Wellbore Stability

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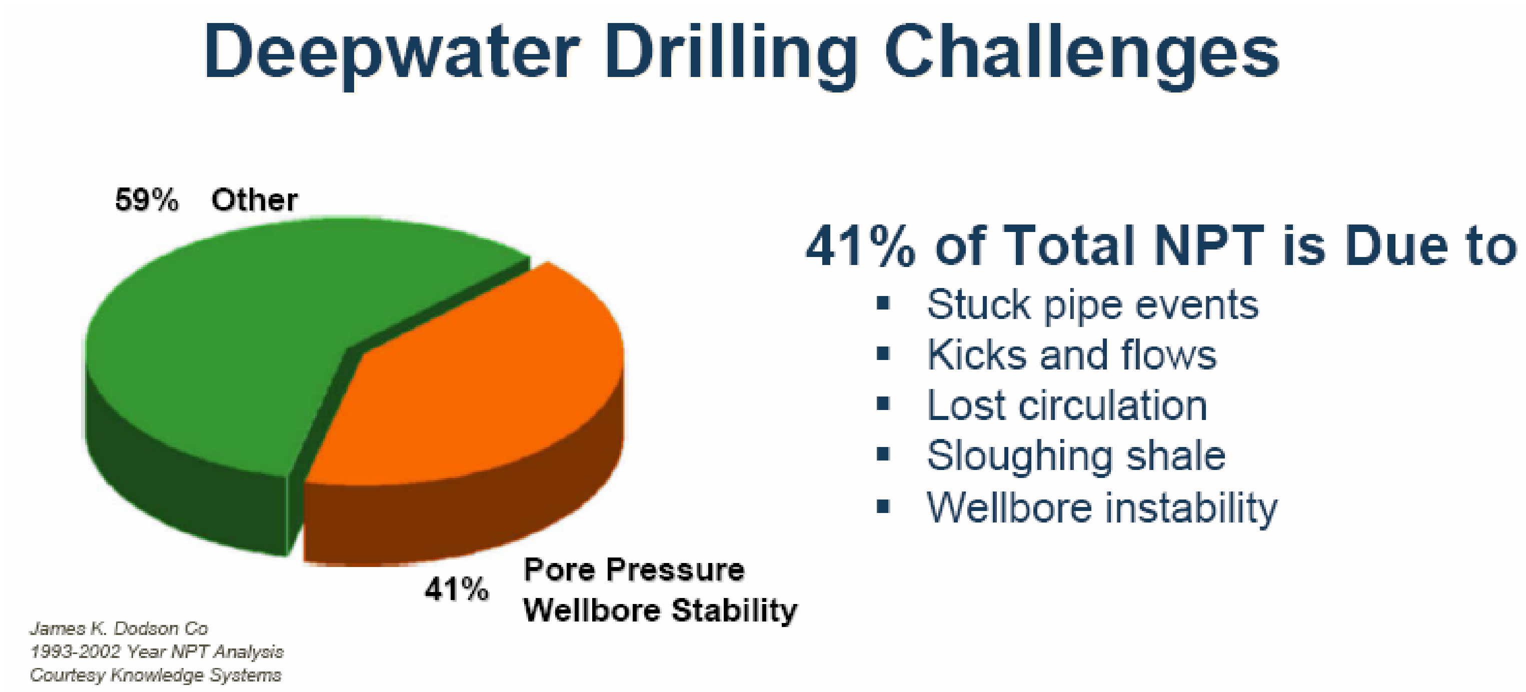
Outline

- Common wellbore stability related problems
- Cost of wellbore stability related NPT
- What causes wellbore instability?
- Modes of wellbore failure
- Safe mud window
- Modeling wellbore stability
- Key Points

Common wellbore stability related problems

- Tight spots, stuck pipe
- Hole caving/collapse, pack-offs
- Sloughing shale, bit balling
- Hole enlargement/shrinkage
- Lost circulation
- Wellbore breathing, kick
- Insufficient hole/casing size @ TD

