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And special thanks to The American Institute of Mining, Metallurgical,
and Petroleum Engineers (AIME) for their contribution to the program.

Optimizing Asset Design - Cradle to Grave

"Bridging the Gap between the Earth Science & Engineering Disciplines using Mechanical Earth Modeling Technology"

Harvey E. Goodman

Chevron Fellow

Rock Mechanics & Mechanical Earth Modeling

Business Driver and Technical Focus Area Selection

Business driver:

Optimize well Design - Reliability and Placement through the life of the gas/oil field asset.

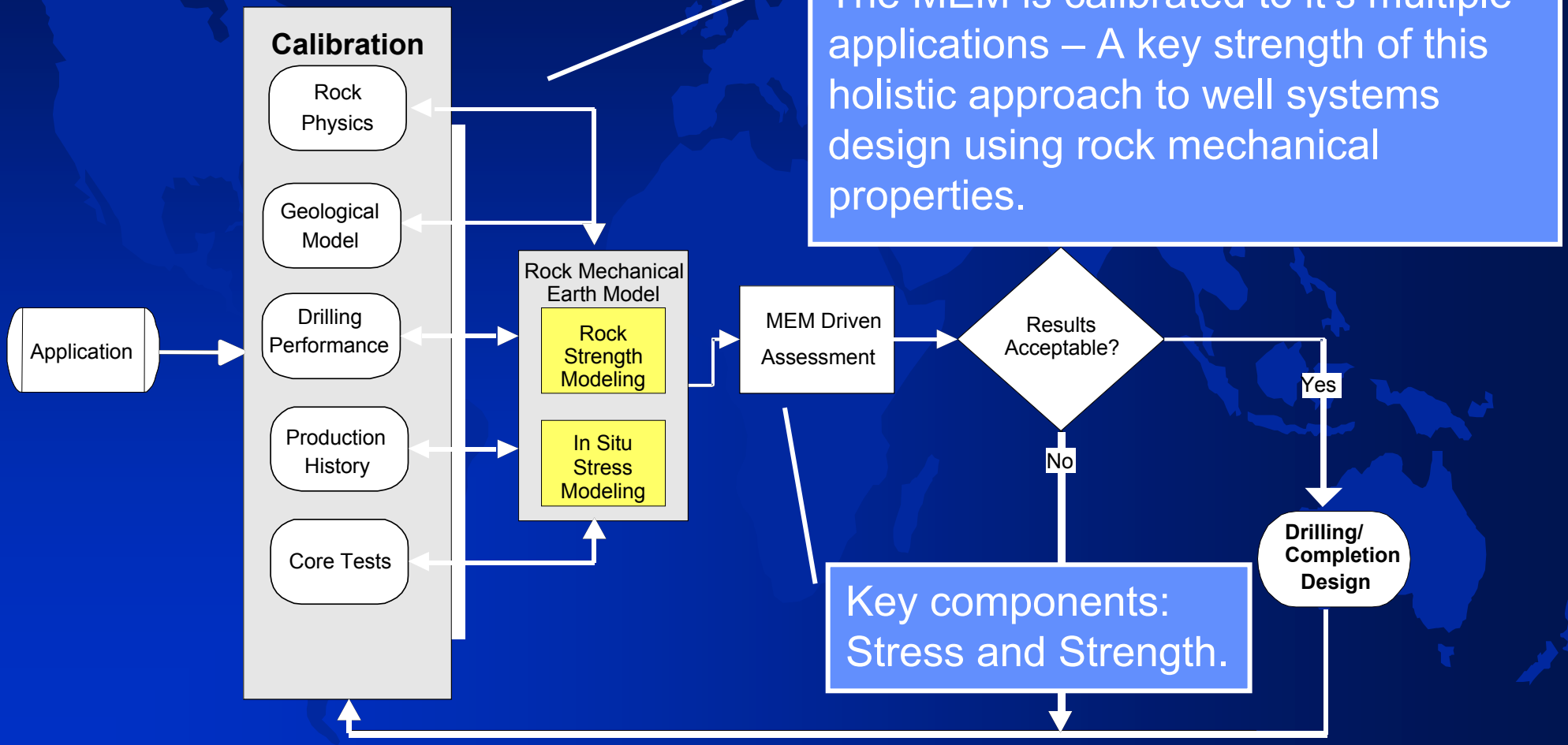
Technical focus:

Link the engineering disciplines necessary to build safe, reliable well systems with the geological and geophysical sciences involved in asset discovery.

Discussion Topics

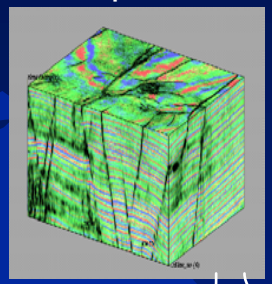
1. The Mechanical Earth Model (MEM) approach to well systems design
   - What is it?
   - How can a MEM add value?
2. Building the MEM from Acoustics Data
   - Rock properties and acoustics predictions
   - Seismic techniques
   - Examples
3. Using the MEM to conceptualize development risks
   - Hole stability
4. Future Trends and Challenges

