Petroleum Geomechanics for Drilling, Completion and Production Cycles

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Outline

- Geomechanical Challenges in Petroleum Fields
- Introduction to Geomechanics
- Drilling and Completion
  - Wellbore Stability
  - Fault Reactivation
- Hydrocarbon Production
  - Reservoir Pressure Reduction (depletion) and Fluid Injection
  - Sand Production
  - Hydraulic Fracturing
  - Compaction and Subsidence
- Summary and Conclusions

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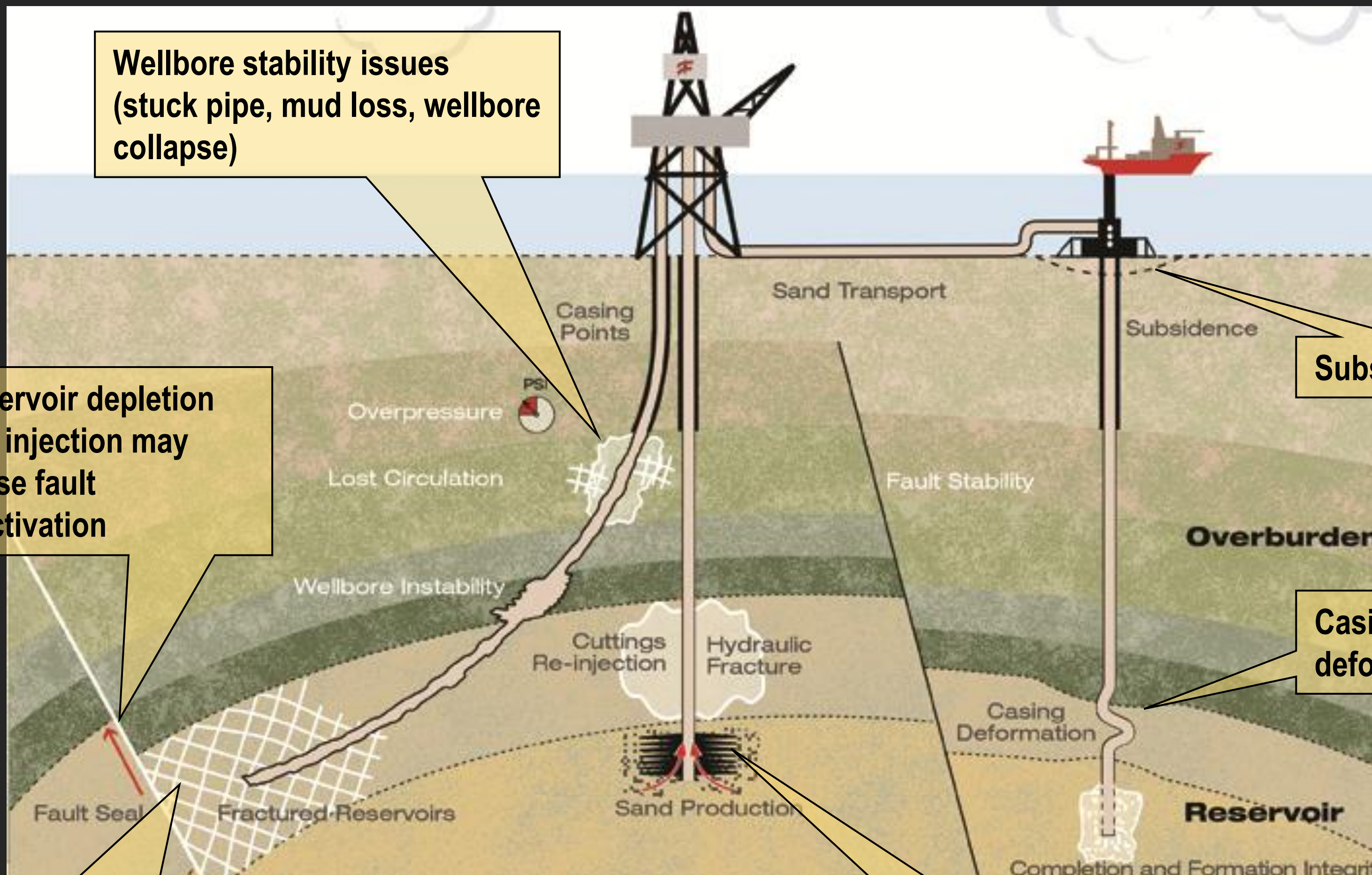
Terminologies

- LOT = Leak off pressure test
- Mud Wight = Drilling fluid pressure
- Mud Weight Window = Operating range of drilling fluid pressure inside the wellbore
- Fracture Pressure = Minimum pressure required to create a tensile fracture at the wellbore wall by injecting fluid into wellbore
- Breakout = Shear failure of wellbore wall by applying inadequate wellbore pressure
- Formation = Lithology of wellbore/reservoir (e.g. sandstone, shale, claystone)
- Mud Loss = Significant invasion of drilling fluid into formation
- UCS = Unconfined Compressive Strength (measured in the lab on cylindrical samples)
- Reservoir Depletion = Reservoir (pore) pressure reduction due to production
- Sand Production = Producing unwanted formation sand grains with hydrocarbon
- Fault Reactivation = Slippage of fault surfaces due to pressure and insitu stress change
- Wellbore Stability = Preventing any type of collapse on the wellbore wall
- Cuttings = Expected drilling debris coming out of the wellbore during drilling
- Cavings = Unexpected chunks of failed rocks coming out of the wellbore

Geomechanical Challenges in Petroleum Fields

Wellbore stability issues (stuck pipe, mud loss, wellbore collapse)

