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# WELLBORE STABILITY

AADE Houston Chapter Joint Committee Meeting - May 18, 2005
Deepwater Industry Group, Fluids Management Group and Emerging Technologies Group

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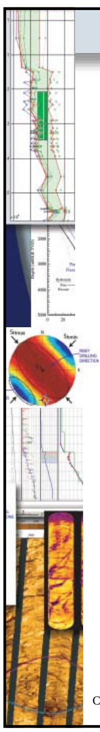

## How Can Geomechanics Add Value?

- **By reducing expensive drilling problems………………**
  - ***Wellbore instability and Fracture Pressure Prediction***
    Reduce stuck pipe, losses, sidetracks, reaming, etc
  - **Underbalanced Drilling Feasibility**
- **By increasing reservoir performance………………**
  - **Production from Natural Fractures**
  - **Sand Production Prediction**
  - **Improved Frac Design**
  - **Reduce Casing Shear and Collapse**
  - **Compaction/Subsidence**
- **By reducing exploration risk………………**
  - **Fault Leakage Analysis**

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## Estimates of Wellbore Instability Costs

- AMOCO: $600MM to $1 Billion per Year
- ARCO: 17% of Total Well Cost
- MOBIL: Min. 10% of Total Well Cost
- Western-Atlas: >$6.4 Billion per Year
- HES & Shell: ~$8 Bil. '96 & ~30% Total Budget
- Soloman Bros: 15% of Total Drilling. Cost in '96
- API Survey: 19-24% Holes w/ Sign. Mud Loss
- GRI & OGS: $500-750MM/year in Shales
- SHELL: >$500MM/year in Shales
- BP(123 GOM): $167.6MM 1985-97

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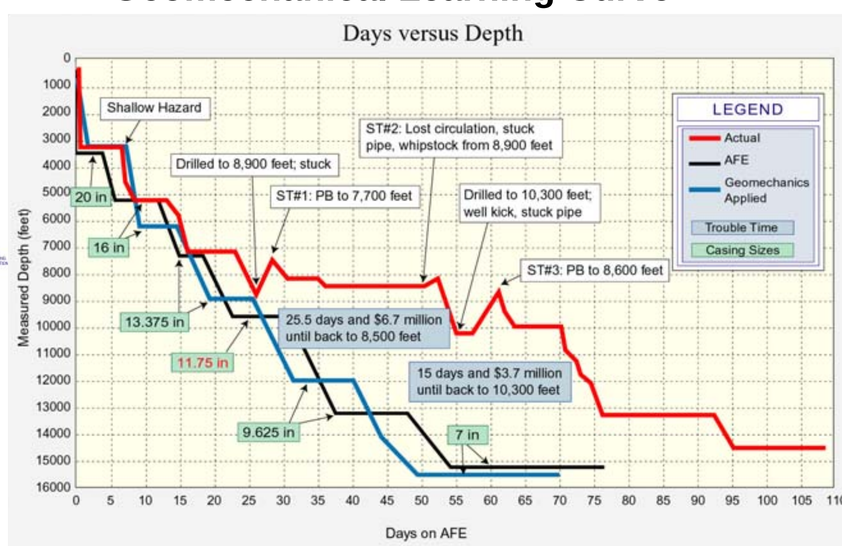
## Geomechanical Learning Curve

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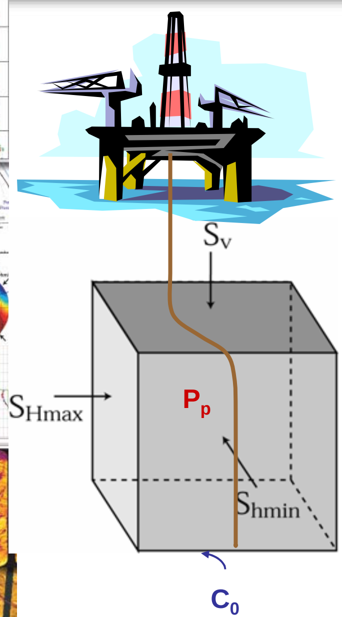
## The Geomechanical Model




### The Principal Stress Tensor

**Description of a geomechanical model for a reservoir involves detailed knowledge of**

- In situ stress orientations
- In situ stress magnitudes
- Pore pressure
- Rock Mechanical Properties

