Geomechanics for Drilling & Wells

ENPC geomechanics seminar

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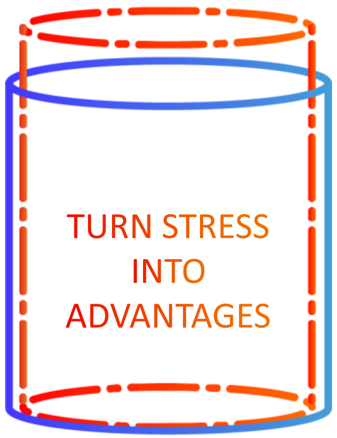


About TotalEnergies: our ambition and mission

TotalEnergies is a **global multi-energy company** that produces and markets energies: oil and biofuels, natural gas and green gases, renewables an electricity.

Active in more than 130 countries, TotalEnergies puts **sustainable development** in all its dimensions at the heart of its projects and operations to contribute to the well-being of people.

As a major player in the energy transition, TotalEnergies' ambition is to **reinvent the way energy is produced and consumed to get to net zero by 2050**, together with society, and to resolve the climate challenge.

OUR MISSION

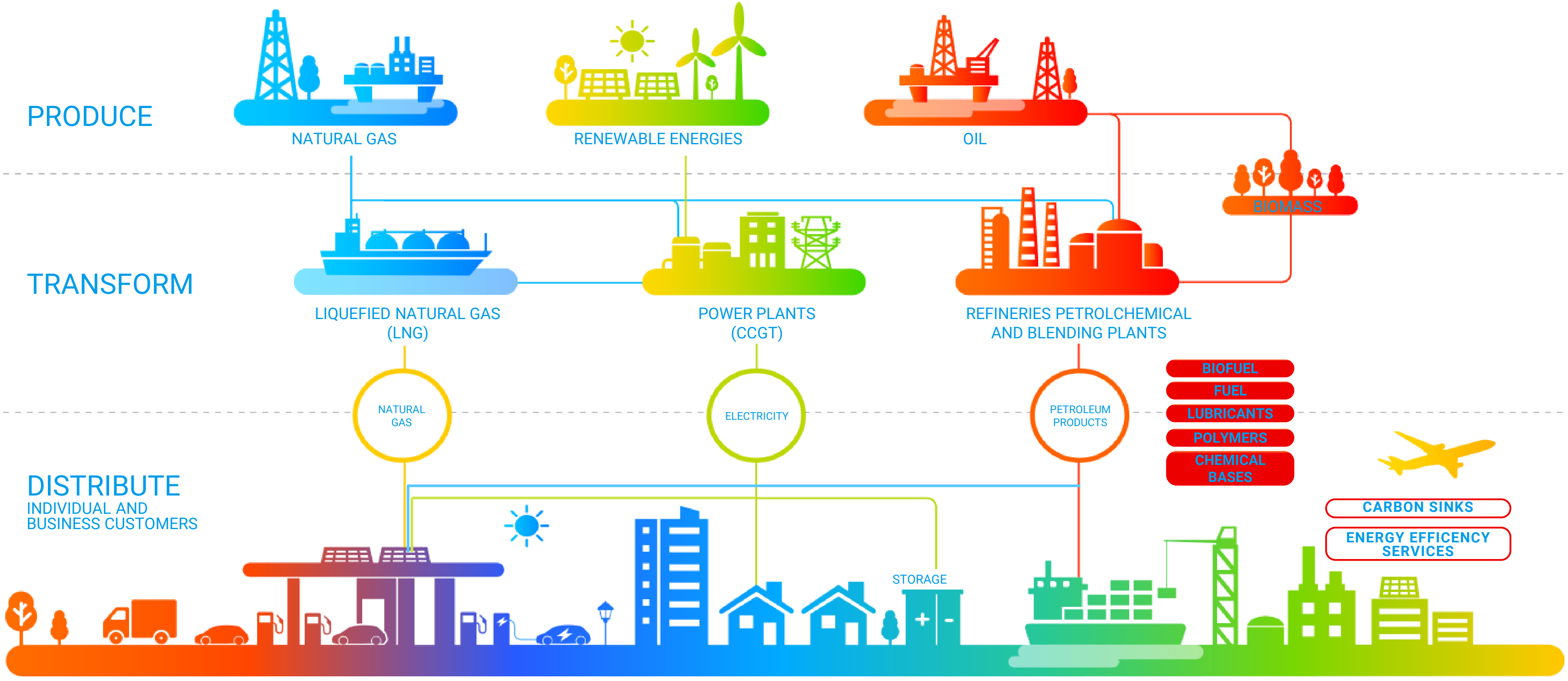
Our 101,000 employees are committed to energy that is more affordable, cleaner, more reliable and accessible to as many people as possible.

More energy

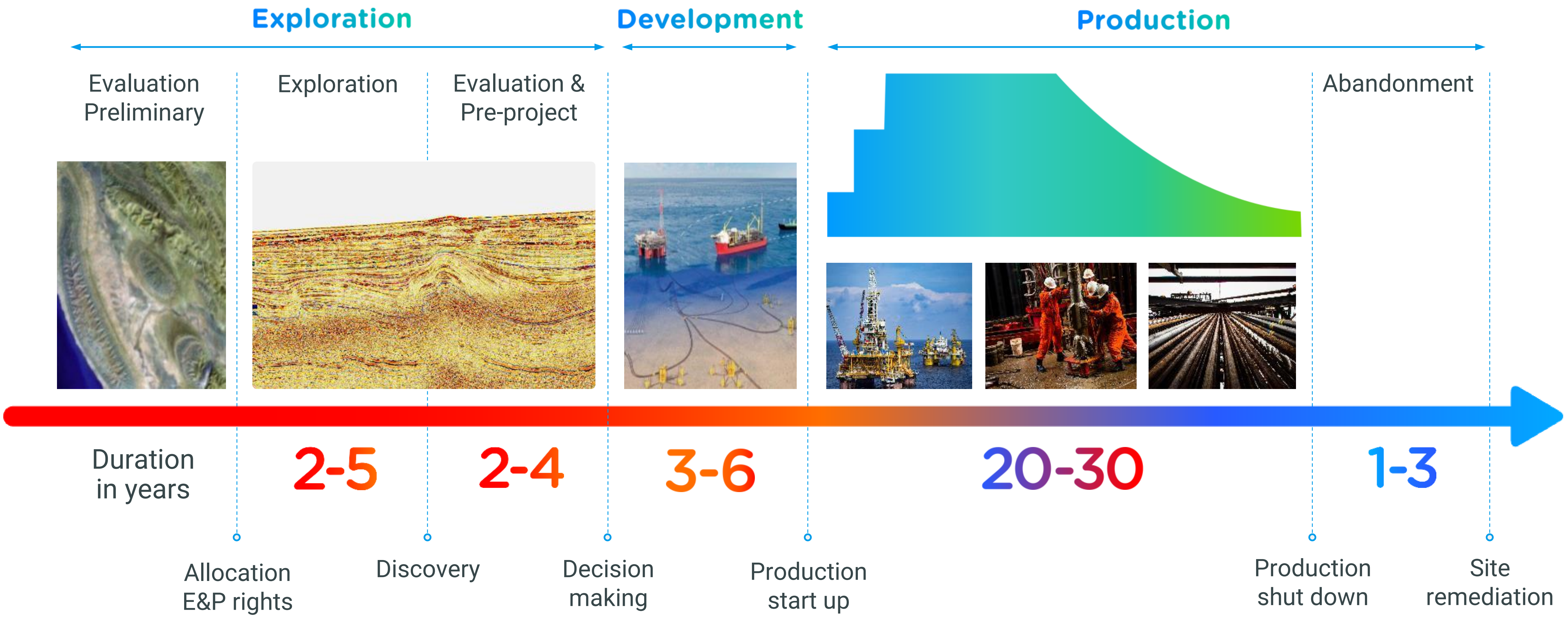
Less emissions

Always more sustainable

A broad energy company – overview



Full E&P Value Chain



Why Geomechanics in energy, CCS and Oil and Gas industry?

What materials and phenomena studies GM?

- ✓ Petroleum geomechanics is **one of Geoscience Specialities**, dealing with the mechanical behavior of geological formations and its interaction with pore pressure and temperature at various scales: around & near wellbore, reservoir scale, faults and fractures

What Issues deals with GM ?

- ✓ Geomechanics investigates and **brings the solutions for Drilling&Wells engineering**, such as wellbore stability, hydraulic fracturing, formation/casing interaction, sand production, waste injection, cap rock integrity, and P&A works
- ✓ It includes also Reservoir scale phenomena such as compaction and subsidence caused by production, maximum safe injection pressure, and induced faulting and seismicity

Who GM works with ?

- ✓ Geomechanics specialists typically work **with specialists** in geophysics, geology, petrophysics, reservoir engineering, drilling & completion engineering, and rock physics **to propose geomechanical solutions**

Geomechanics perimeter of competencies

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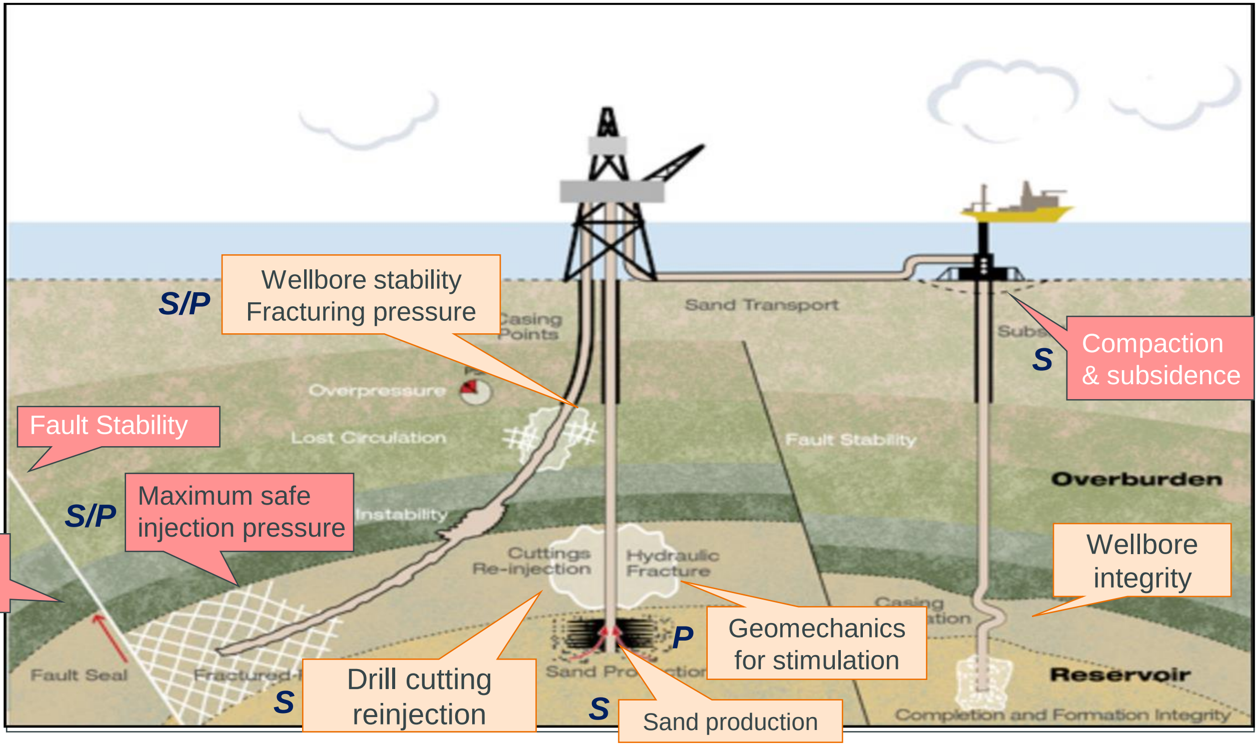
What is Geomechanics?

- ✓ Geomechanics is the study of **how subsurface rocks deform or fail** in response to changes of stress, pressure and temperature

Where does geomechanics impact?

Drilling Geomechanics

Reservoir Geomechanics

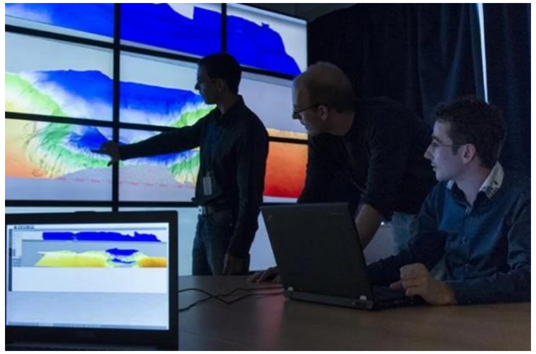


S : Safety
P: Performance

How Geomechanics is involved?

- Geomechanics acts as a bridge between the subsurface team and drillers by quantifying the magnitudes of in situ stresses and the range of MMW covering different Pp scenarios.
- The Geomechanics Entity is an excellent place to train young drillers to become future drilling masters, 6 drillers passed in GM in the last decade ☺
- The profiles of PPFG & MMW leads to kick off the well design, preparation by drillers, and later are used during whole drilling&completion operations. Such stress data will be also used in productions and P&A works.

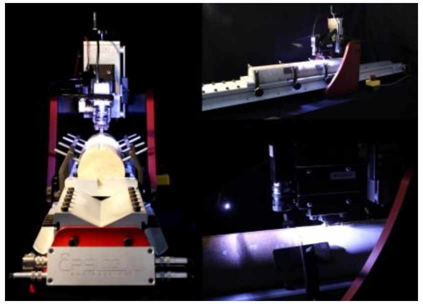
Geoscience Subsurface

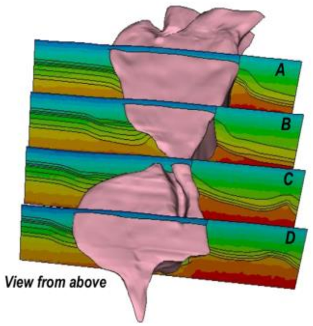


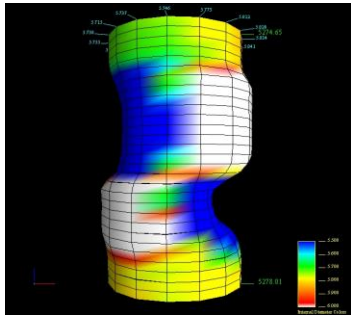
Drilling & Completion

Geomechanics Entity in TotalEnergies OneTech

- We are about 35 peoples working in the Geomechanics Entity in TotalEnergies OneTech, which is part of Drilling&Wells Métier (Division),
- We have a world-class of Rock Mechanics Laboratory (10 heavy loading frames)
- We deliver about 150 studies per year
- The Rock Mechanics Lab produce ~400 tests per year
- We follow-up of drilling operation of sensitive wells
- We carried out also geomechanics related R&D actions
- We hosted ~7 internships per year







Geomechanics and Energy Transition

***CCUS :**

- Cap rock integrity,
- fault sealing
- Maximum allowable injection pressure
- Induced seismicity
- Integrity of wells: sealing of interface rock/cement/casing interface due to cycles of injection
- P&A of wells

Many CCS projects in Norway, Netherland, Denmark, UK and others

H2 storage in salt cavity:

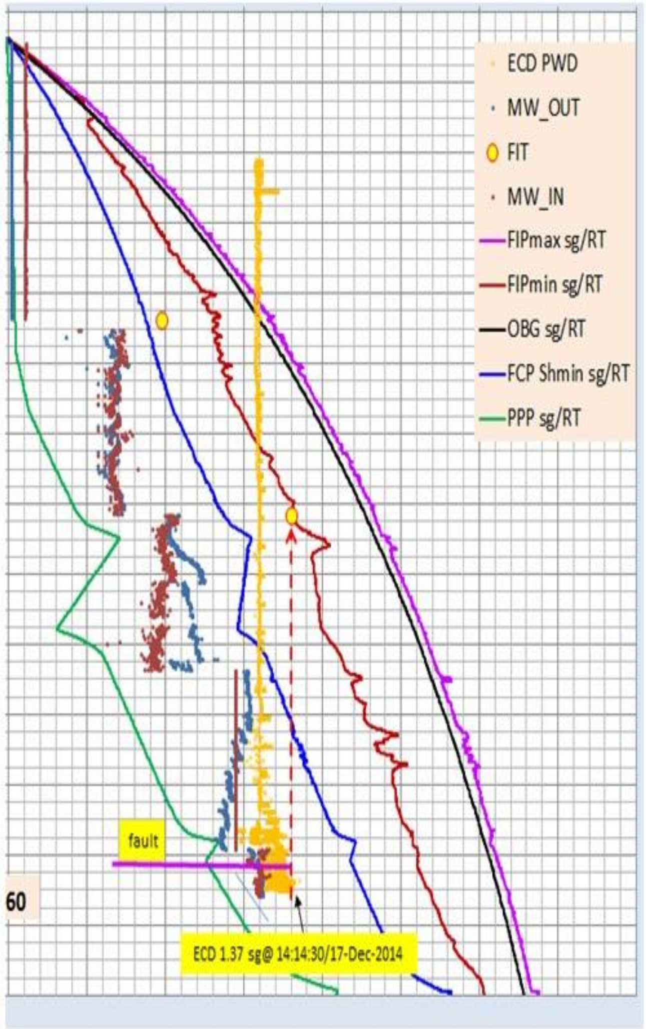
- Leaching & Stability of the cavity
- Range of pressure variation
- Sealing of salt/cement/casing interface
- Monitoring of the stability of the cavity
- P&A of the cavity

*** (a high-level description)**

Why is Geomechanics important for well design and drilling operation ?

- The well architecture or design is founded on the two curves: PPP/MMW and FG curves.

- The prediction of FG & MMW is based on the Ppore and in situ stress model (OBG, S_{hmin}, S_{hmax}) and formation strength model.
- Dealing with various drilling difficulties and well control events needs the geomechanics inputs : kick, losses, cross flow, cavings, tight spots, over torque, stuck pipe, salt/shale creeping, and drilling through rubble zone & depleted reservoir, etc …
- The strategy of FIT/LOT is defined by drillers in taking into account the uncertainty of geomechanical model on the margin between FG and maxi PP in the next section. The interpretation of FIT/SVT/LOT is done by Geomechanical Specialist.
- The design of completion and well testing program need the geomechanical studies: sanding risks, MW in DST, etc … .

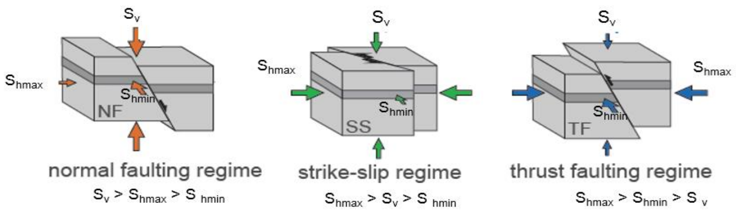


FG: Fracture Gradient, MMW: Minimum Mud Weight, OBG: overburden gradiant, PPP: pore pressure profile, S_{hmin}&S_{hmax}: the minimum and maximum horizontal stress , FIT: Formation integrity test, LOT: leak-off test, SVT: step volume test

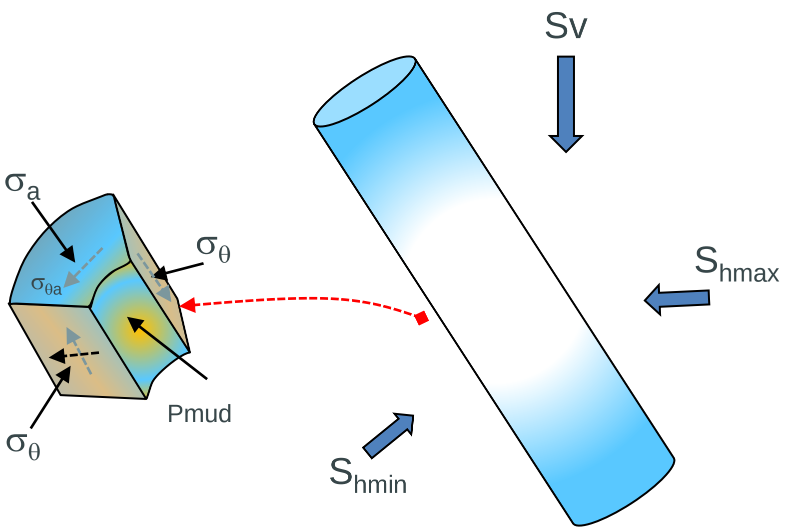
Geomechanics Concept & Vocabulary

- Structure of a cylindrical hole: a poro-elastic model for computation of stress concentration around the hole
- Three principal stresses: S_v, S_{hmin}, S_{hmax}. Vertical is always one of principal stress,
  S_v increases always with depth! Not true in certain cases !
- Stress is always coupled with Ppore (and T)
- Formation strength changes at various scales and are affected by natural fractures
- Three mechanisms of failure considered: shear, tensile, mixed shear&tensile
- Time dependent effects
- **Key question to Geomechanist**: at which MW take place the failure (shear or tensile) of the rock and its propagation?