Reservoir depletion and injection may cause fault reactivation



Subsidence

Casing deformation

Natural fractures, permeable zones and hydraulic fracturing stimulation

Sand production prediction

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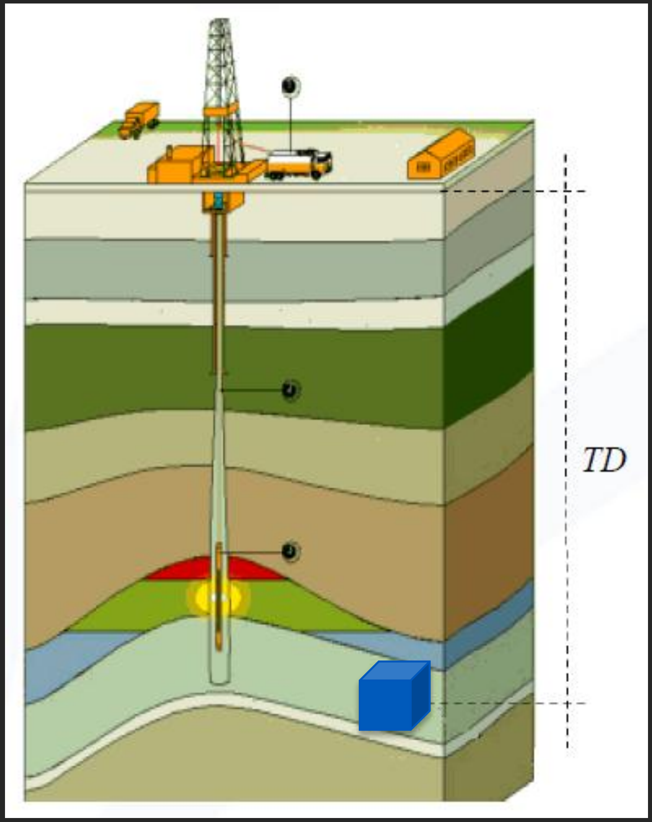
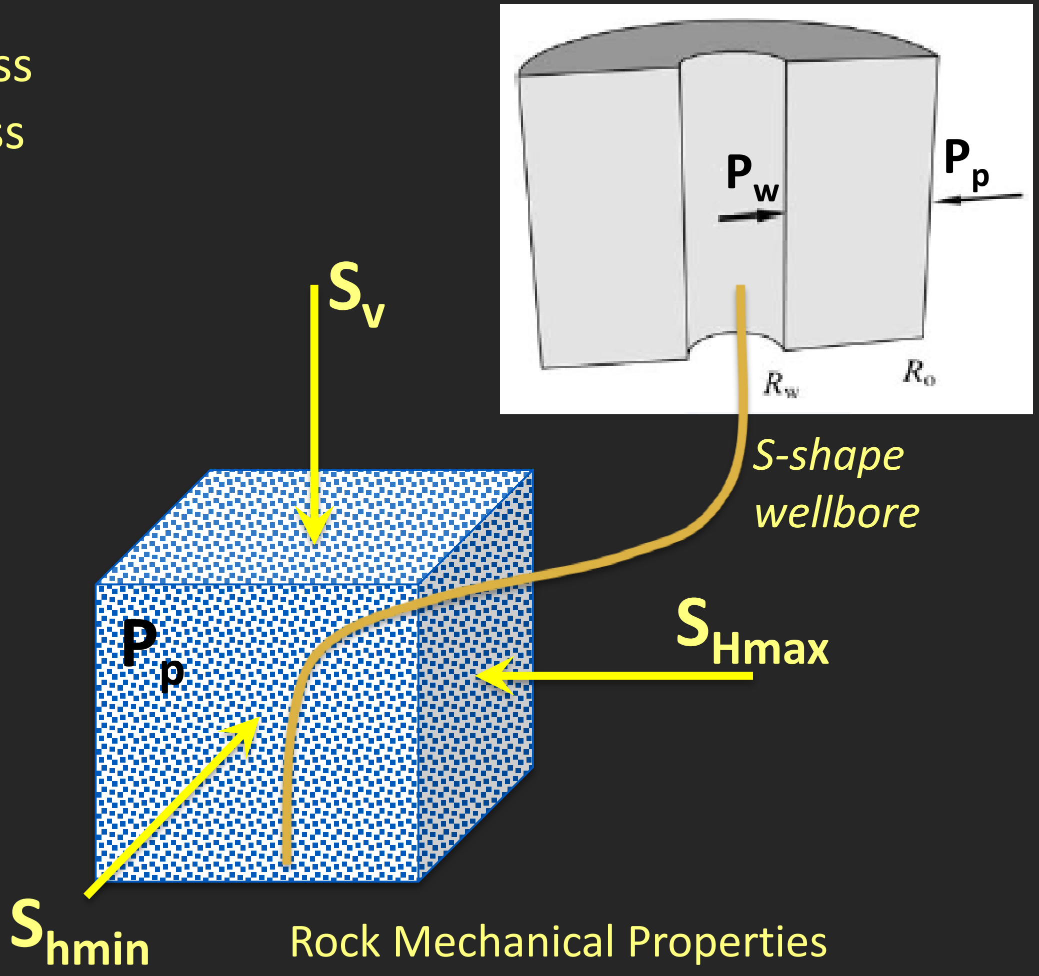
Earth Stresses and Rock Mechanical Properties

S_v	Vertical Stress
S_{Hmax}	Maximum Horizontal Stress
S_{hmin}	Minimum Horizontal Stress
P_p	Pore Pressure

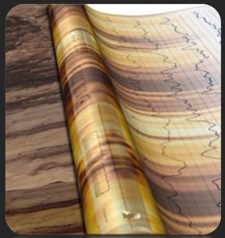




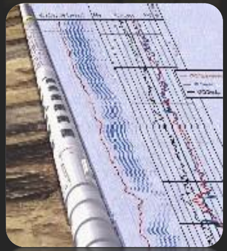
Rock Mechanical Properties
UCS, Cohesion,
Friction, Elastic Moduli

Field Data Requirements

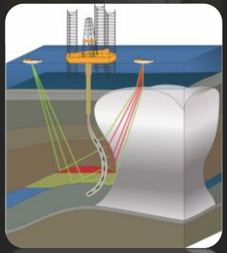

Pore Pressure, Wireline Logs, Logging While Drilling Data as GR, Bulk Density, Resistivity, Porosity, Image, Seismic → Insitu Stress, pore pressure

Leak-off and microfrac insitu tests to calculate fracture leak-off pressure → Insitu Stress, pore pressure

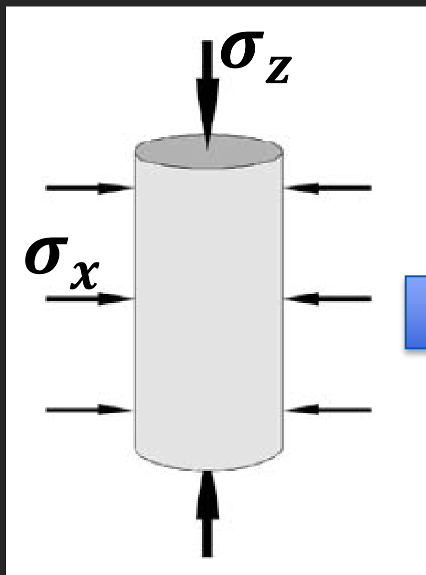


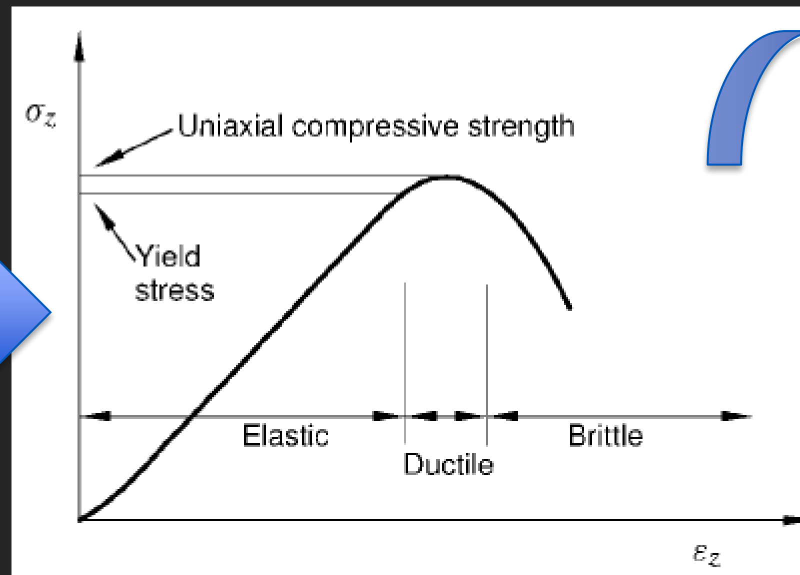

Analysis of wellbore failure using Image logs and “active” geological structures → Insitu Stress, pore pressure