Cost of Wellbore Instability Problems



www.knowsys.com, Dodson 20 yrs GOM database

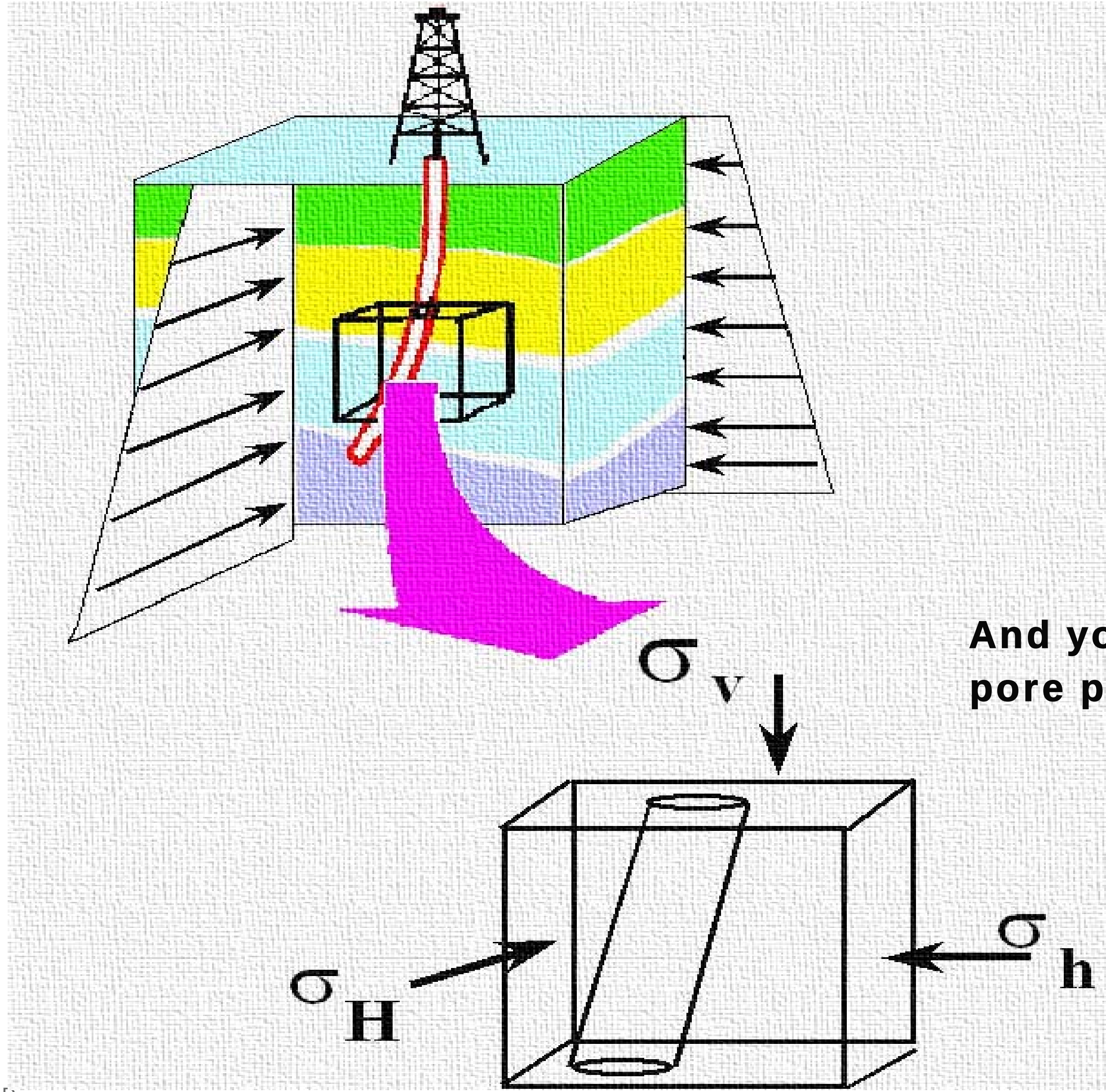
Courtesy Guizhong Chen, Chevron ETC

Cost of Wellbore Instability Problems

- Deepwater hole problem-related NPT ~ 10%
- 2006 worldwide E&P spending estimate ~ $275 Bn, 10% is ~$27.5 billion
- Deepwater hole problems cost ~$26 Bn (Sweatman, 2006)
- Deepwater drilling NPT ~ 25%. Hole problem NPT ~40% (Knowledge System Inc.).

Courtesy Guizhong Chen, Chevron ETC

State of Stress



And you also have pore pressure

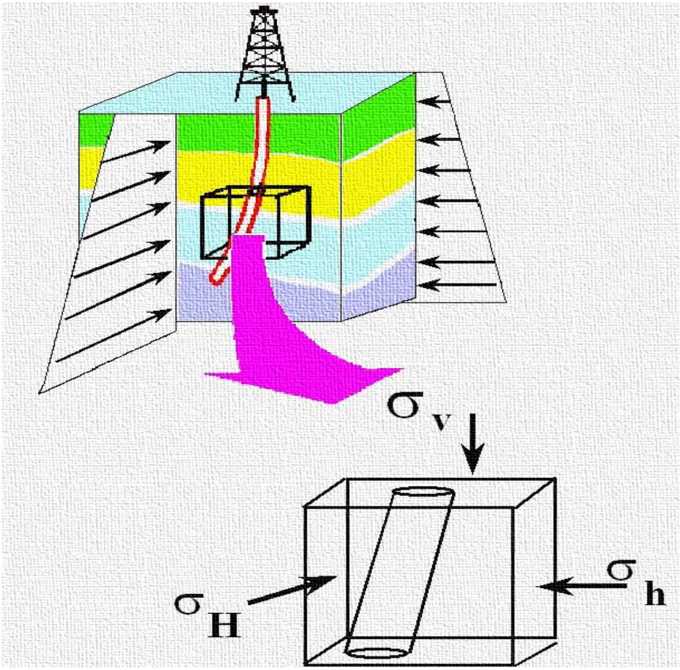
Why Does Wellbore Instability Occur?

Stress-strength imbalance

- Local (near-wellbore) stress exceeds rock strength

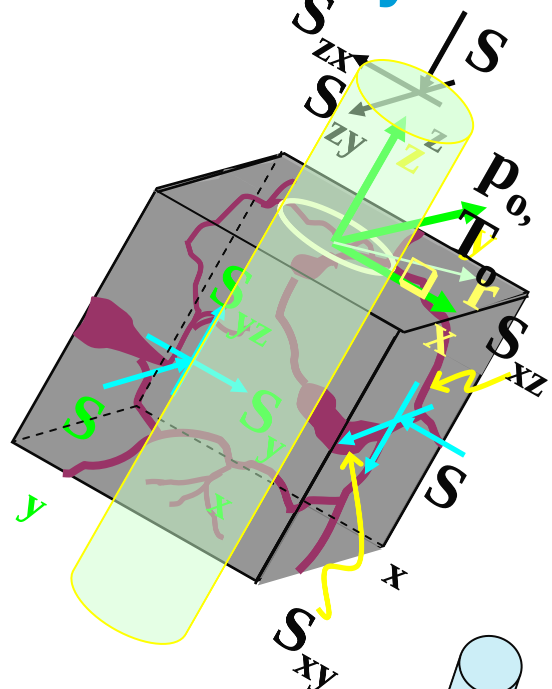
Factors that influence local stress state