Far field stress



Near wellbore stress



The stress concentration decreases with the rate $(r_0/r)^2$, at $r = 2r_0$, the concentration is decreased by a factor of 4

Geomechanics Concept & Vocabulary

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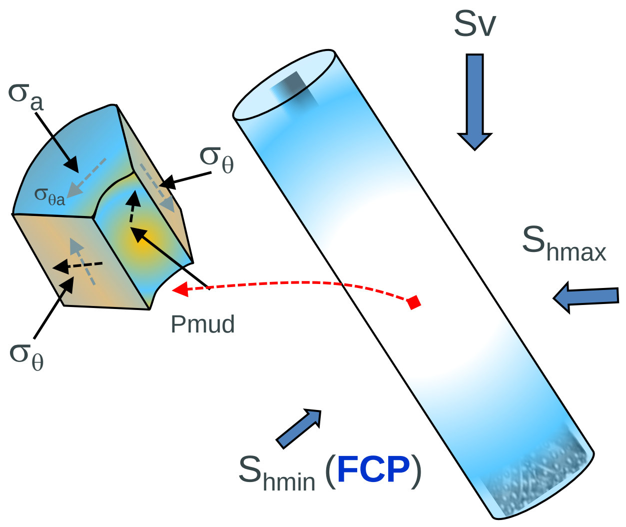
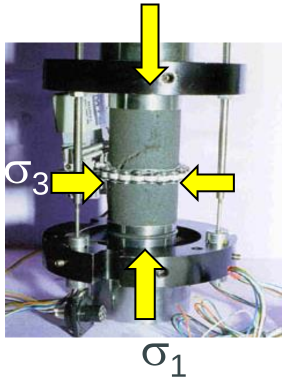
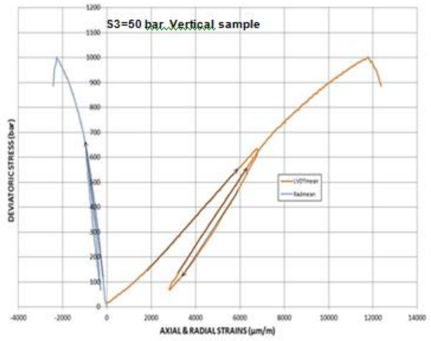
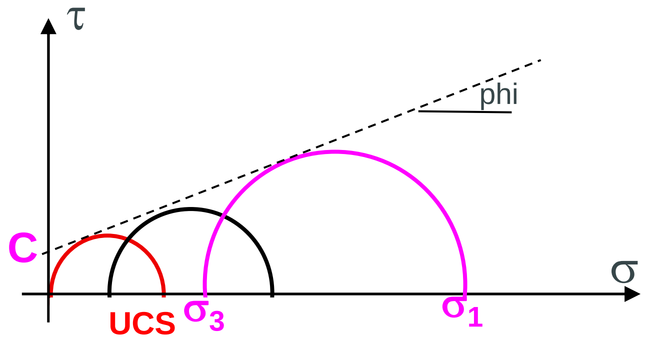
- Stress:
  - **S_v** vertical stress, integration from density log
  - **S_{hmin}** (**FCP**): the minimum horizontal stress
  - S_{hmax} : the maximum horizontal stress
  - Azimuth of S_{hmax} , lots of uncertainty in certain cases



- Strength:
  - **Phi**: Fraction angle (deg, 20°~ 35°for shale, 25-35° for sand)
  - **C**: Cohesion (MPa), Mohr-Coulomb criterion
  - **UCS**: uniaxial compressive strength (MPa), ~ 3x**C**

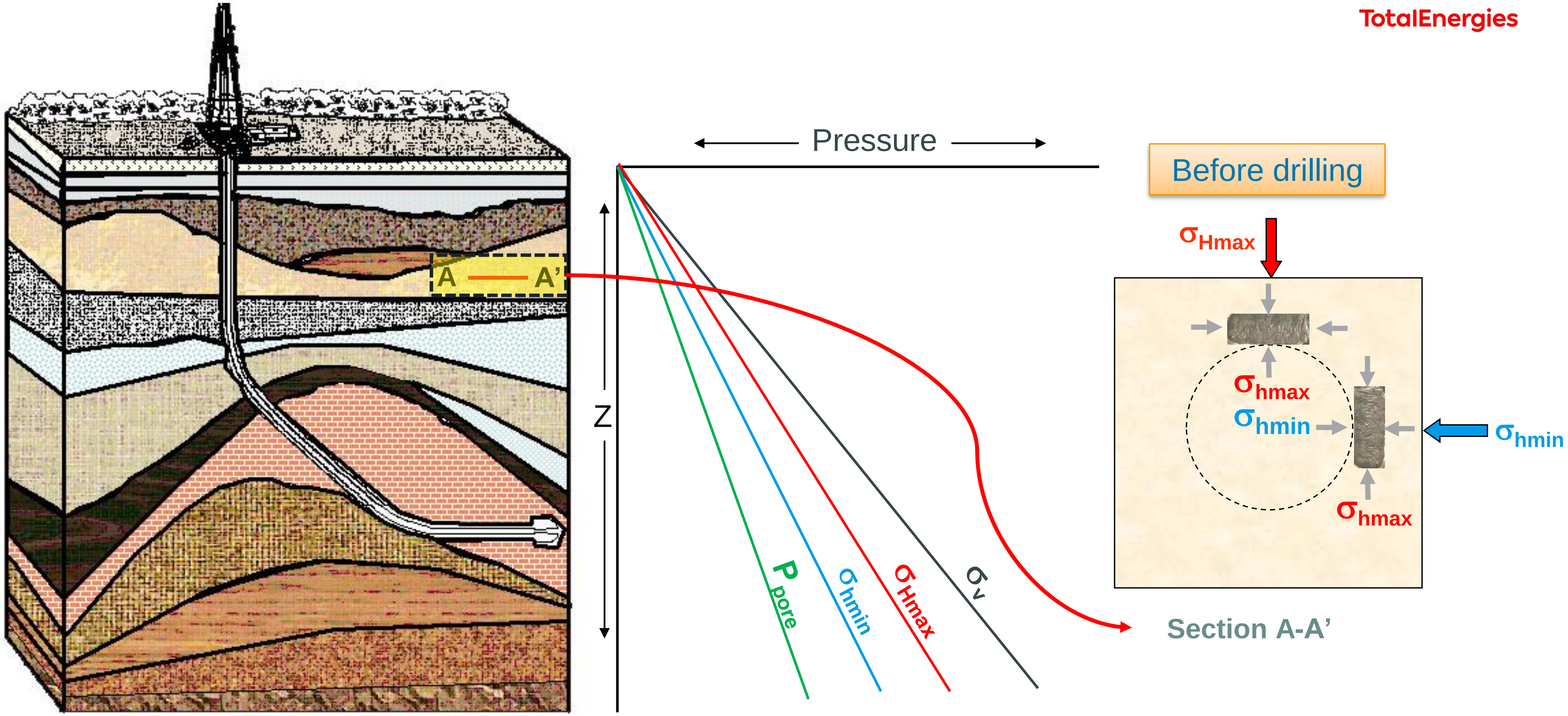




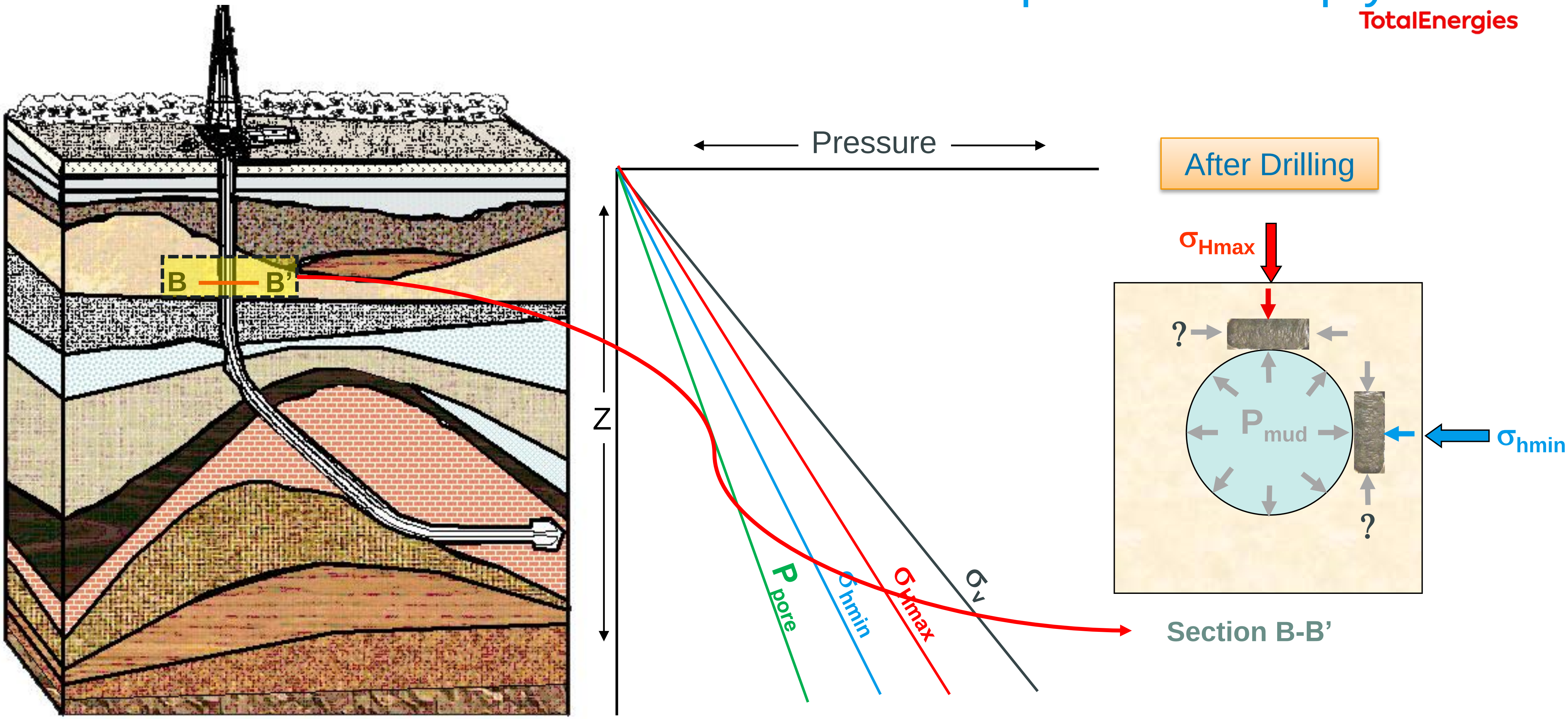


The azimuth of S_{hmax} may changes in different layers in certain cases

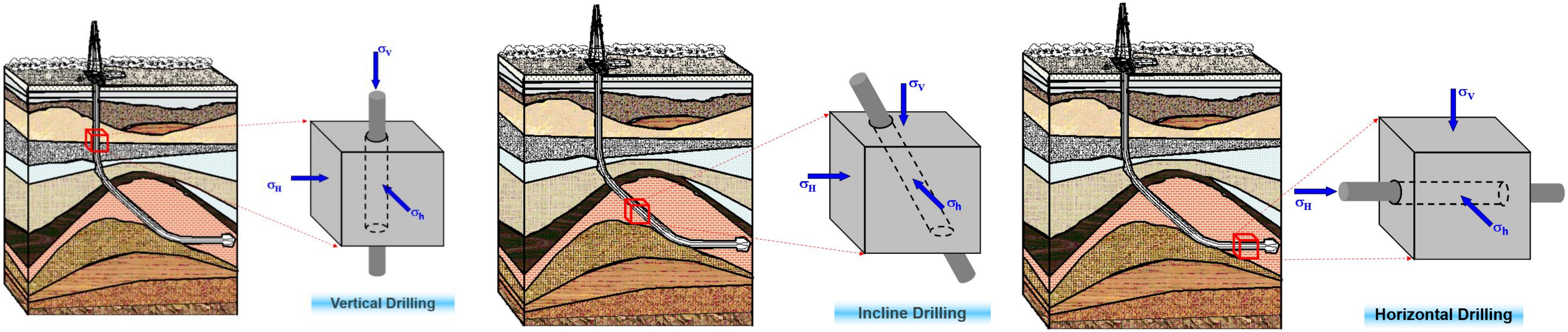
Stress around a borehole Geomechanics in a vertical well



Stress around a borehole
Geomechanics in a vertical well: P mud to replace the empty area



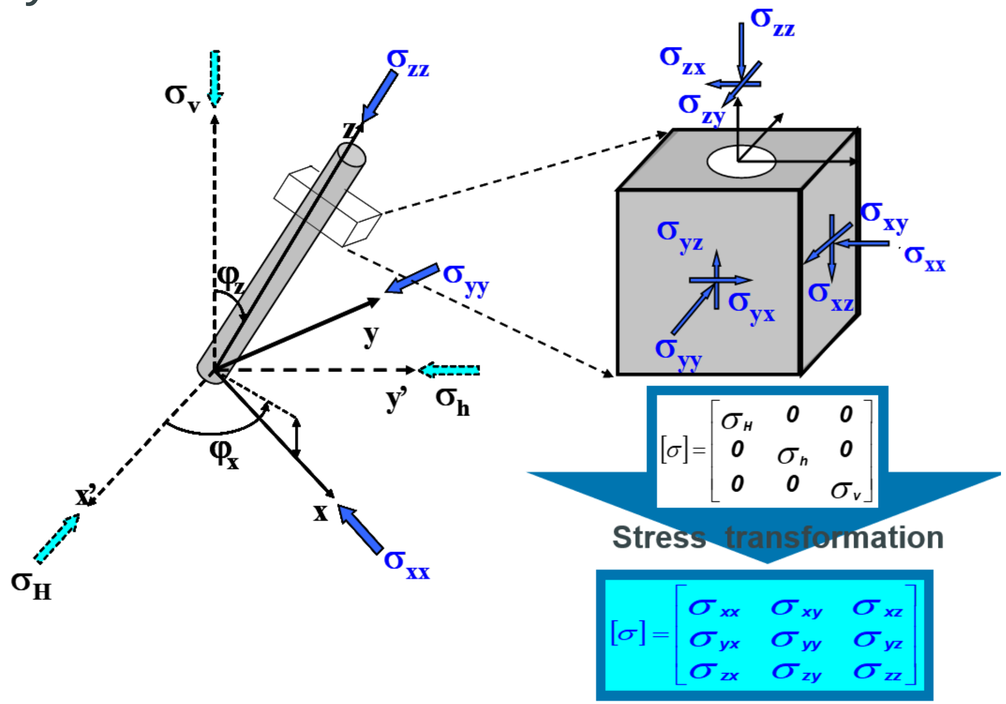
Wellbore stability during drilling and during production



kick, losses, cross flow, cavings, tight spots, over torque, stuck pipe, salt/shale creeping, and drilling through rubble zone & depleted reservoir, etc …

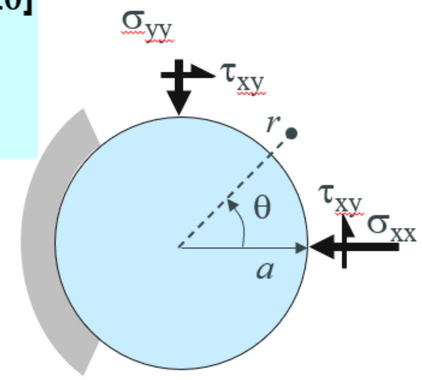
Wellbore stability during drilling and during production

- Stress transformation into wellbore related coordinate system



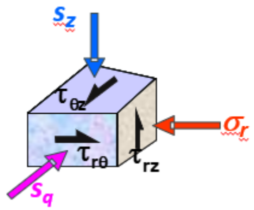
- Inclined Wellbore Elastic Solution, Bradley, 1976

$$\sigma_r=\left(\frac{\sigma_{xx}+\sigma_{yy}}{2}\right)\left(1-\frac{a^2}{r^2}\right)+\left(\frac{\sigma_{xx}-\sigma_{yy}}{2}\right)\left(1+\frac{3a^4}{r^4}-\frac{4a^2}{r^2}\right)\cos[2\theta]+\tau_{xy}\left(1+\frac{3a^4}{r^4}-\frac{4a^2}{r^2}\right)\sin[2\theta]+p_w\frac{a^2}{r^2}$$



$$\sigma_\theta=\left(\frac{\sigma_{xx}+\sigma_{yy}}{2}\right)\left(1+\frac{a^2}{r^2}\right)-\left(\frac{\sigma_{xx}-\sigma_{yy}}{2}\right)\left(1+\frac{3a^4}{r^4}\right)\cos[2\theta]-\tau_{xy}\left(1+\frac{3a^4}{r^4}\right)\sin[2\theta]-p_w\frac{a^2}{r^2}$$

$$\sigma_z=\sigma_{zz}-\nu\left[2(\sigma_{xx}-\sigma_{yy})\frac{a^2}{r^2}\cos[2\theta]+4\tau_{xy}\frac{a^2}{r^2}\sin[2\theta]\right]$$



$$\tau_{r\theta}=-\left(\frac{\sigma_{xx}-\sigma_{yy}}{2}\right)\left(1+\frac{3a^4}{r^4}-\frac{4a^2}{r^2}\right)\sin[2\theta]+\tau_{xy}\left(1+\frac{3a^4}{r^4}-\frac{4a^2}{r^2}\right)\cos[2\theta]$$

$$\tau_{\theta z}=\left(-\tau_{xz}\sin[\theta]+\tau_{yz}\cos[\theta]\right)\left(1+\frac{a^2}{r^2}\right)$$

$$\tau_{rz}=\left(\tau_{xz}\cos[\theta]+\tau_{yz}\sin[\theta]\right)\left(1-\frac{a^2}{r^2}\right)$$

Wellbore stability during drilling and during production

Elastic Solution at wellbore wall

$$\sigma_r(r=a) = p_w$$

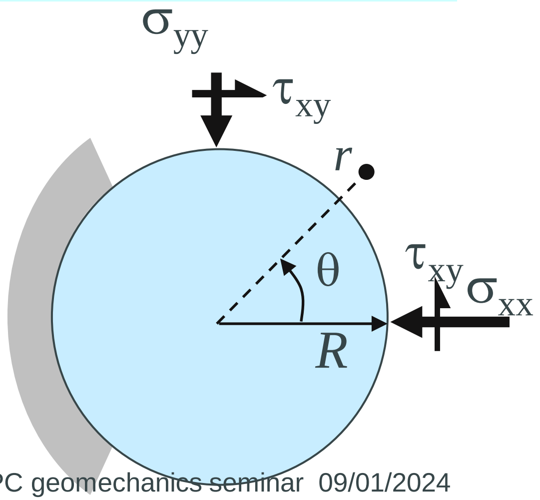
$$\sigma_\theta(r=a) = (\sigma_{xx}+\sigma_{yy}) - 2(\sigma_{xx}-\sigma_{yy})\cos[2\theta] - 4\tau_{xy}\sin[2\theta] - p_w$$

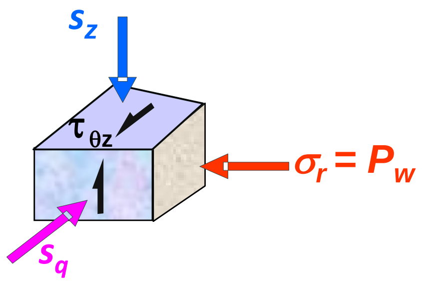
$$\sigma_z(r=a) = \sigma_{zz} - \nu\left[2(\sigma_{xx}-\sigma_{yy})\cos[2\theta] + 4\tau_{xy}\sin[2\theta]\right]$$

$$\tau_{r\theta} = 0$$

$$\tau_{\theta z} = 2(-\tau_{xz}\sin[\theta] + \tau_{yz}\cos[\theta])$$

$$\tau_{rz} = 0$$





Let's focus on Vr well: Saying goodbye to inclination…

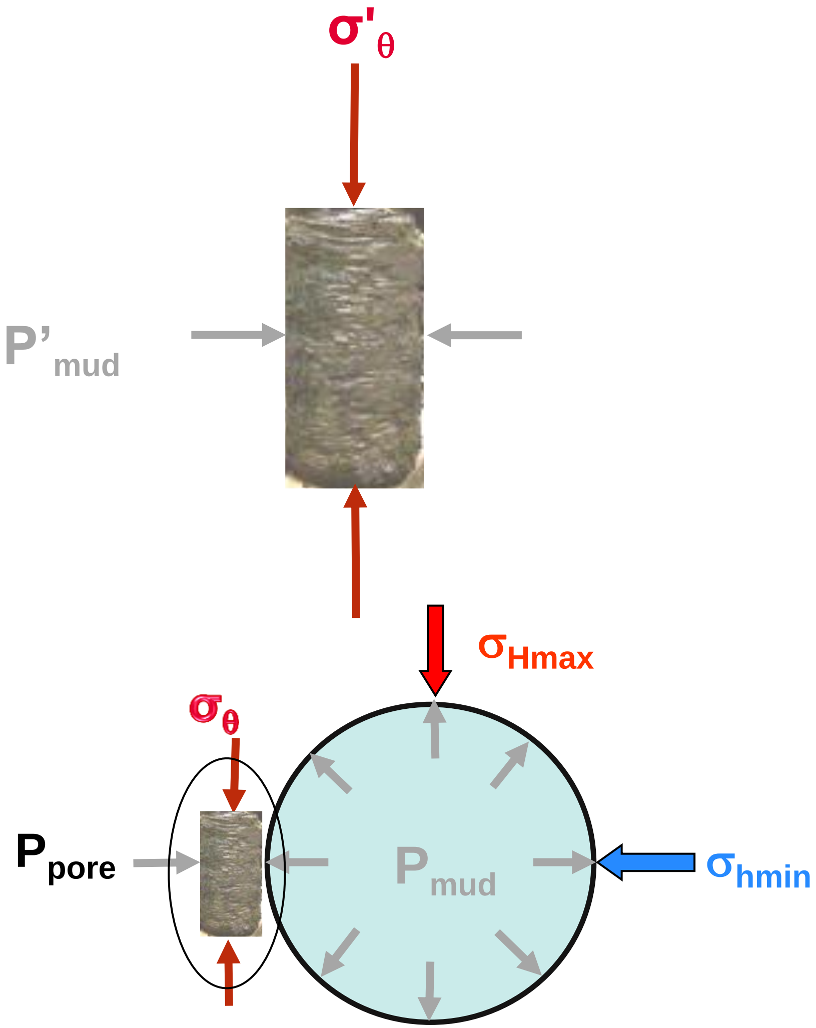
Effective stresses at wellbore wall:

- $\sigma'_r = P_w - P_p$
- $\sigma'_\theta = \sigma_H + \sigma_h - 2(\sigma_H - \sigma_h)\cos(2\theta) - P_w - P_p$
- $\sigma'_z = \sigma_v - 2v(\sigma_H - \sigma_h)\cos(2\theta) - P_p$

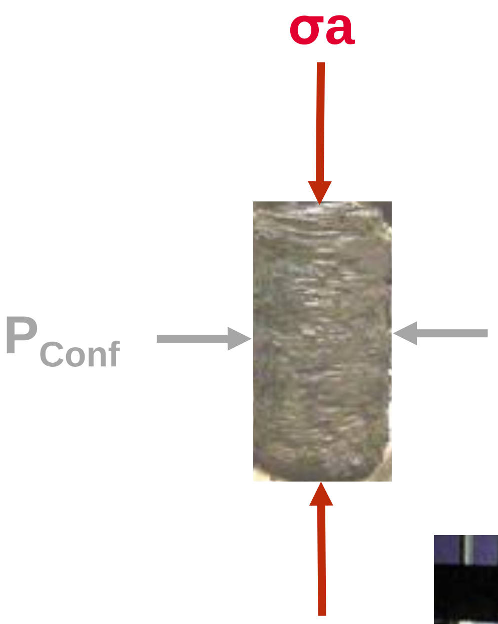
✓Focusing on vertical Focusing on the borehole wall

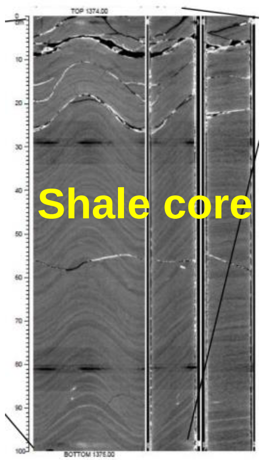
Simulate compression stresses in the lab

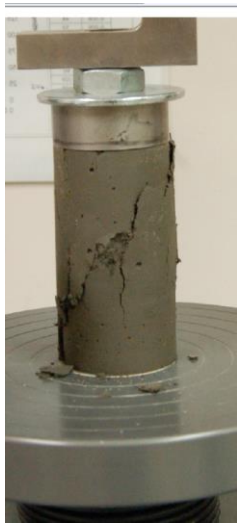
Wellbore stresses



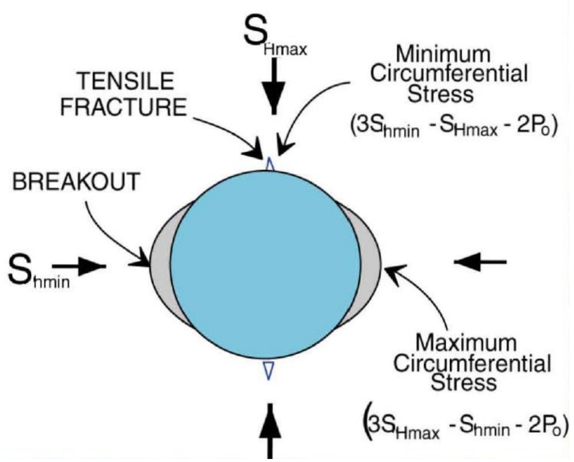
Lab stresses





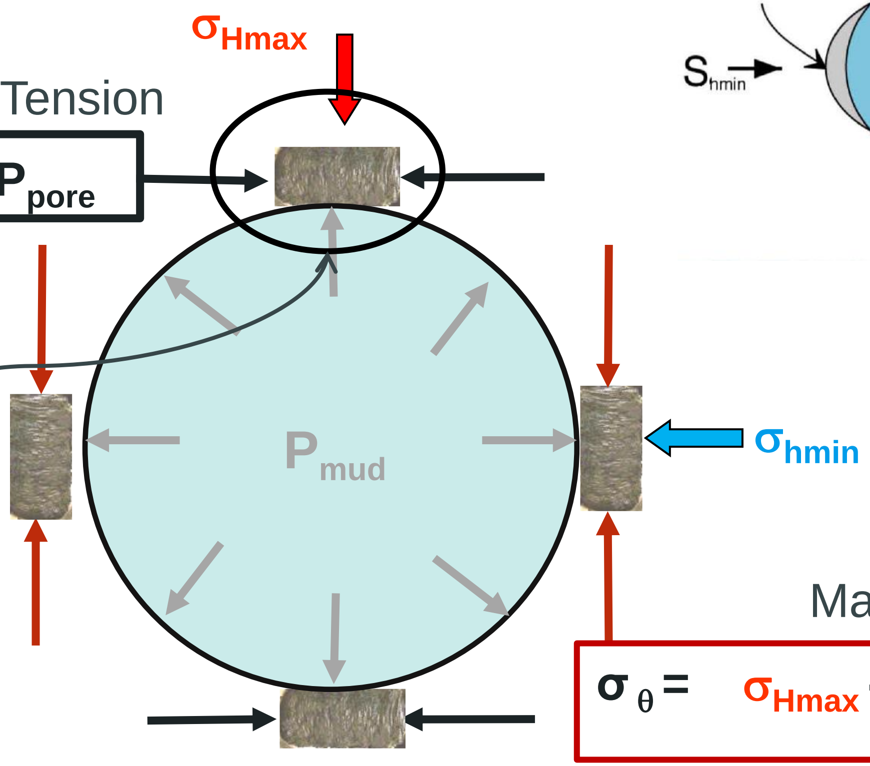


Stress around a vertical well: reminder



Min compressional, possibly Tension

$\sigma_\theta = 3\ \sigma_{Hmin} - {}_{Hmax} - P_{mud} - P_{pore}$



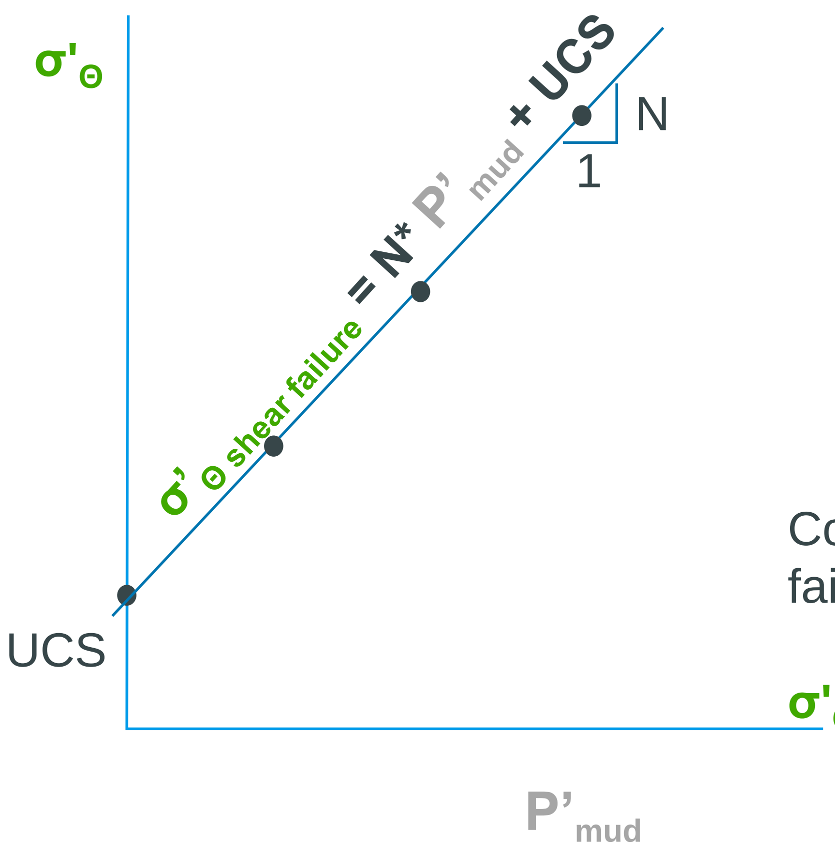
Let’s test this rock sample in the lab

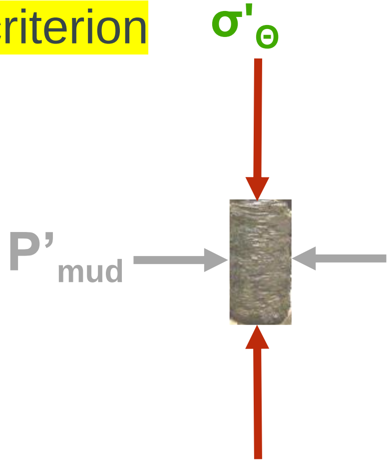
Max compressional

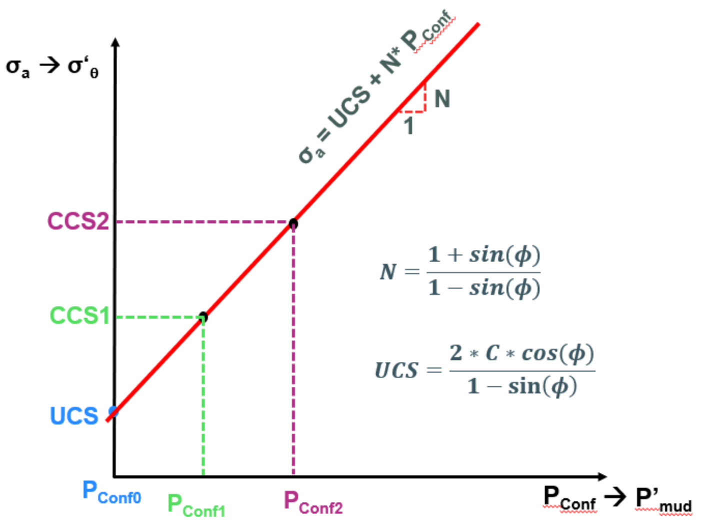
$\sigma_\theta = \sigma_{Hmax} - \sigma_{Hmin} - P_{mud} - P_{pore}$

Shear failure around a vertical wellbore :

Minimum mud weight to avoid initiating shear failure around a vertical wellbore : Mohr-Coulomb failure criterion







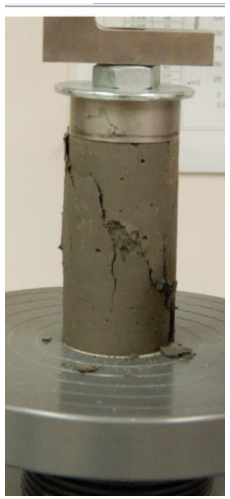
$$N = \frac{1 + sin(\phi)}{1 - sin(\phi)}$$

$$UCS = \frac{2 * C * cos(\phi)}{1 - sin(\phi)}$$

Tot

Compression shear failure with P'mud = 0

$\sigma'_{\Theta \text{ shear failure}}$ = UCS



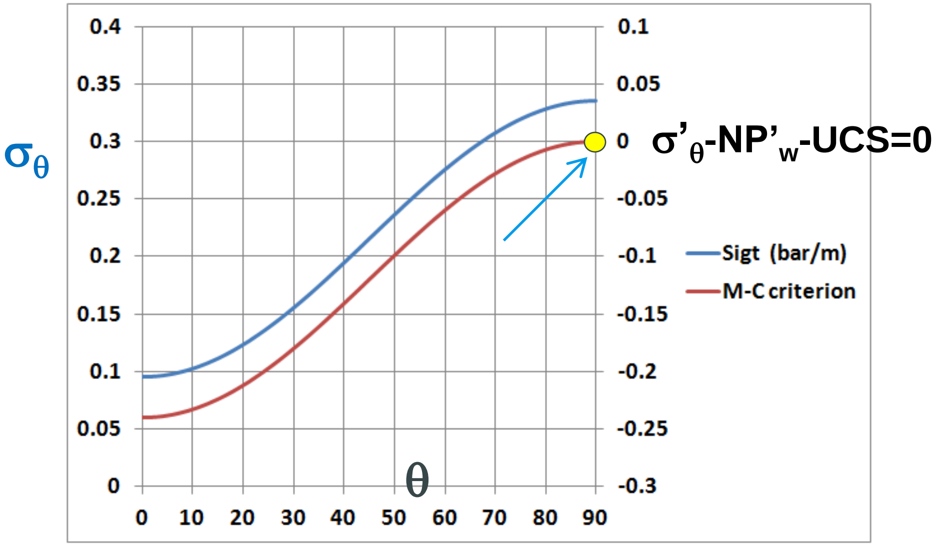
✓Convenient way to write the MC failure criterion

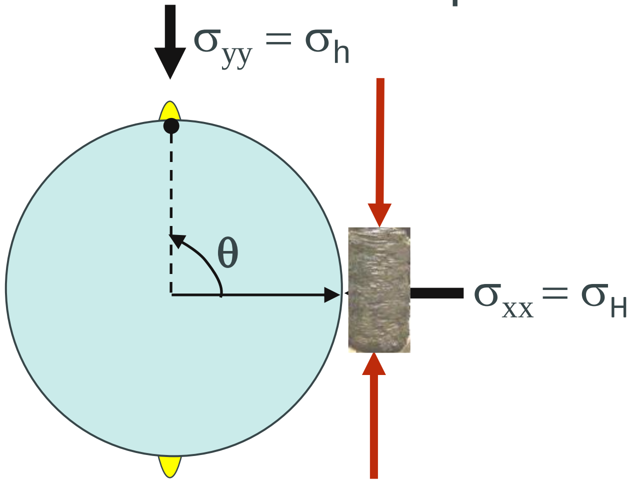
✓$\sigma_\theta = UCS + N * P'mud$

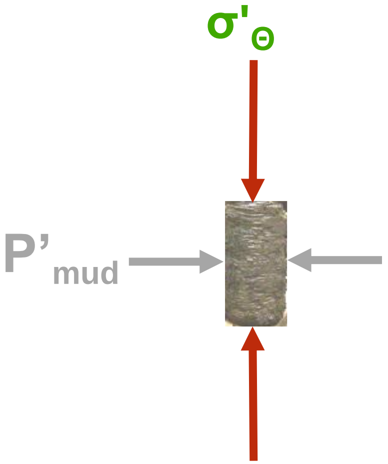
Shear failure around a vertical wellbore

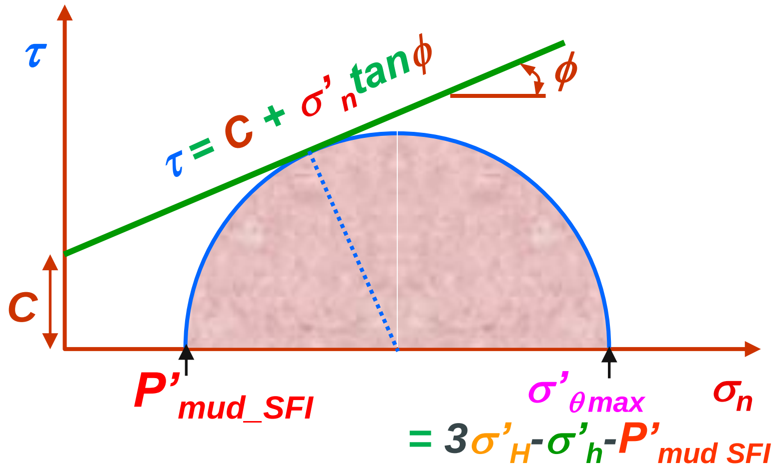
Minimum mud weight to avoid initiating shear failure around a vertical wellbore : Mohr-Coulomb failure criterion

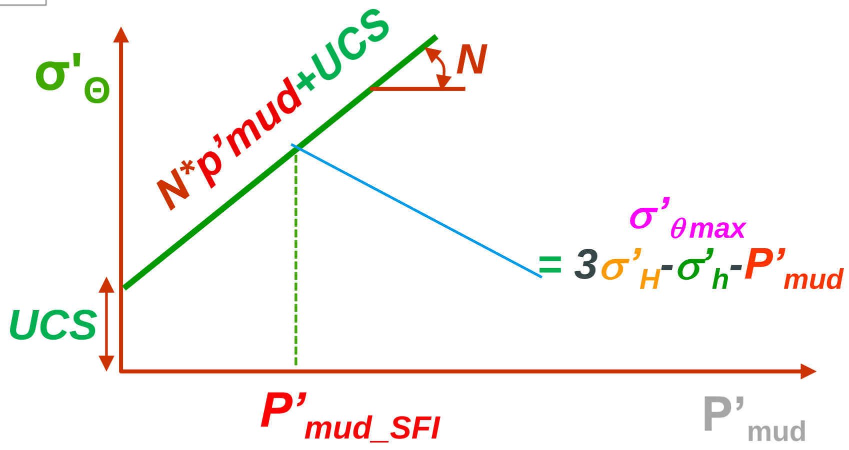
- Mud weight to initiate shear failure at one point

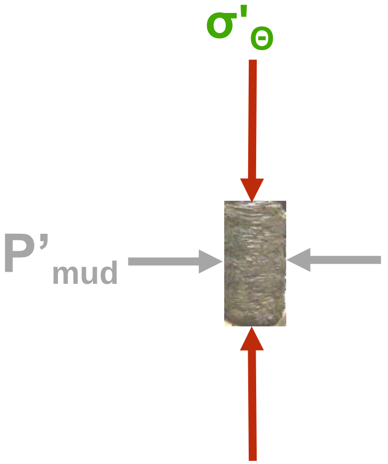












Shear failure around a vertical wellbore

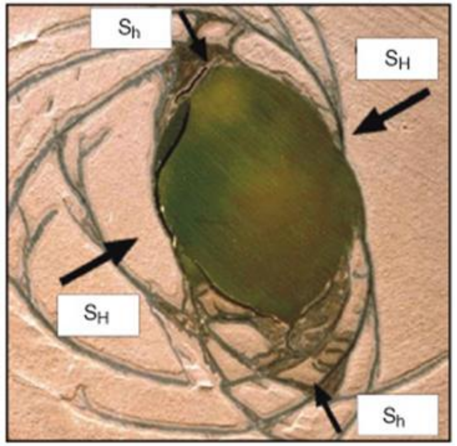
Minimum mud weight to avoid initiating shear failure
around a vertical wellbore : Mohr-Coulomb failure criterion

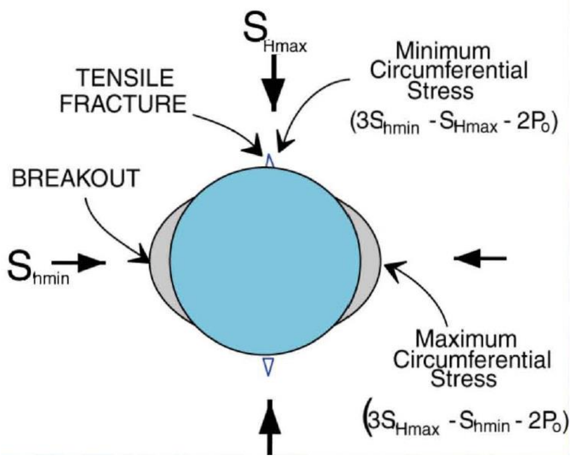
1. Highest compressive effective hoop stress

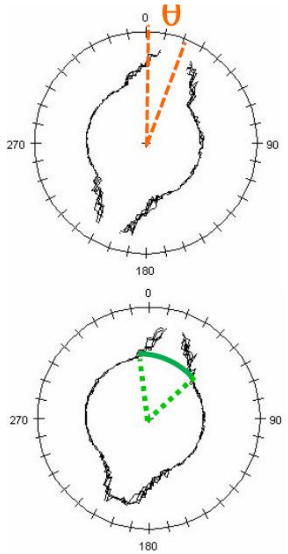
$$\mathrm{Max}(\sigma'_{\Theta\ compression}) = 3\,\sigma_{Hmax} - \sigma_{Hmin} - P_{mud} - P_{pore}$$

