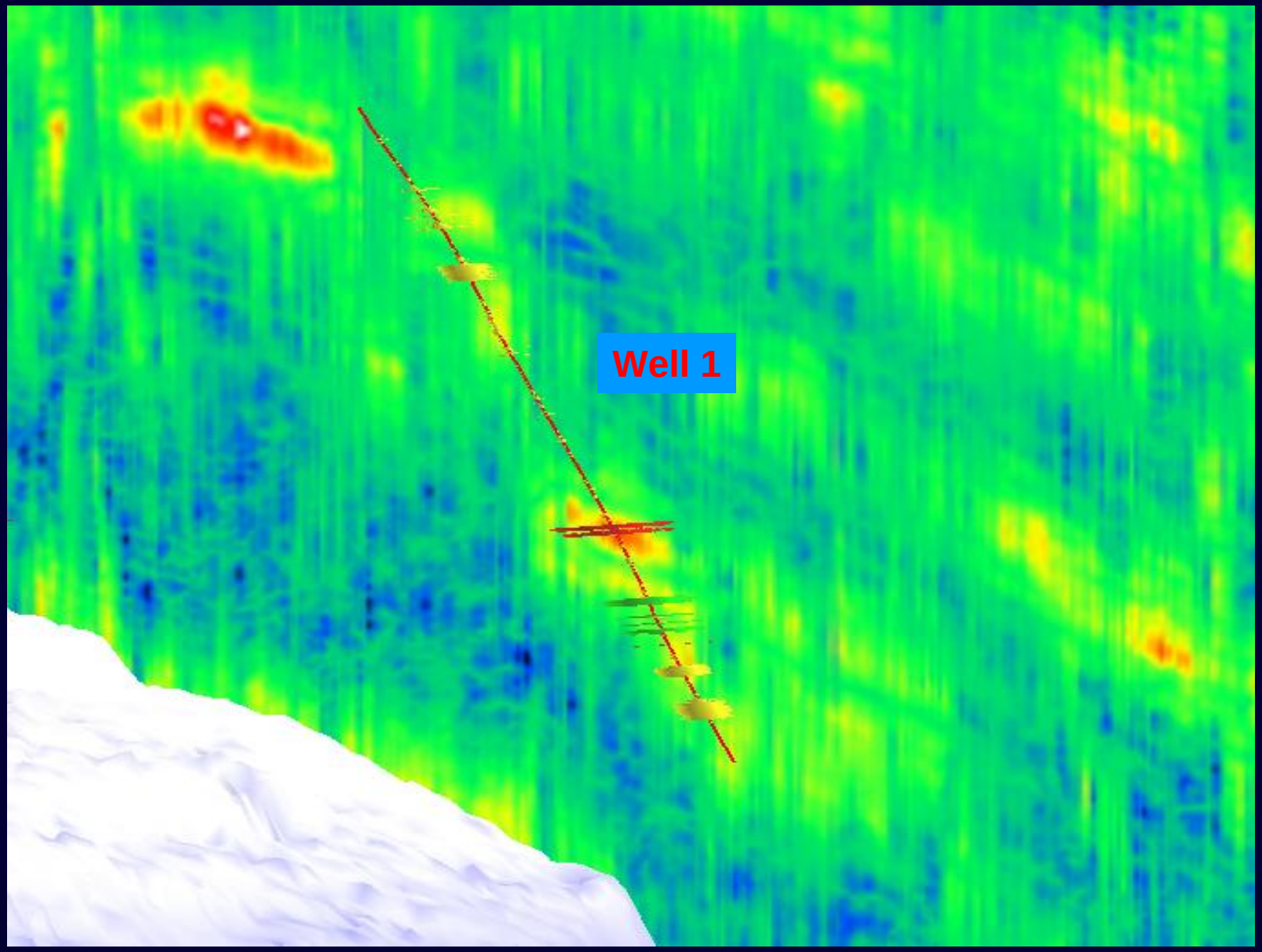
Anomalous Absorption, Deep Water GOM



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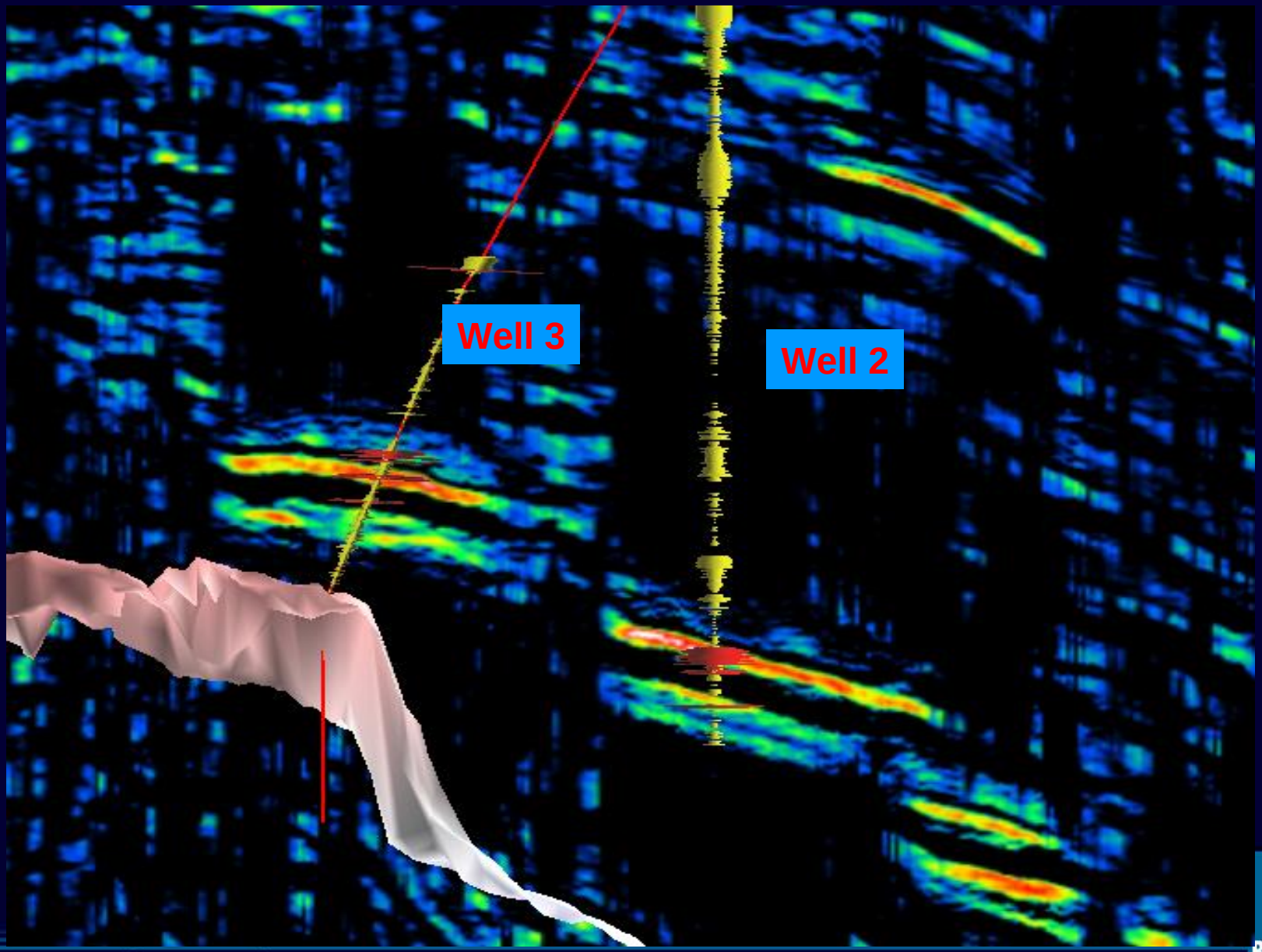