**Other considerations: Mud Chemistry, Weak Bedding Planes, Fractures, Thermal Effects**

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## Building a Geomechanical Model

### GEOMECHANICAL DATA SOURCES

| | |
|---|---|
| Vertical Stress | $S_v$ ⇐ Integrated density<br>Density from sonic/seismic |
| Pore Pressure | $P_p$ ⇐ Measurements (RFT, DST, PWD)<br>Log-based (sonic, resistivity)<br>Seismic (ITT, velocity cubes) |
| Least Principal Stress | $S_{hmin}$ ⇐ XLOT, LOT, minifrac,<br>lost circulation, ballooning |
| $S_{Hmax}$ Magnitude<br>$S_{Hmax}$ Orientation | Analysis of wellbore failure<br>Crossed dipole sonic (orientation)<br>"Active" geological structures |
| Rock Strength | Core tests, logs, cuttings, analysis of wellbore failure |

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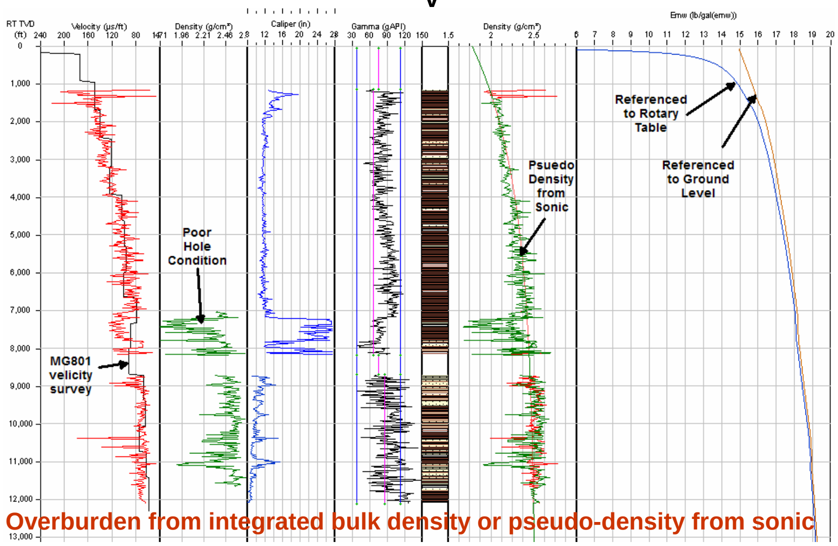
# Vertical Stress – $S_v$ or Overburden




Overburden from integrated bulk density or pseudo-density from sonic

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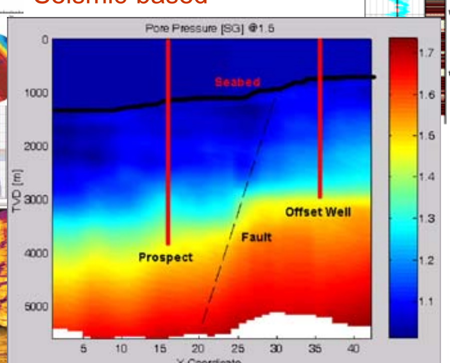
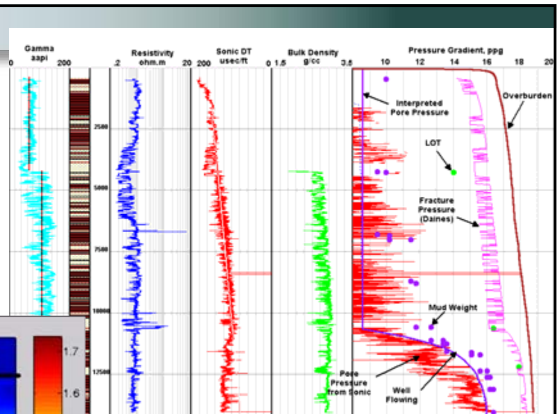
# Pore Pressure