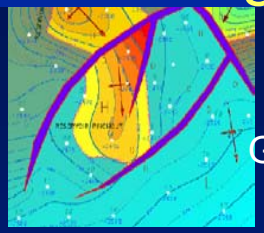
Mechanical Earth Model or MEM



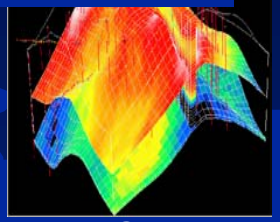
The Mechanical Earth Model
Big Picture

Seismic Interpretation



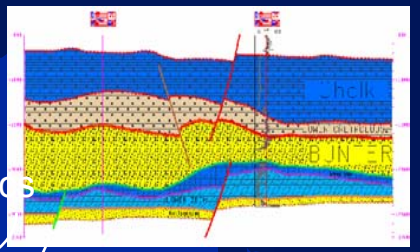


Geol. Maps



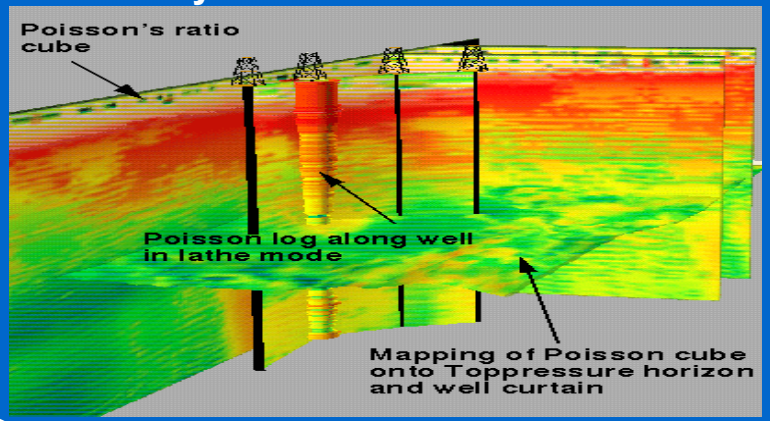
Geostatistics

Reservoir Characterization

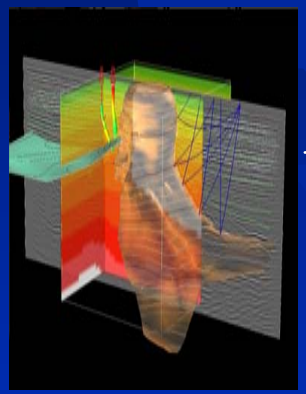


Cross -Sections

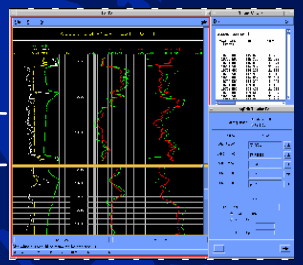
Dynamic Poisson's Ratio



G O C A D



Stratigraphic Modeling

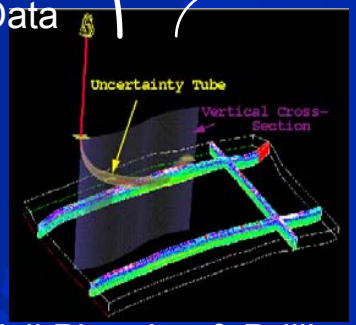


Petrophysics

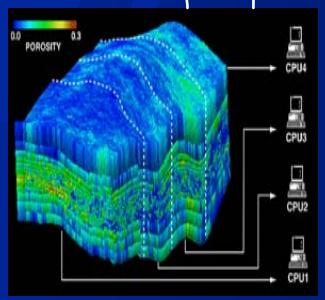
Historical Operational Data

Drilling

Real Time Drilling Data



Well Planning & Drilling Simulation



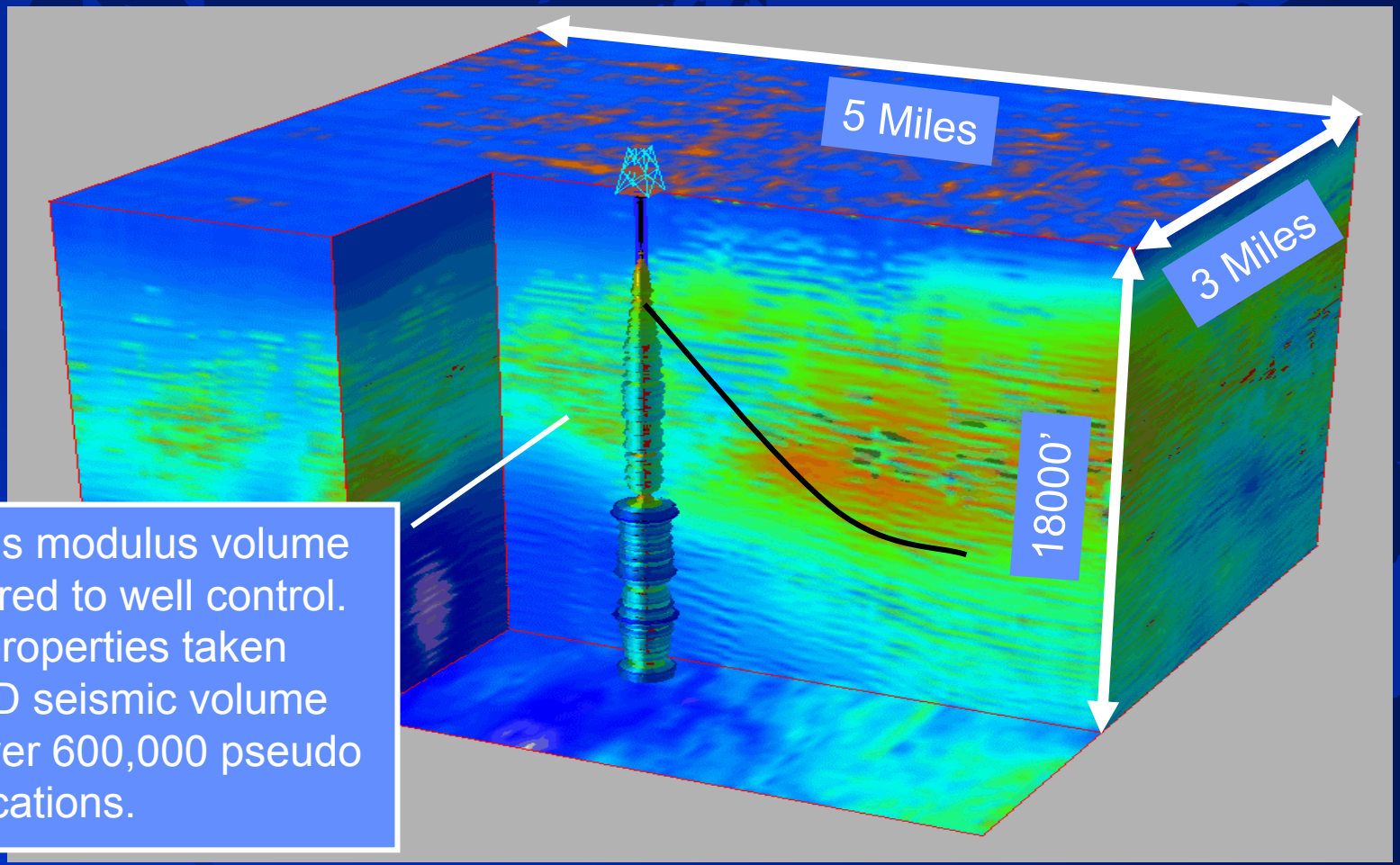
Reservoir Simulation

Historical Production Data

Production

Real Time Production Surveillance

The Mature Mechanical Earth Model



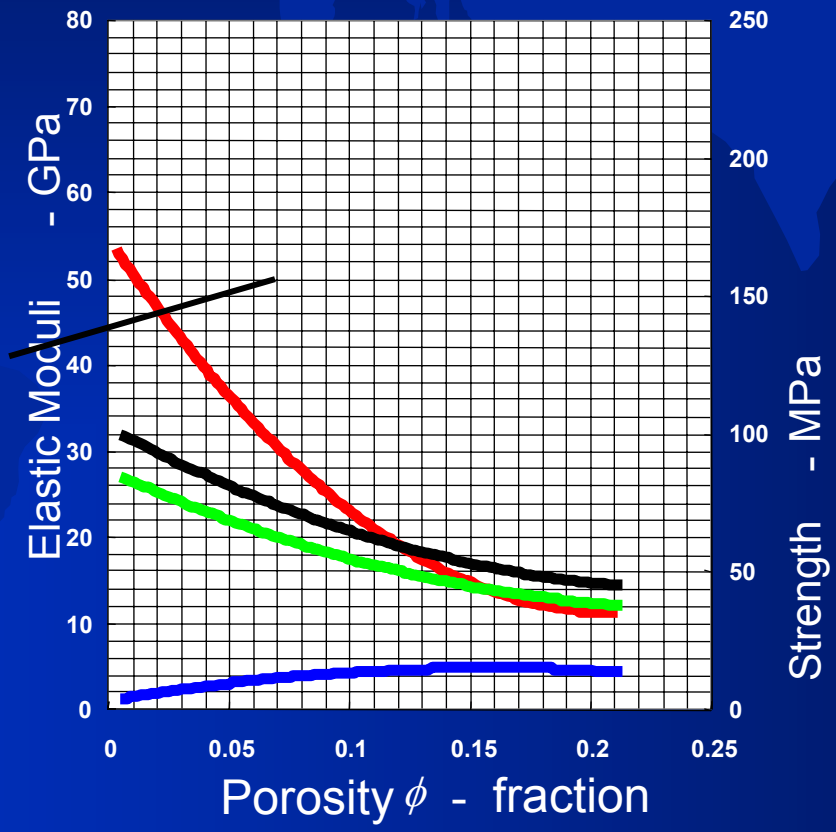
Young’s modulus volume compared to well control. Rock properties taken from 3D seismic volume with over 600,000 pseudo well locations.

Rock Physics and Engineering Properties

- Frame properties are used to estimate rock strength and stress magnitude.

As porosity decreases rock stiffness increases effecting strength and stress propagation tendencies.

Porosity, Elastic Moduli & Compressive Strength



Comp Strength

Bulk Modulus Kb

Shear Modulus G

Pore Vol Modulus Kp

How we use acoustics to define the MEM.
But first, some background:

The P Wave

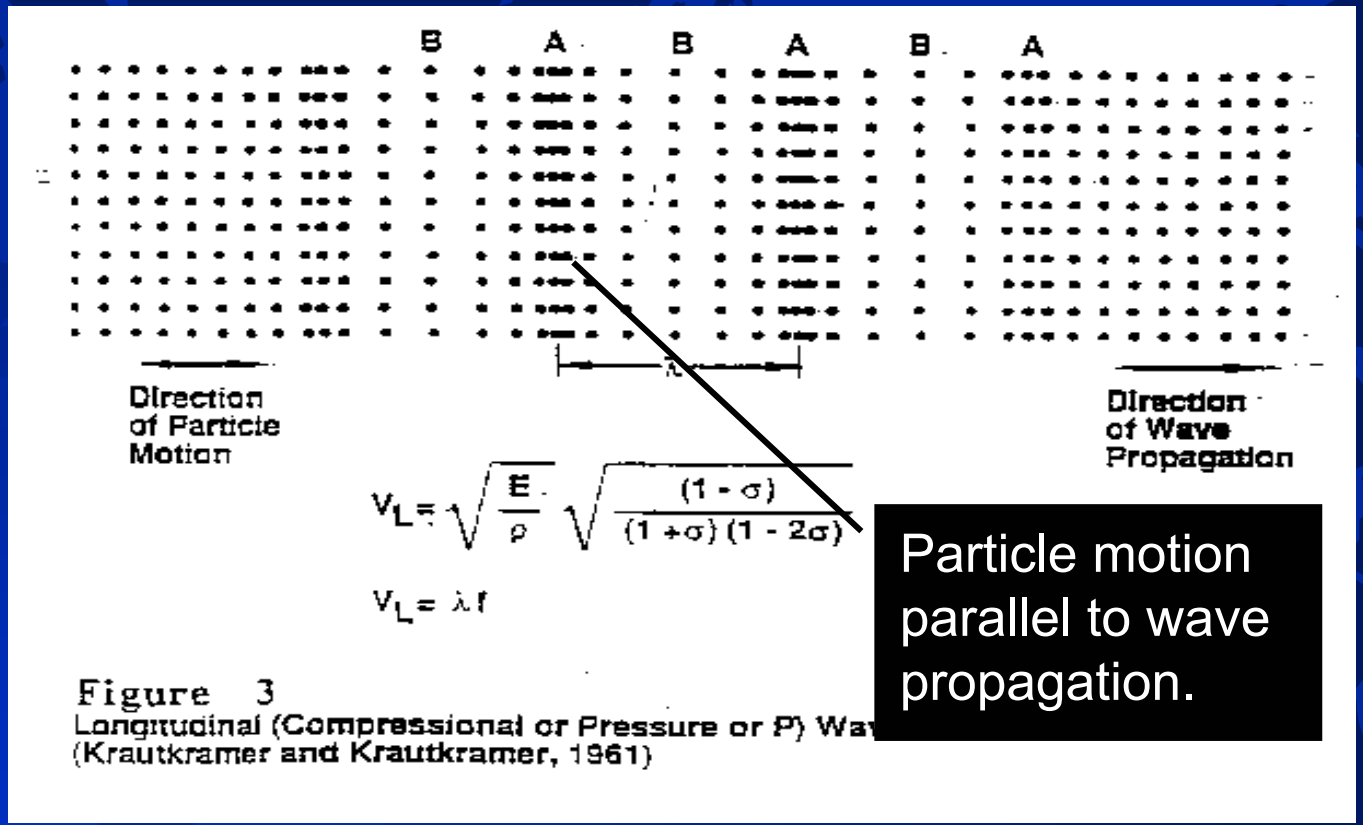
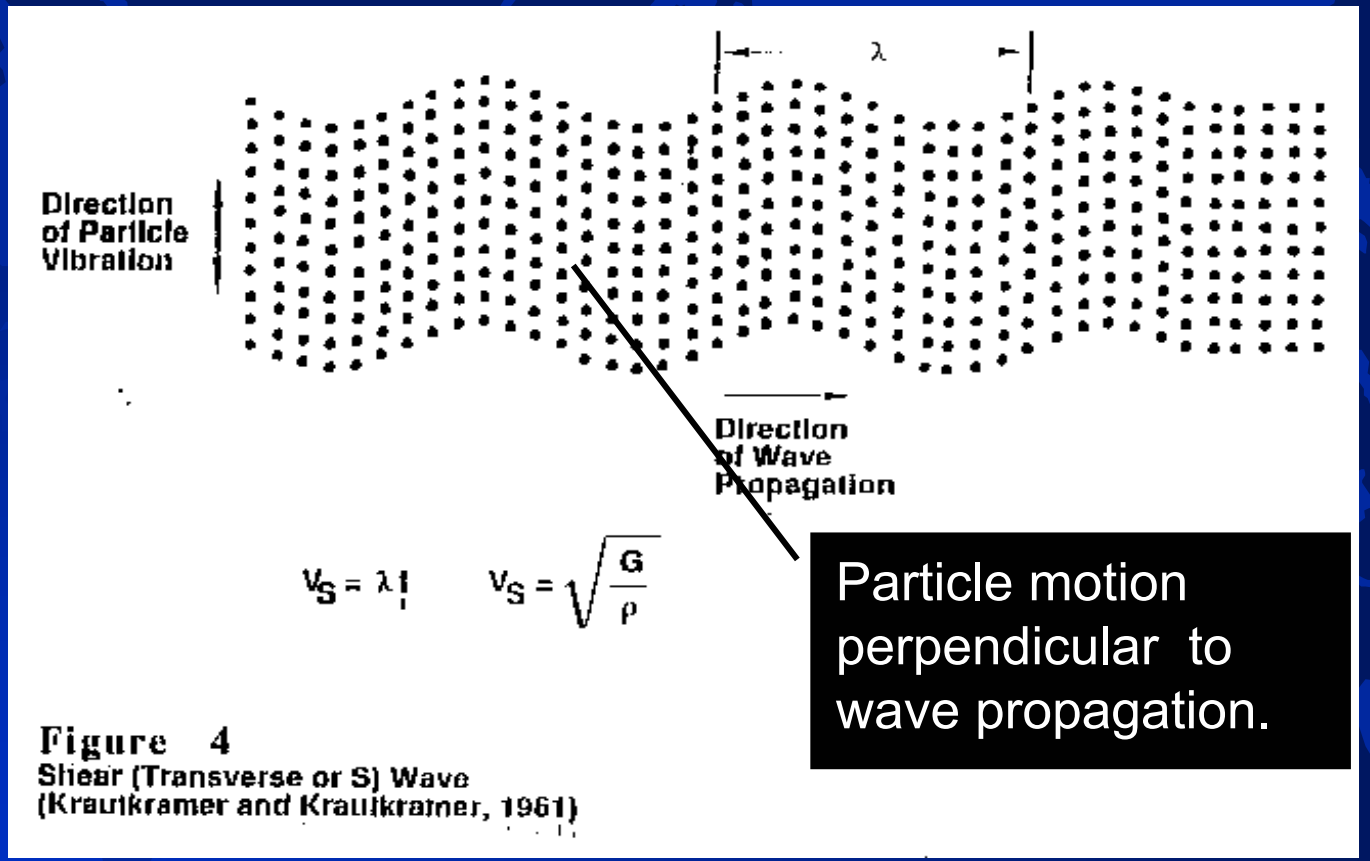