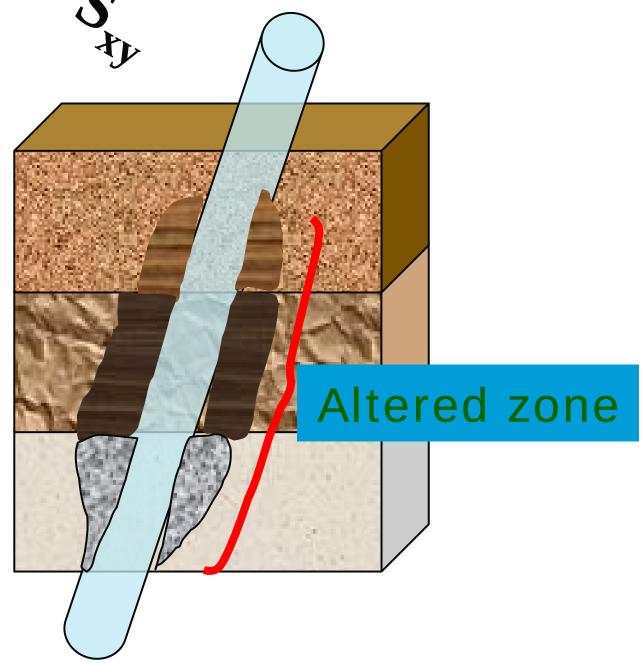
- In-situ (far-field) stresses: Overburden and horizontal stresses
- Pore pressure
- Tectonics: Faulting regime (normal/strike slip/thrust)
- Formation vs. drilling fluid temperature
- Drilling process: ECD, swab/surge, orientation



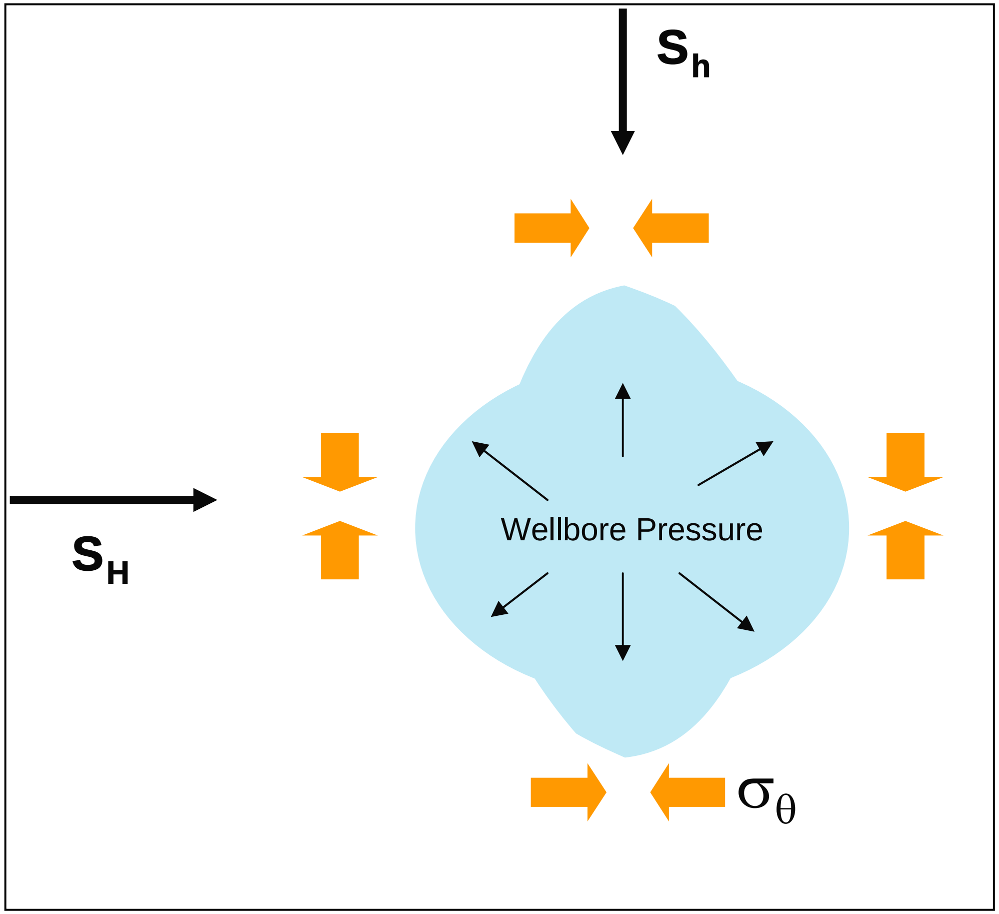
Why Does Wellbore Instability Occur?

- Formation strength - too low
- Abnormal in-situ stresses
- Naturally fractured formations
- Abnormally high/low pore pressure
- Chemically active formations
- Temperature gradient