RAI-Q Indicator (Low Impedance – High Attenuation)



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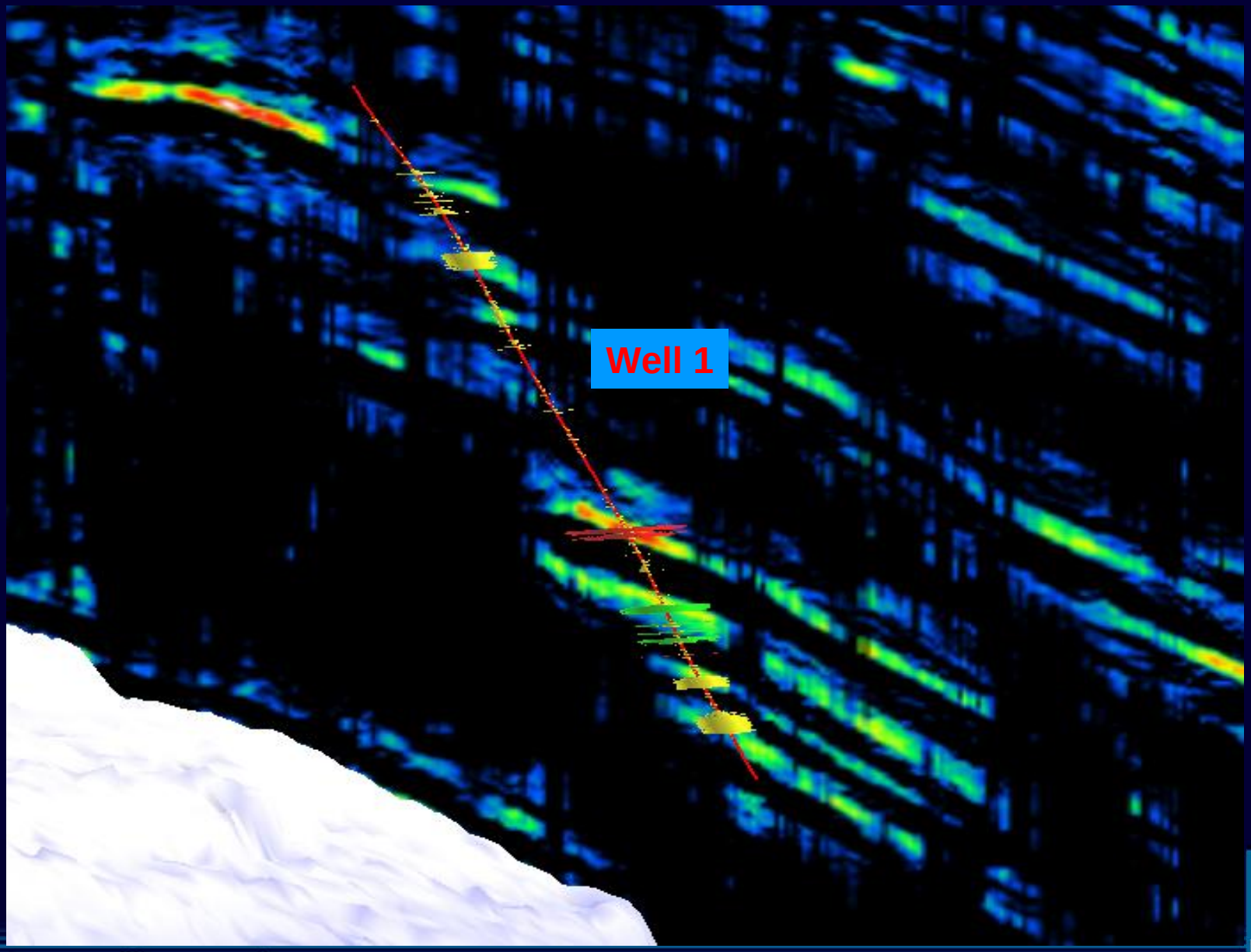
RAI-Q Indicator, Deep Water GOM