Figure 3
Longitudinal (Compressional or Pressure or P) Wav
(Krautkramer and Krautkramer, 1961)

Particle motion parallel to wave propagation.

The S Wave



Particle motion perpendicular to wave propagation.

Figure 4
Shear (Transverse or S) Wave
(Krautkramer and Krautkramer, 1961)

P & S Velocities

- Depend on the elastic properties of the travel medium
  - Hard rock has fast P & S velocities.
  - Soft rock has slow P & S velocities.

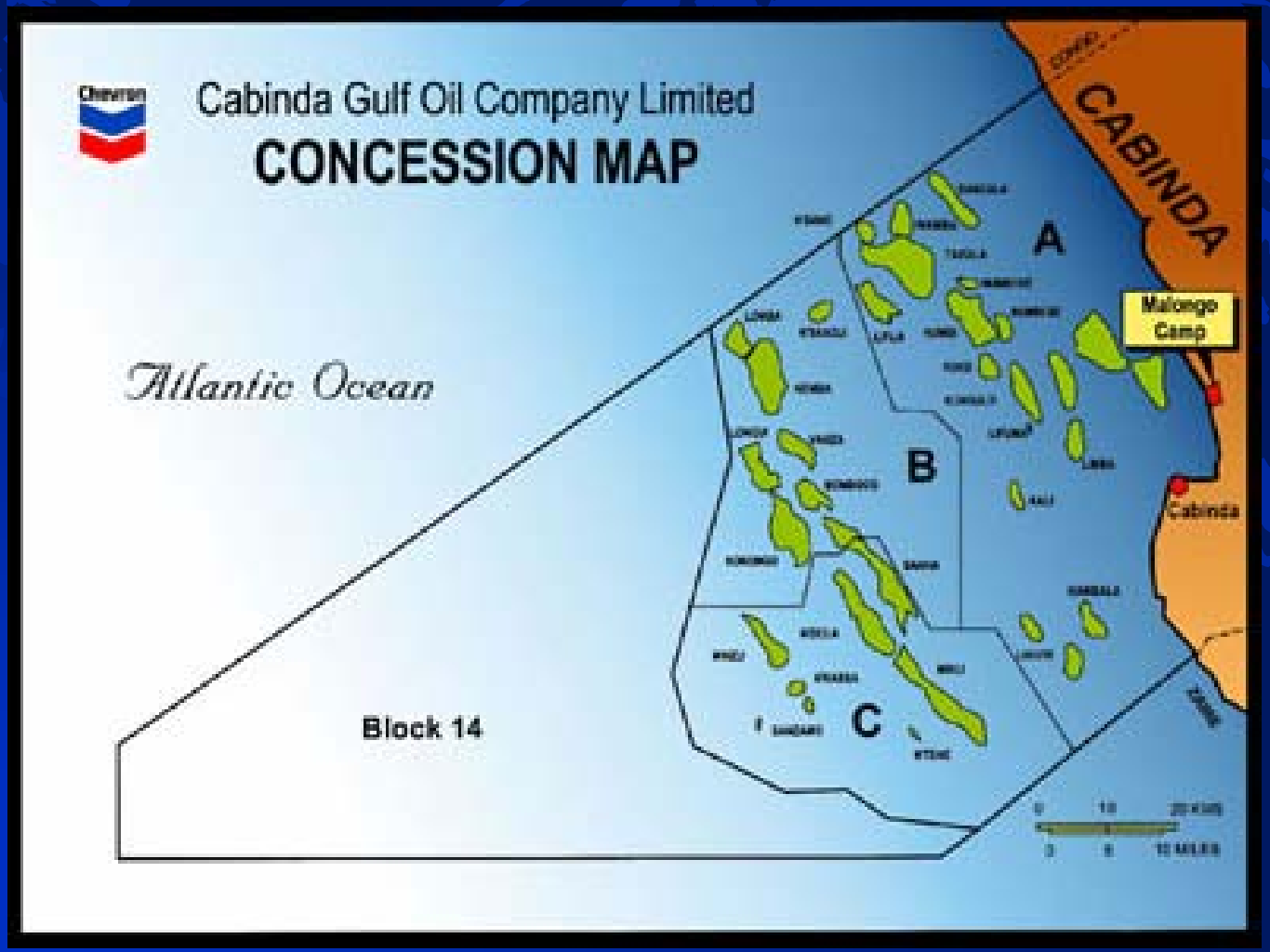
$$V_p = \sqrt{\frac{\frac{4}{3}G + K_b}{\rho_b}}$$

$$V_s = \sqrt{\frac{G}{\rho_b}}$$

Shear (G) and bulk (K_b) moduli are rock stiffness terms; both inversely proportional to bulk density (ρ_b).

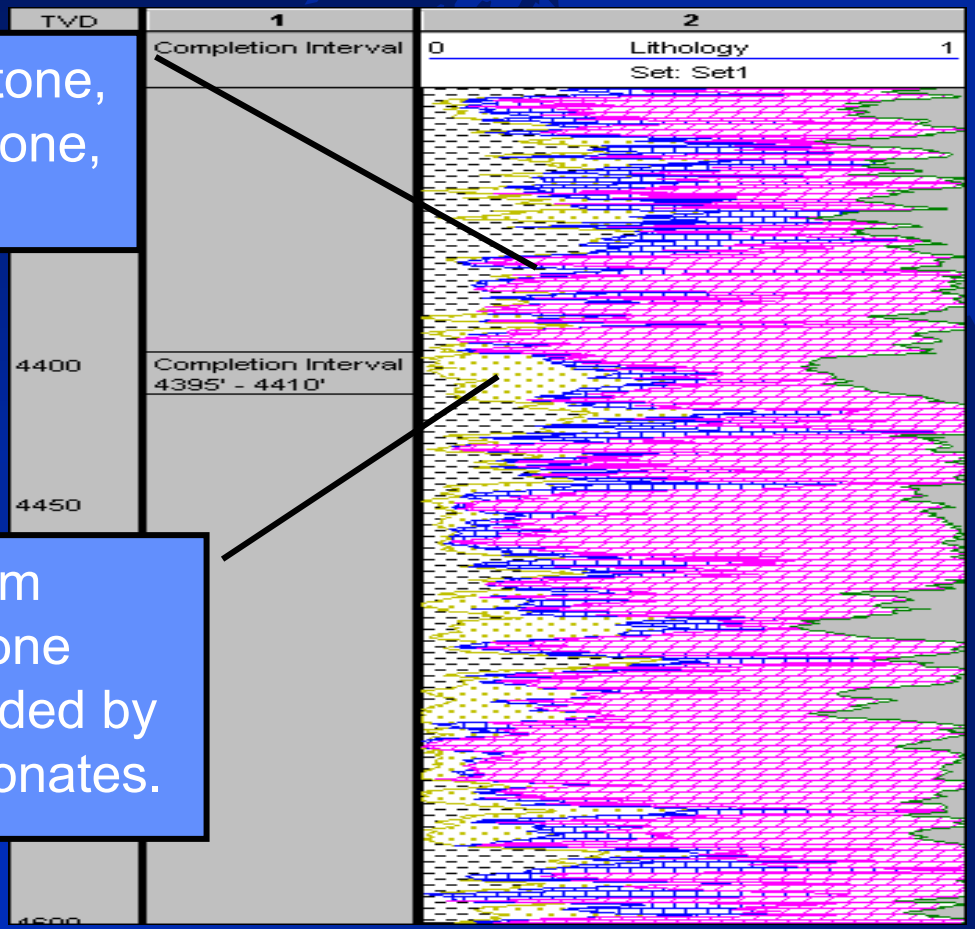
How well can we predict Shear wave velocity? What do we need to know first?