Modes of Wellbore Instability: Compressive (Shear) failure

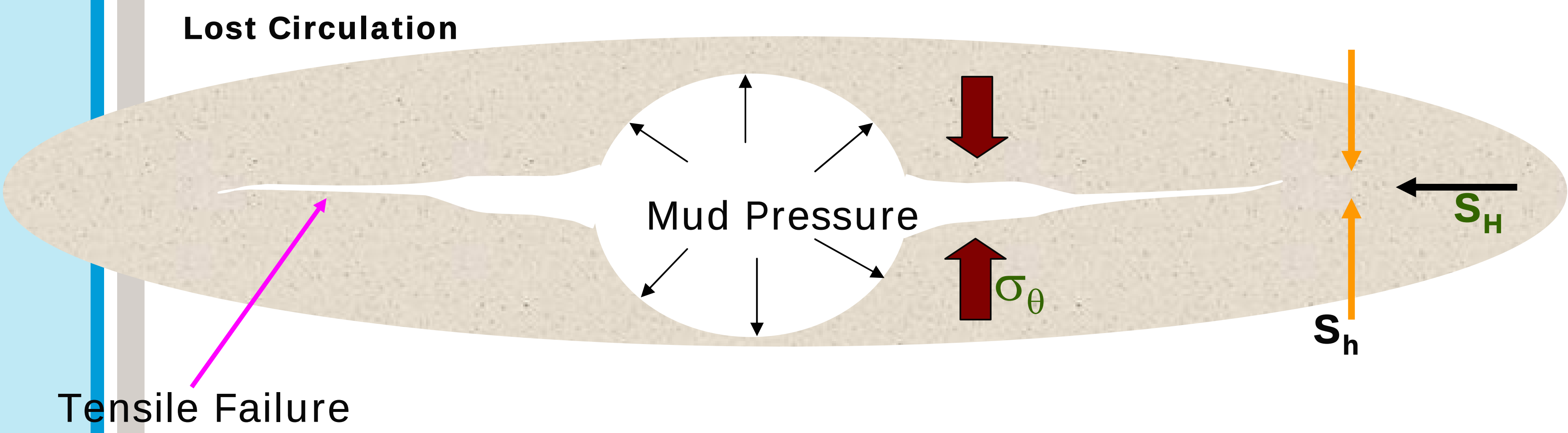


Release of compressive stresses

Stress concentrations due to hole geometry

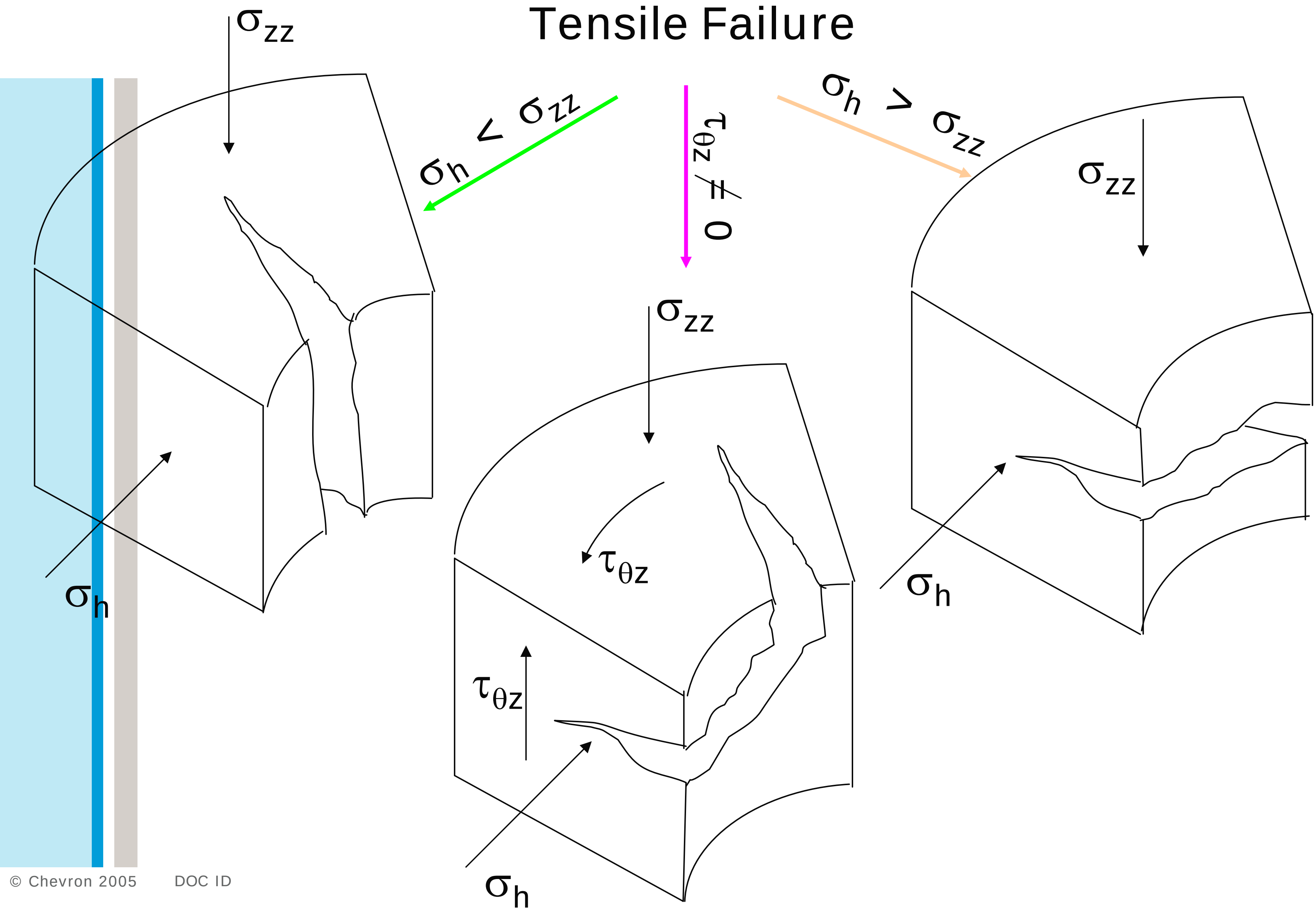
If radial mud support is insufficient => **shear failure**

Modes of Wellbore Instability: Tensile failure



- Occurs when excessive wellbore pressure causes near-wellbore stress to overcome tensile strength of the rock
- Maximum horizontal stress orientation may be deduced from the preferential direction of fracturing

Modes of Wellbore Instability: Tensile failure (Cont.)