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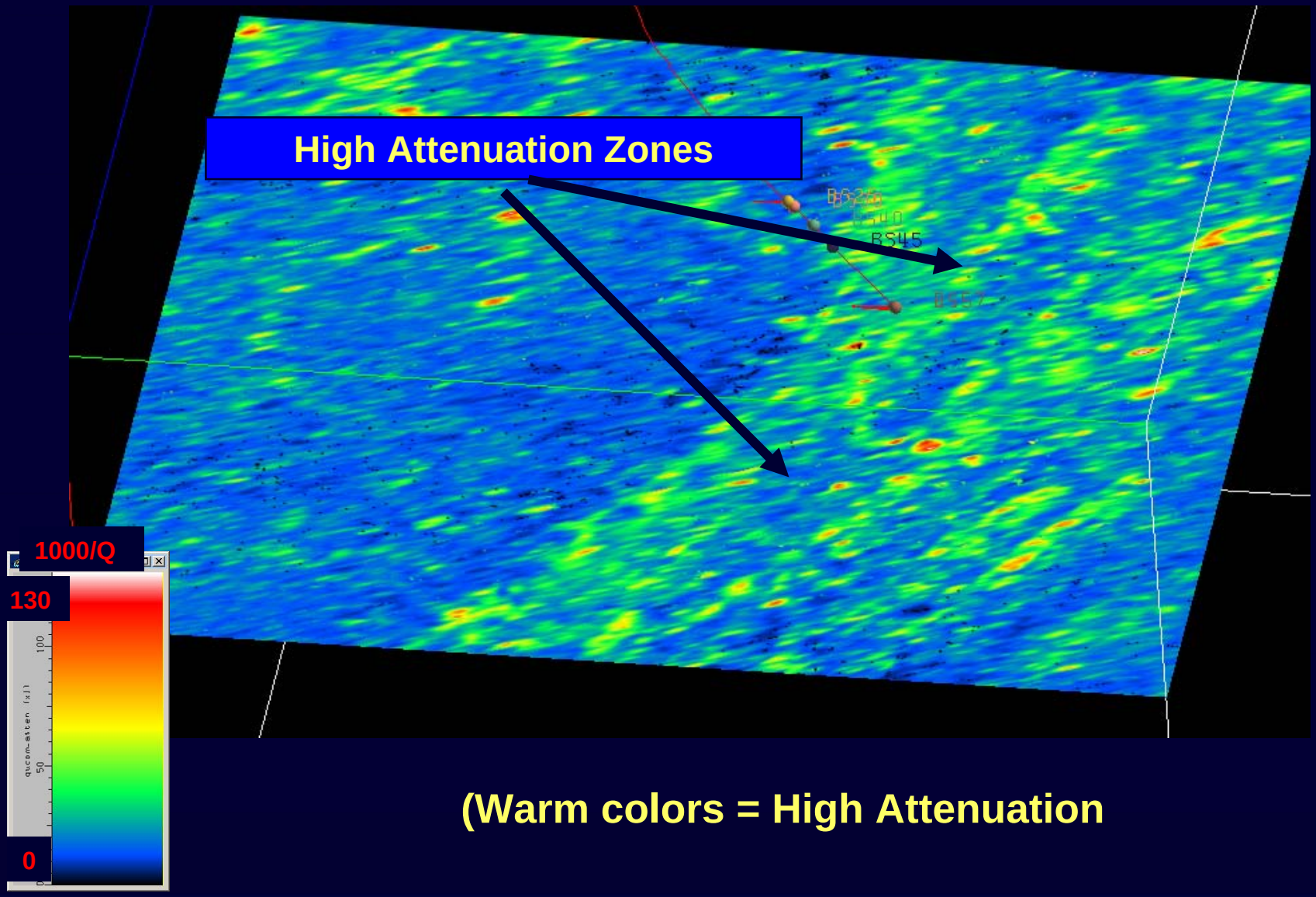
Q by Minimum Phase Inverse Method (patent #2)