Seismic-based




Log-based

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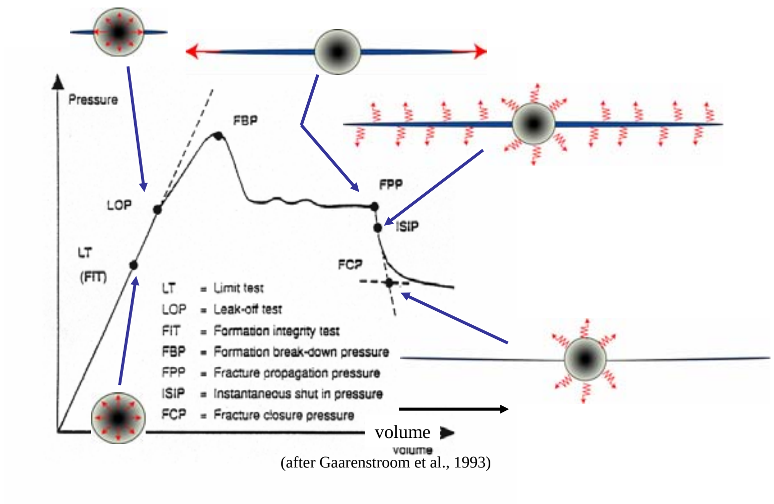
# Least Principal Stress ($S_{hmin}$) from XLOT




(after Gaarenstroom et al., 1993)

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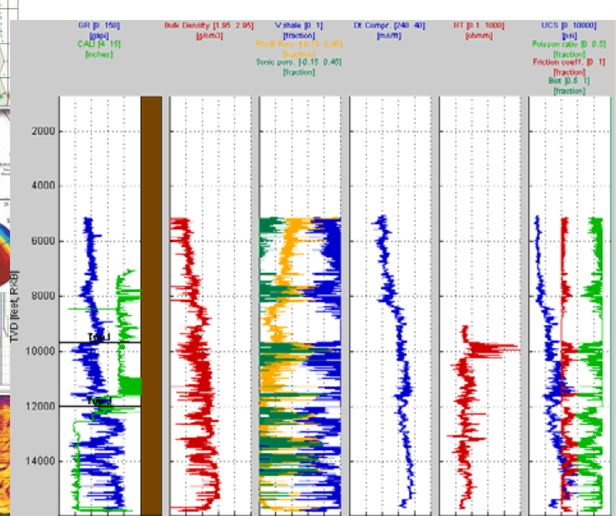
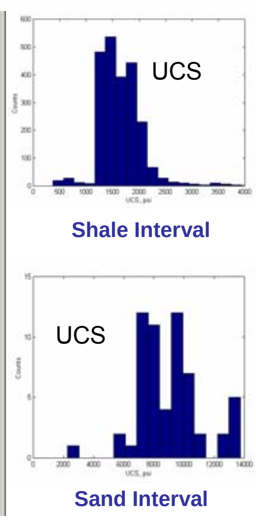
# Rock Mechanical Properties from Log Data

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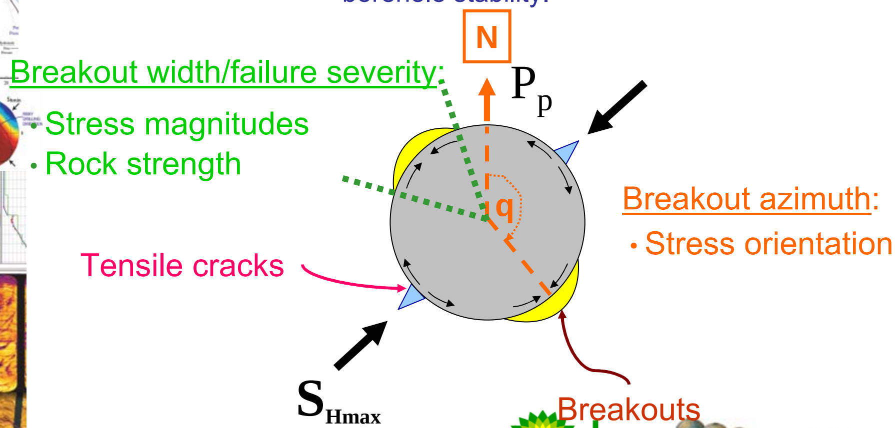
# Observations of Borehole Failure to Constrain the Stress State

The mechanical interaction of the borehole in a given lithology with the current stress field governs borehole failure – hence, borehole stability.