Angola Offshore



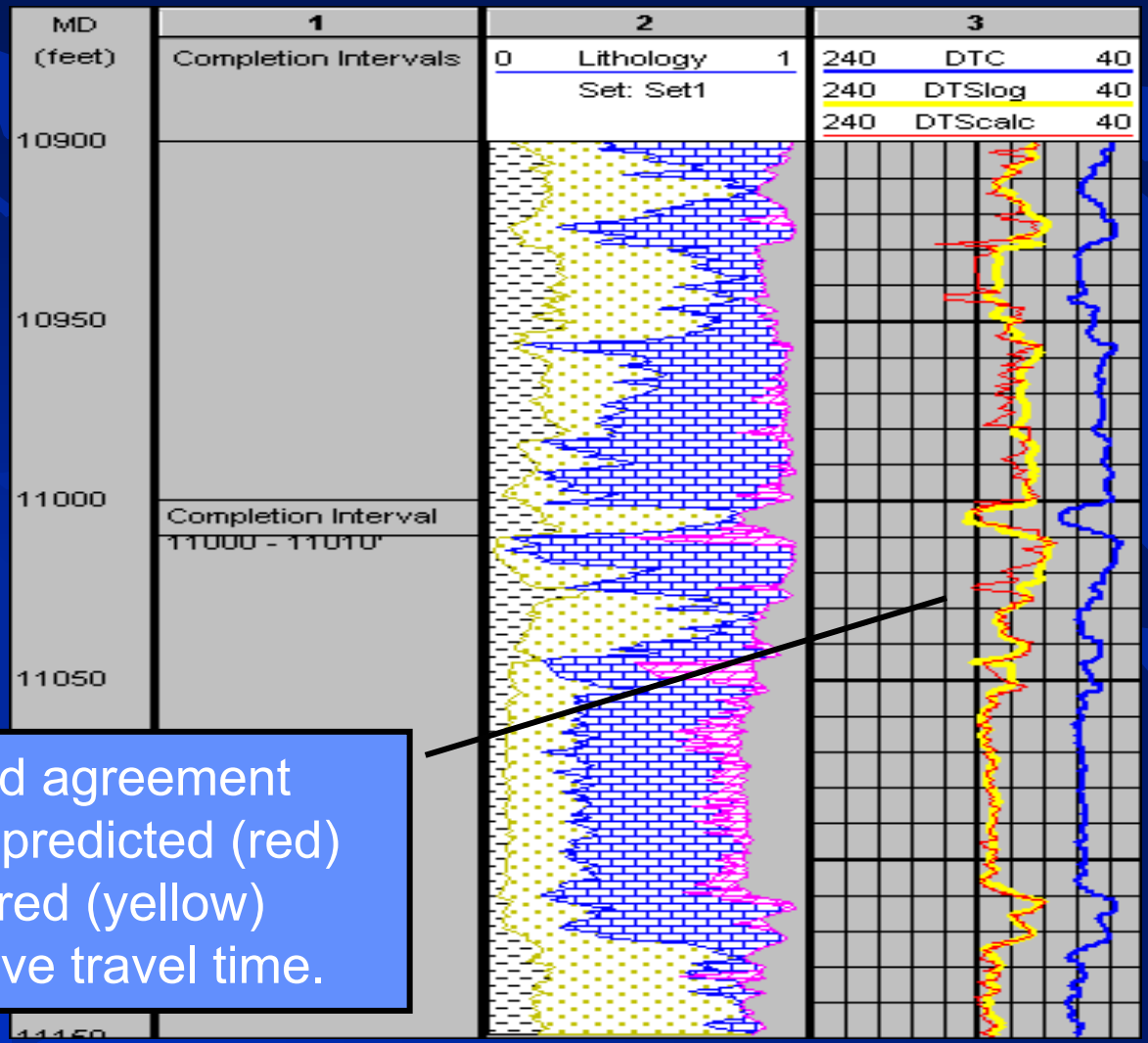
Complex Lithology, West Africa

Mixture of sandstone, dolostone, limestone, and minor shale.



Production from friable sandstone intervals bounded by hard stiff carbonates.

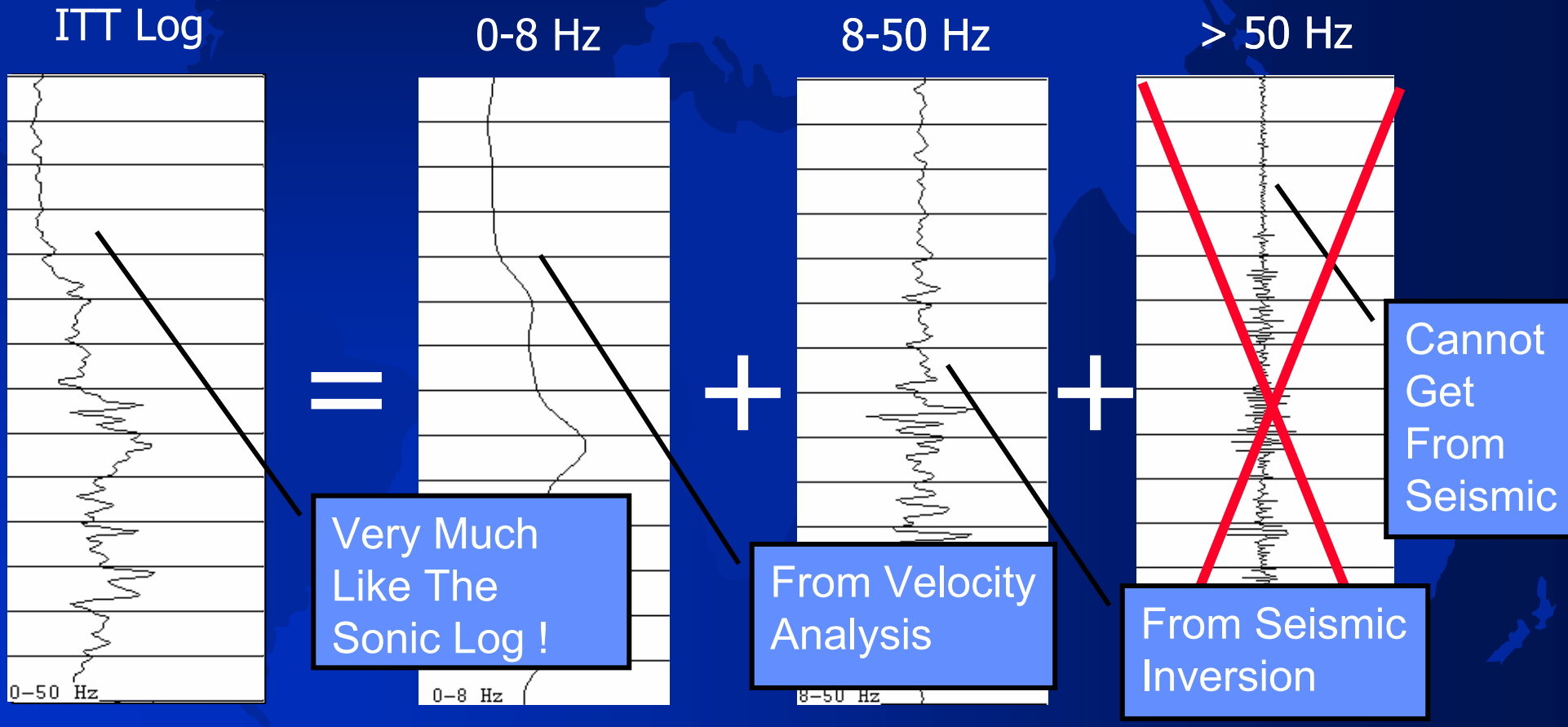
Complex Pinda Fm S-Wave Modeling



Very good agreement between predicted (red) & measured (yellow) shear wave travel time.

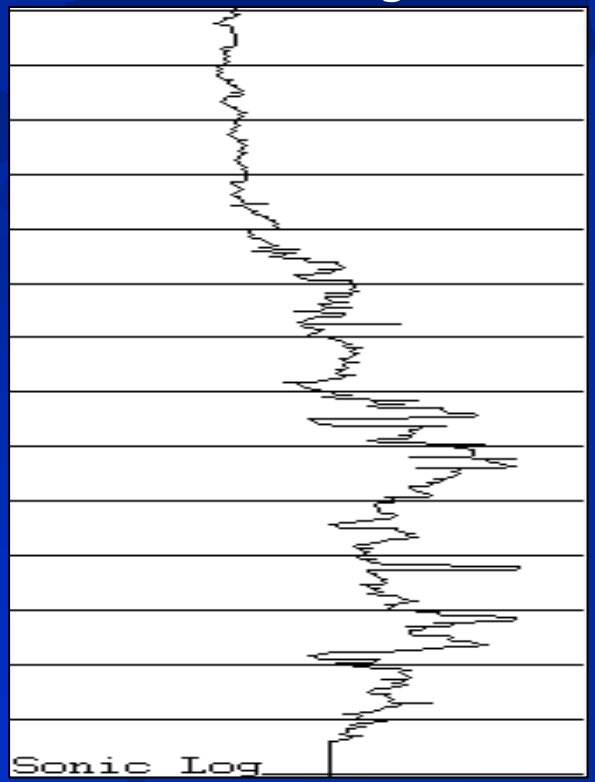
A brief look at how we manage to characterize P-wave velocity and lithology from seismic data sets.