(Warm colors = High Attenuation

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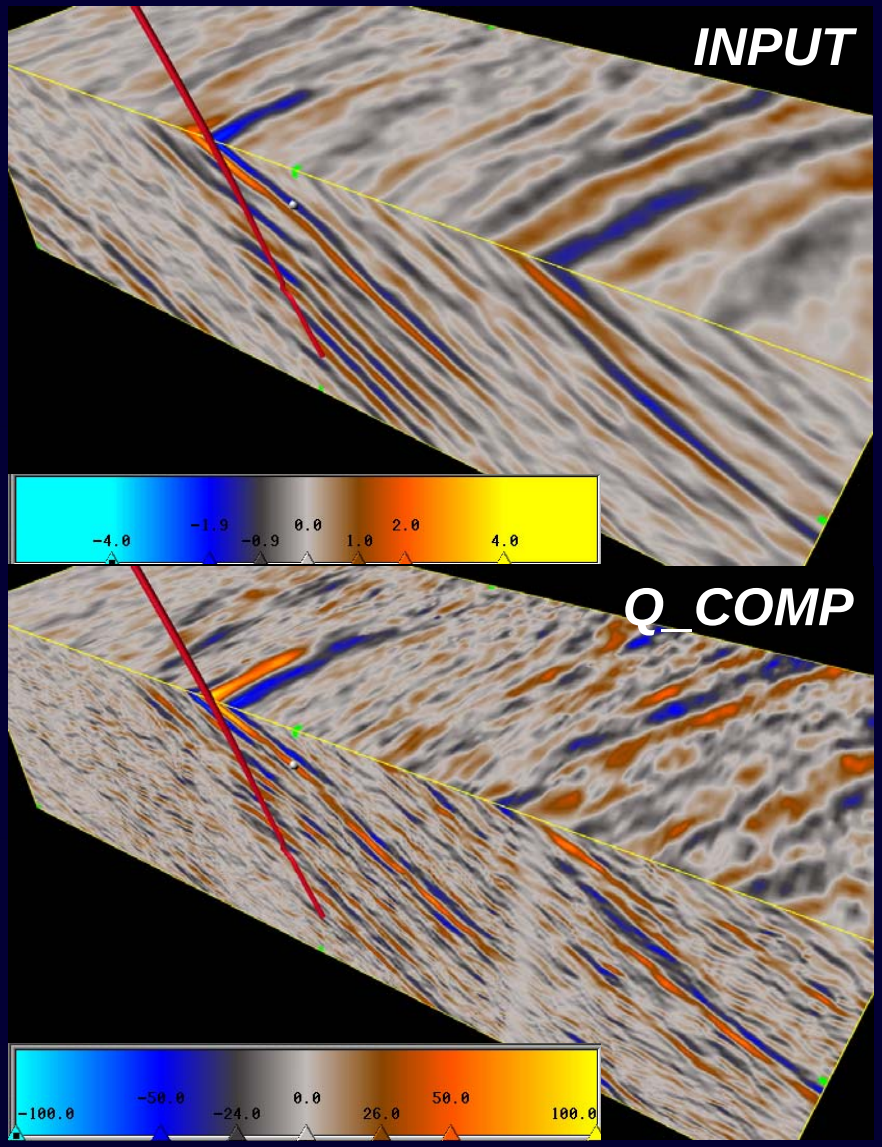
Q Compensation for Improved Resolution



Q compensation corrects the time/phase shift due to the absorption effect

Vertical resolution is improved with low noise addition

Noise addition may be attenuated by application of Edge Preserving Smoothing

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Commercial Applications

- Unconsolidated Sands, GOM
- Carbonate Oil Reservoirs, Tunisia
- Gas Hydrates, Nakai Trough
- Tight Gas Sands, Green River Basin
- Many others.