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# Examples of Instability


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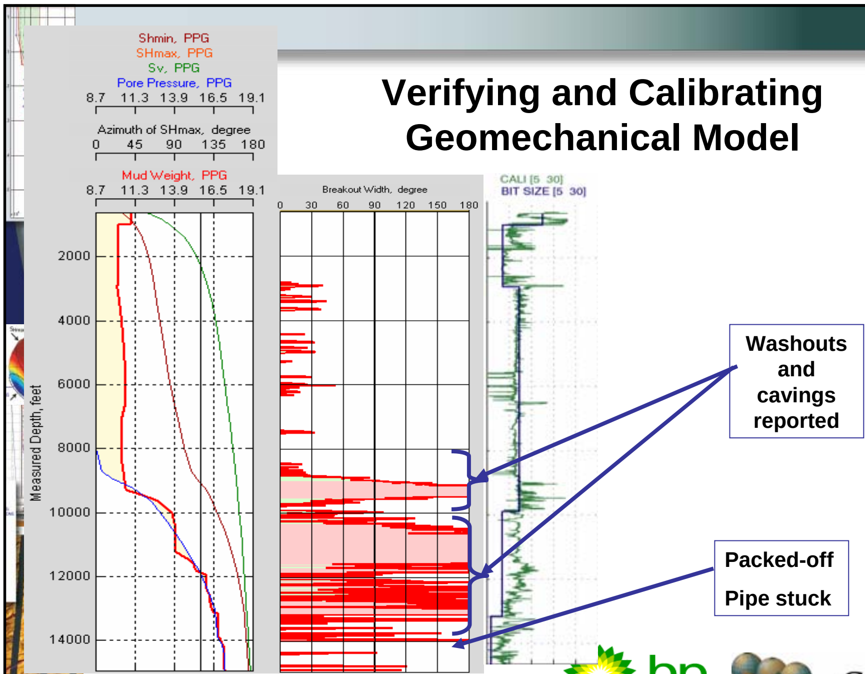
## Verifying and Calibrating Geomechanical Model

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## Wellbore Stability Prediction

## Wellbore Stability

Aim: Reduce drilling costs by incorporating geomechanics into the well planning and drilling process

- Optimizing Mud Weights and mud properties
- Minimizing Casing Strings
- Optimizing Wellbore Trajectory
- Optimizing Surface Location

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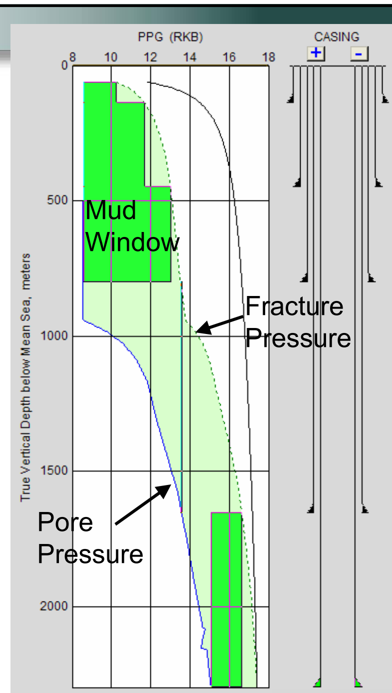
## Traditional Well Design

**Is based on a pore and fracture pressure estimate from**
- **Offset wells**
- **Log-based analysis**

**This method is typically less reliable when drilling**
- **Deviated wells**
- **In 'tectonic' areas**
- **Dipping weak bedded formations**
- **Fractured or 'rubbleised' formations**
- **In depleted reservoirs**

**In these cases we need to consider Geomechanics in the well planning and drilling process**

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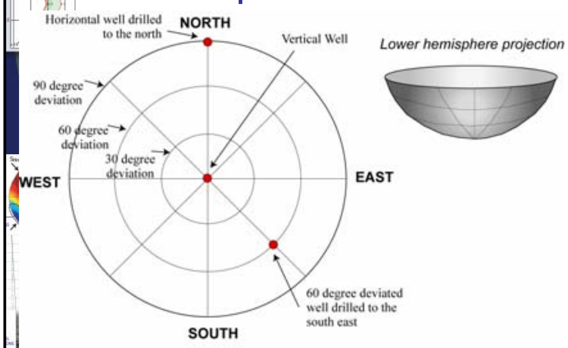
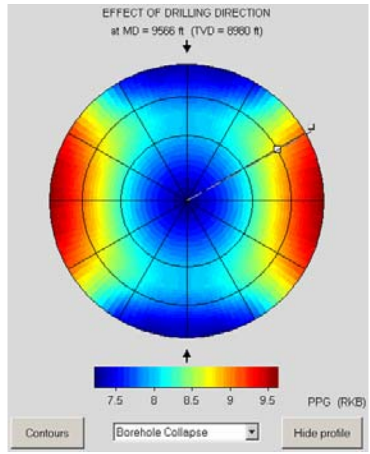
## Importance of Drilling Direction – Wellbore Stability