ITT (interval travel time or pseudo-sonic log) as Sum of Seismic Velocities

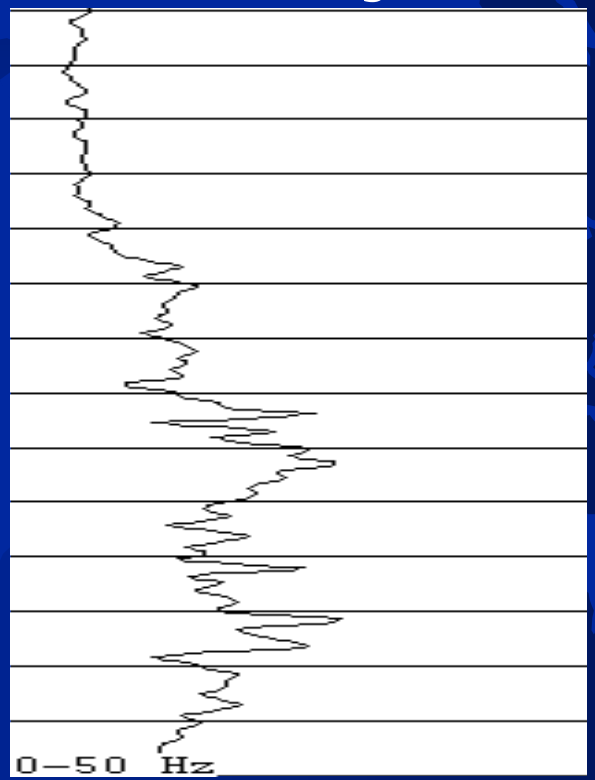


Not Perfect But Pretty Good !

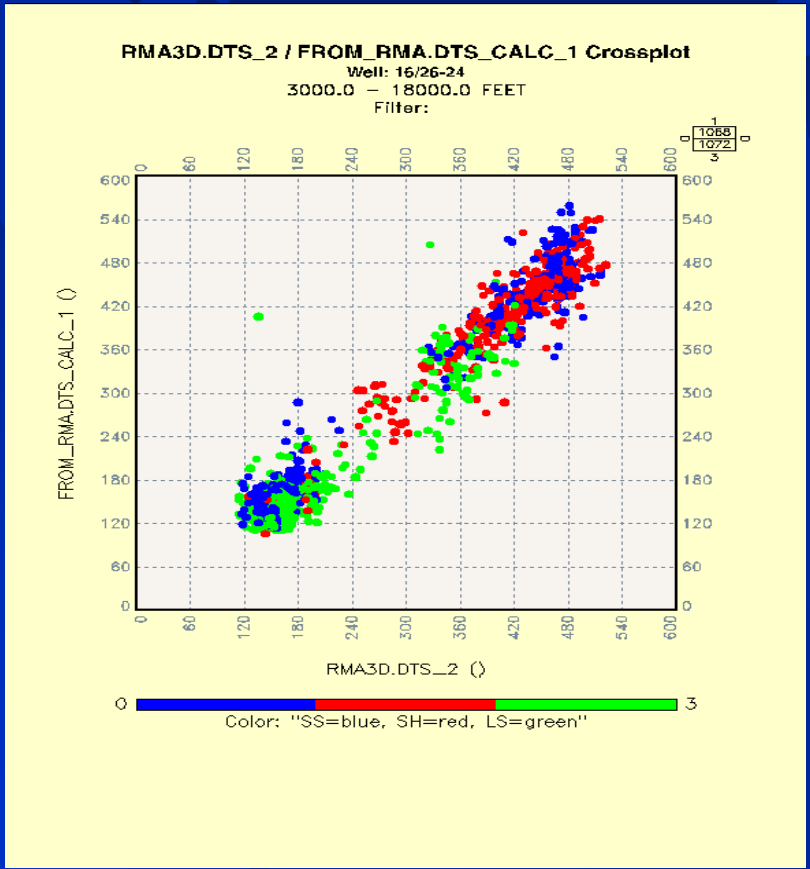
Sonic Log



ITT Log



Seismic and Well Log Derived Shear Wave Velocity with Respect to Lithology



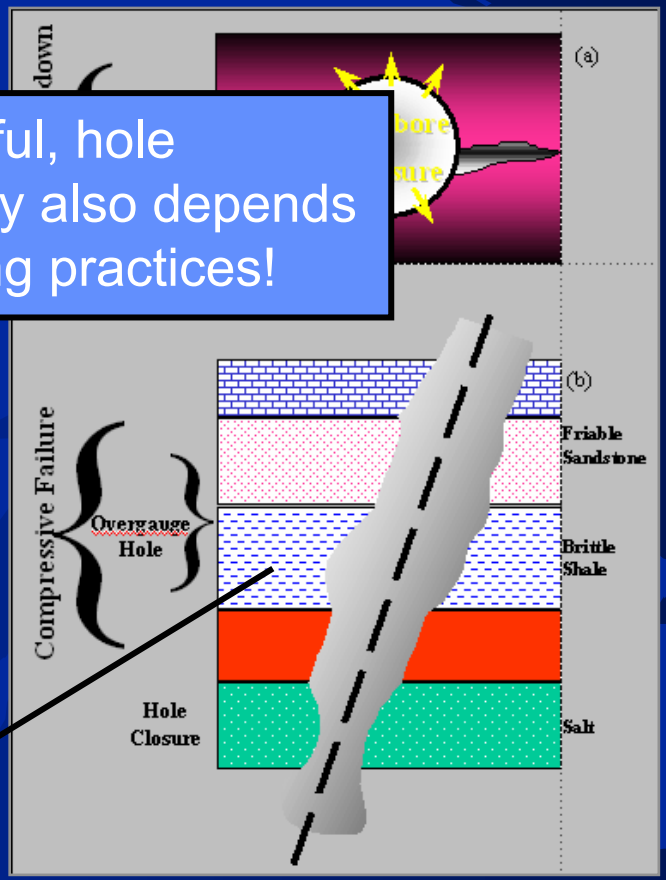
- Vertical axis is the shear slowness coming from sonic log and log based lithologies.
- Horizontal axis is the shear slowness from the seismic inversion.

Rock Mechanics Of Hole Failure

Symptoms:

- Large size and volume of cavings/cuttings
- Oversize hole
- Stuck pipe by packing off
- Hole fill after tripping
- Restricted circulation/increase in pump pressure

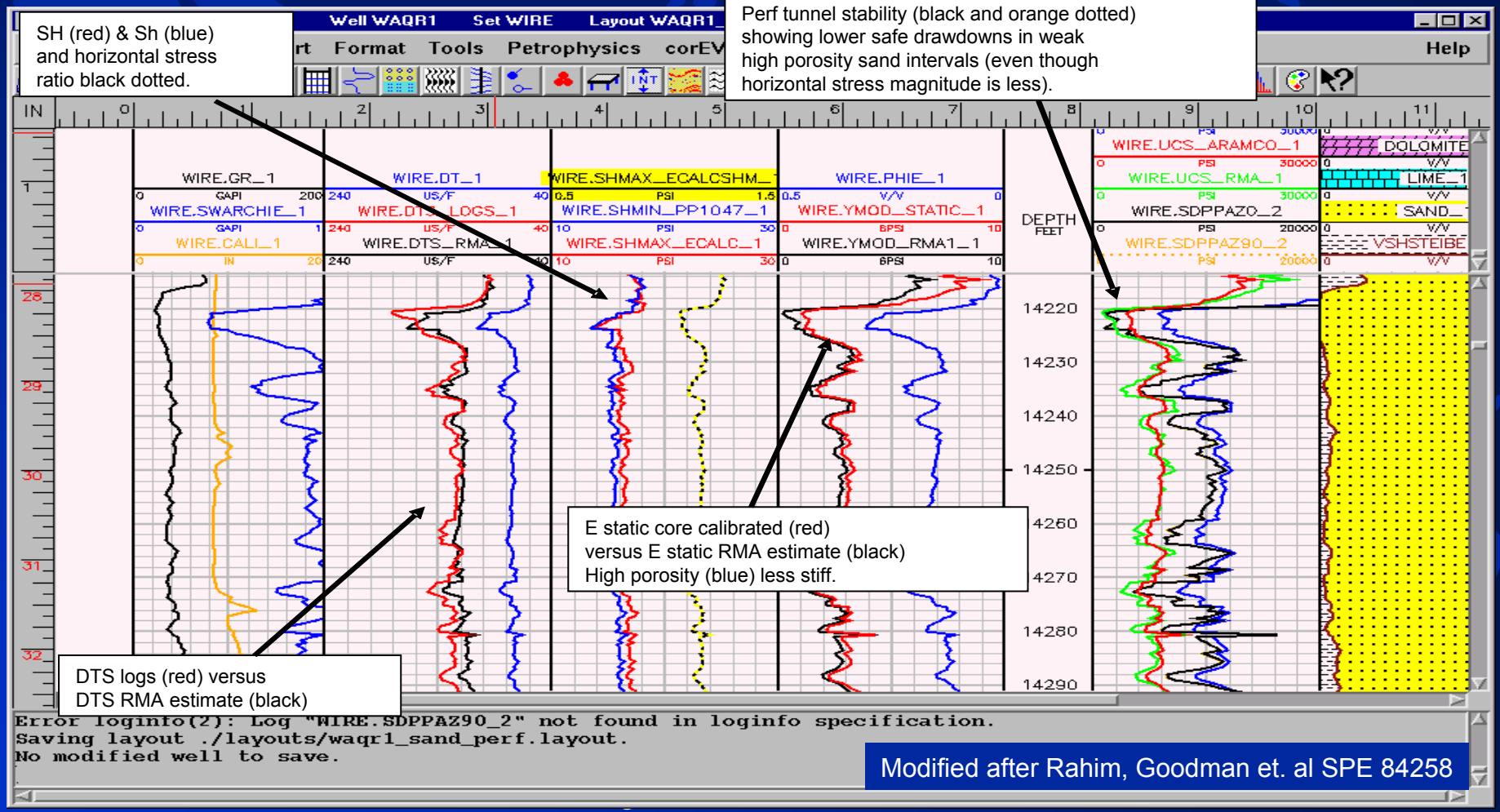
Be careful, hole instability also depends on drilling practices!