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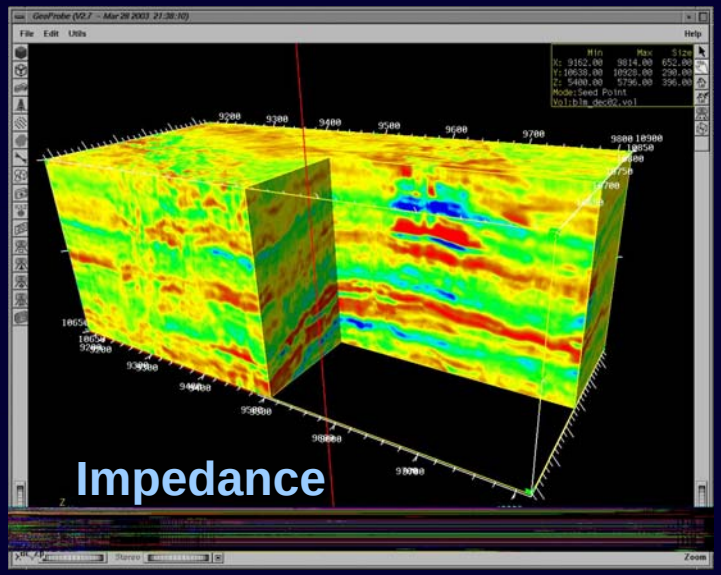
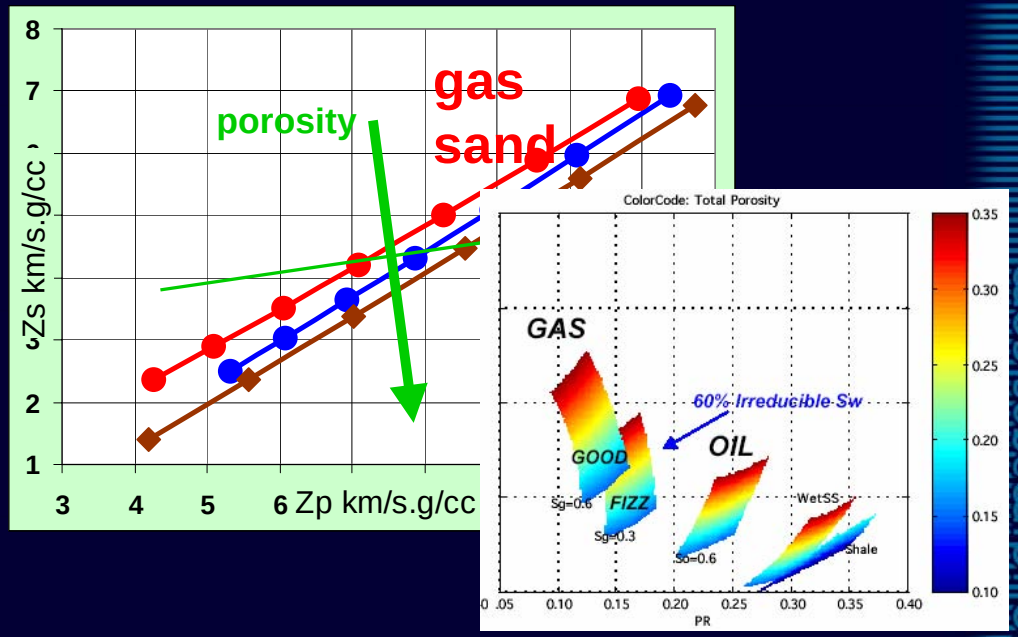
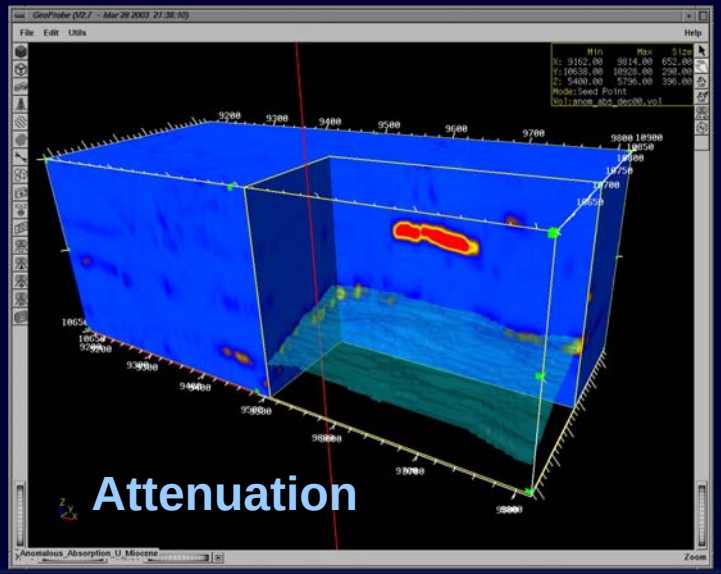
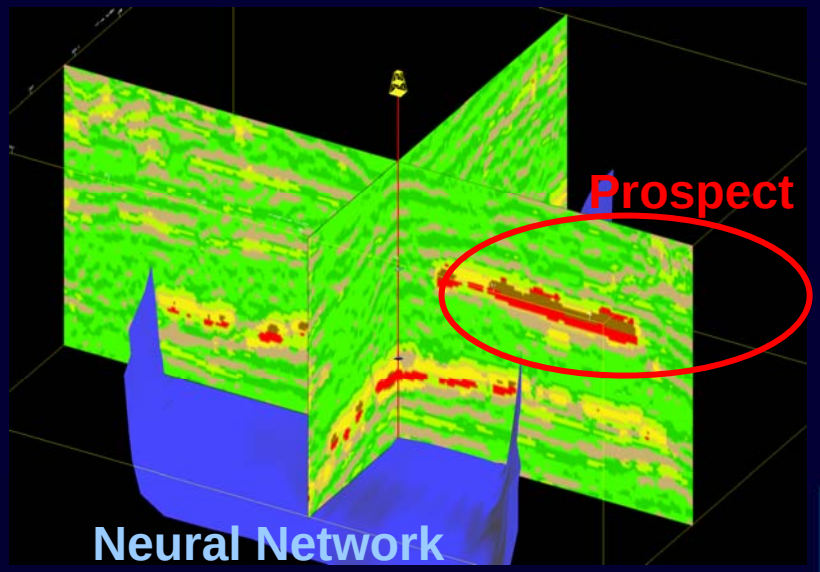
Multi-Attribute Reservoir Characterization, Deep GOM