### Lower Hemisphere Stereo Net




**Horizontal wells drilled perpendicular to the direction of $S_{Hmax}$ required the highest mud weight weights**

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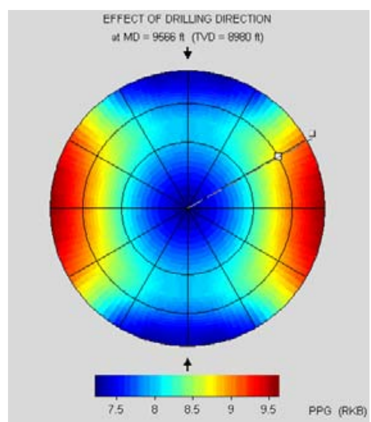
## Shear Failure (Pressure Cavings)




Failure due to Stress in Massive Shales

Solution: Raise Mud Weight

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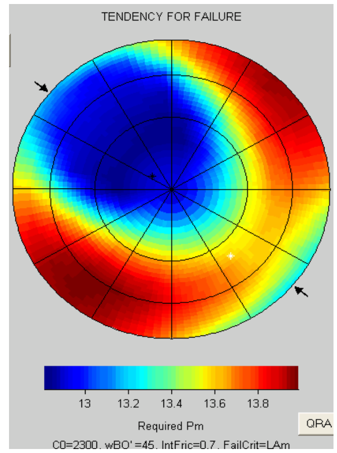
## Platy Cavings




Failure due to Stress Anisotropy (weakly bedded or fissile) Formations

Solutions: Raise Mud Weight, Angle-of-Attack

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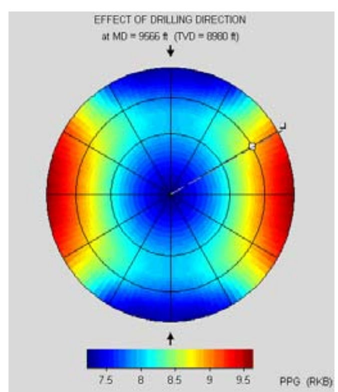
## Blocky Cavings ('Rubble')


Sub-salt 'rubble'




Failure due to Stress and Time-Dependent Mud Penetration into Fractures (Fractured Rocks, Around Salt, Along Faults)

Solutions: Raise Mud Weight, Prevent Mud Penetration

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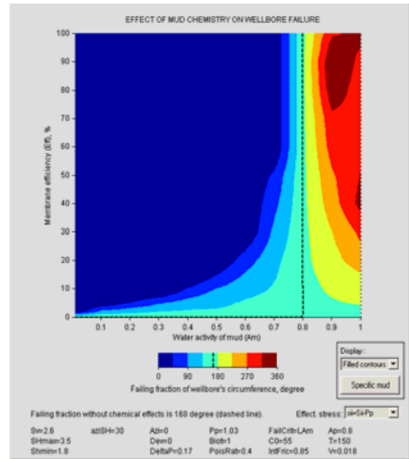
## Chemical Wellbore Instability


Failure due to Stress and Time-Dependent Swelling and/or Water Penetration into and out of shale

Solutions: Raise Mud Weight, Alter Mud Chemistry, Change mud Type

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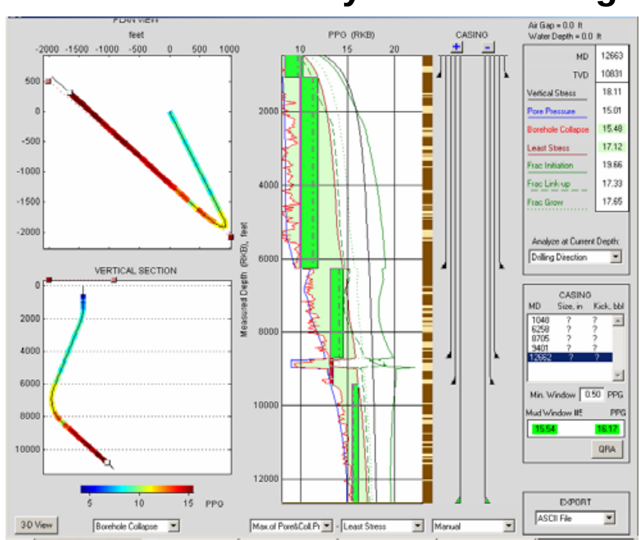
## Wellbore Stability Well Planning