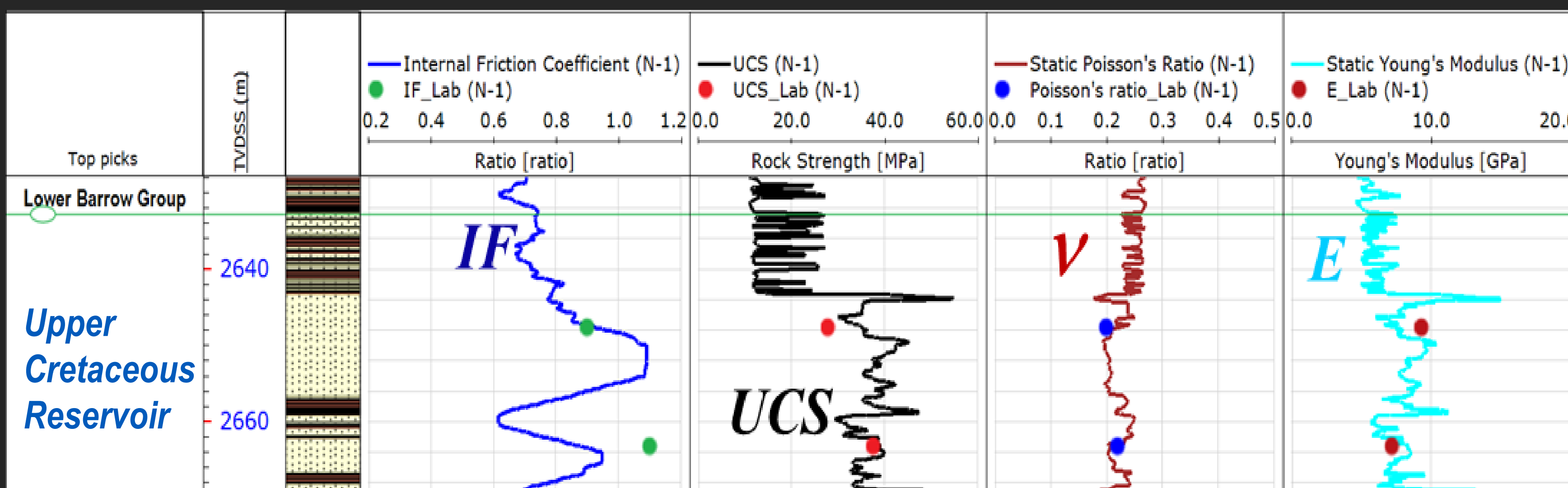
Laboratory measurements, logs, analysis of wellbore failure → Rock mechanical properties

Rock Mechanical Properties

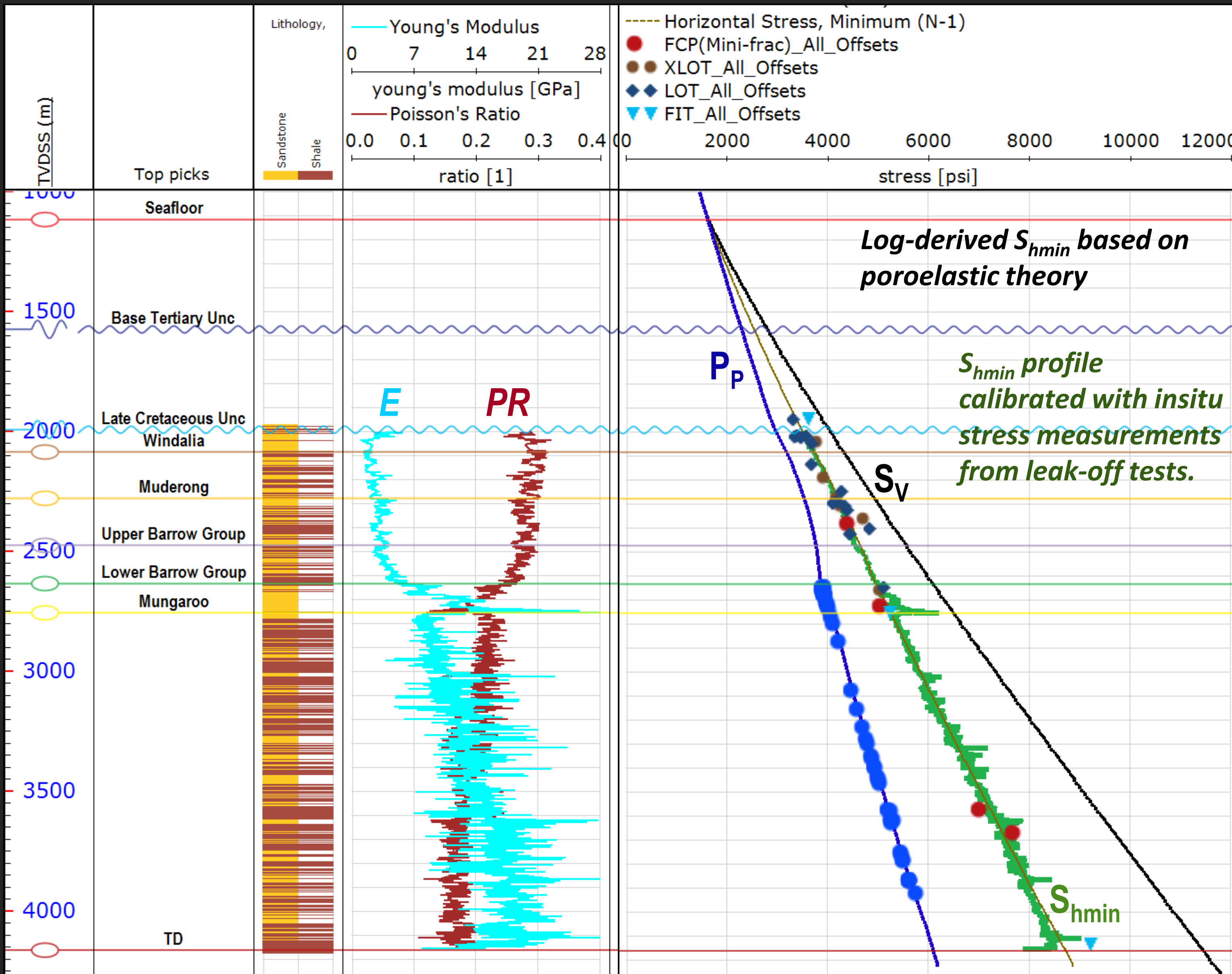




- Elastic (Young's) Modulus
- Poisson's Ratio
- Peak Compressive Strength



Horizontal Stress (S_{Hmax} and S_{hmin})



Fully Integrated Subsurface Geomechanical Modelling

Well Centric 1-Dimentional Geomechanical Model

Well log data

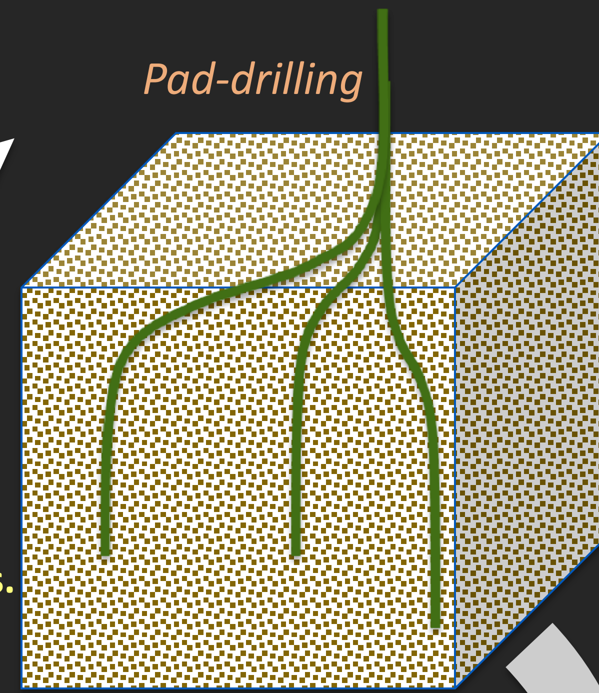
Estimate Pp and insitu stresses in well location