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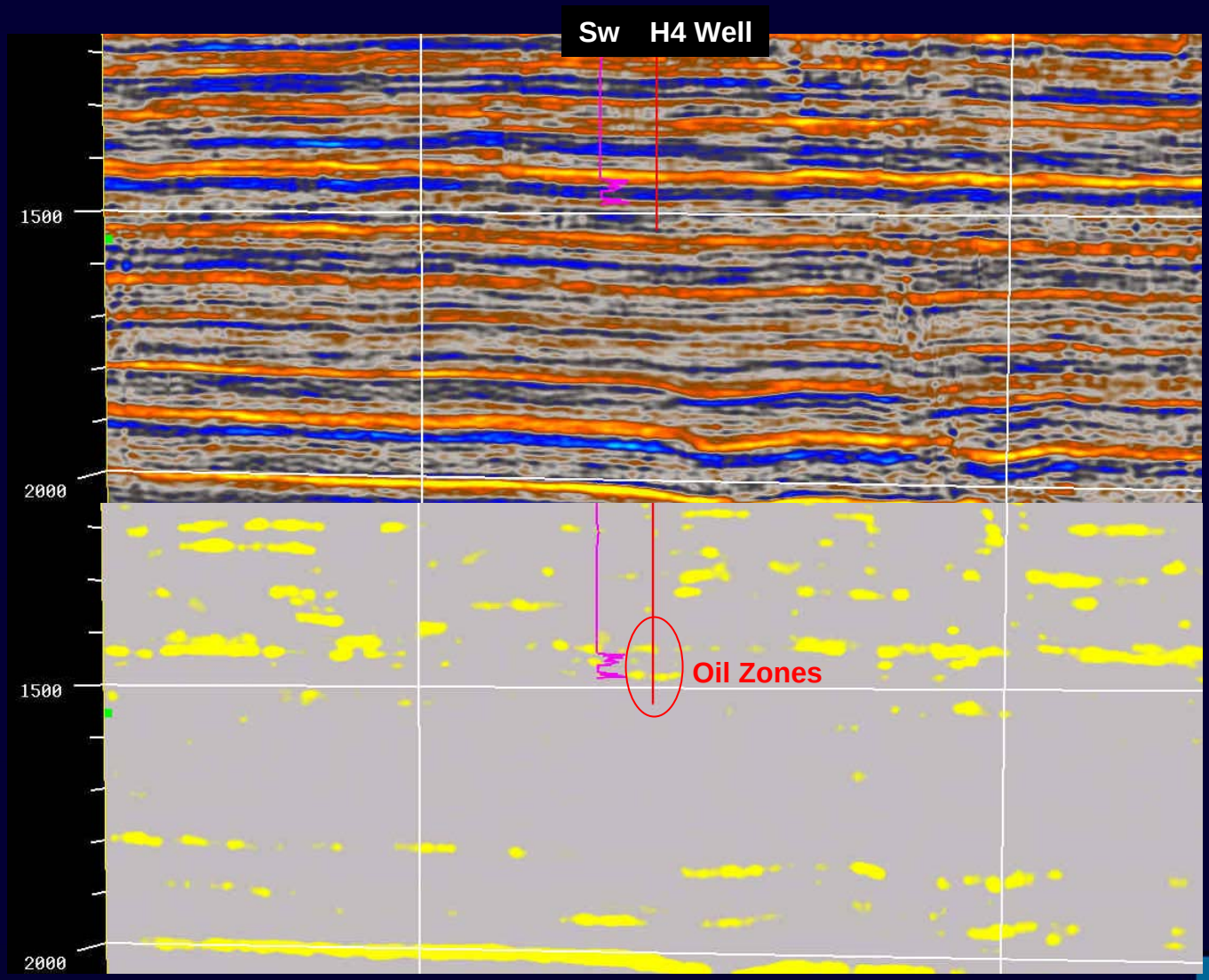
Carbonate Oil Reservoir, Tunisia