Common practice estimates stress and rock strength that caused hole failure.

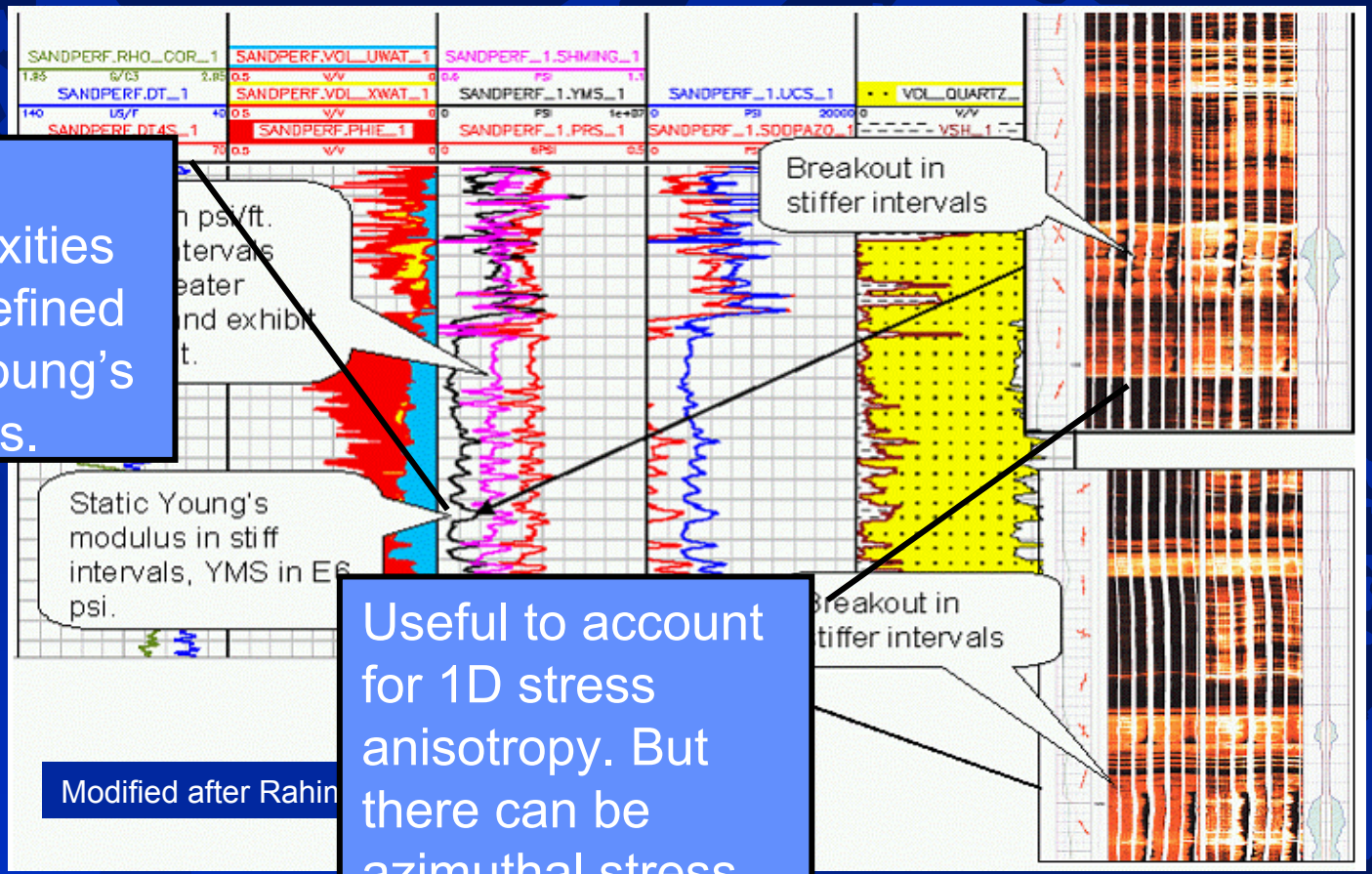
We Can Predict Rock Strength and Static Young's Modulus From Acoustics.

Formation Strength and Static Young's Modulus from Logs.