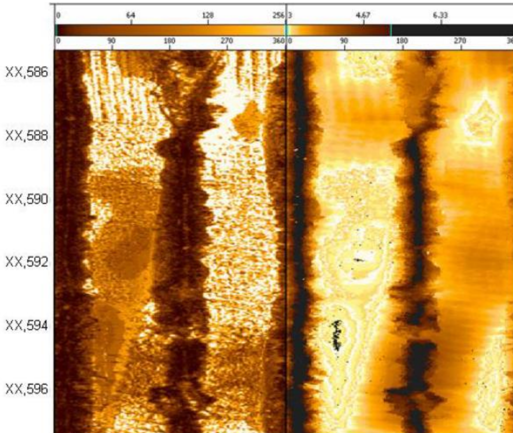
2. Condition to avoid failure

$$\mathrm{Max}(\sigma'_{\Theta\ compression}) < \sigma'_{\Theta\ shear\ failure} = N^{*}\,P'_{mud} + UCS$$









Compressional failure (breakouts)

Shear failure around a vertical wellbore

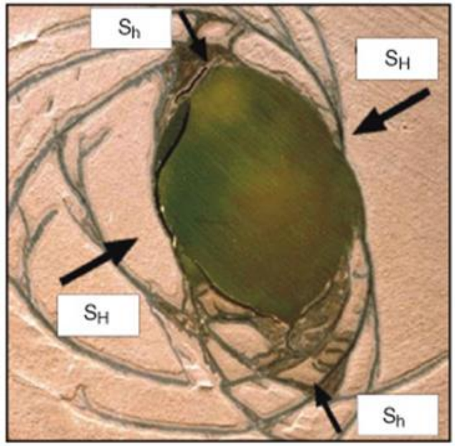
Minimum mud weight to avoid initiating shear failure around a vertical wellbore : Mohr-Coulomb failure criterion

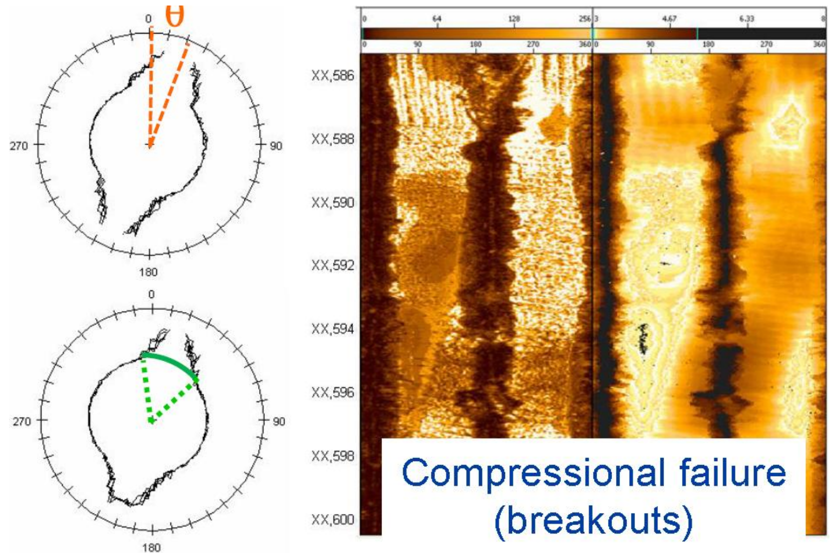
$$Max(\sigma'_{\Theta\ compression}) < \sigma'_{\Theta\ shear\ failure} = N^*\ P'_{mud} + UCS$$

$$3\ \sigma_{Hmax} - \sigma_{Hmin} - P_{mud} - P_{pore} < N^*\ (P_{mud} - P_{pore}) + UCS$$

$$3\ \sigma_{Hmax} - \sigma_{Hmin} + (N-1)^*P_{pore} - UCS < (N+1)^*\ P_{mud}$$

$$P_{mud} > \frac{3\ \sigma_{Hmax} - \sigma_{Hmin} + (N-1)P_{pore} - UCS}{(N+1)}$$

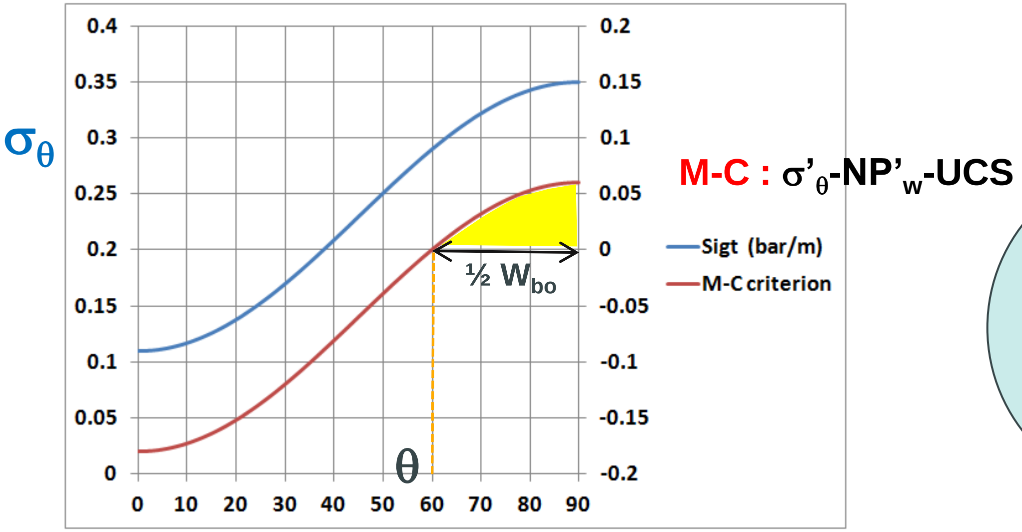


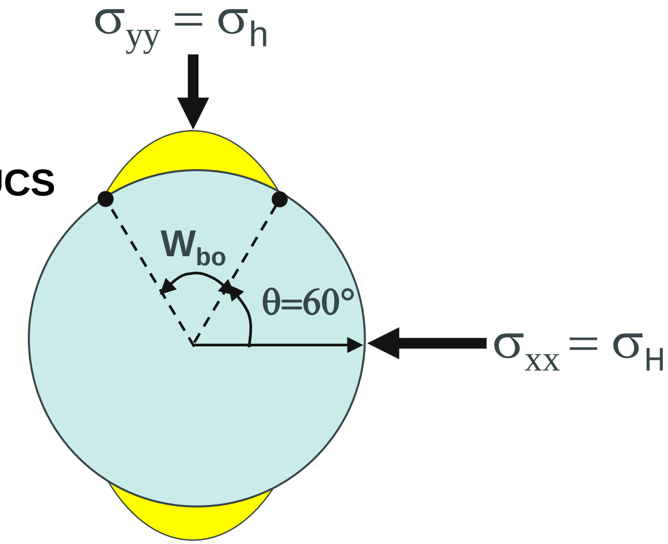


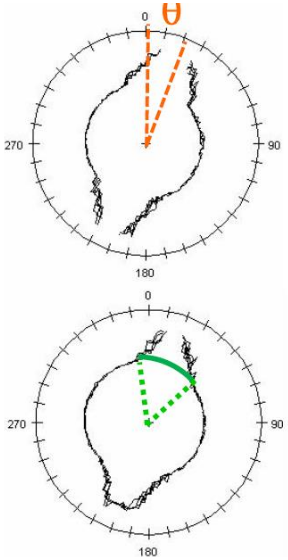
Compressional failure (breakouts)

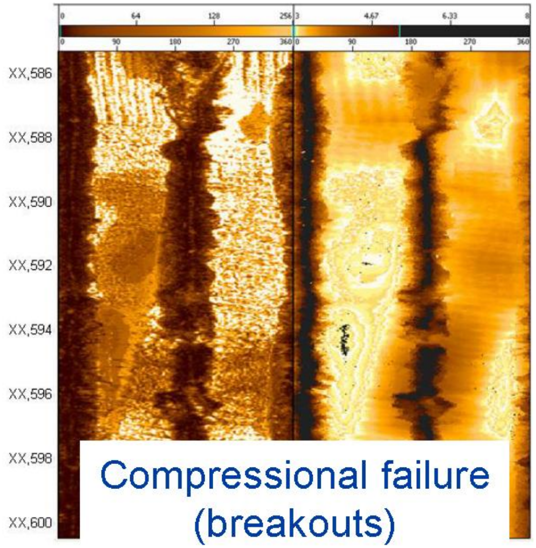
Wellbore stability during drilling and during production

- Break out angle concept
- Mud weight to initiate shear failure within a sector of angle phi around the hole (example: 60°)









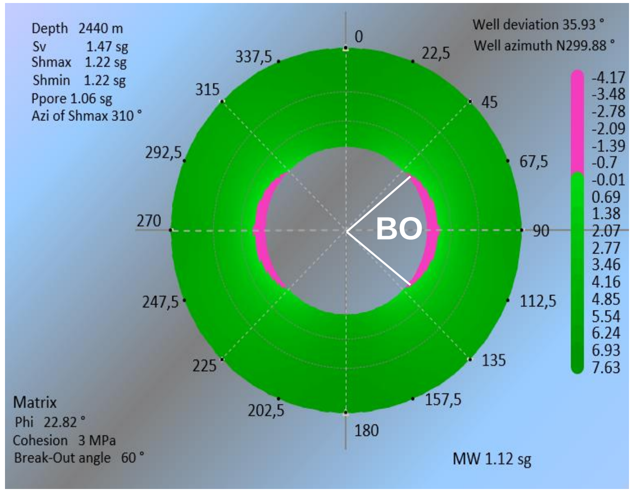
Wellbore stability during drilling and during production

Breakout angle (BO) and allowable instability

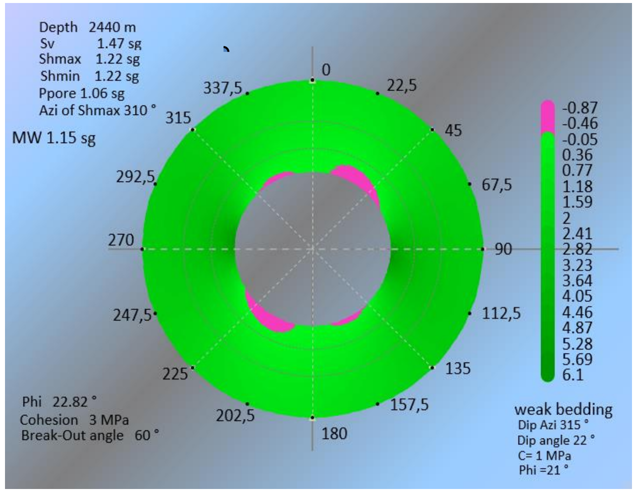
BO is the width of failure zone

- MMW is very sensitive to the BO, so the allowable instability
- For a vertical well: BO 60°~ 90°
- For a high deviated well (> 80) BO 30° ~ 60°

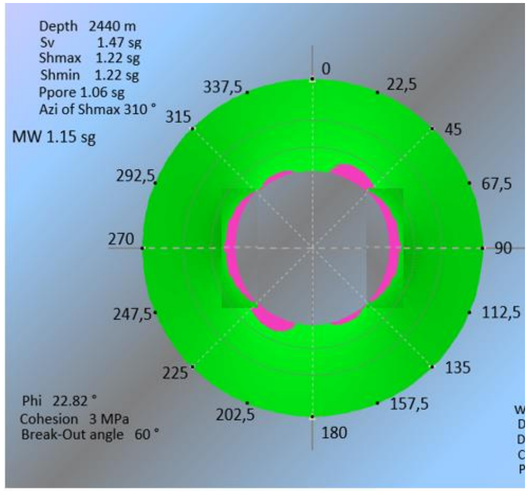
Rock without weak bedding



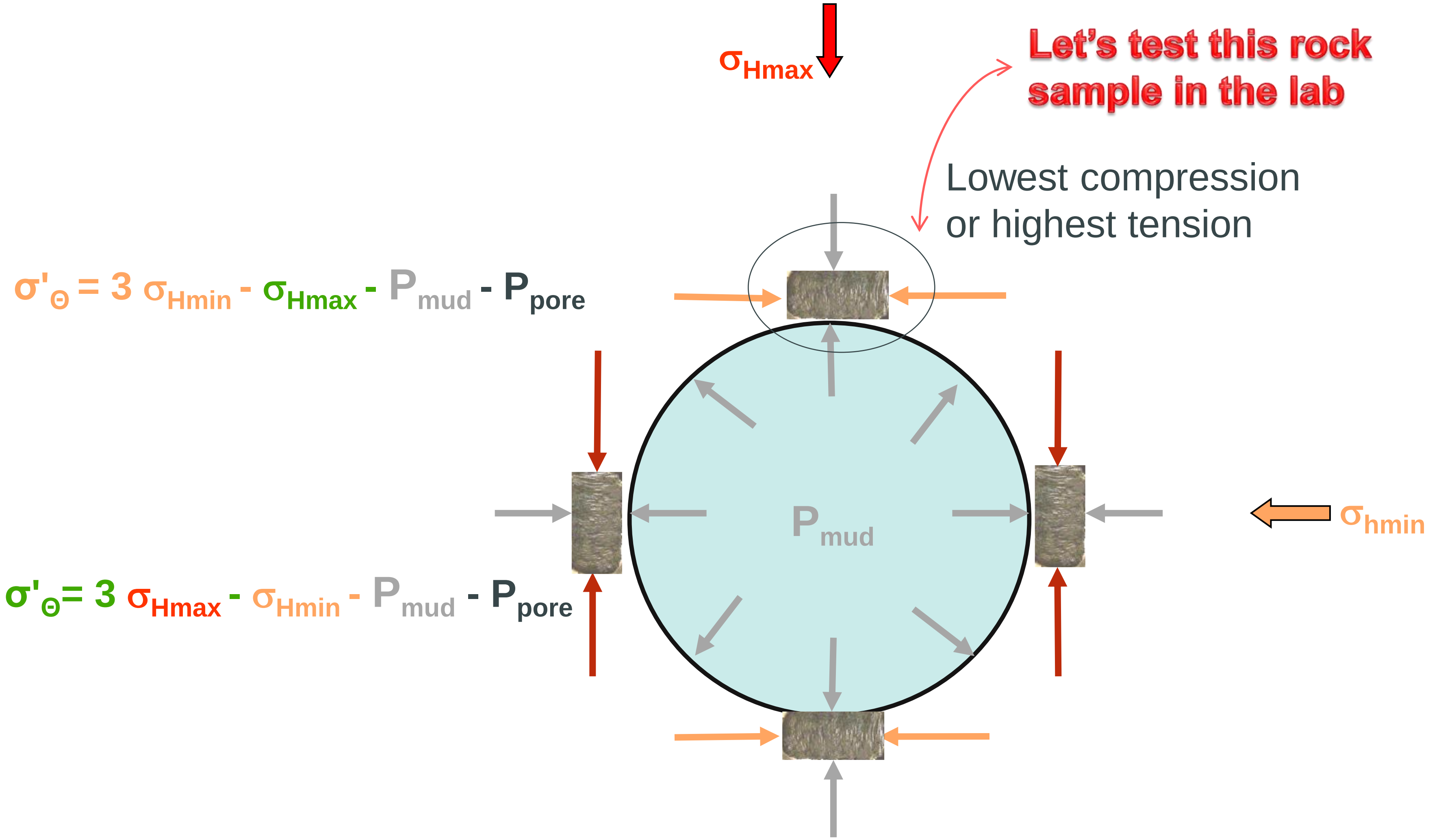
Failure zone around weak bedding



The sum



Tensile failure: failure around the well if Pmud is too High



Tensile failure: failure around the well if Pmud is too High

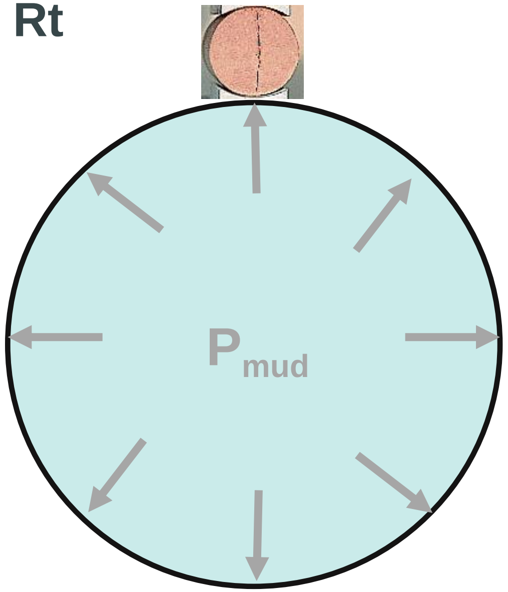
To calculate the Maximum mud weight to avoid initiating
Tension fracture around a vertical wellbore

1. Highest tension effective hoop stress

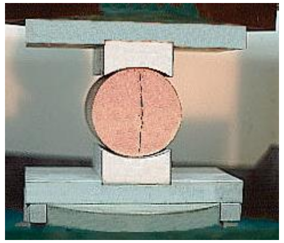
2. Condition to avoid initiation of the tension frac

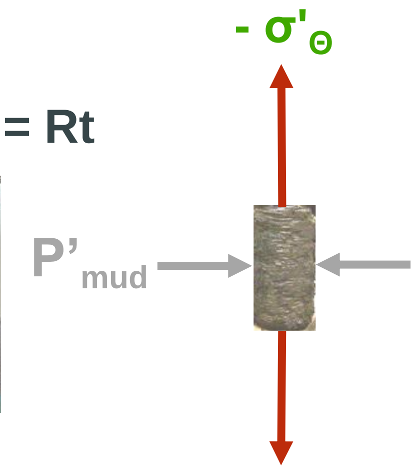
$Max(\sigma'_{\Theta\ tension}) = -(3\ \sigma_{Hmin} - \sigma_{Hmax} - P_{mud} - P_{pore})$

$Max(\sigma'_{\Theta\ tension}) < \sigma'_{\Theta\ tension\ frac} = Rt$



$-\sigma'_{\Theta} = \sigma'_{\Theta\ tension\ frac} = Rt$





Tensile failure: failure around the well if Pmud is too High

To calculate the Maximum mud weight to avoid initiating Tension fracture around a vertical wellbore

$Max(\sigma'_{\Theta\ tension}) < \sigma'_{\Theta\ tension\ frac} = -Rt$

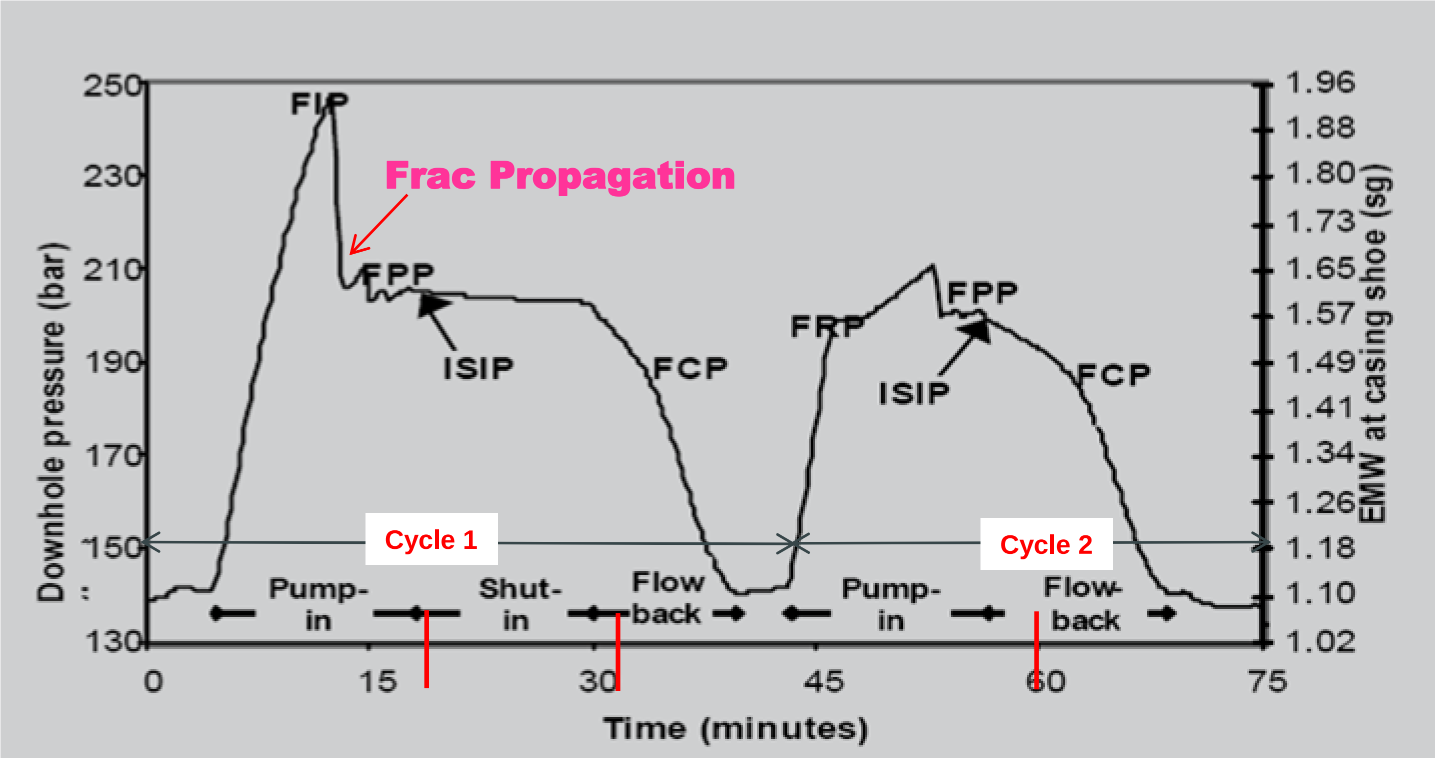
$-(3\ \sigma_{Hmin} - \sigma_{Hmax} - P_{mud} - P_{pore}) < Rt$