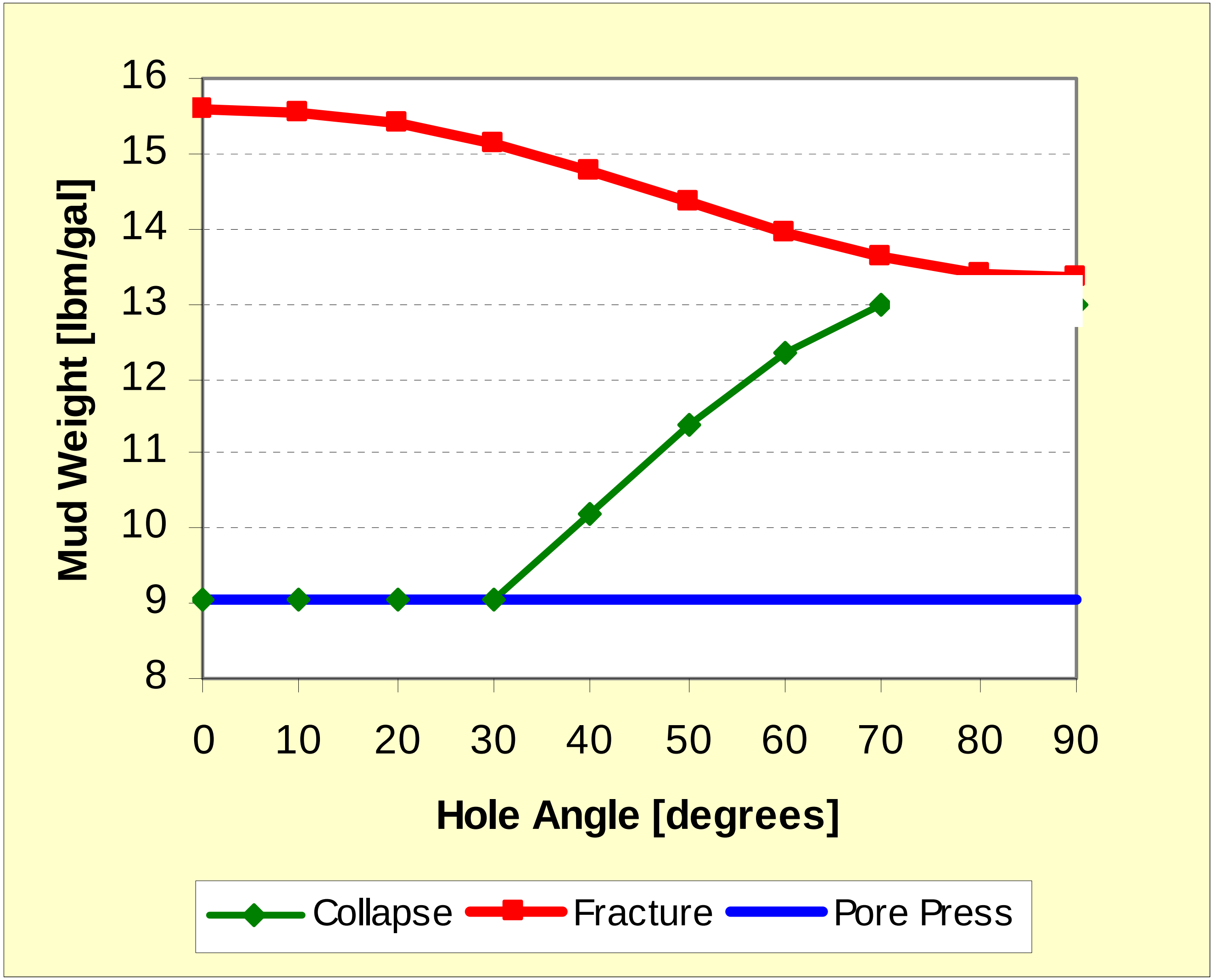


Safe Mud Window

The safe mud window can be described by the collapse and fracture initiation pressures

- The collapse pressure is the minimum well bore pressure required to prevent the onset of shear failure
- The fracture initiation pressure is the maximum wellbore pressure allowed without initiating a tensile fracture

Effect of hole deviation on safe mud window

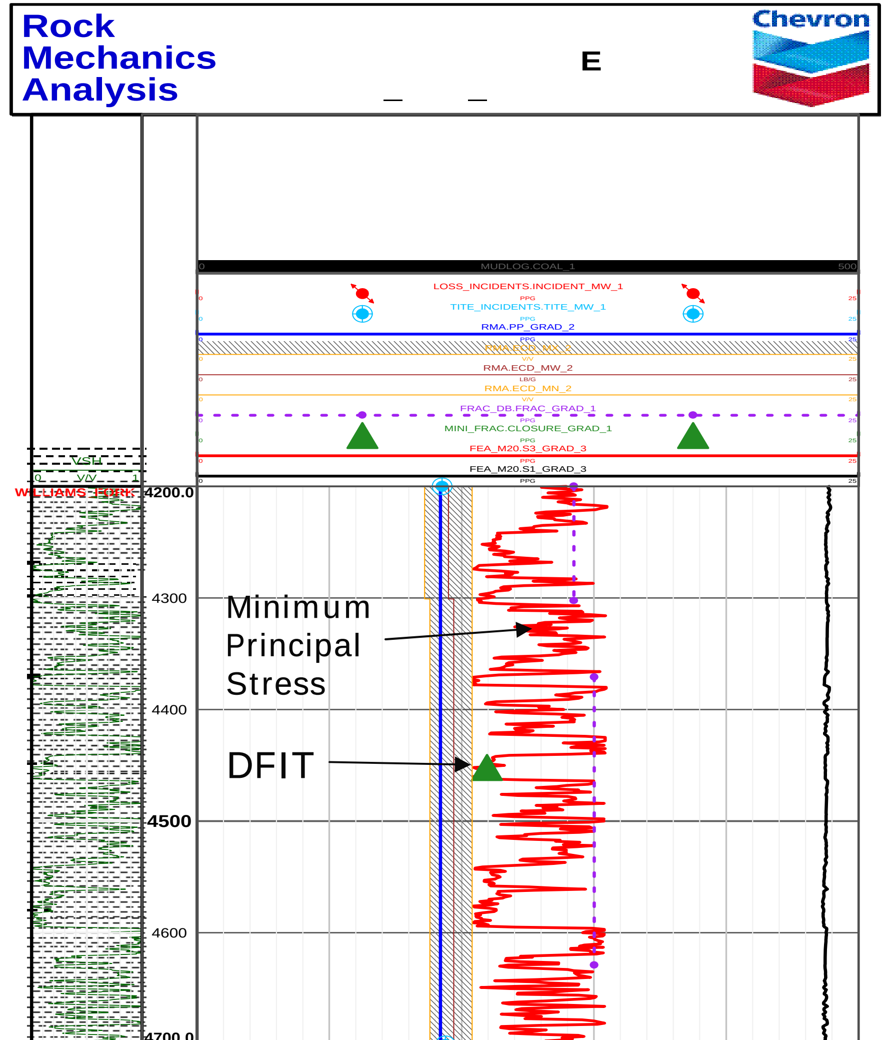


Wellbore Stability Modeling

- Estimating Insitu Gradients
  - Overburden – Integration of bulk density log
  - Pore Pressure – MDT, well logs, seismic velocity
  - Minimum Principal Stress – f(Overburden, Pore Pressure), LOT/XLOT, mini-frac, DFITs, lost circulation events, wellbore breathing
  - Maximum Horizontal Stress, SHmax – Inversion of wellbore breakouts, dipole sonic logs, regional geology, 3D Finite Element Modeling (MEM)