Impedance

Anomalous Absorption



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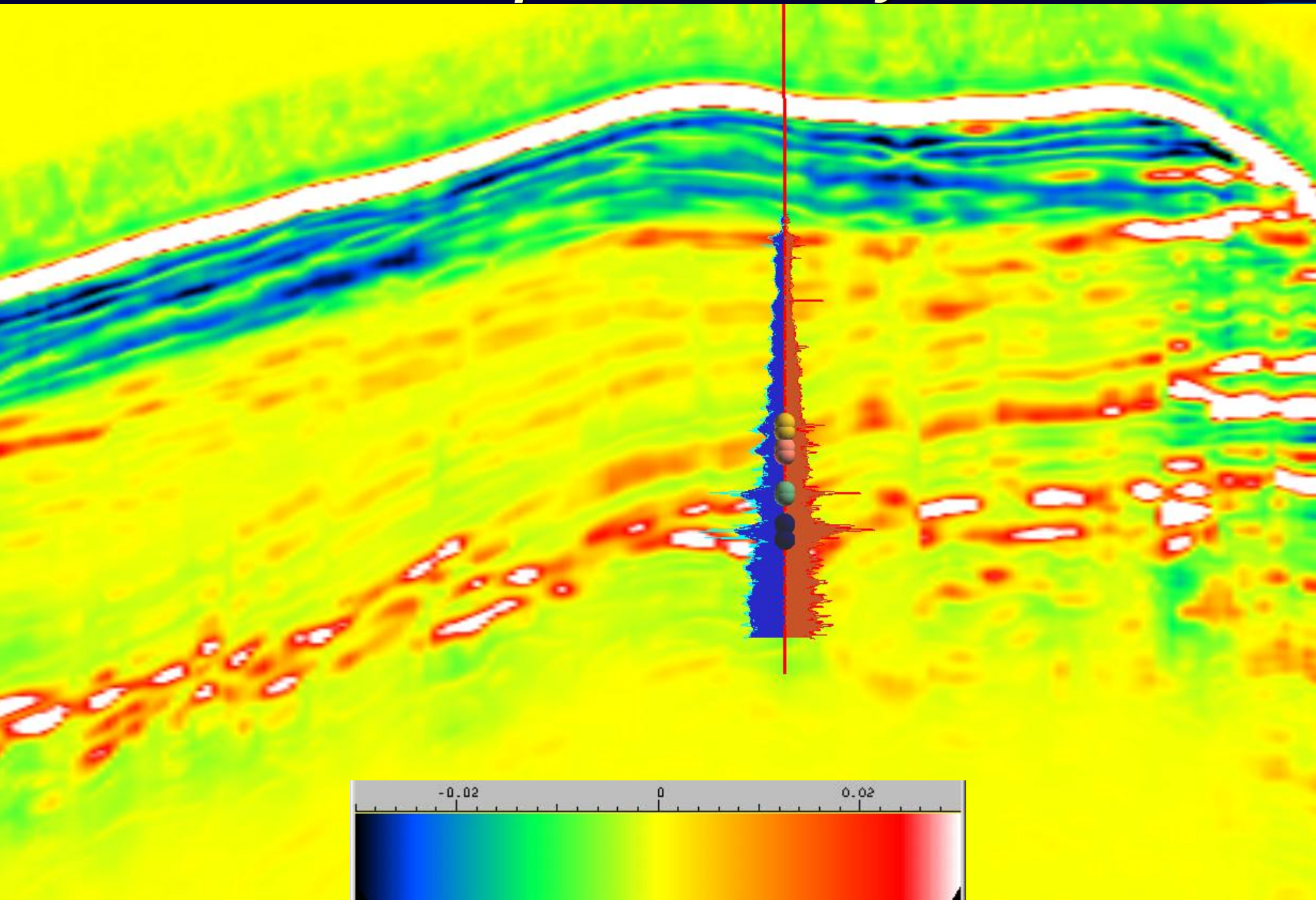
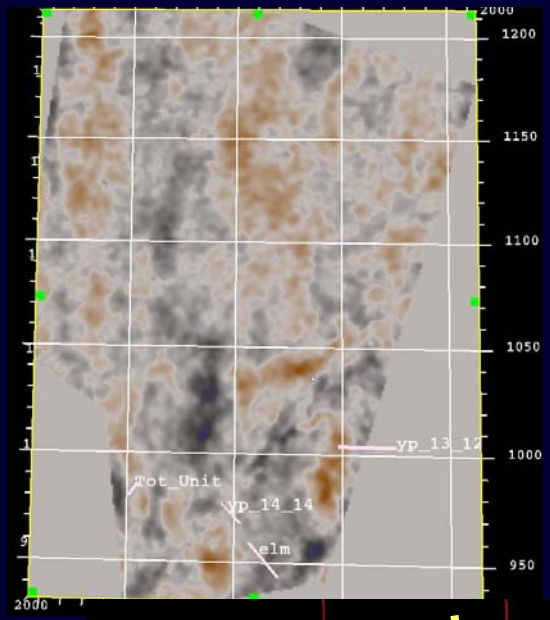
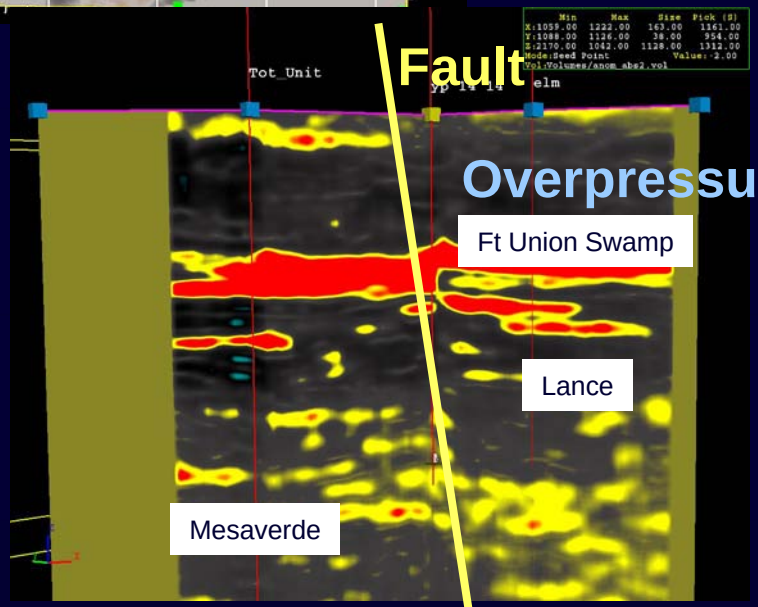
Anomalous Absorption –Gas Hydrate