$3\ \sigma_{Hmin} - \sigma_{Hmax} - P_{mud} - P_{pore} > -Rt$

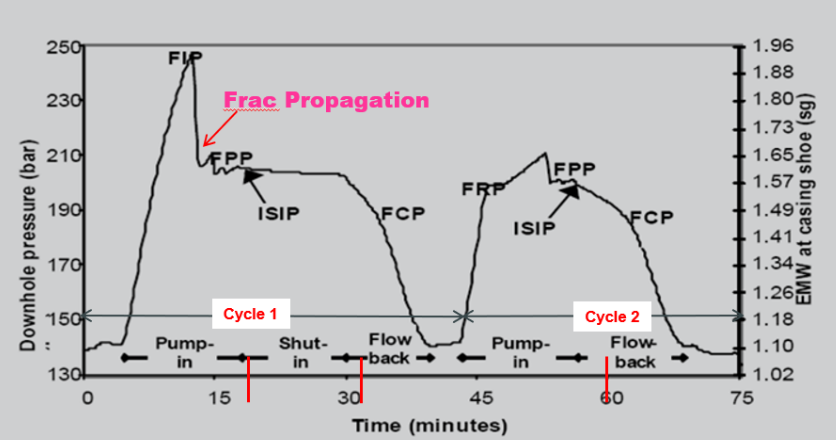
$3\ \sigma_{Hmin} - \sigma_{Hmax} - P_{pore} + Rt > P_{mud}$

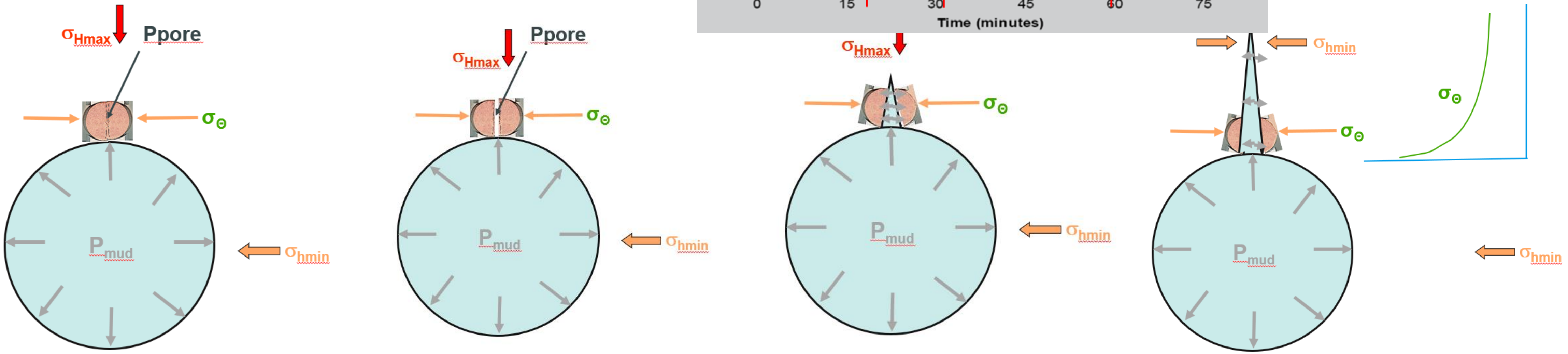
$P_{mud} < 3\ \sigma_{Hmin} - \sigma_{Hmax} - P_{pore} + Rt$

$$P_{br} = 3\sigma_h - \sigma_H - P + To,$$



Tension frac propagation after initiation





Fracture Initiation

Ppore - σ_Θ = Rt

P_{mud} ≡ FIP =3 σ_{Hmin} - σ_{Hmax} - P_{pore} + Rt

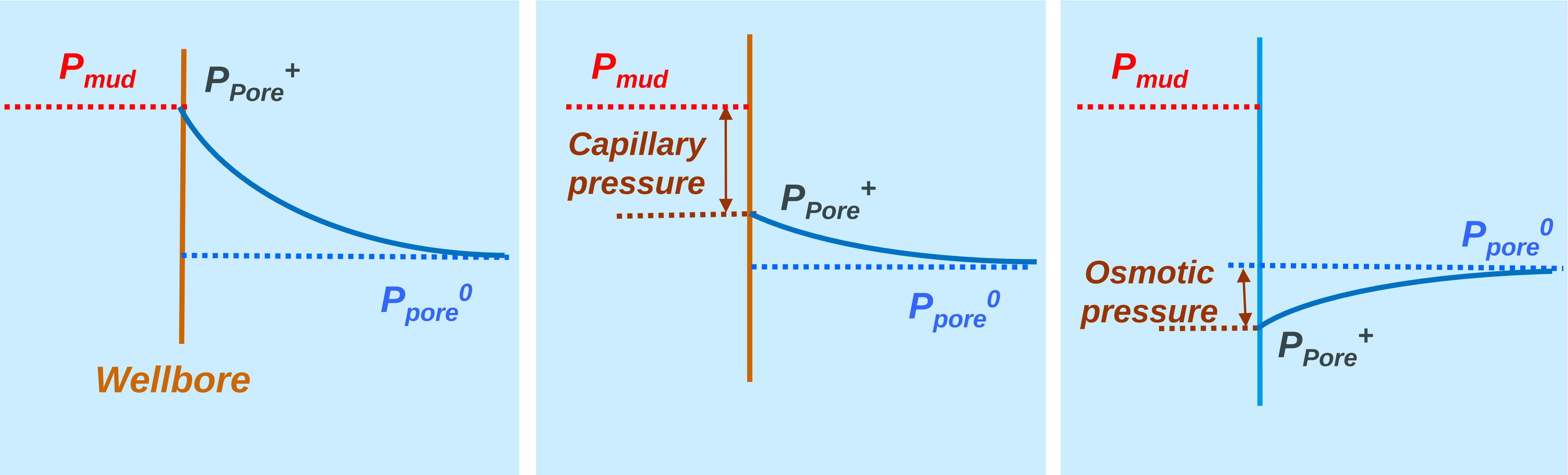
Mud penetration

Fracture Propagation
Far from well, stress normal to the fracture is σ_{hmin}

FPP= > σ_{hmin}

Wellbore stability: mud chemistry effects

- Interaction between Pw and Ppore can induce time dependent failure
- Increase MW after long OH times



Sea water	OBM	Silicate or glycol muds
Mud overbalance --> 0	*Overbalance = Pcap*	*ΔOverbalance = Posm*

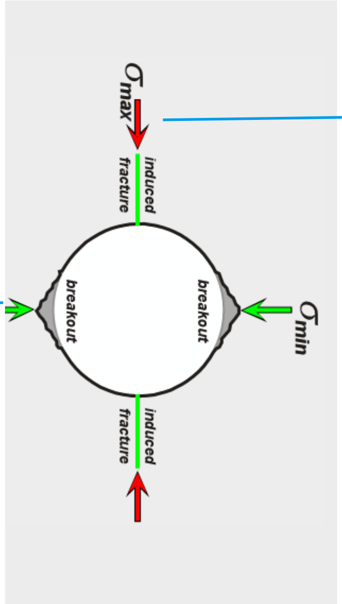
Mud Weight window between shear and tensile failures (or between wellbore collapse and hydraulic frac / mud losses)

TotalEnergies

$$\frac{3\,\sigma_{Hmax} - \sigma_{Hmin} + (N-1)P_{pore} - UCS}{(N+1)} < P_{mud} < 3\,\sigma_{Hmin} - \sigma_{Hmax} - P_{pore} + Rt$$

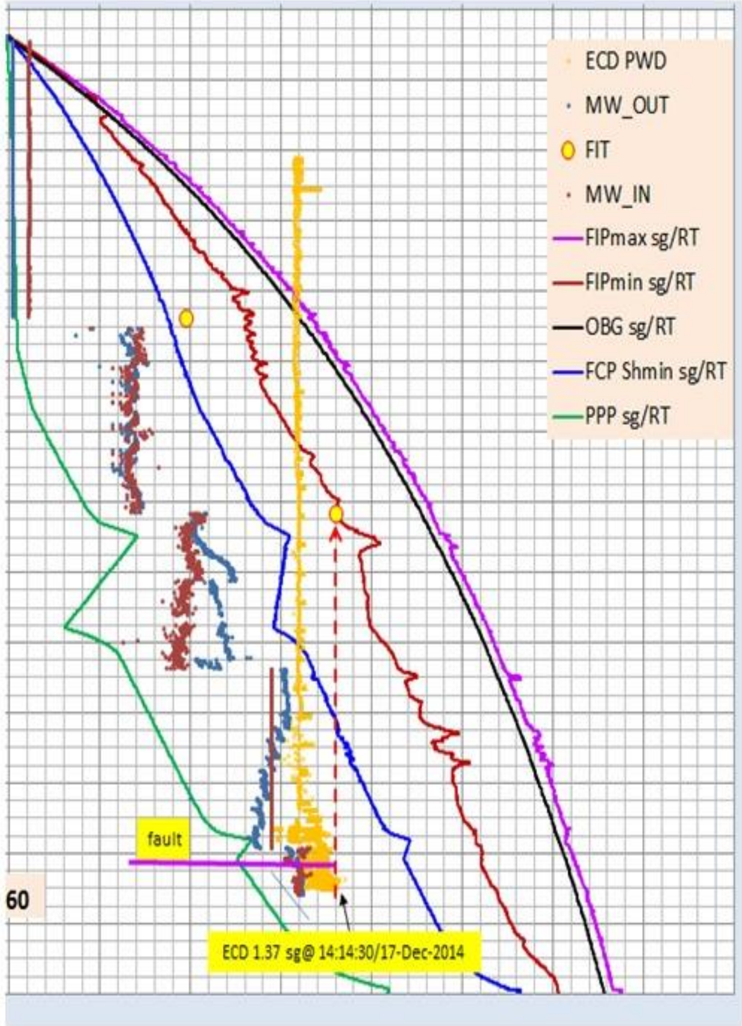
Compressive shear failure

Wellbore instability



Tensile hydraulic frac

Mud losses



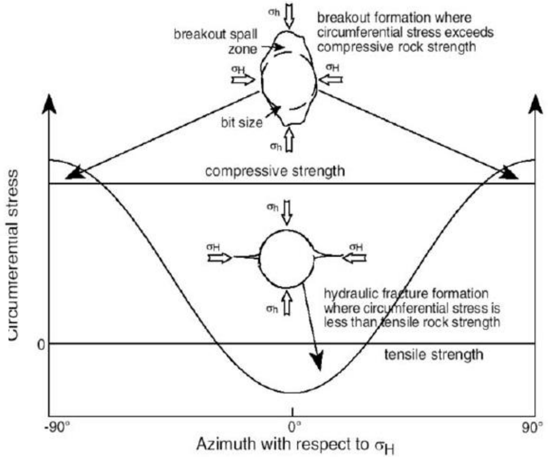
A Mw between wellbore collapse and hydraulic frac / mud losses

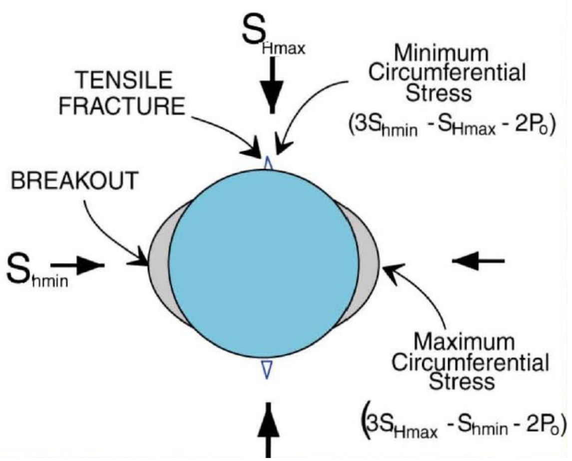
Wellbore Stability analysis

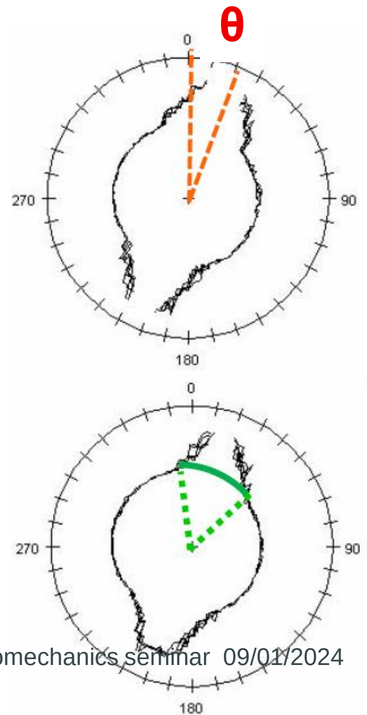
- Break-out occurrence:
  - Break-out position → σ_{Hmax} orientation
  - Break-out width → σ_{Hmax} magnitude

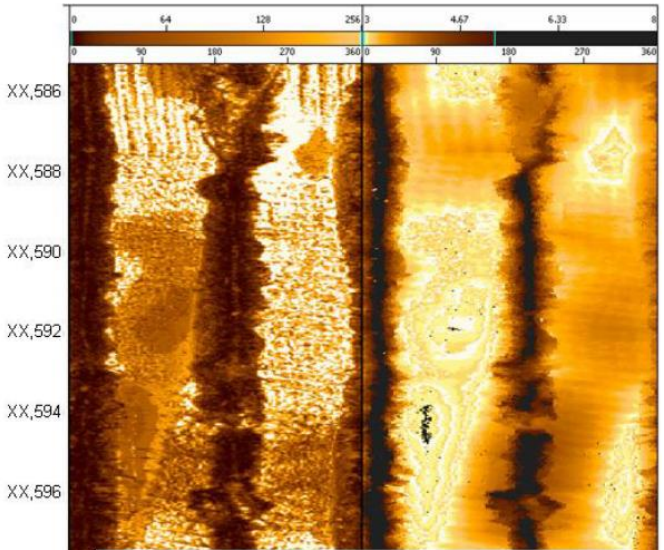
$$\sigma_{Hmax} = \frac{(UCS + P_p + P_{mud}) - \sigma_{hmin}(1 + 2\cos 2\theta_b)}{1 - 2\cos 2\theta_b}$$

- DITF occurrence : $P_{br} = 3\sigma_h - \sigma_H - P + To,$

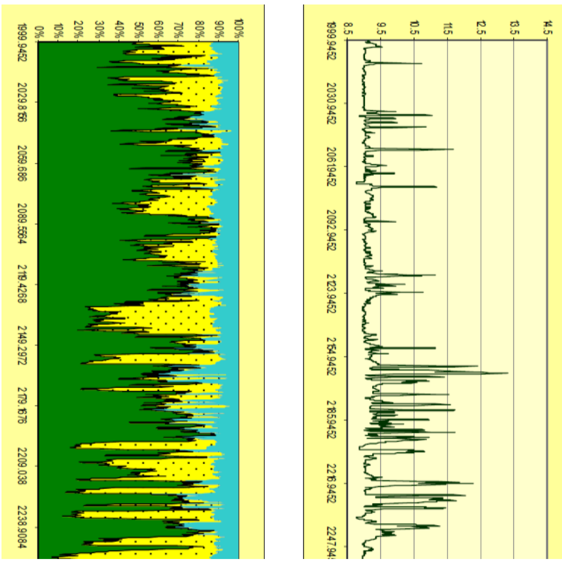




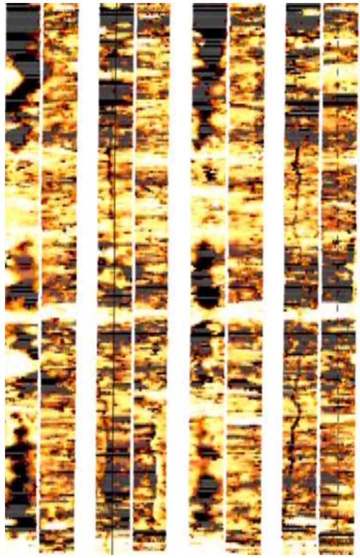




Compressional failure (breakouts)



② caliper



③ Hole imagery

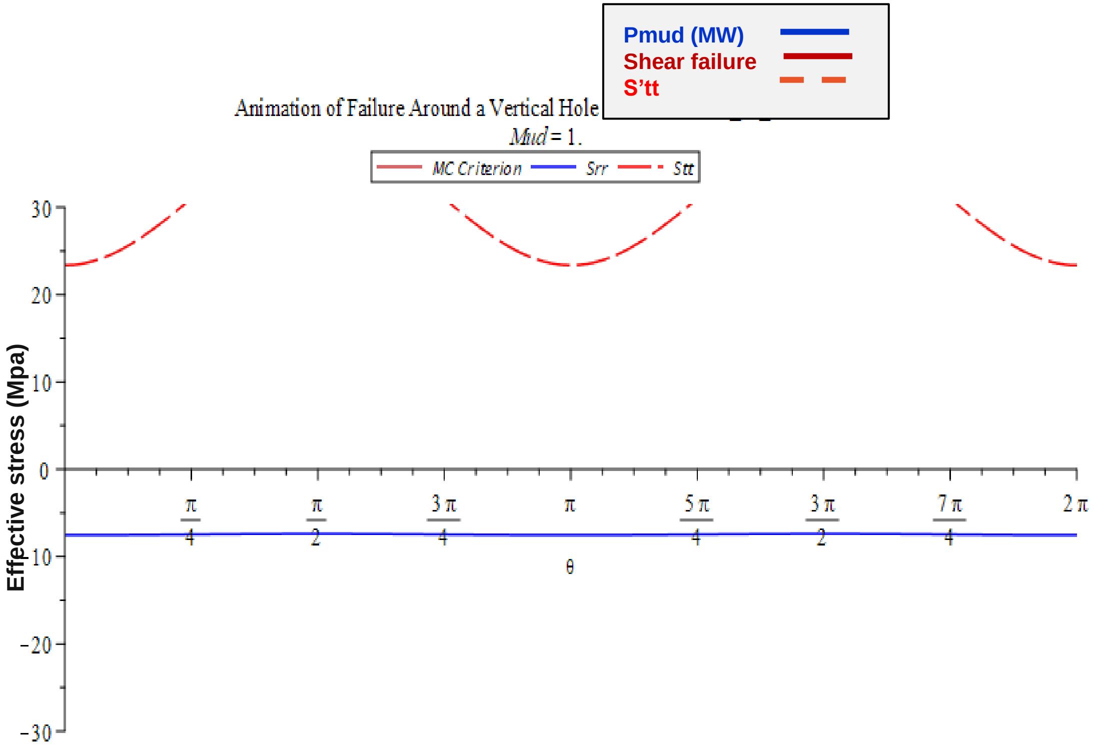
Shear failure condition for a VERTICAL WELL

- Shear failure occurs when the compressive stress somewhere along the borehole wall is too high
  - To relax the compressive stress we can increase Pmud (MW)

- **Reminder:** The MC criterion considers the highest and lowest compressive stresses:
  - $\boldsymbol{\sigma_{max} = UCS + N * \sigma_{min}}$

- Most of the time $\boldsymbol{\sigma_\theta > \sigma_z > \sigma_r}$ applies, but this can change under some conditions for example if Pw>>Ppore

- $\sigma'_r = P_w - P_p$
- $\sigma'_\theta = \sigma_H + \sigma_h - 2(\sigma_H - \sigma_h)\cos(2\theta) - P_w - P_p$
- $\sigma'_z = \sigma_v - 2v(\sigma_H - \sigma_h)\cos(2\theta) - P_p$



Z = 4000m, Shmin(FCP) = 1.45sg, Shmax = 1.55sg, Sv = 1.70 sg, Pp = 1.20 sg, C = 3.84MPa, Phi = 25.4°