Wellbore Stability Modeling: Calibrating Insitu Stress

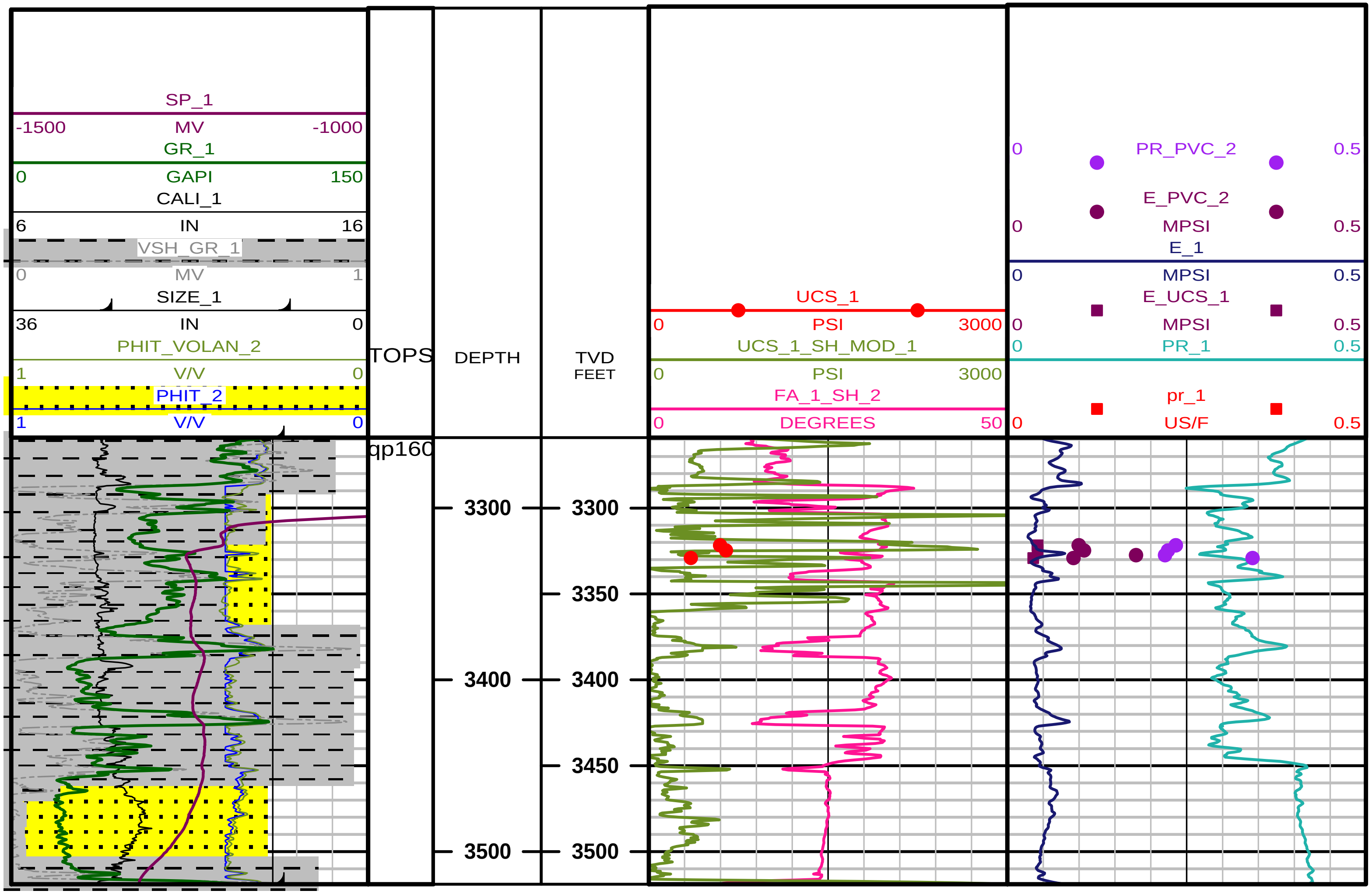
Minimum principal stress calibrated to DFIT



Wellbore Stability Modeling: Rock Properties

- Rock Mechanical Properties
  - Correlations with log data (sonic, porosity etc)
  - Laboratory tests
    - Triaxial, thick walled cylinder tests
    - Rock mechanical and failure parameters
      - Young's Modulus, Poisson's ratio
      - UCS, friction angle
- Model calibration
  - Mud weight, ECD
  - Tight spots, pack-offs, mud loss, breathing