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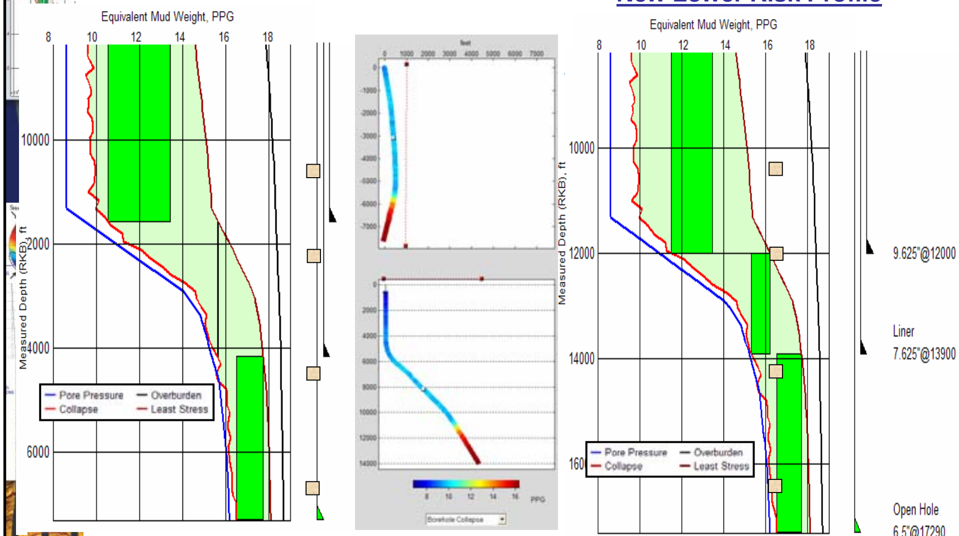
# Improved Well Planning

**Existing Profile** | **New Lower Risk Profile**

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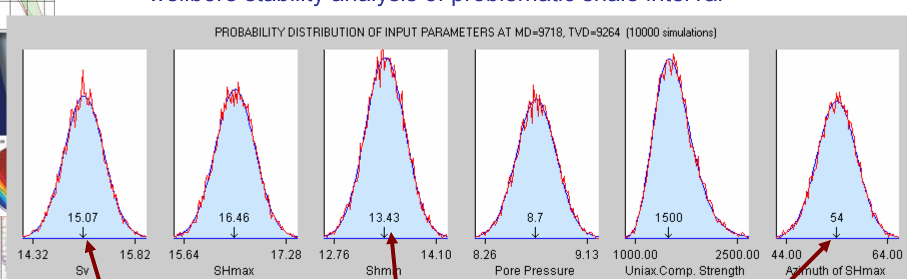
# Quantitative Risk Assessment (QRA) - Input

- Include uncertainties associated with the geomechanical model into the wellbore stability analysis of problematic shale interval




**Large uncertainty due to incomplete density log coverage**

**Large uncertainty due to lack of reliable leak off tests**

**Well constrained by wellbore failure observations from image log**

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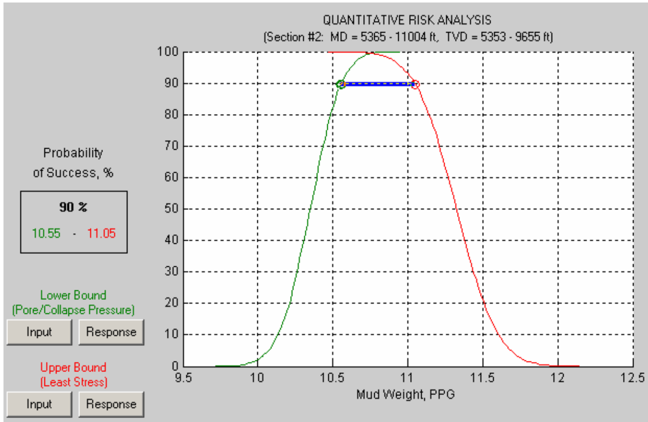
# QRA – Chance of Successful Drilling




Collapse
Frac Gradient

- In the problematic shales a 10.6 ppg gives a ~90% chance of successful drilling for the main hole of XX-Y.
- As long as the bottom hole pressure does not exceed 11 ppg there is a 90% chance to avoid frac'ing of the casing shoe.