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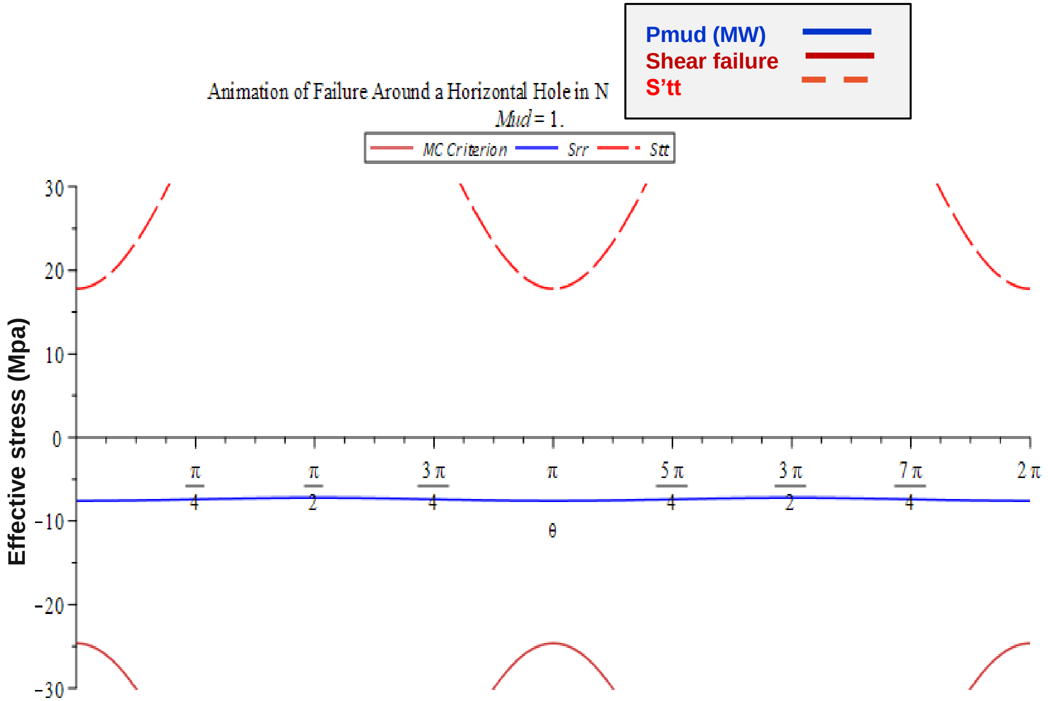
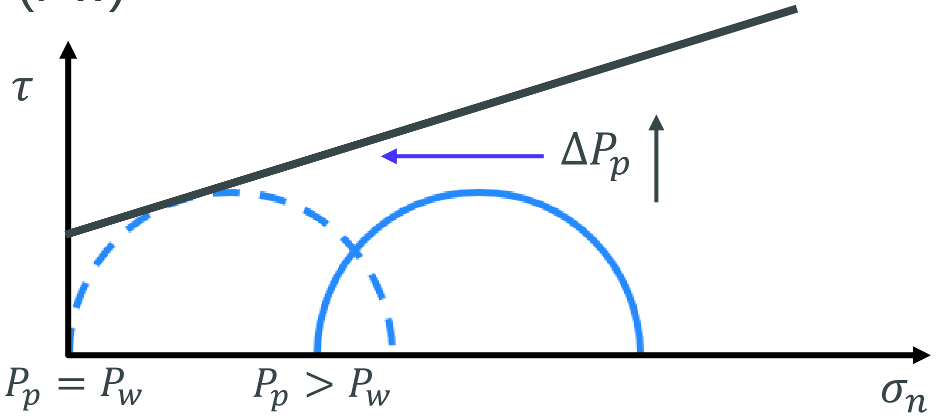
Shear failure condition for a HORIZONTAL WELL

- Horizontal well drilled along Shmin (FCP, σ_h)
  - $\sigma'_r = P_w - P_p$
  - $\sigma'_\theta = \boldsymbol{\sigma_v} + \sigma_h - 2(\boldsymbol{\sigma_v} - \sigma_h)\cos(2\theta) - P_w - P_p$
  - $\sigma'_z = \boldsymbol{\sigma_v} - 2v(\boldsymbol{\sigma_v} - \sigma_h)\cos(2\theta) - P_p$
  - The higher the stress anisotropy the higher compressional stress the borehole wall sees
  - The higher Pw is needed to avoid shear failure



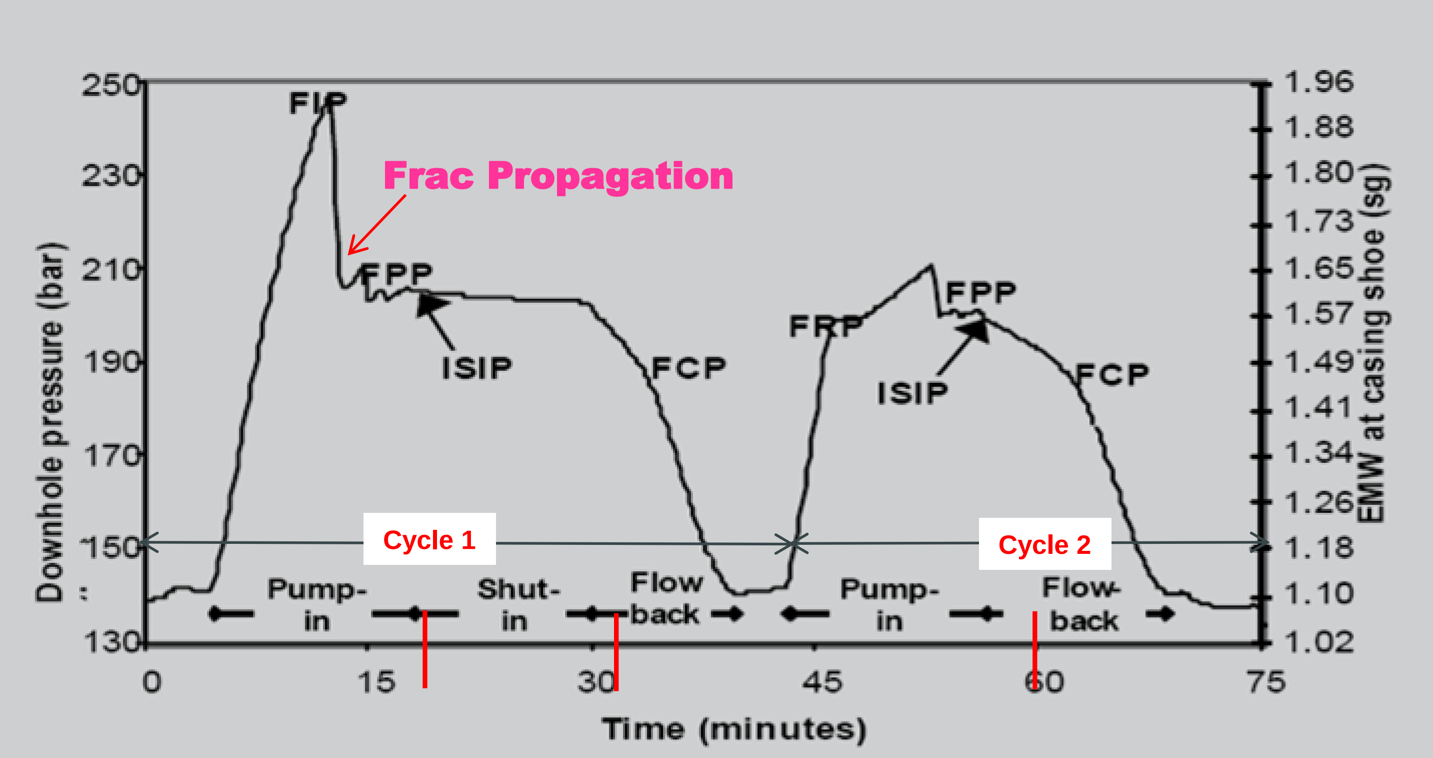
Z = 4000m, Shmin(FCP) = 1.45sg, Shmax = 1.55sg, Sv = 1.70 sg, Pp = 1.20 sg, C = 3.84MPa, Phi = 25.4°

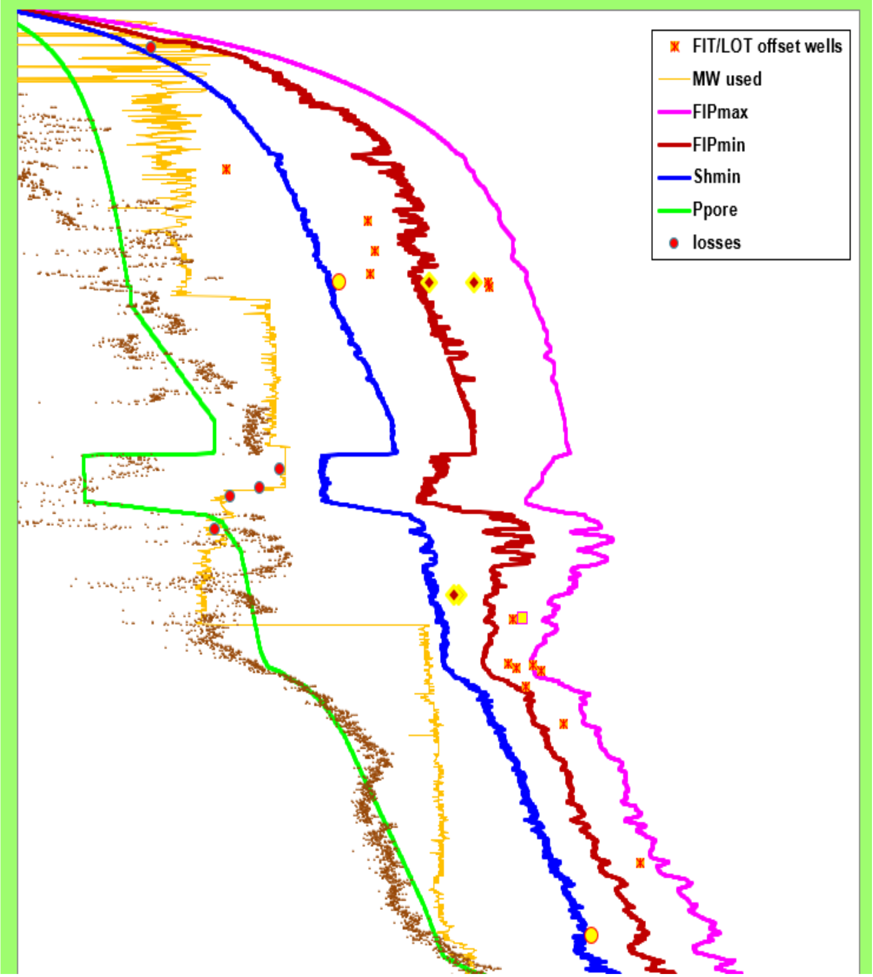
- Over time the pore pressure (Ppore) in the near wellbore region will equalize with well pressure (Pw)



Practical Wellbore Stability

- **LOP: Leak-Off Pressure**
- **FIP: fracture initiation pressure, called also breakdown pressure.**
- **FPP: fracture propagation pressure.**
- **ISIP: instantaneous shut-in pressure, recorded right after pumps shut in.**
- **FCP: fracture closure pressure, it is generally equal to the minimum in situ stress.**
- **FRP: fracture re-opening pressure.**





Practical Wellbore Stability

❑ Definition of FCP, FIP_{min}, FIP_{max}, LOP

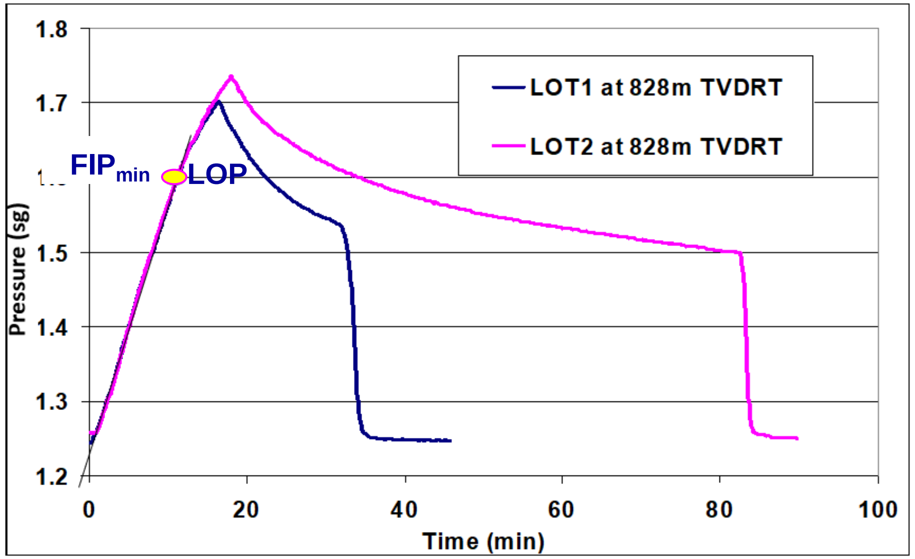
❶ From LOT test point of view

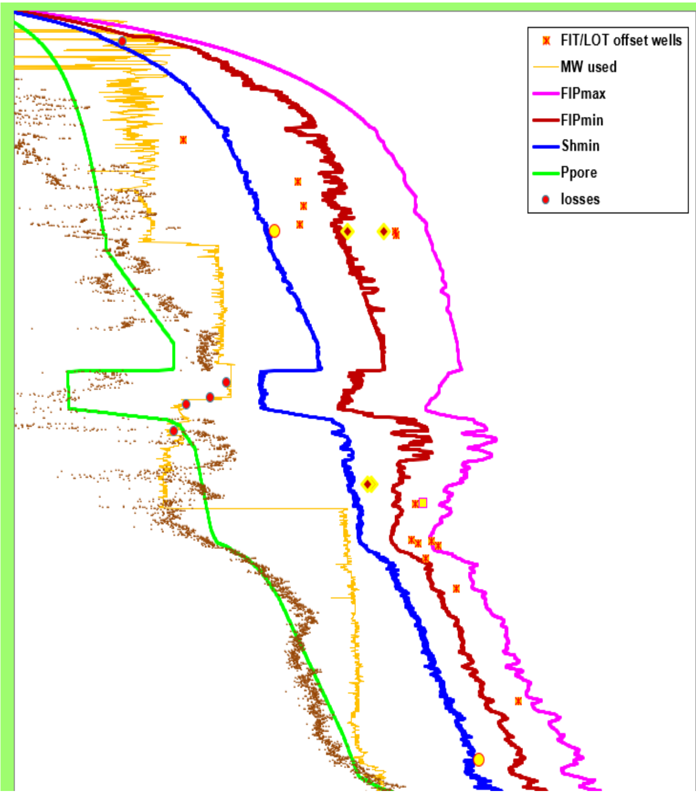
- **FIP_{max}** : Breakdown pressure, observed usually in hard formation (upper limit of the predicted fracture pressure gradient)

- **FIP_{min}** : Inflexion point on P-t or P-V curve, without sharp breakdown, (lower limit of predicted fracture pressure gradient)

- **FCP**: Fracture closure pressure

- **LOP**: Leak-off pressure recorded. It is the onset of significant injection through a fracture





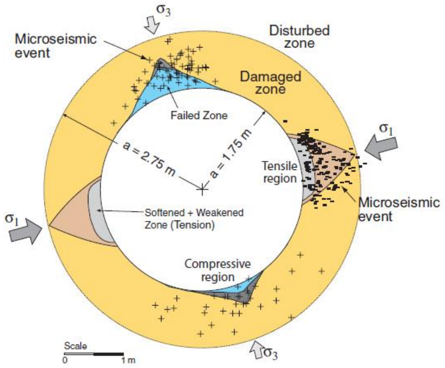
Su K. et al, 2019, EAGE

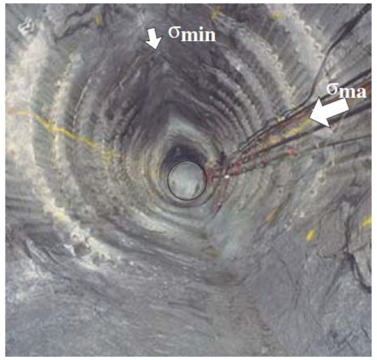
https://www.earthdoc.org/docserver/fulltext/2214-4609/2019/Mo_PP_07.pdf?expires=1618846014&id=id&accname=fromqa191&checksum=C36D6D9A080CF7D8216C445892470866