Estimate rock properties in well location

3D Geomechanical Model

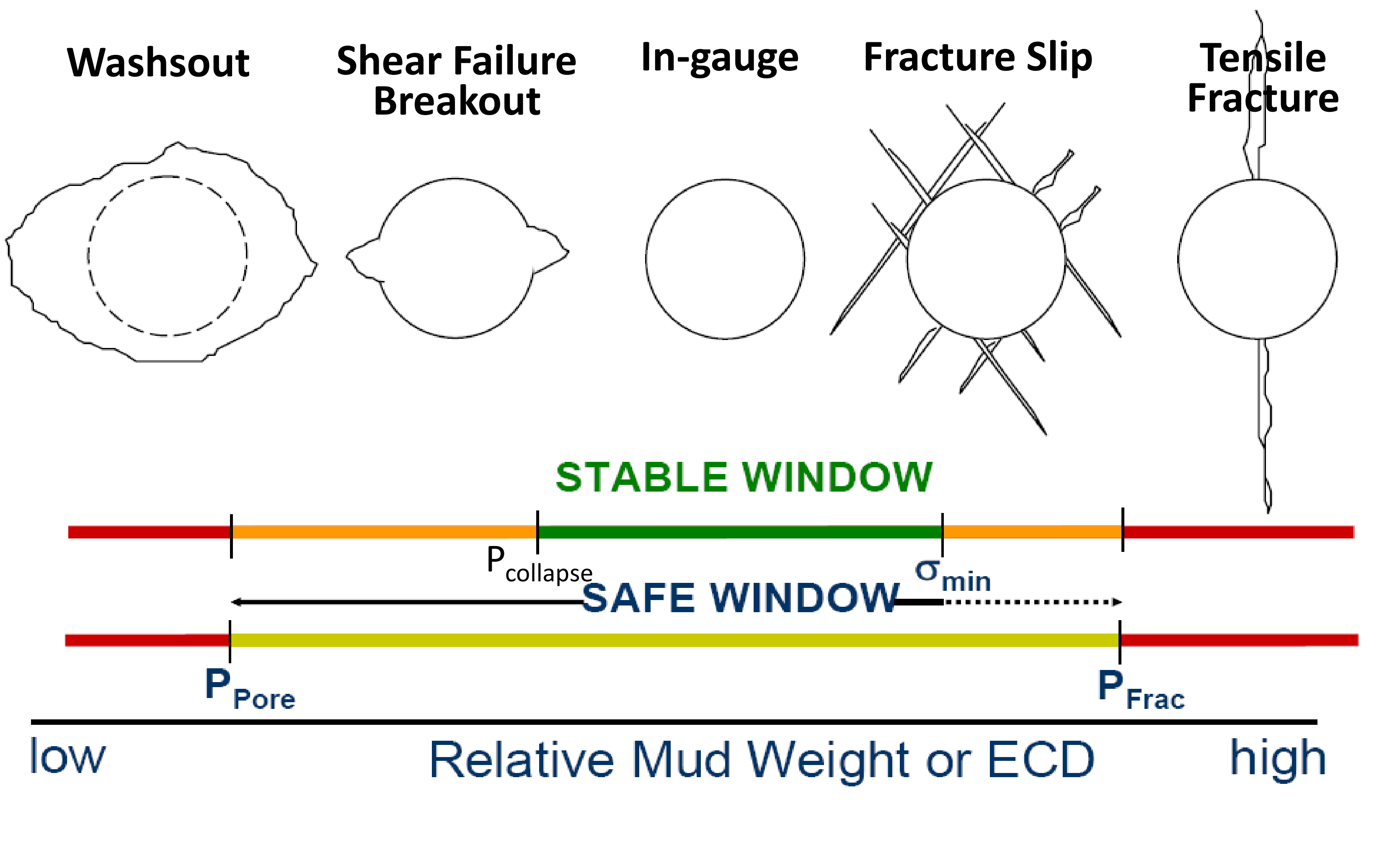
Pp
S_v
S_{Hmax}
S_{hmin}
Rock Props.