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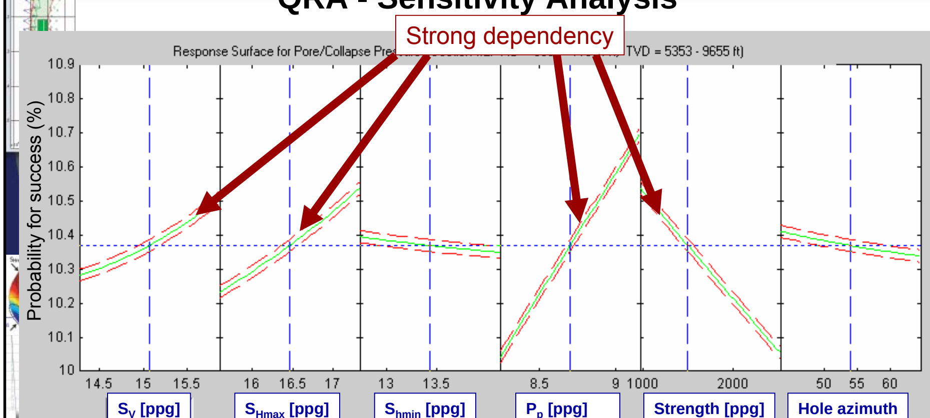
# QRA - Sensitivity Analysis