Practical Wellbore Stability

① In situ observation of hole ovalisation

3.5m in diameter

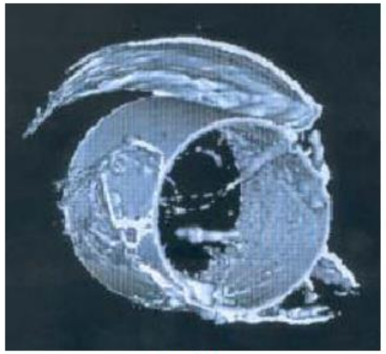




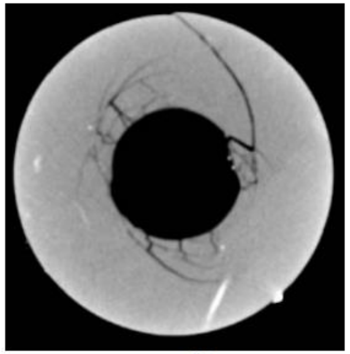
CD Martin & K Su 2005

in lab

~10cm in diameter



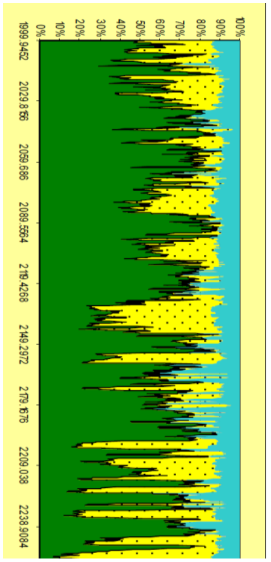
vue 3D

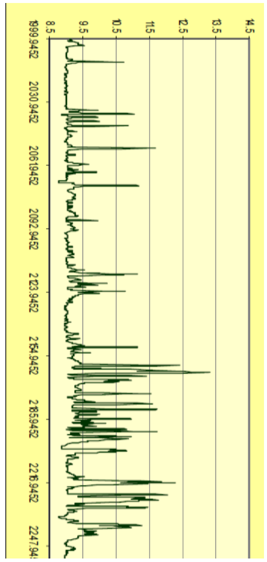


vue 2D

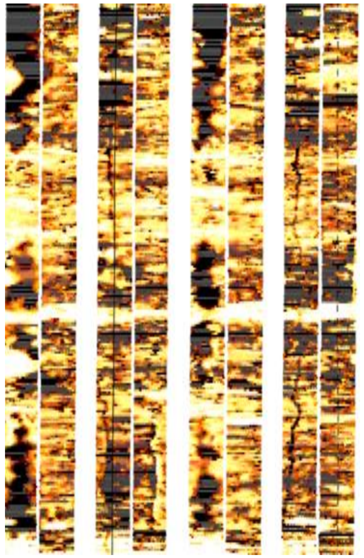
K Su 2005

② caliper





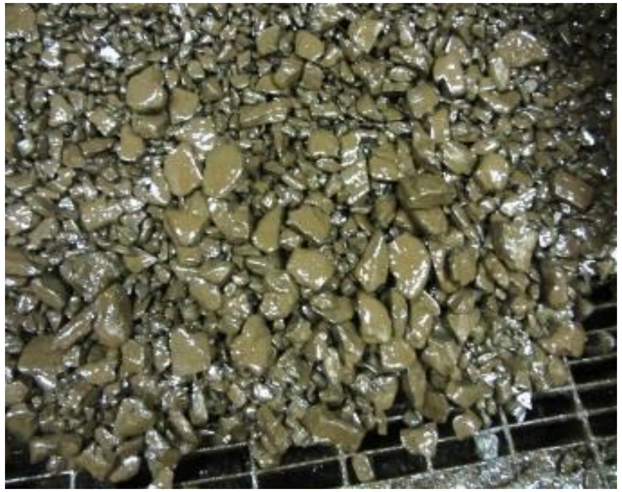
③ Hole imagery



Practical Wellbore Stability: Observation on the rigs: cavings

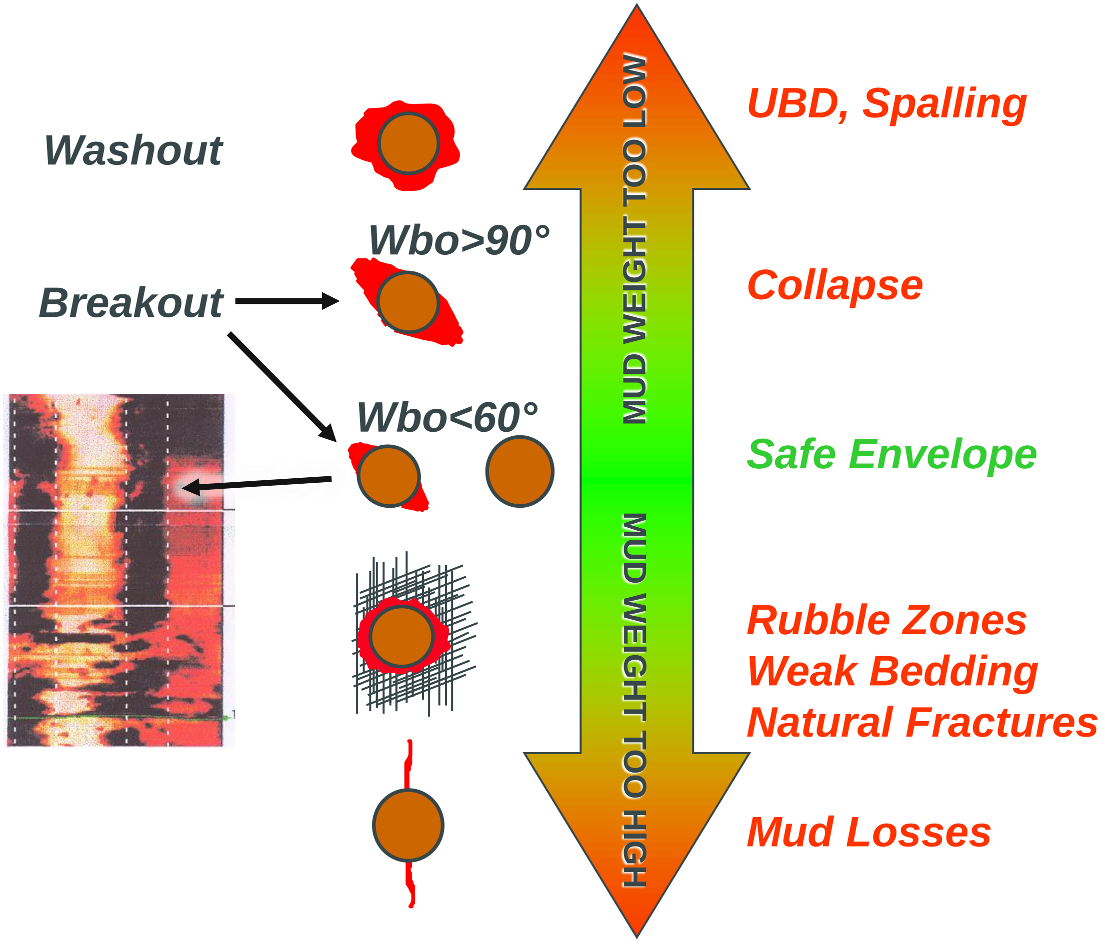




Practical Wellbore Stability: Observation on the rigs: cavings

Common figures of wellbore instability

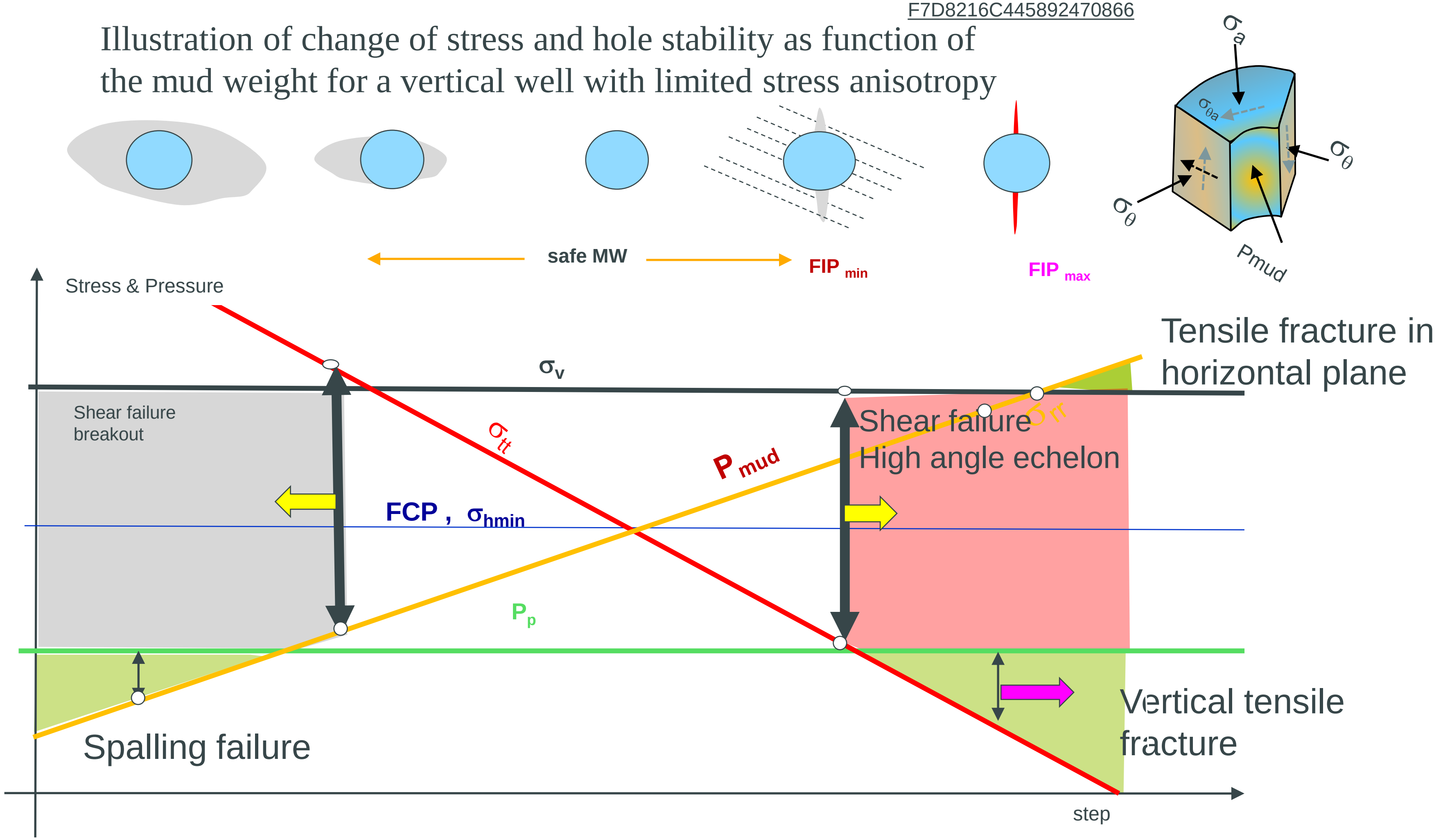


❑ Definition of FCP, FIP_{min}, FIP_{max}, LOP

Su K. et al, 2019, EAGE, PPP WS

https://www.earthdoc.org/docserver/fulltext/2214-4609/2019/Mo_PP_07.pdf?expires=1618846014&id=id&accname=fromqa191&checksum=C36D6D9A080CF7D8216C445892470866

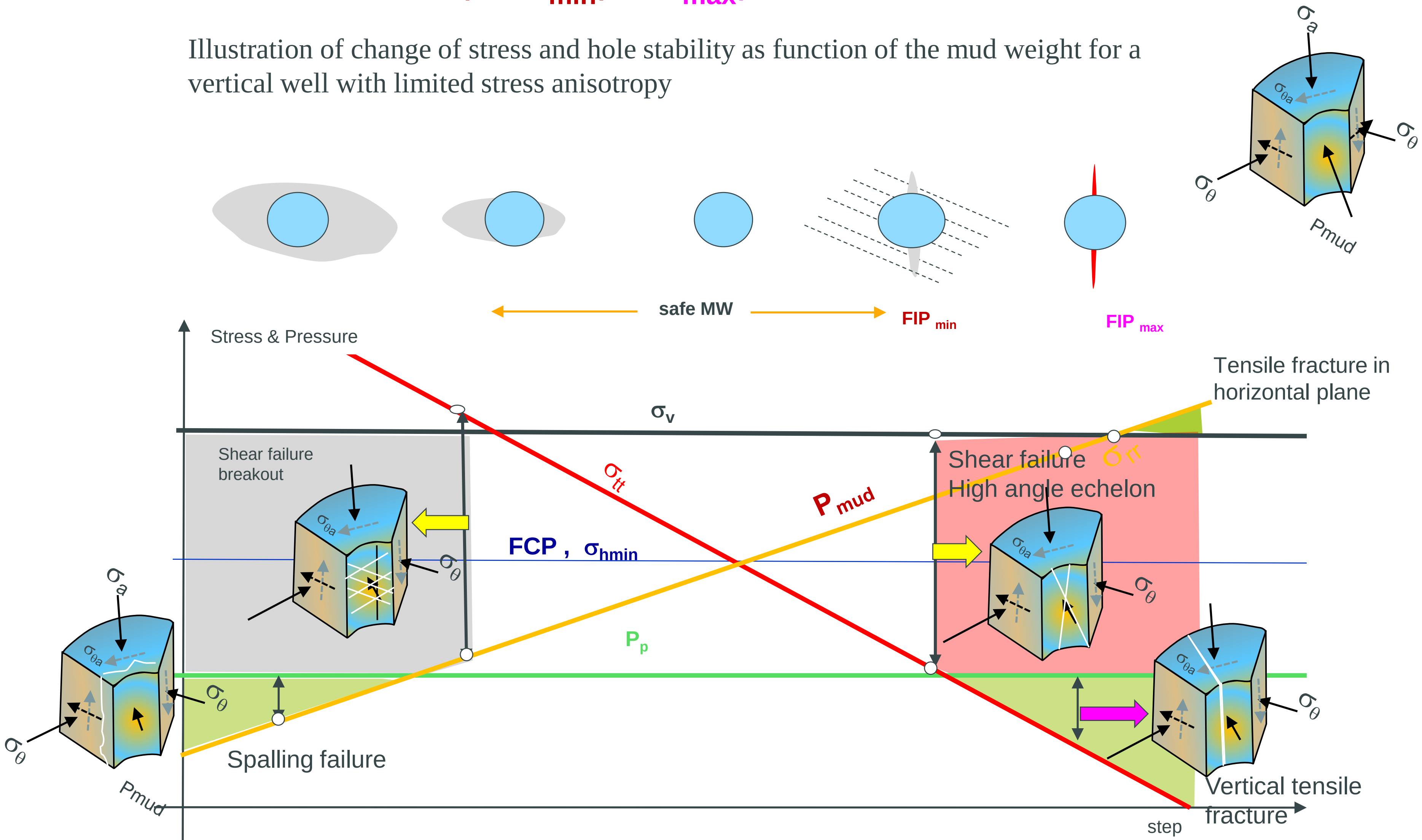
Illustration of change of stress and hole stability as function of the mud weight for a vertical well with limited stress anisotropy



2 –Geomechanics Concept & Vocabulary

❑ Definition of FCP, FIP_{min}, FIP_{max}, LOP

Illustration of change of stress and hole stability as function of the mud weight for a vertical well with limited stress anisotropy

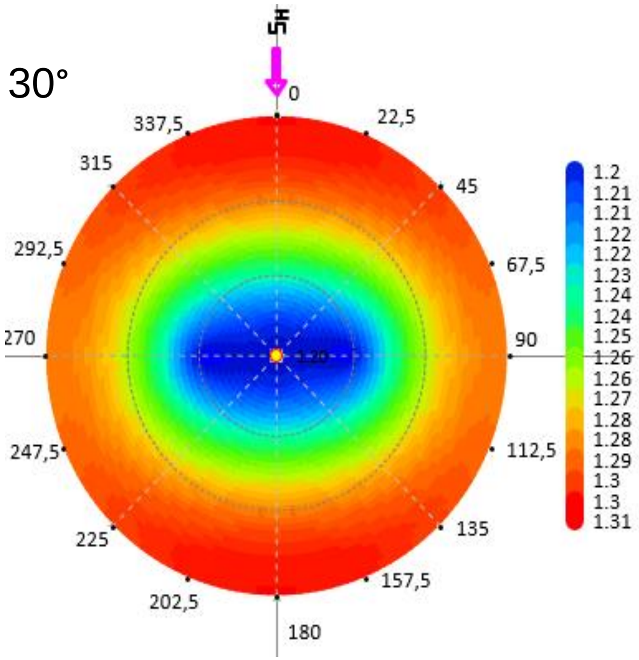


Different plots in wellbore stability study

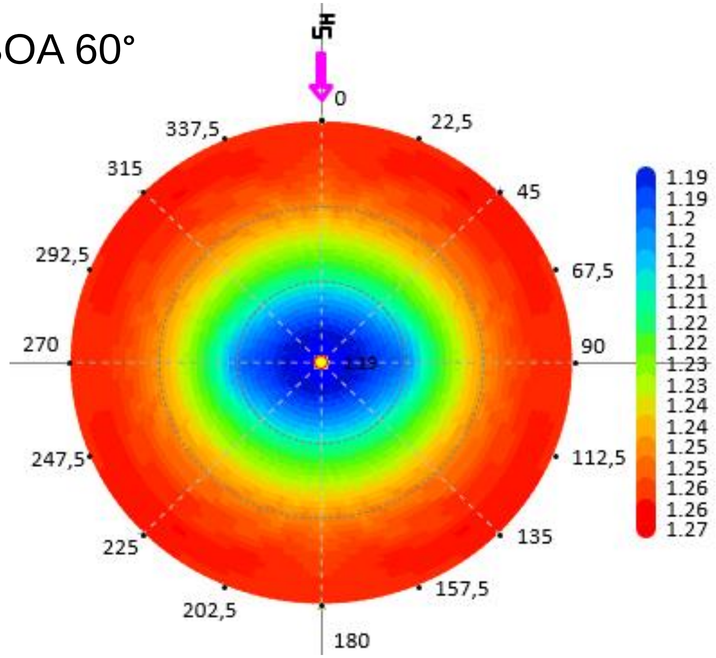
Stereonet → Inclination & azimuth effects

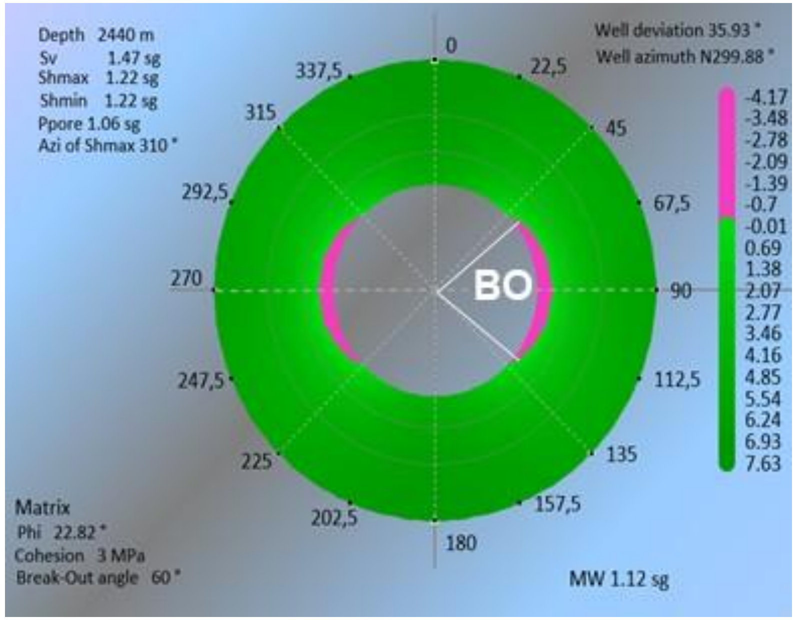
- Different methods to show minimum mud weight

BOA 30°



BOA 60°



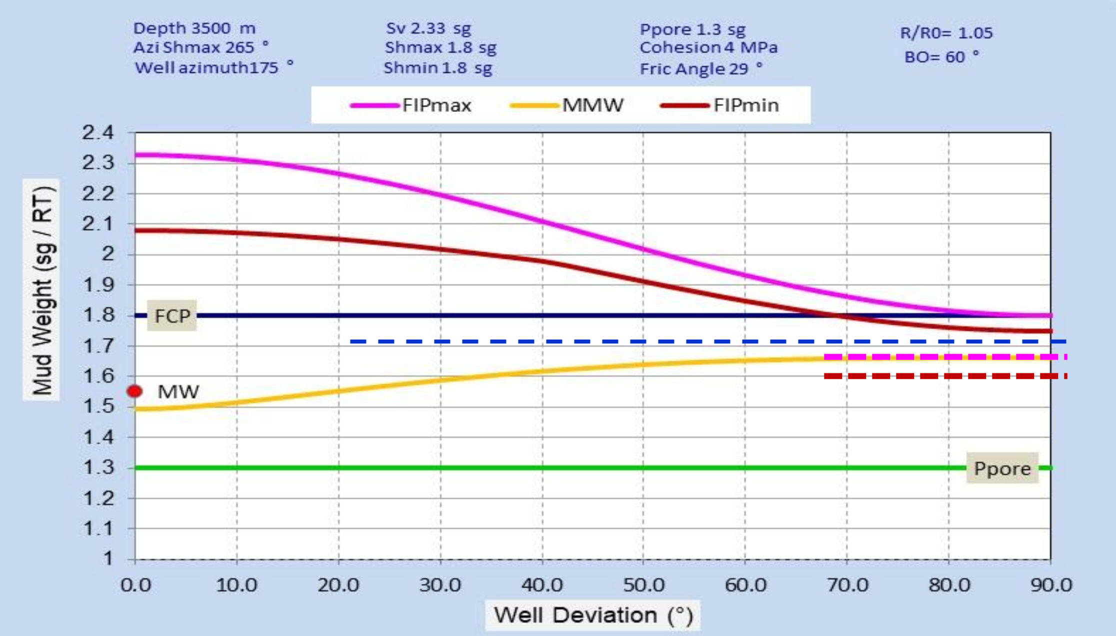


Z = 4000m, Shmin(FCP) = 1.45sg, Shmax = 1.55sg, Sv = 1.70 sg, Pp = 1.20 sg, C = 3.84MPa, Phi = 25.4°

Different plots in wellbore stability study

Well trajectory effect

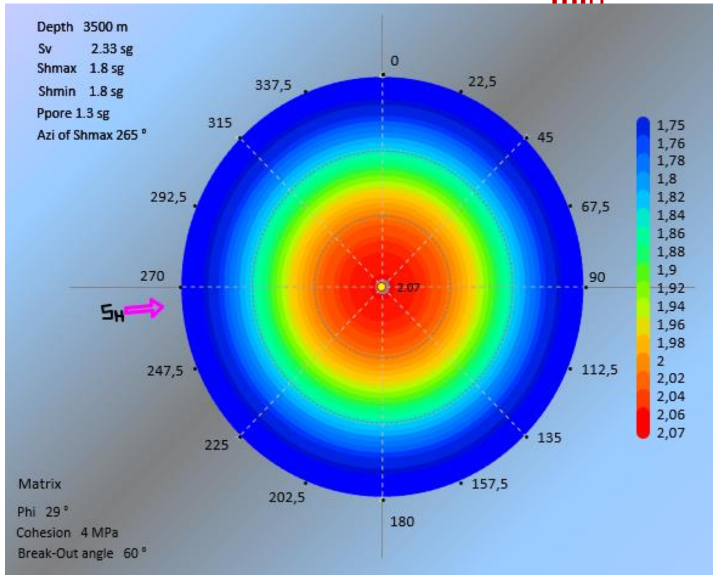
Isotropic horizontal stresses case



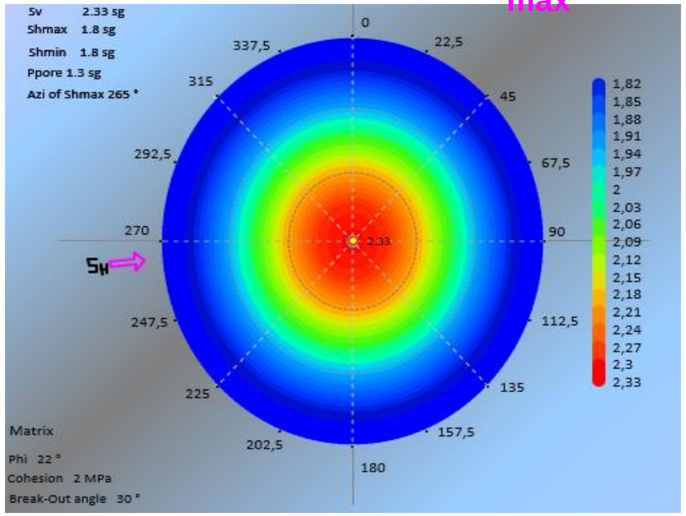
➔ FIP_{min} >= FPP (FCP+ Δ sg),
fracture propagation pressure

➔ FIP_{max} >= FIP_{min} + ~ 0.10 sg

Stereonet of FIP_{min}



Stereonet of FIP_{max}



TotalEnergies

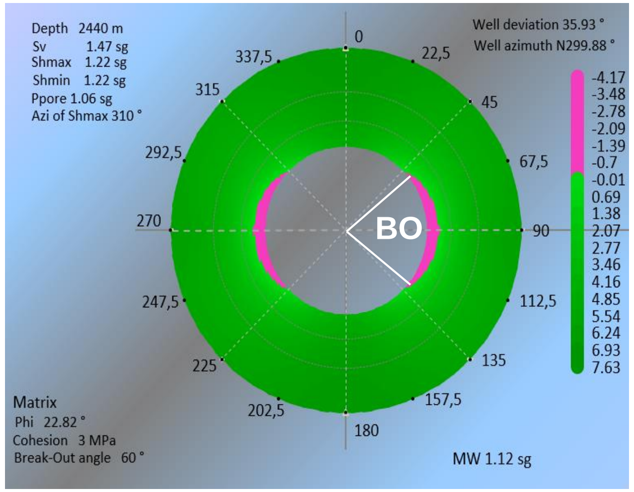
Different plots in wellbore stability study

Breakout angle (BO) and allowable instability

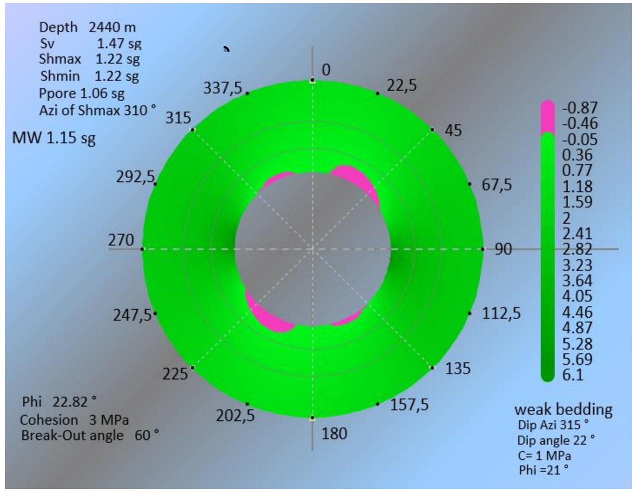
BO is the width of failure zone

- MMW is very sensitive to the BO, so the allowable instability
- For a vertical well: BO 60°~ 90°
- For an high deviated well (> 80) BO 30° ~ 60°

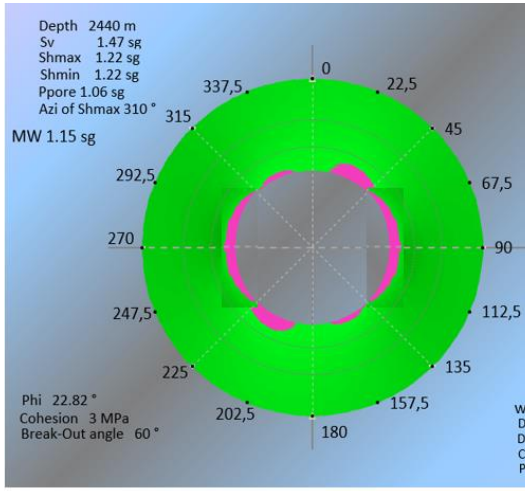
Rock without weak bedding



Failure zone around weak bedding



The sum

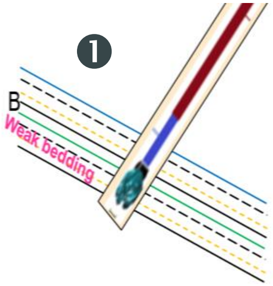


Different plots in wellbore stability study

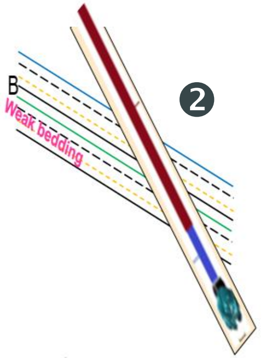
Optimization of well trajectory regarding the hole stability?