Wellbore Stability Modeling: Calibrating Rock Properties



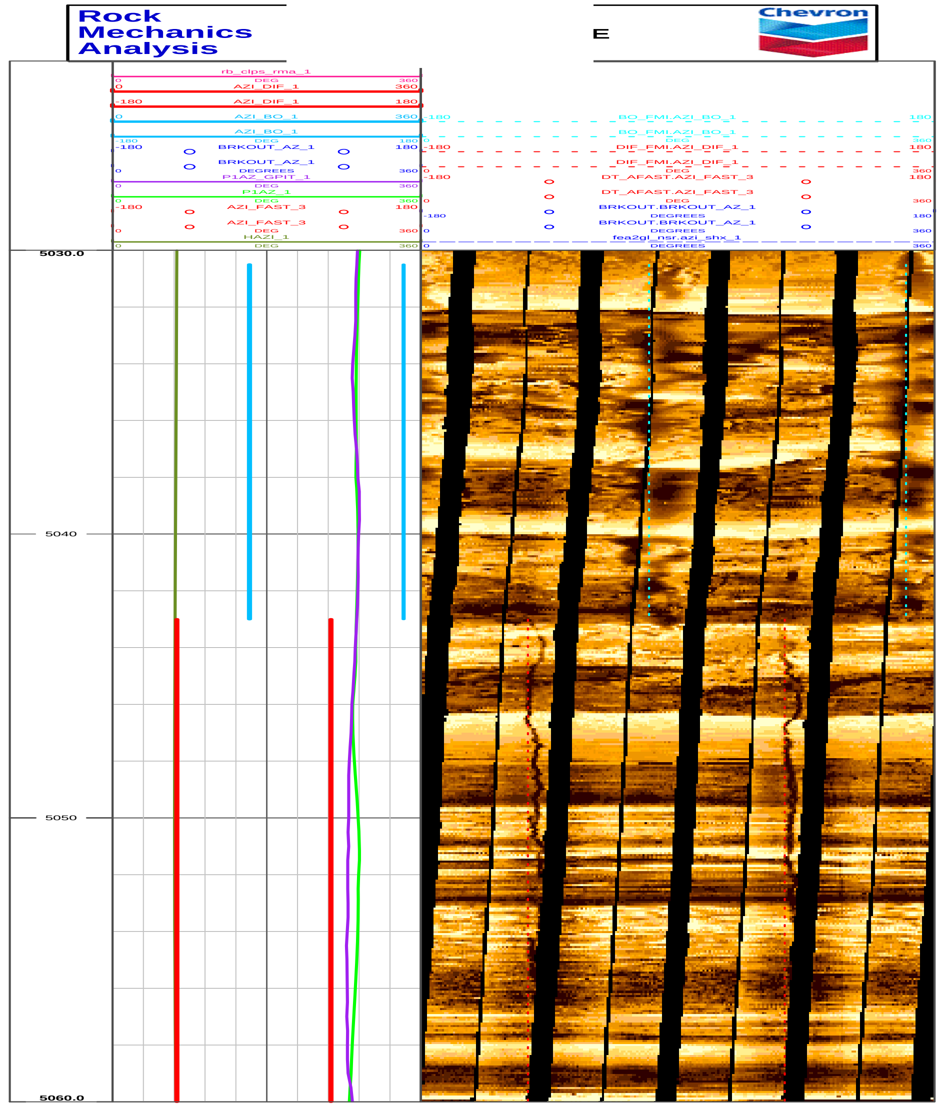
Wellbore Stability Modeling: Failure Criteria

- Commonly-used failure criteria
  - Drucker-Prager
  - Modified Lade (SPEDC June 1999, Ewy; SPE 56592)
  - Mohr-Coulomb
  - Strain-based elastoplastic models (numerical schemes)

- Need to be calibrated against field well data to select most appropriate failure criteria

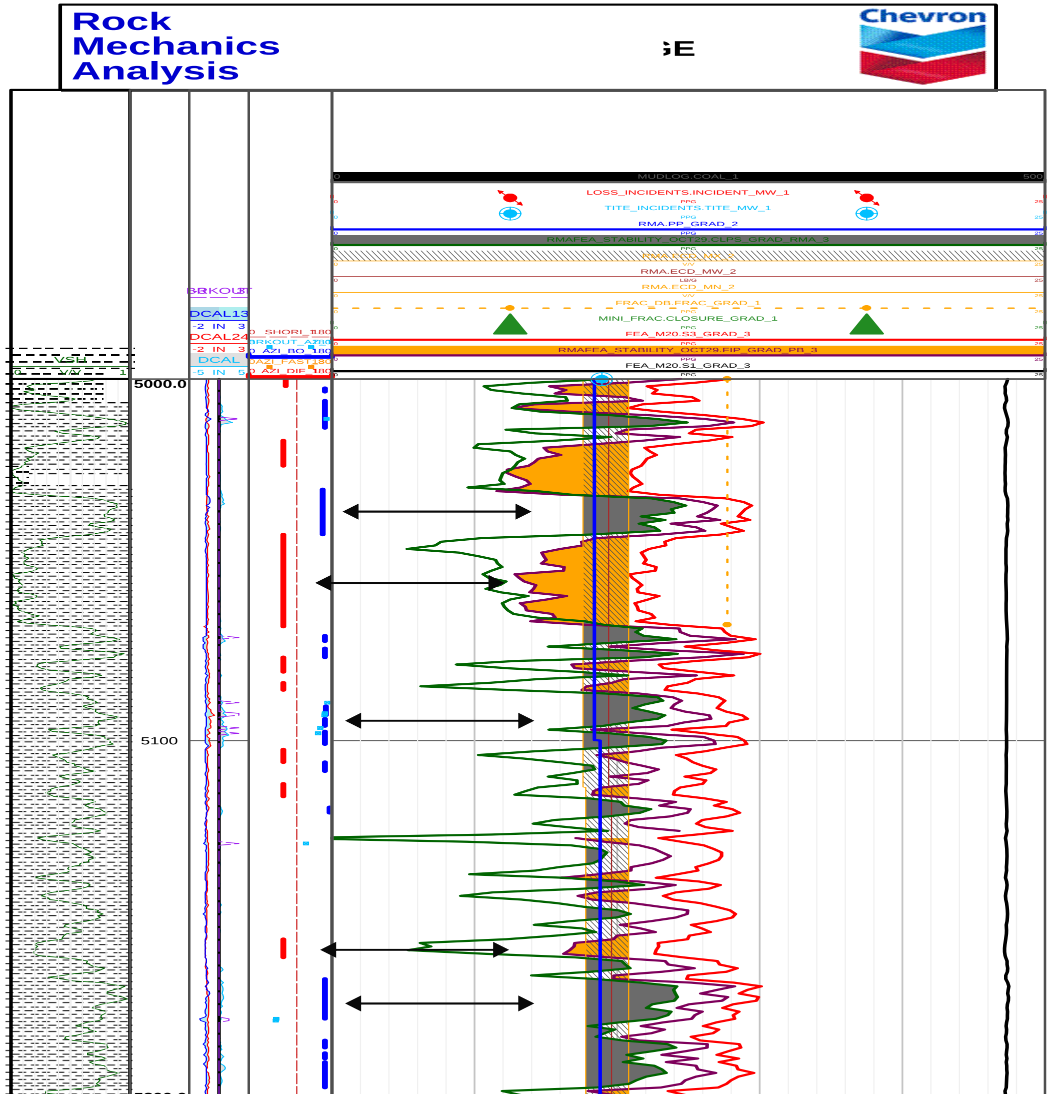
Wellbore Stability Analysis: Using Image Logs