**Predictions depend on better knowledge of $S_{Hmax}$, $P_p$, rock strength, and $S_V$.**

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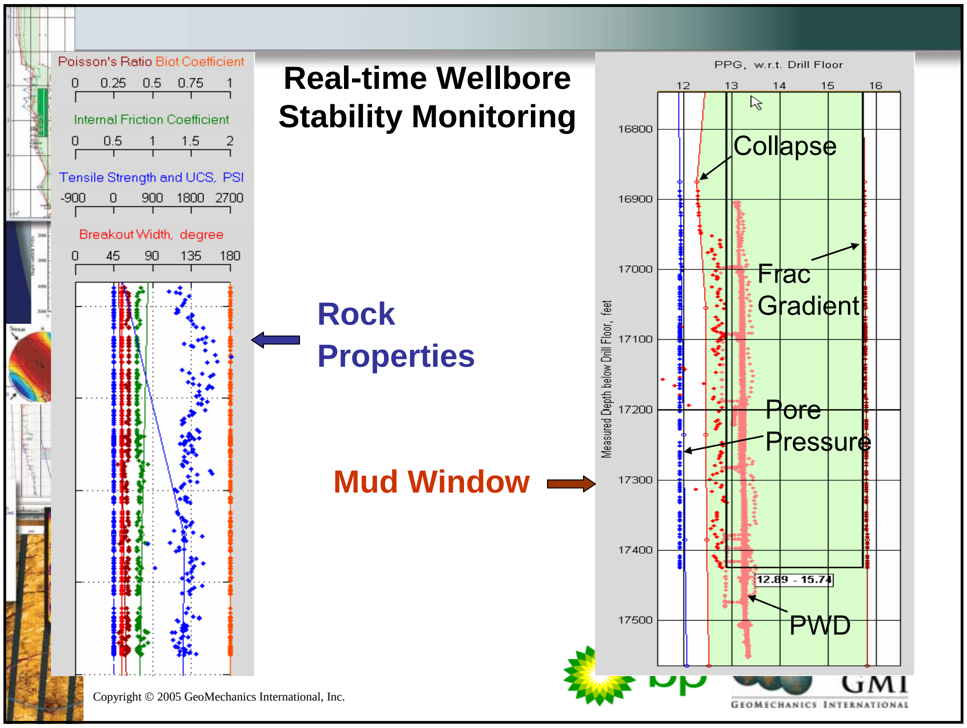
Real-time Wellbore Stability Monitoring
Poisson's Ratio Biot Coefficient
0 0.25 0.5 0.75 1
Internal Friction Coefficient
0 0.5 1 1.5 2
Tensile Strength and UCS, PSI
-900 0 900 1800 2700
Breakout Width, degree
0 45 90 135 180
Rock Properties
Mud Window
PPG, w.r.t. Drill Floor
12 13 14 15 16
Measured Depth below Drill Floor, feet
16800
16900
17000
17100
17200
17300
17400
17500
Collapse
Frac Gradient
Pore Pressure
12.89 - 15.74
PWD
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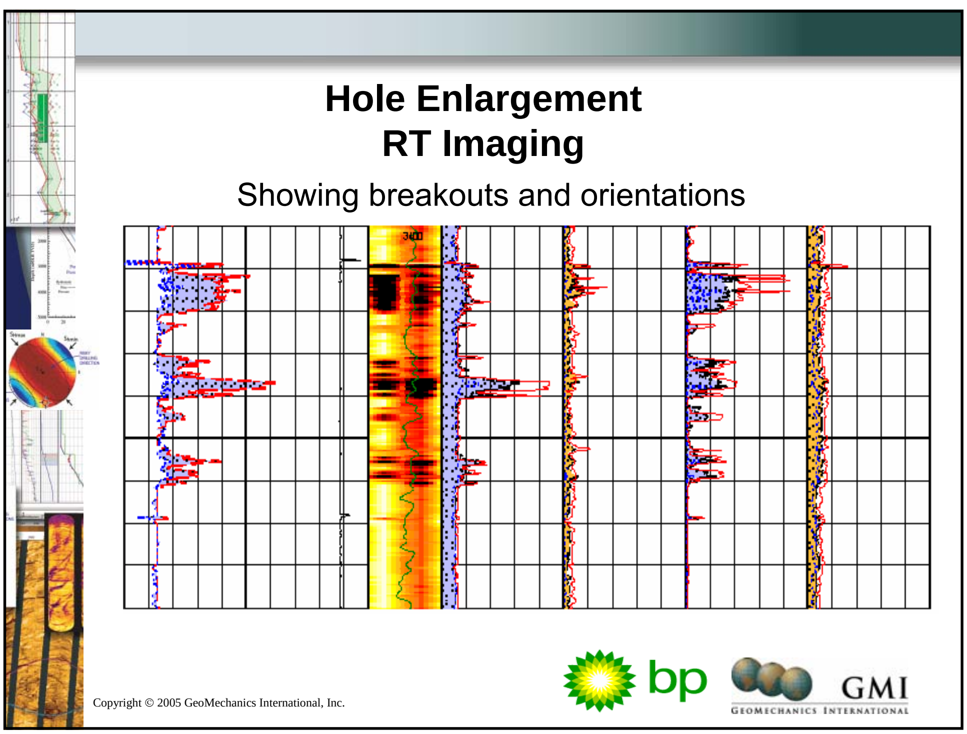
Hole Enlargement
RT Imaging
Showing breakouts and orientations
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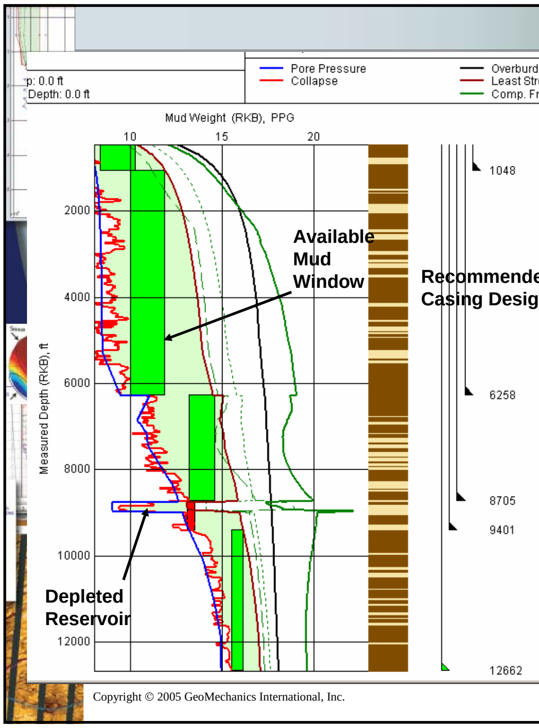


## Pore Pressure, Fracture Pressure, and Wellbore Stabilty The Complete Picture

- Well planning and drilling should incorporate Geomechanics to reduce wellbore stability and lost circulation risk
- This is especially important for high angle wells, 'tectonic' areas, and depleted reservoirs
- Pore pressure and Wellbore stability prediction should be performed together

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## Thank You