Pad-drilling

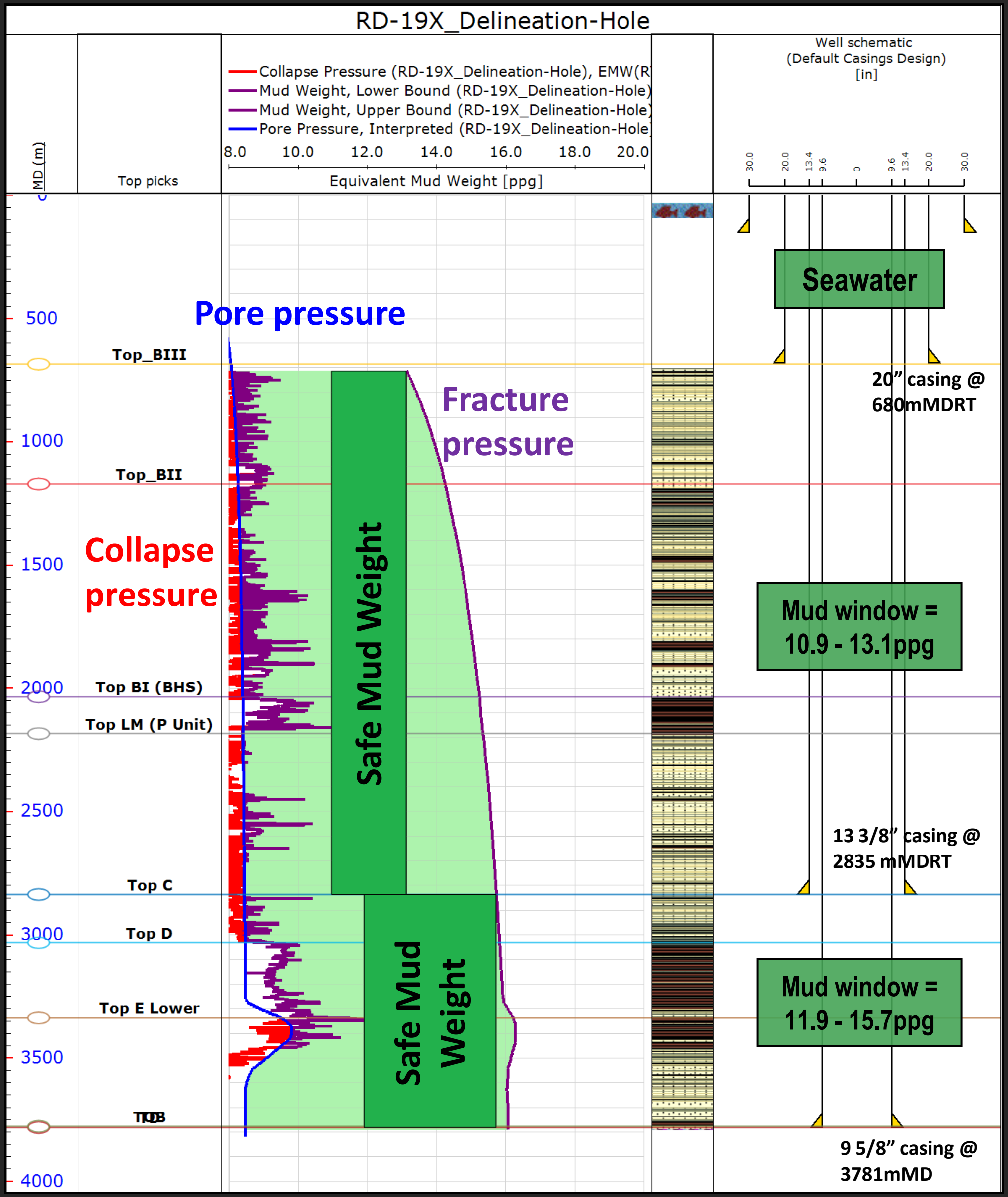


Finite Element Simulations for 3D Dynamic Modelling and its Applications

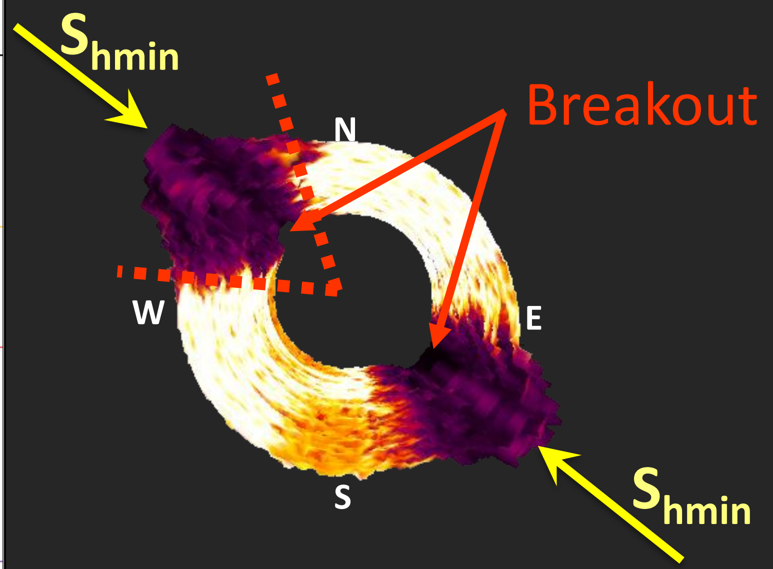
Mud Weight Window and Wellbore Geometry



Wellbore Stability



Ultrasonic Image Log Wellbore View



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Wellbore Failure Inferred from Cavings/Cutting

Normal drilling cuttings usually contain "bit marks"

Cavings are categorized into three basic types:

Angular
shear failure

rough, curved surfaces

Splintery
abnormal pressure

long, thin, concave surfaces

Tabular/blocky
bedding failure

flat, parallel, old surfaces

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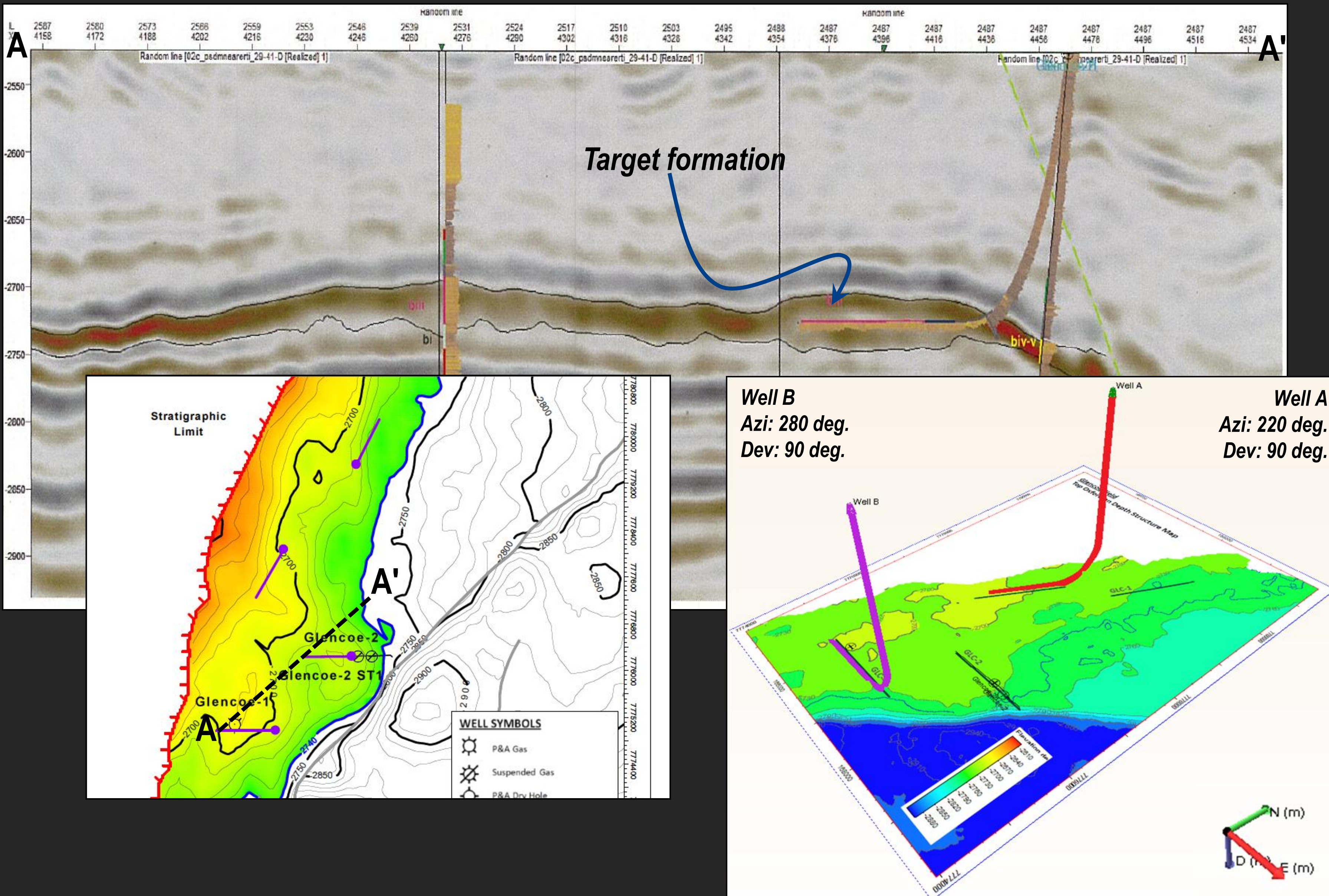
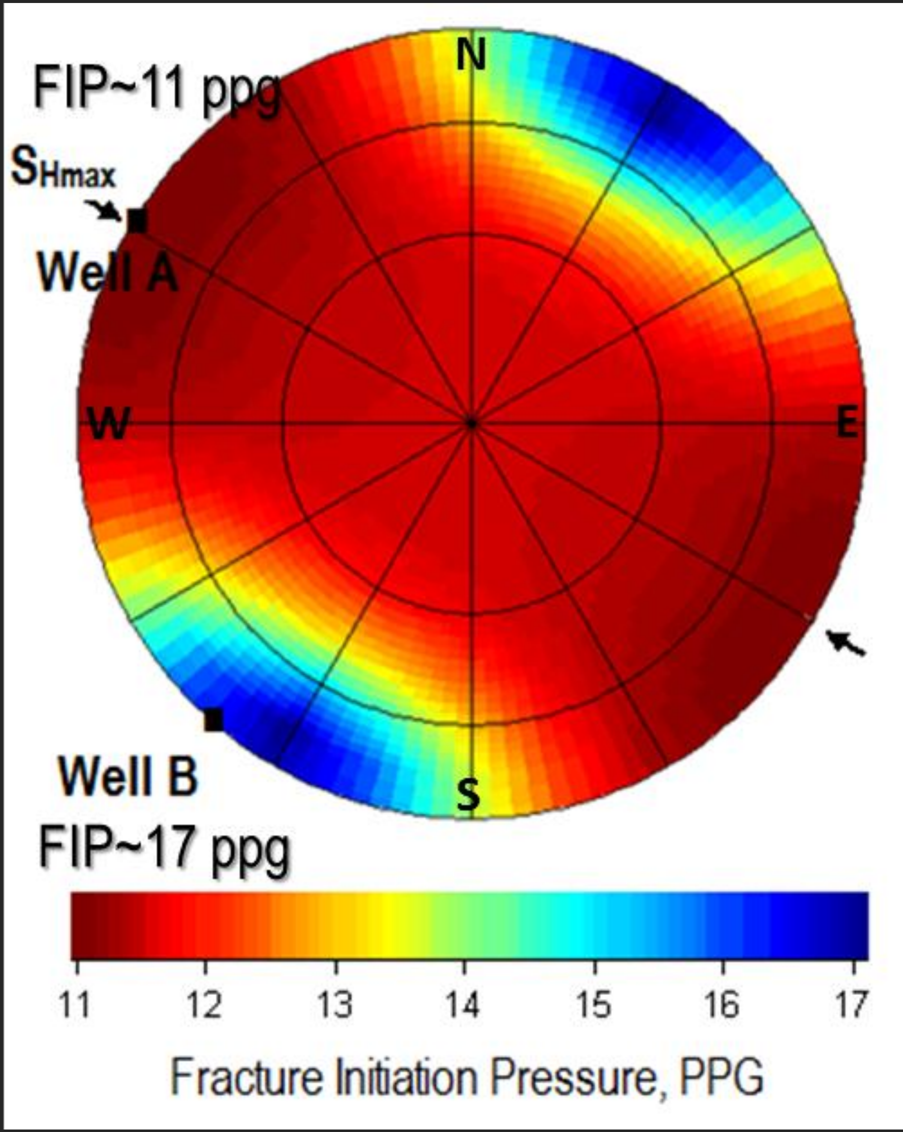
Wellbore Placement