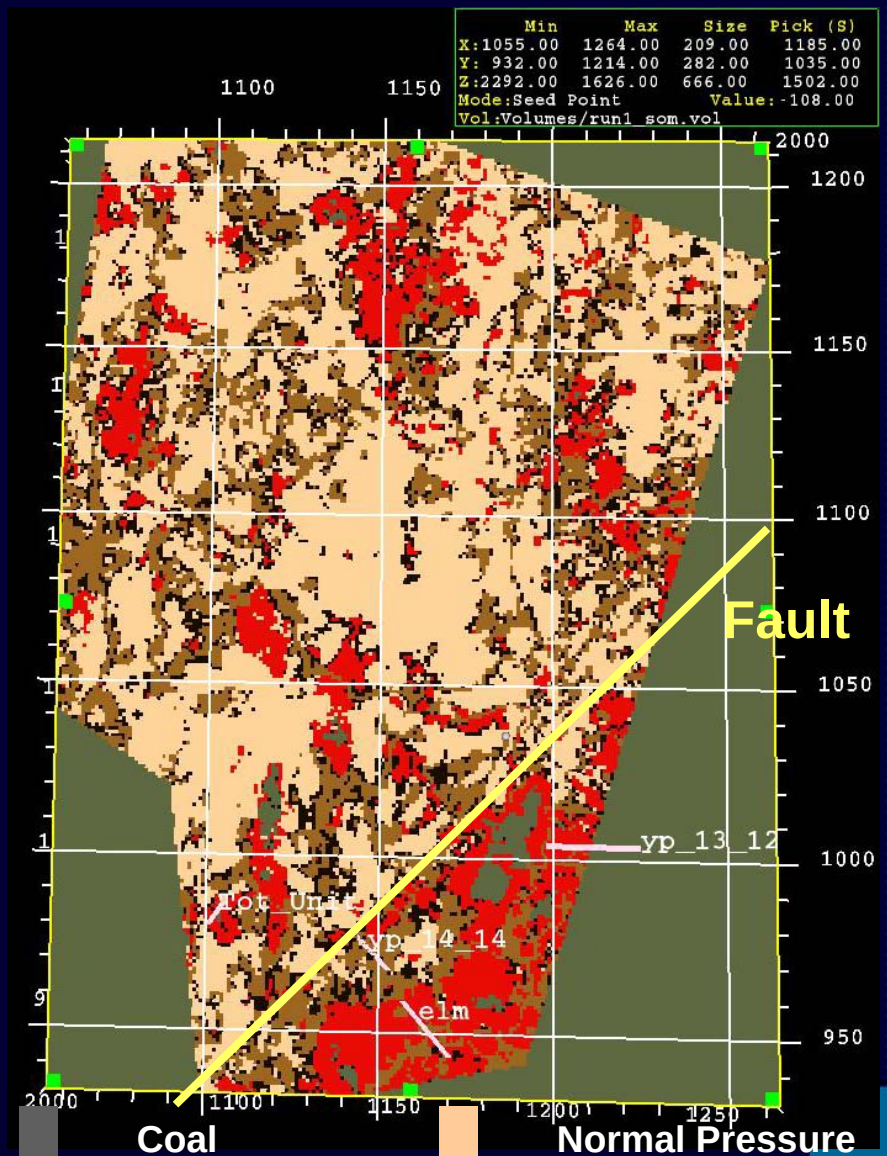


Green River Basin; Overpressure





AA



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Opportunities and Challenges

- Q Field Studies (with industry co-funding)
- Applications to Specific Problems
  - “Fizz-gas” (anomalous amplitudes from non-commercial gas accumulations)
  - Gas hydrates
  - Coal-bed methane
  - Tight gas sands
  - Fractured reservoirs
  - Carbonates
- Combining Q with AVO, Acoustic Impedance, and other seismic attributes

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