- Breakouts, drilling induced tensile failures (DIF) observed on FMI images
- Offset by 90 degrees



Wellbore Stability Analysis: Calibration

- Calibration with observed breakouts and induced fractures
- Calculations incorporate 3D stresses from the finite element MEM



Example WBS models

- Log-based with field proven correlations, multiple depths
  - **RMA** (Chevron): SPE 103055, 47358
- Analytical solutions including more complex thermal, poroelastic and chemical effects
  - **PBORE-3D**, U of Oklahoma: www.pmi.ou.edu, SPE 56759, 106345
  - **GMI-SFIB**, Geomechanics International: SPE 92588
  - **Stabview**, Advanced Geotechnology (Weatherford)
    - Advgeotech.com, SPE 74447
- Numerical models

Courtesy Guizhong Cheng, Chevron ETC

Key Points

- Wellbore instability costs are significant
- Wellbore stability depends on drilling practices, insitu rock parameters
- Wellbore instability occurs when the near-wellbore stresses exceed rock strengths
- Wellbore stability analysis needs to be carried out using well logs, core measurements, drilling reports
- Hole orientation, chemical interaction and temperature can have significant effects on stresses around the wellbore and can affect breakdown and collapse pressures

Acknowledgments

- Guizhong Chen
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THANK YOU

Effect of Temperature on Stability

- Temperature affects both fracture initiation and collapse pressures
- Thermal effect on stress:

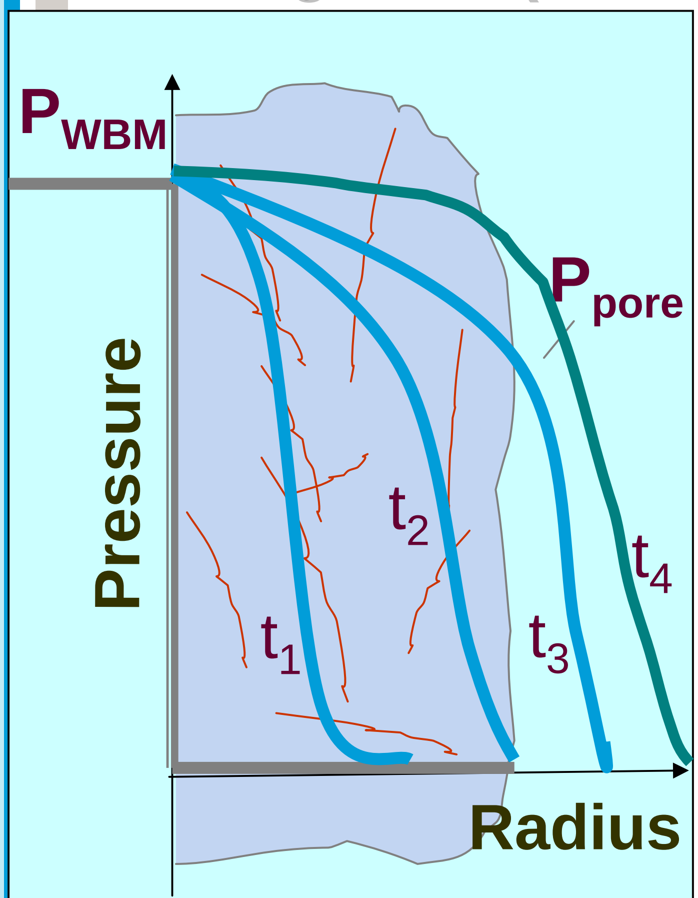
$$\Delta\sigma_T = \frac{E\alpha_T(T - T_f)}{1 - \nu}$$

E=Young's Modulus
α_T=thermal expansion coeff
T=mud temperature
T_f=formation temperature
ν=Poisson's Ratio

  - Stiffer rock -> higher thermal effect
- Injection of cold mud can result in lost circulation due to reduced breakdown pressure

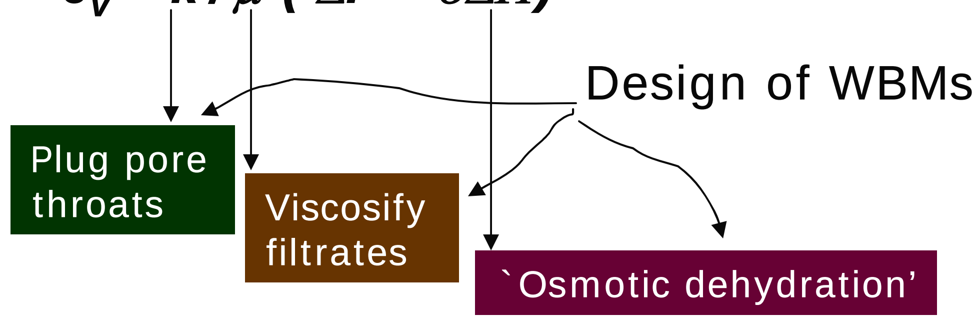
Chemical Effects on Stability

Penetrating Fluid (WBM)



- Hydration of near-wellbore zone
- Near wellbore shale deteriorates
- Near-wellbore pore pressure elevates
- Effective mud pressure support lost
- Shear/Tensile failure due to annular pressure fluctuations

$$J_v = k/\mu\ (\Delta P - \sigma\Delta\Pi)$$



Wellbore Stability Analysis: Using Drilling Events