Modified after Rahim, Goodman et. al SPE 84258

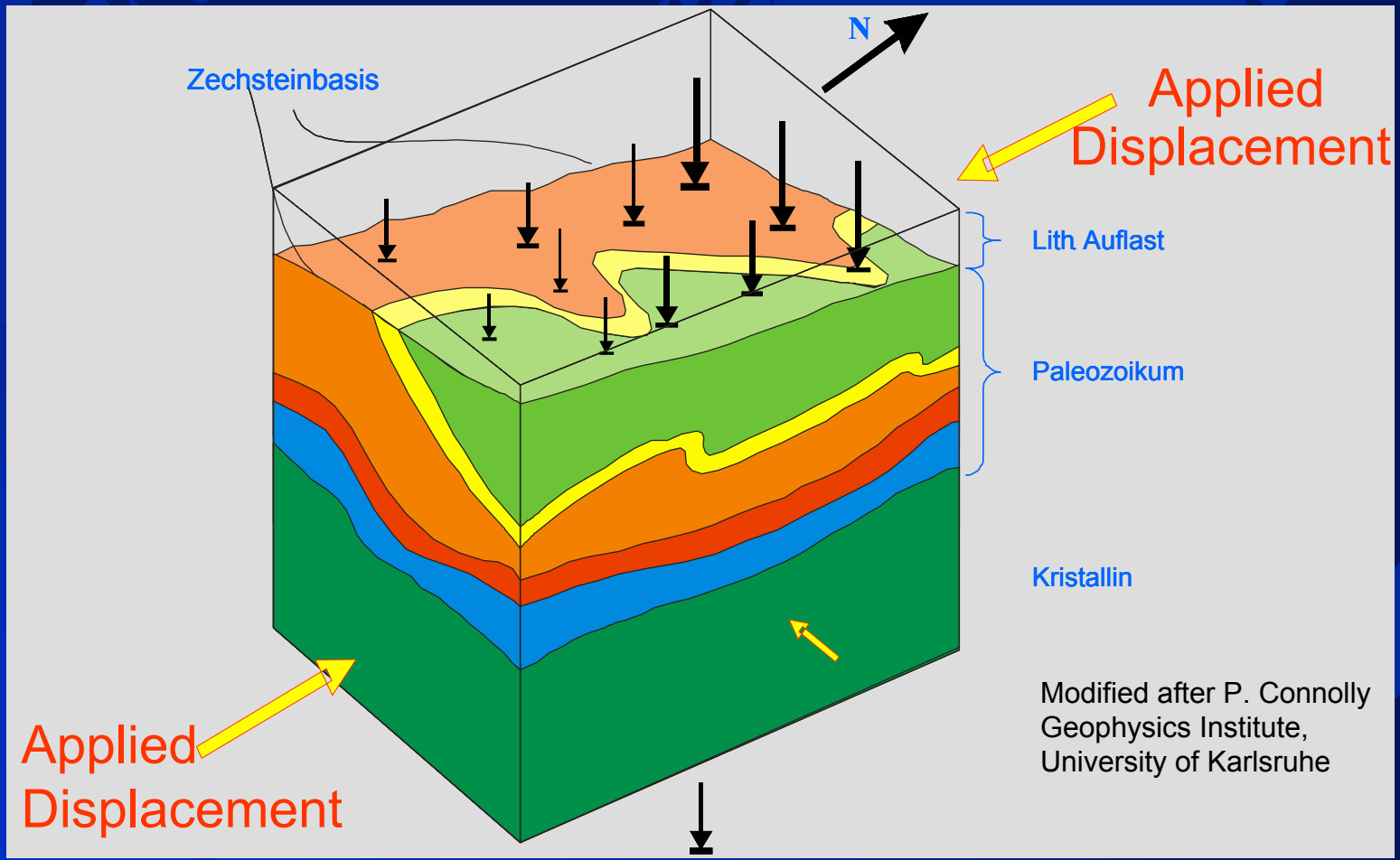
Layer Dependent BO



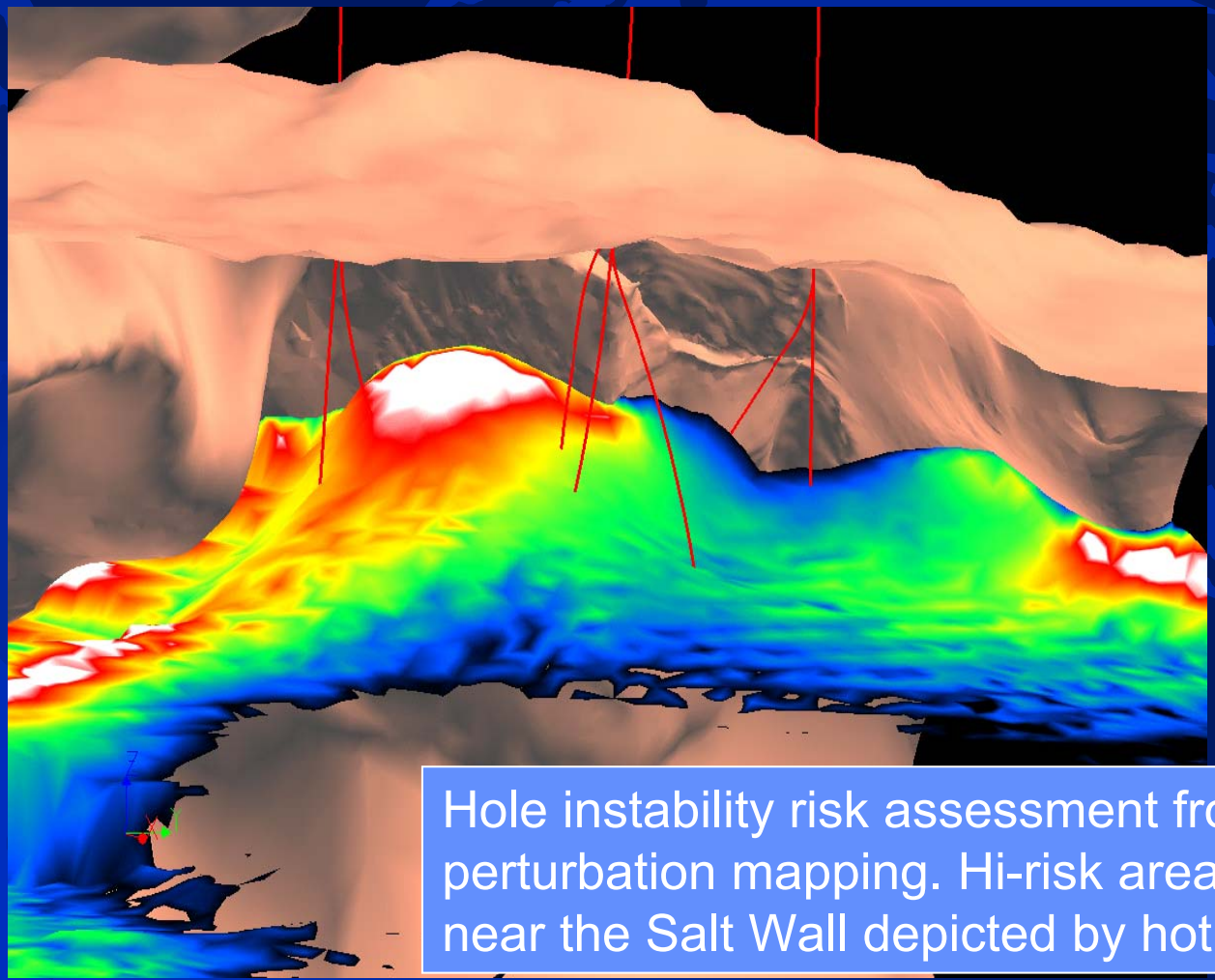
- We believe the stiffer formation layer intervals are more highly stressed; essentially the load bearing members of the geologic section.

- We now use this concept to predict stress character across the geologic structure using MEM properties & numerical modeling.

Stresses in the 3D Volume

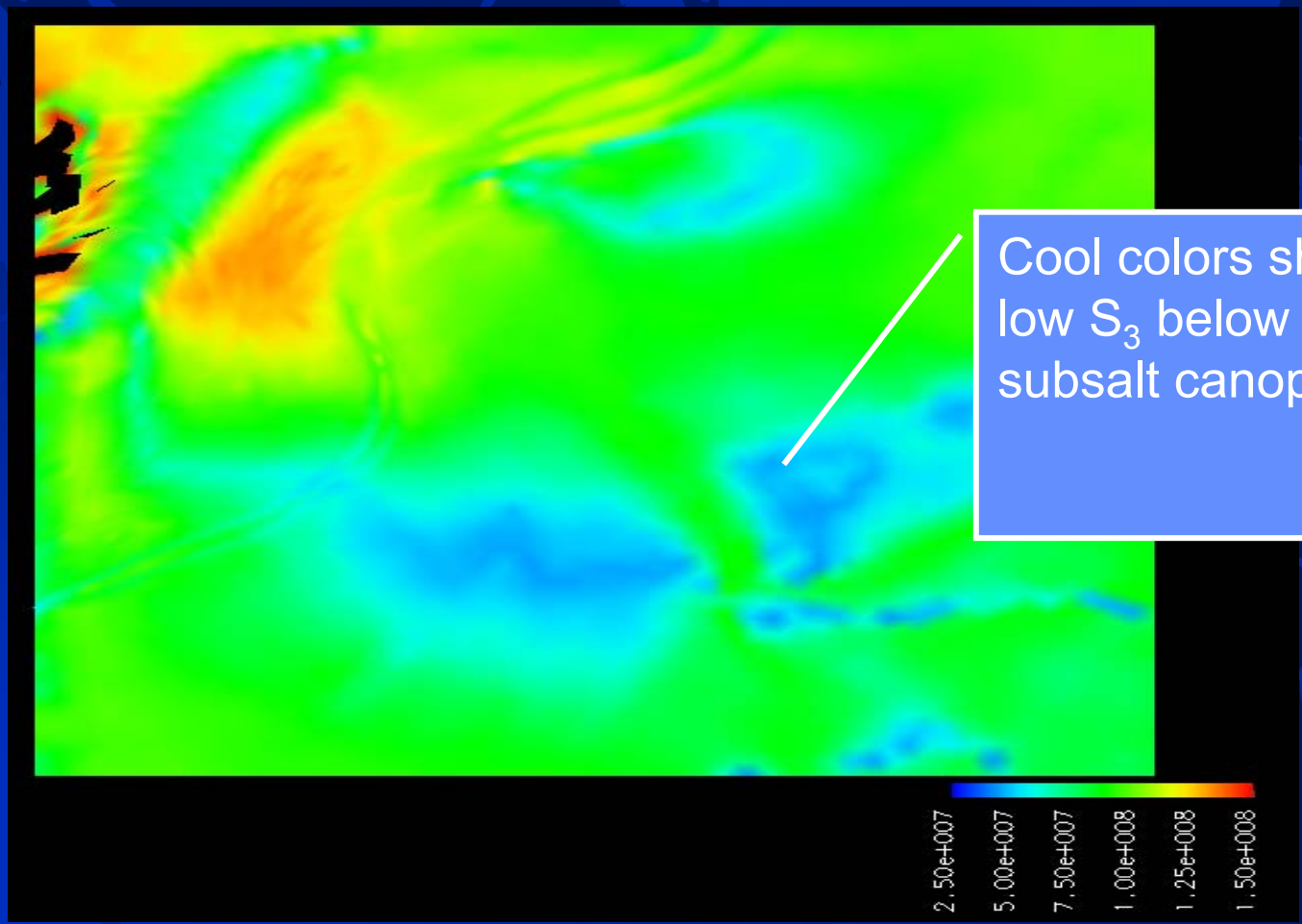


Stresses at Salt/Clastic boundaries



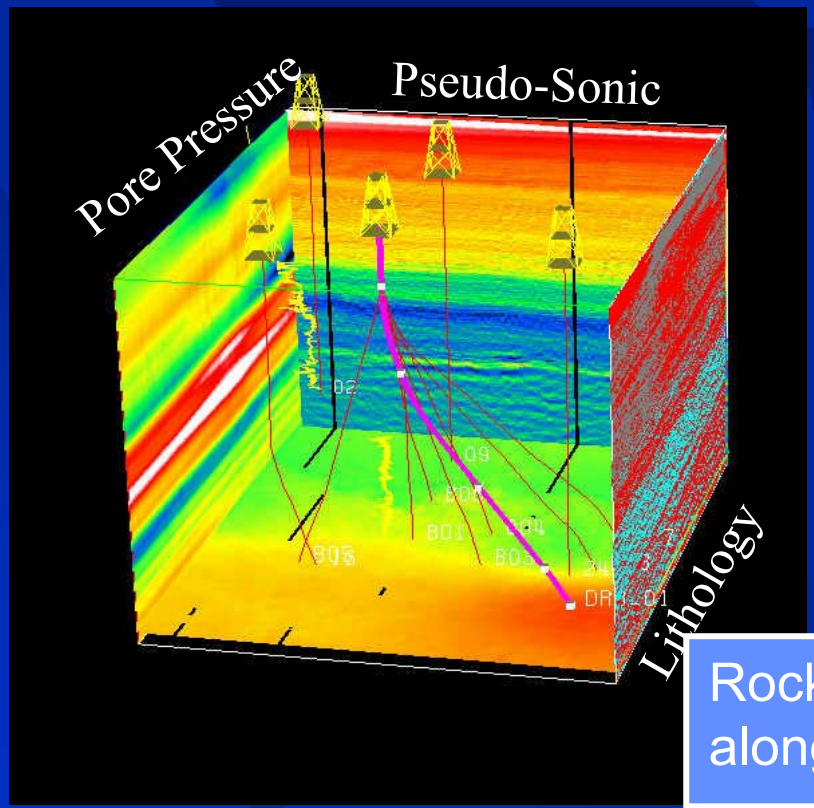
Hole instability risk assessment from stress field perturbation mapping. Hi-risk areas updip near the Salt Wall depicted by hot colors.