Effects of Well Trajectory on Wellbore Stability

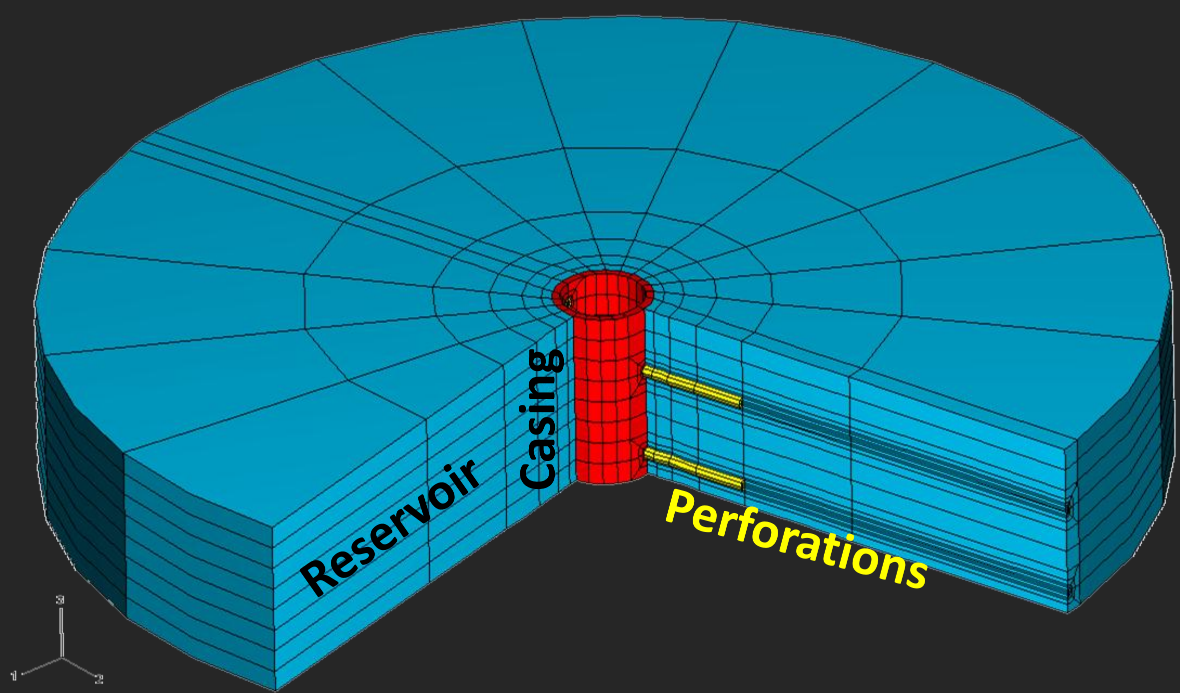


FIP = Fracture Initiation Pressure

High dependency of FIP to wellbore azimuth.

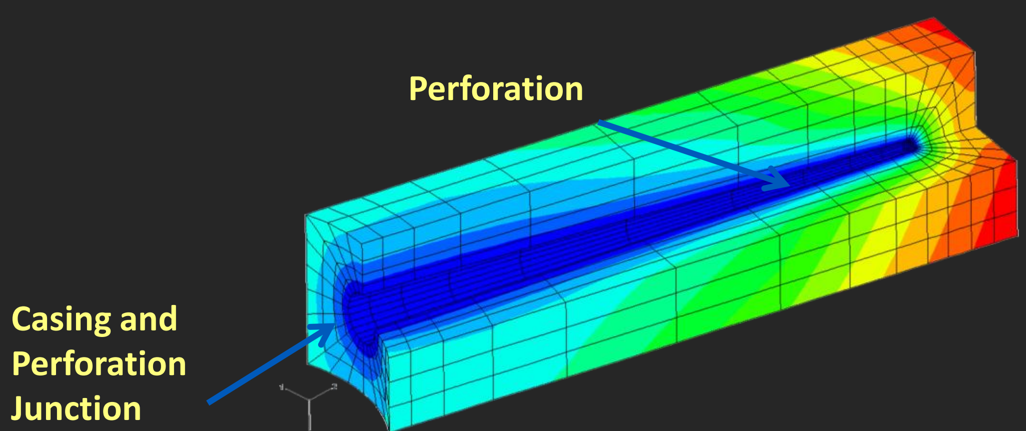
Stereonet (lower hemisphere) plot

Finite Element Model for Sanding Analysis



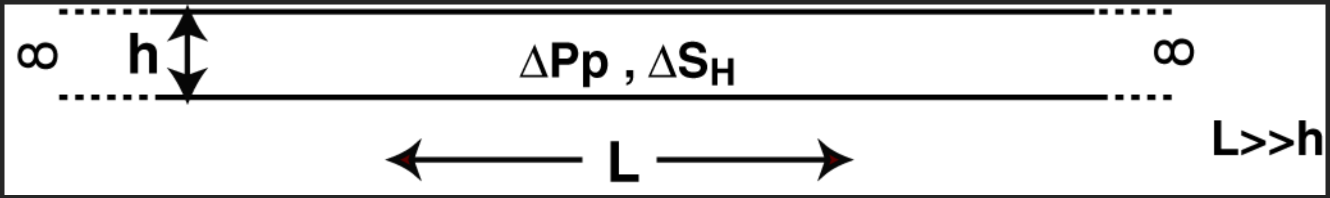
Arbitrarily Oriented Well Trajectory:

Open hole & Cased and perforated completions



Mesh shows the results of FE simulations with pore pressure contoured in color

Changes of Horizontal Stresses with Depletion



Using instantaneous application of force and pressure with no lateral strain:

L: Length (lateral extent) of reservoir

h: Height (thickness) of reservoir

ΔP_P:Change in pore pressure

ΔS_H: Change in horizontal stresses

$S_H \equiv S_{hmin} \equiv S_{Hmax}$

ν: Poisson's ratio

α: Biot's coefficient

A: Stress Path

$$\Delta S_H = \alpha \frac{(1-2\nu)}{(1-\nu)} \Delta P_p$$

$$A = \frac{\Delta S_H}{\Delta Pp} \approx 0.75$$

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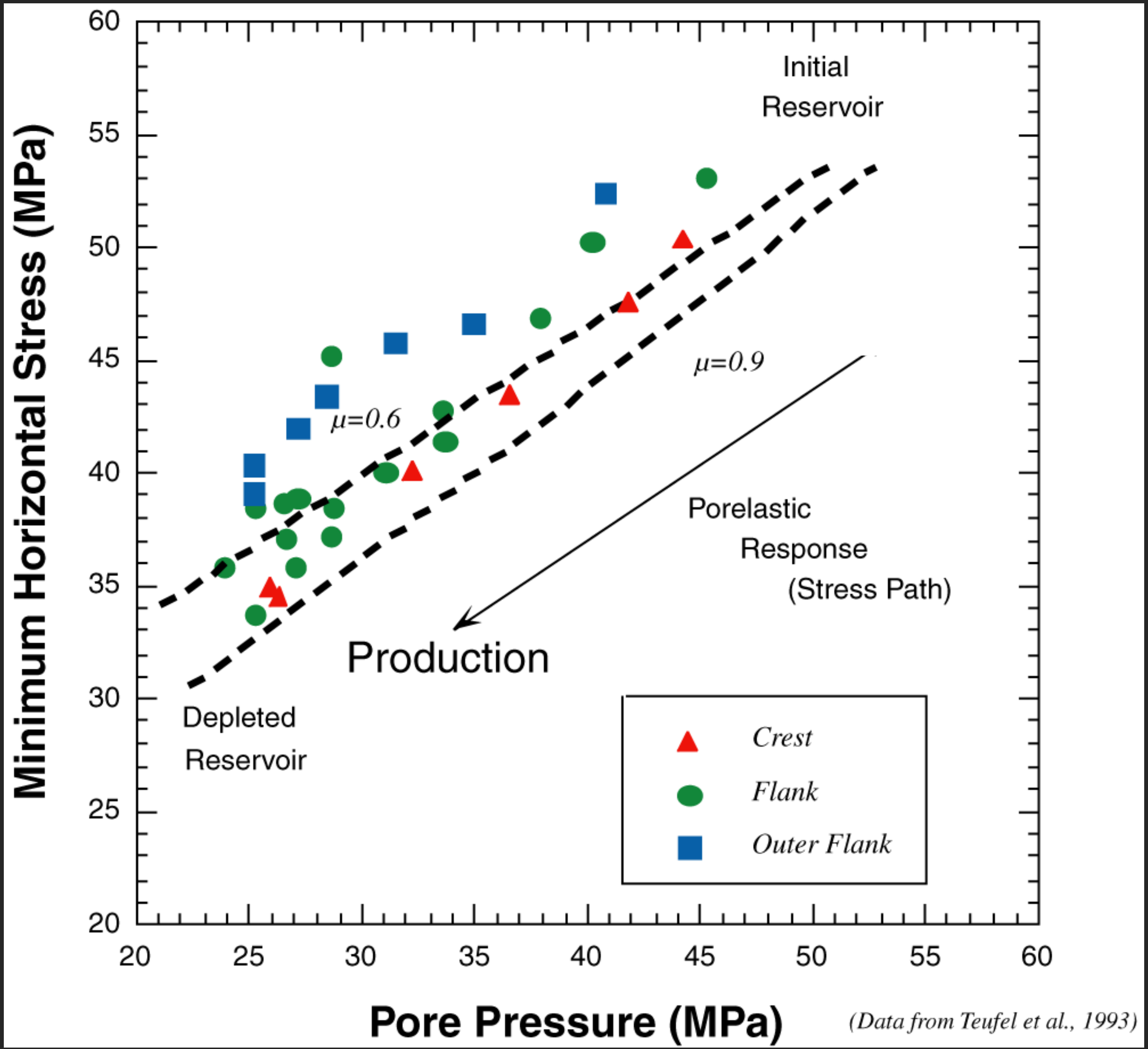
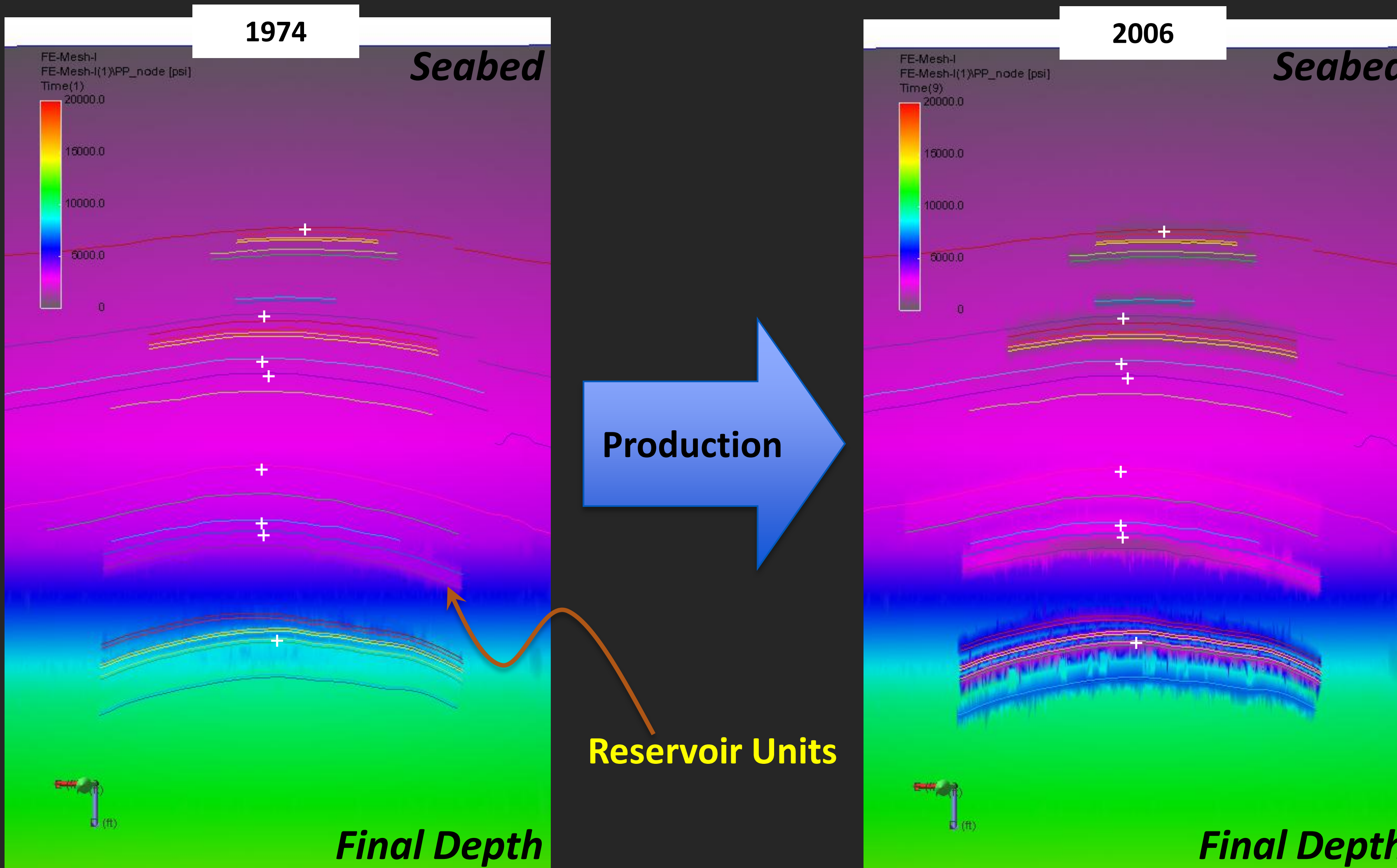
Stress and Pressure Evolution