- **<u>Shale lamination</u>** forms weak bedding having low frication angle, so low strength. It can be the source of sever instability
- Up dip drilling is more stable
- Mud chemistry and BHA composition are also very important
- The practice of hole cleaning is important too

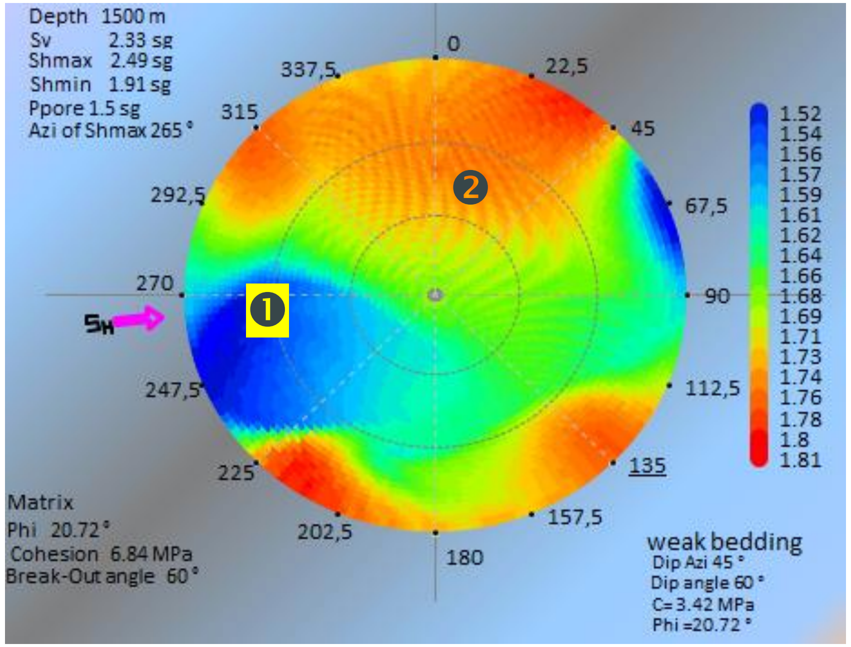
Up dip→ better

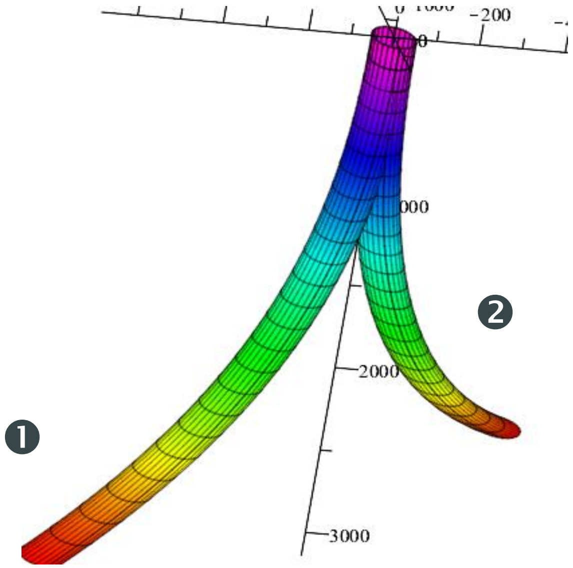


Down dip→ worse than up dip



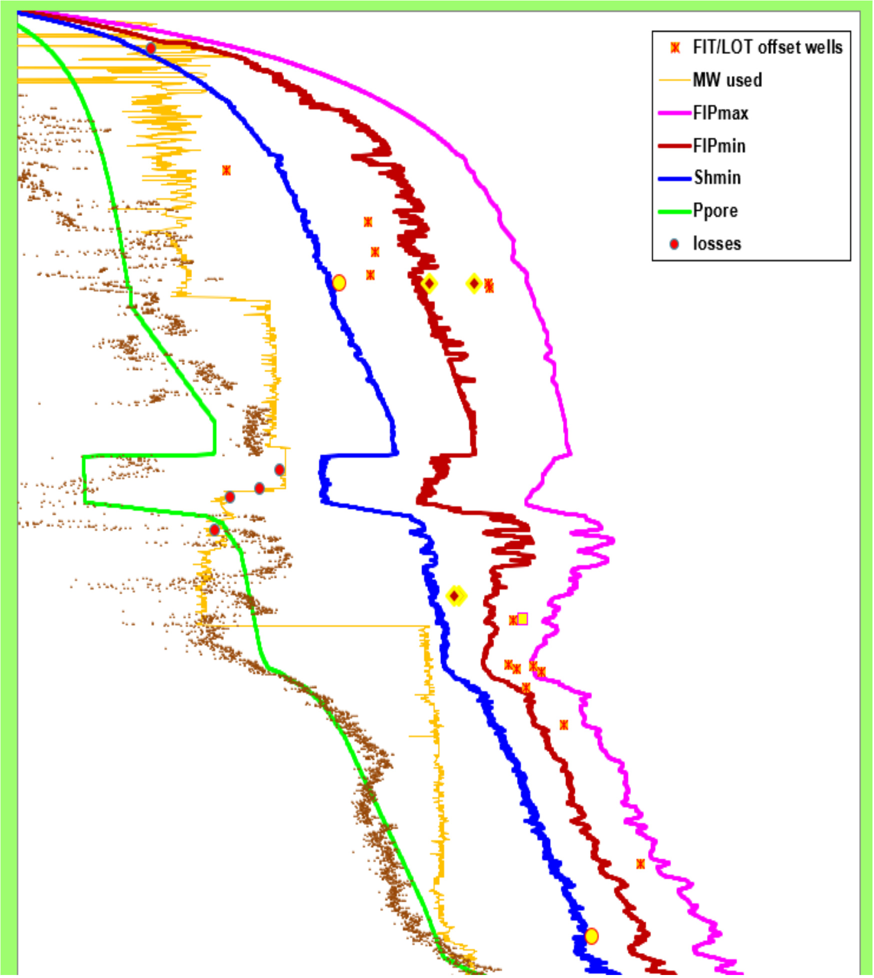
Cross dip: worse case



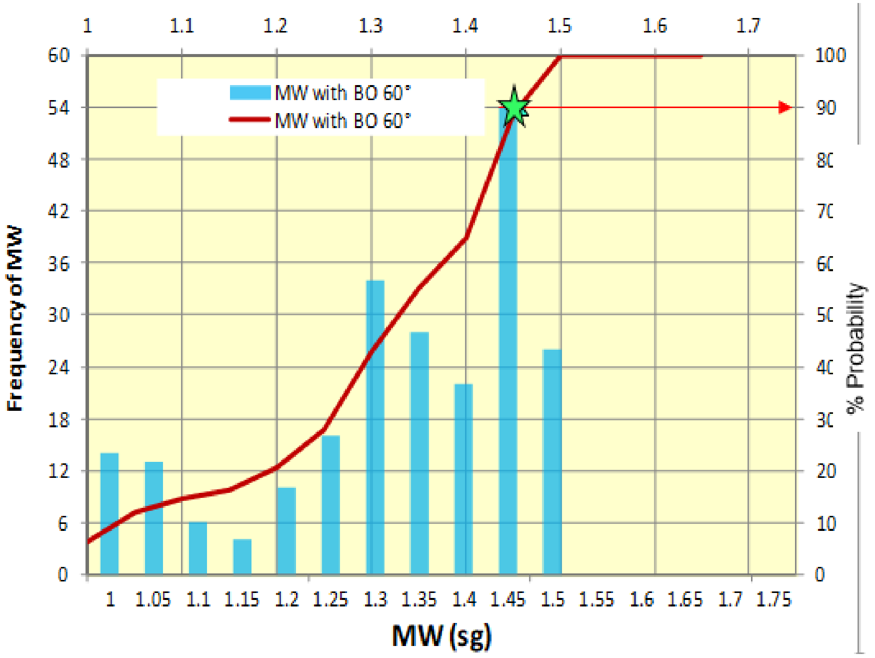


Different plots in wellbore stability studies

MW & FIP profiles

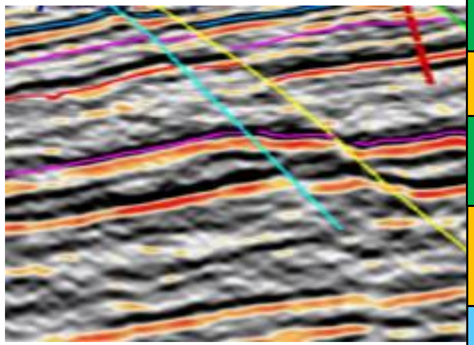


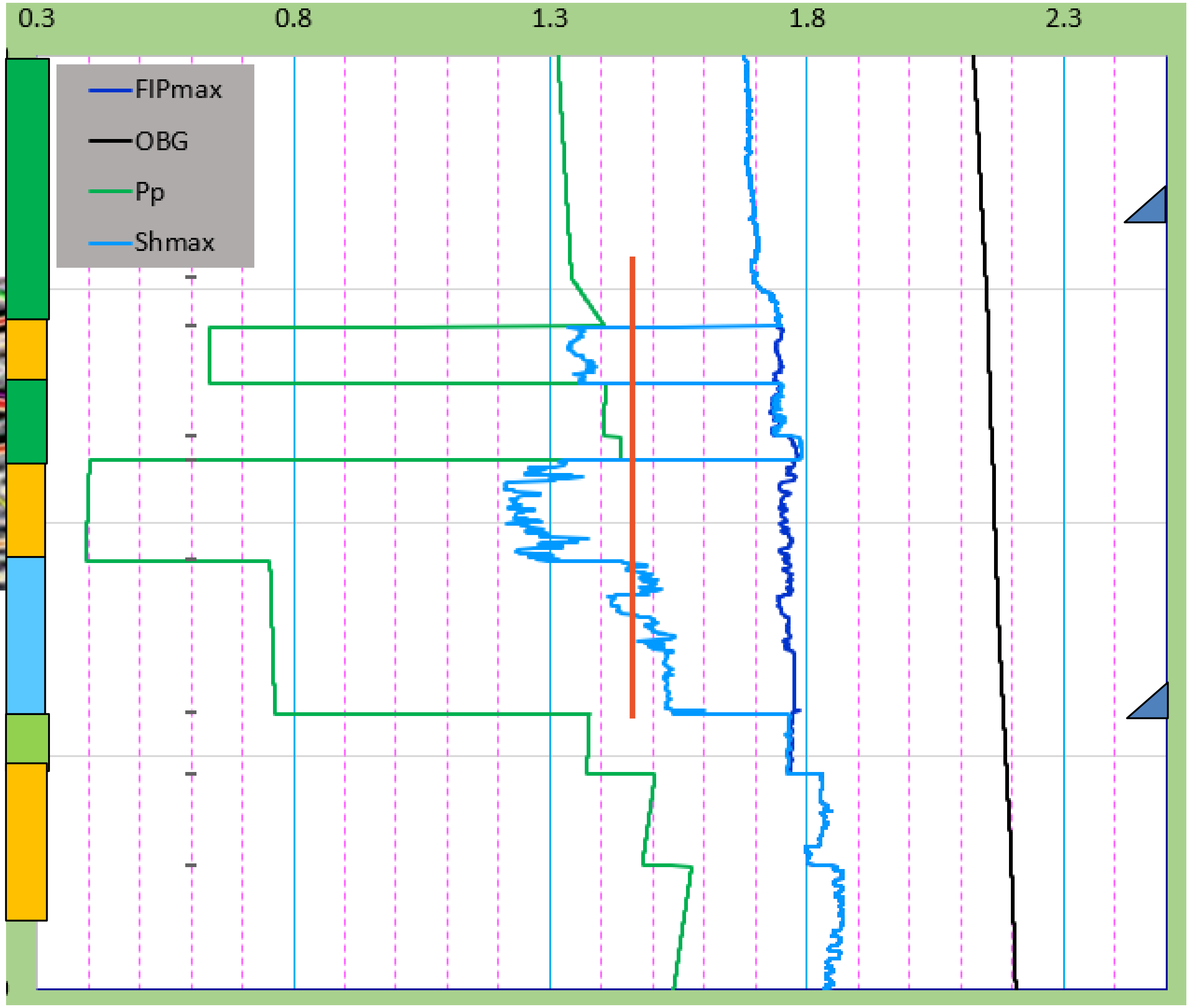
MW distribution over an interval



Wellbore Strengthening

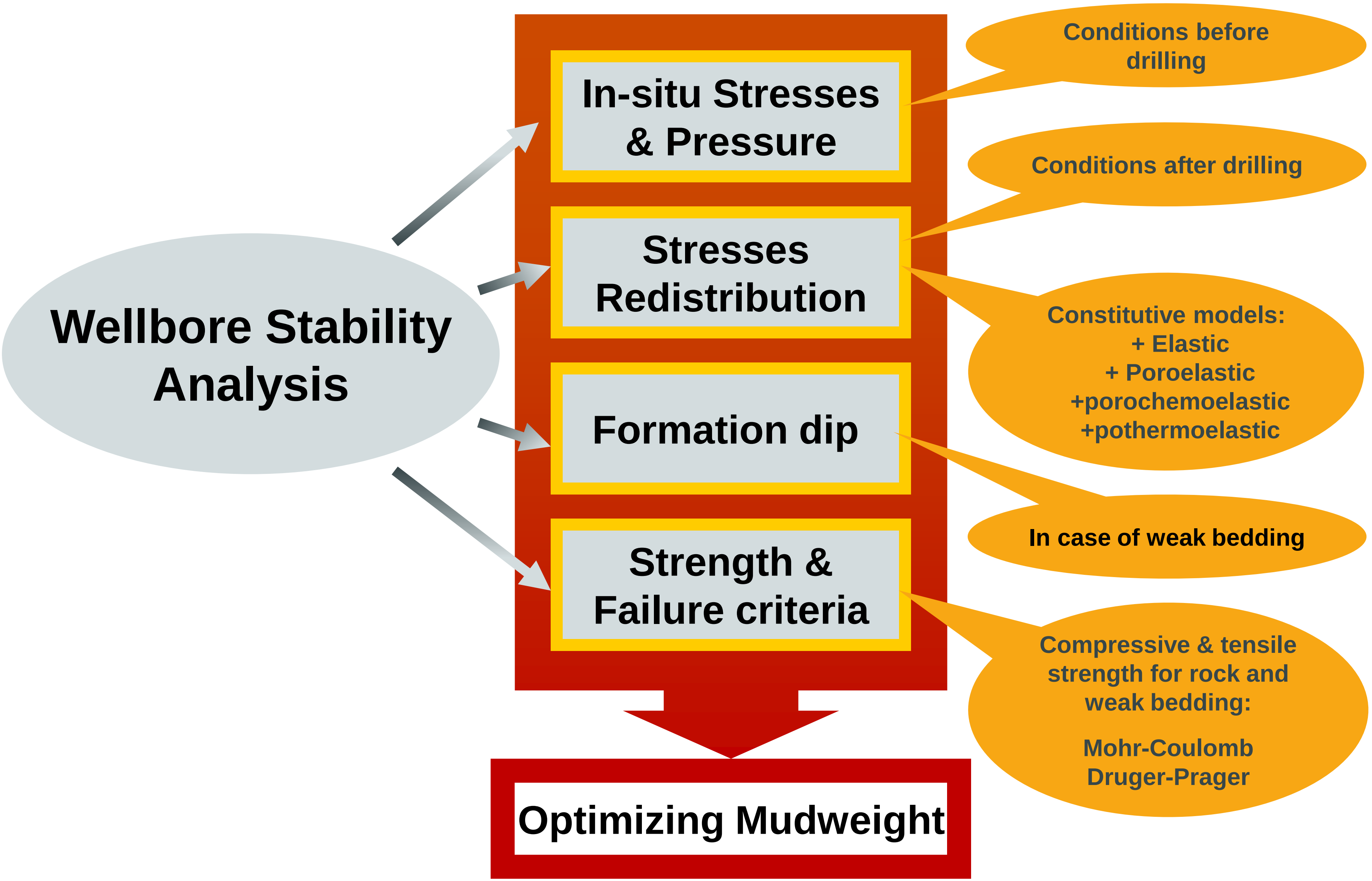
Huge difference between P_{shale} and $P_{reservoir}$





Wellbore stability during drilling and during production

Minimum mud weight calculations to avoid instability phenomena caused by wellbore rock failure



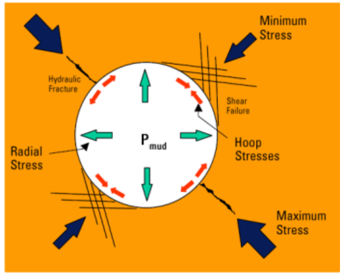
Wellbore stability during drilling and during production

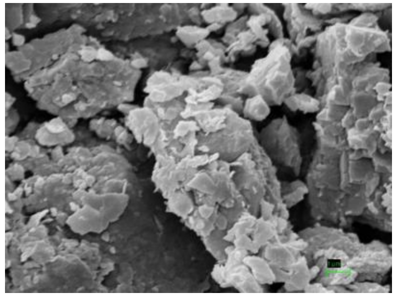
M4S1

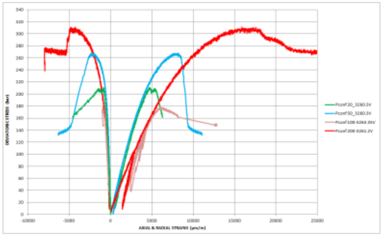
Typical data acquisition program

TotalEnergies

- Acquire the following logs
  - > Density, sonics, GR, Calipers/images
- In situ stress determination
  - > ELOT (after risk assessment) + Density + images (DIF & breakouts)
- Take a core for following characterizations
  - > XRD to identify the types of clays and corresponding CEC
  - > Mud pressure penetration tests with various tests followed by strength measurements to evaluate chemical weakening by the mud
  - > Triaxial tests at various bedding inclinations
- Formations dips from seismic correlated to wells
- Review instability events on old wells and establish empirical correlations with inclination, azimuth, logs, MW, Mud type
- Perform MW calculations and validate it with instability events already experienced
- Implementation in well design and execution







Summary: geomechanics important for well design and drilling operation

- The well architecture or design is founded on the two curves: PPP/MMW and FG curves.
- The prediction of FG & MMW is based on the Ppore and in situ stress model (OBG, S_{hmin}, S_{hmax}) and formation strength model.
- Dealing with various drilling difficulties and well control events needs the geomechanics inputs : kick, losses, cross flow, cavings, tight spots, over torque, stuck pipe, salt/shale creeping, and drilling through rubble zone & depleted reservoir, etc …
- The strategy of FIT/LOT is defined by drillers in taking into account the uncertainty of geomechanical model on the margin between FG and maxi PP in the next section. The interpretation of FIT/SVT/LOT is done by Geomechanical Specialist.
- The design of completion and well testing program need the geomechanical studies: sanding risks, MW in DST, etc … .

Thank you

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