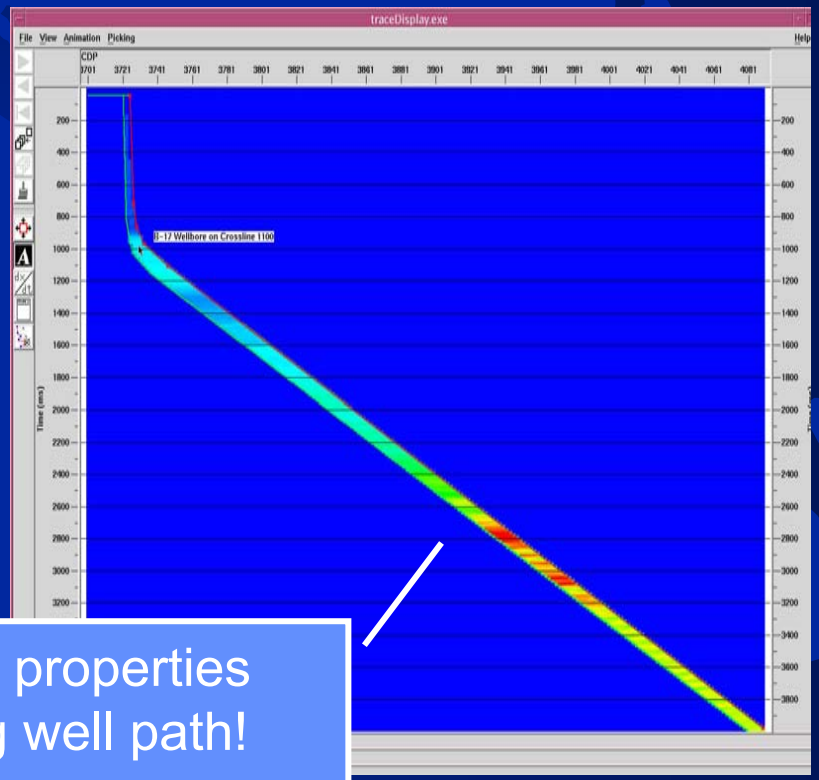
S_3 (minimum principle stress) along Base of Salt surface.



Cool colors show low S_3 below subsalt canopy.

Hole Stability Forecast Using MEM

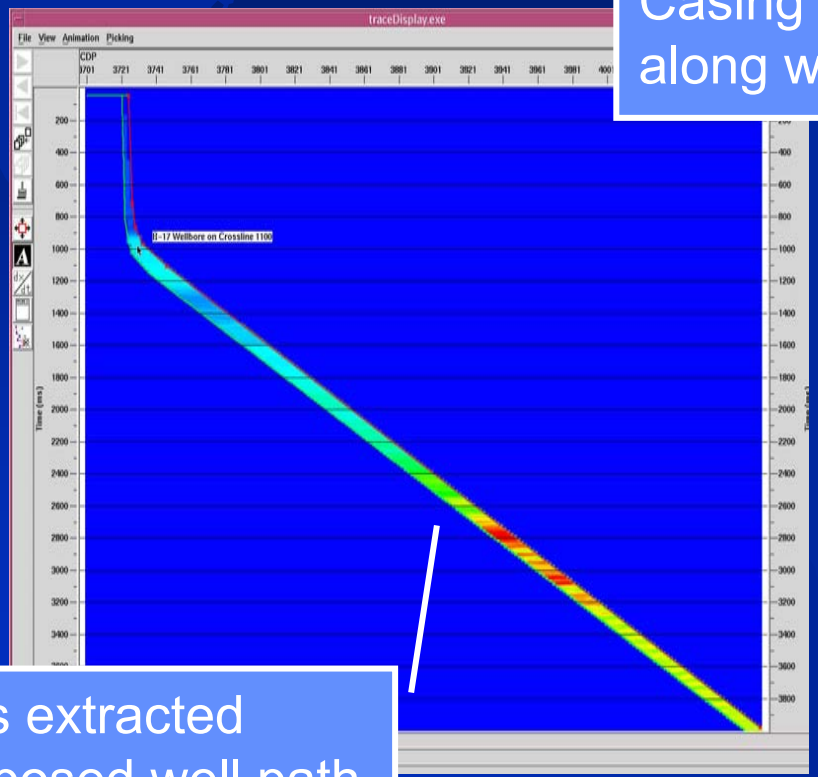


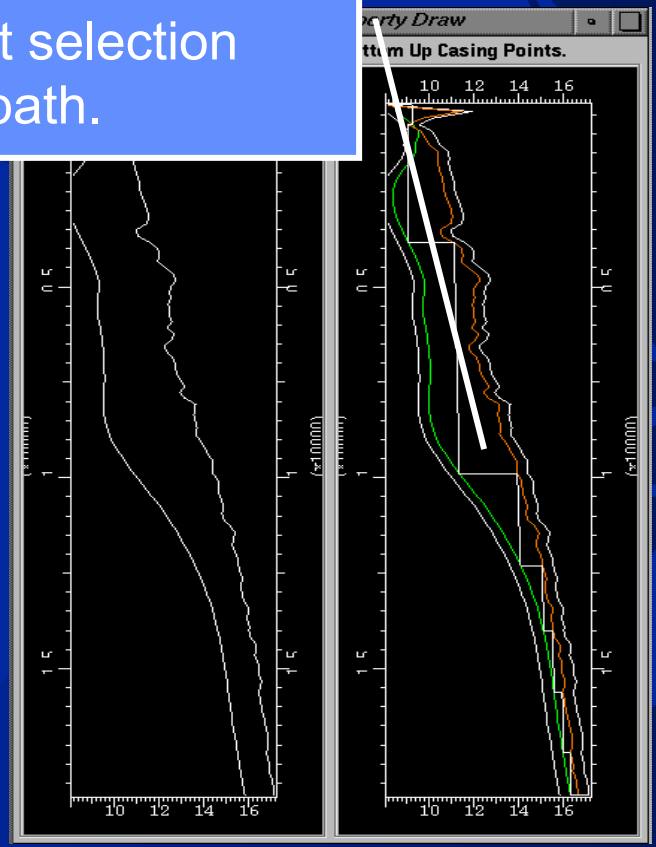


Rock properties along well path!

Casing Seat Selection

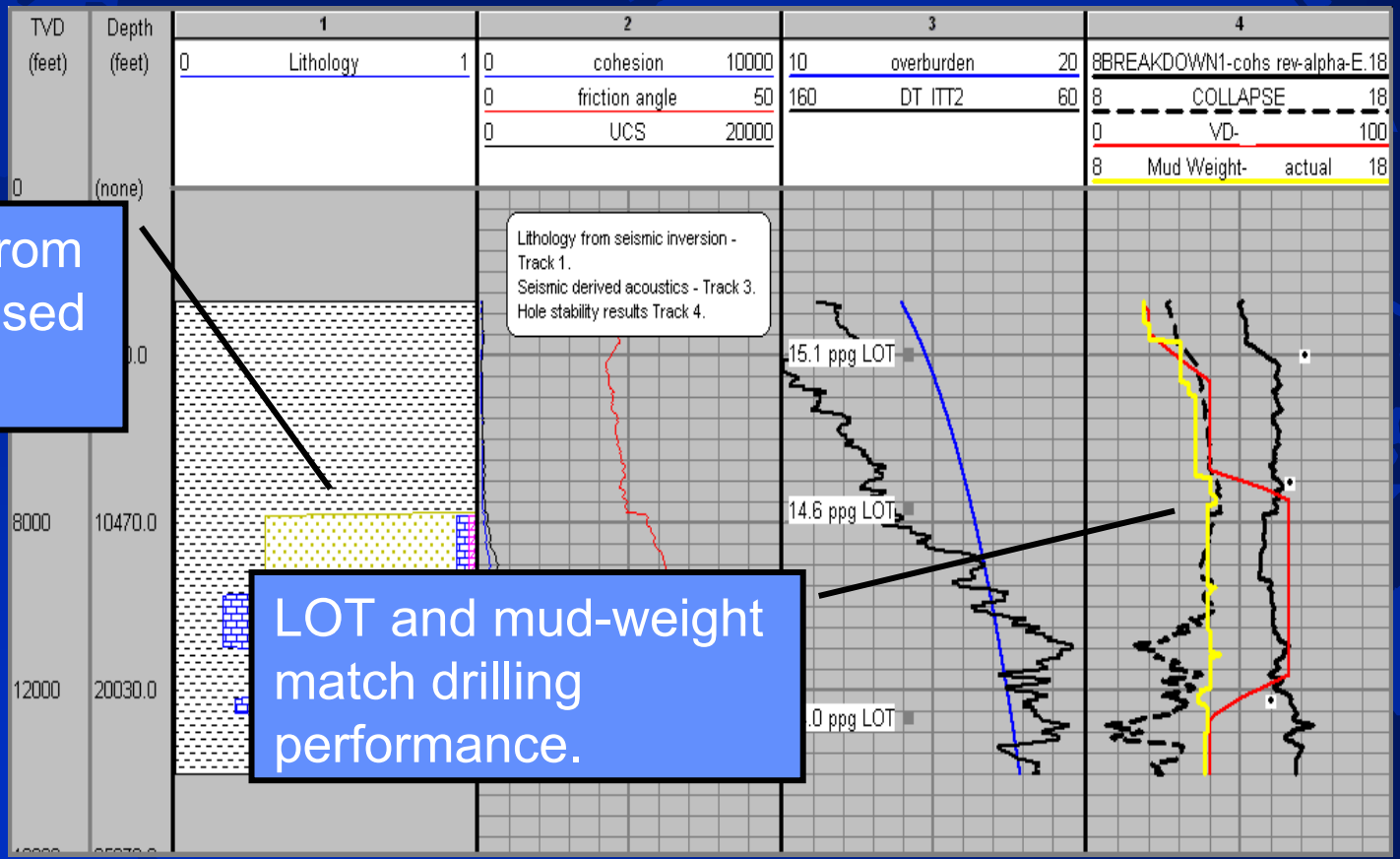
Casing seat selection along well path.





Properties extracted along proposed well path using MEM.

Hole Stability Forecast for ERD Well



Lithology from seismic based MEM.

LOT and mud-weight match drilling performance.

Future Trends and Challenges

- The capability to build a reliable MEM from the seismic dominated data volumes used by Explorationists, enables Well Engineers to accommodate the uncertainty of the subsurface picture into the well systems design.
- The multi-disciplined skill sets necessary to optimize asset development planning can be linked during the MEM creation process.

Future Trends and Challenges

- There is great opportunity to grow MEM technical applications in the Field Management Team environment.
- Major challenge is that MEM requires extensive work in the overburden.
- Challenges remain in characterizing rock properties in the overburden, especially azimuthally anisotropy recognition and mitigation.