The crest and flank of the reservoir follow a typical normal faulting stress path, indicating that normal faulting may be contributing to the subsidence as well as maintaining permeability in the reservoir.



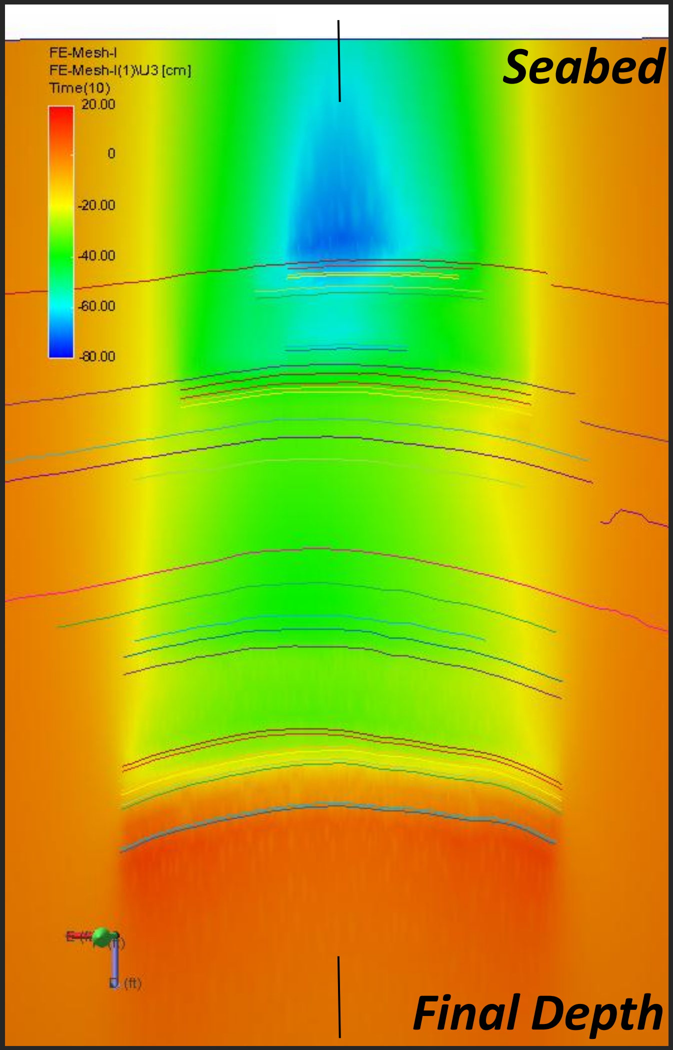
Mapped Pore Pressure in 3D FEM Dynamic Model



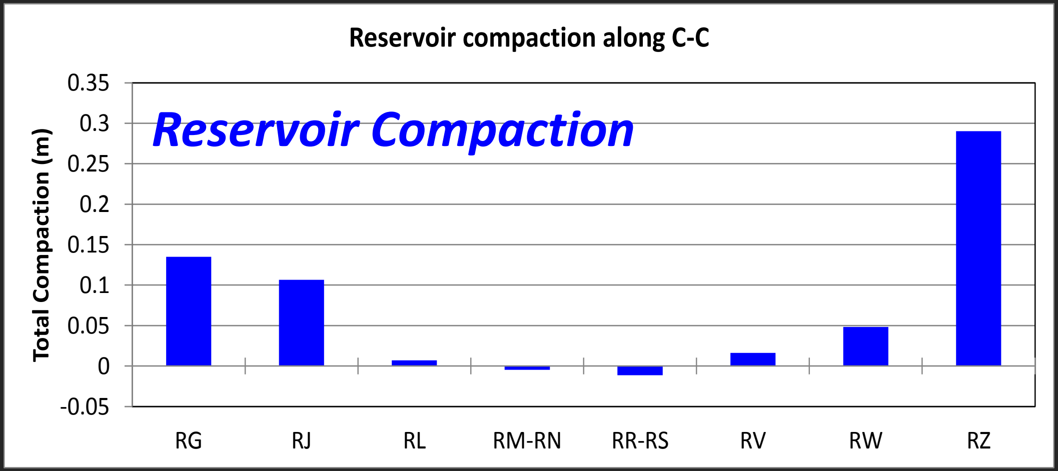
Pore pressure Contours

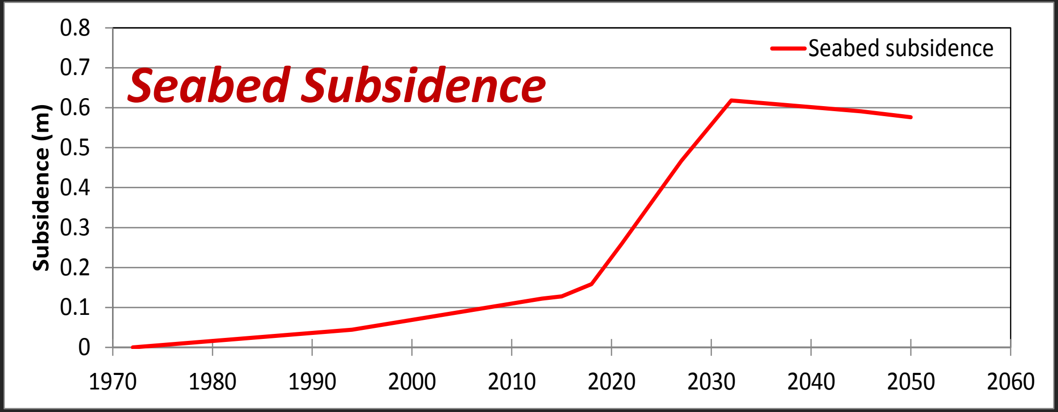
Pore pressure Contours

FE Model of Subsidence Due to Reservoir Compaction and Pore Collapse



Displacement Contours





There are real examples in the world that subsidence due to reservoir compaction were observed and made severe issues (e.g. Ekofisk subsidence 1980s) in North Sea.

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Summary

- Geomechanics helps to understand the mechanics of interactions of drilling fluid (mud), principal insitu stresses, pore-fluid pressure and formation rock mechanical properties in the entire Petroleum Engineering process.
- In drilling phase, it helps to define the safe mud weight to avoid influx of formation pore-fluid into the well while maintaining wellbore stability without fracturing the wellbore wall.
- During well completions, an improperly defined geomechanical model can lead to unexpected costly problems such as sand production.
- In production phase, a coupled 3D dynamic reservoir geomechanical model is essential for field development plans such as fluid injection to enhance production or reservoir stimulation by hydraulic fracturing.

Thank you

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