Chapter Four

Wellbore Stability

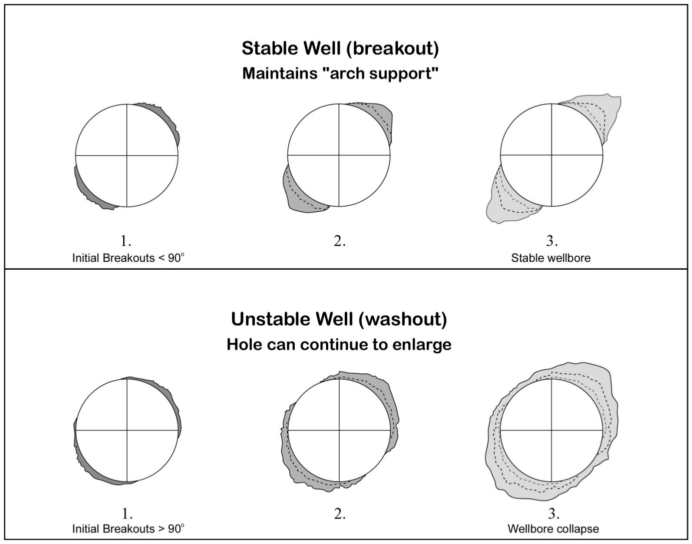
Overview of Geomechanics
RTS Geomechanics Services

Wellbore stability and different types of failures

- Breakouts and Mud Weight
- Time-Dependent Wellbore Stability Effects
- Instabilities Due to Slip on Weak Bedding Planes
- Identifying Wellbore Failure on the Rig
- Drilling Salt

Baker Hughes

Wellbore Stability and Mud Weight



The Key to Wellbore Stability is Controlling the Width of Failure Zones

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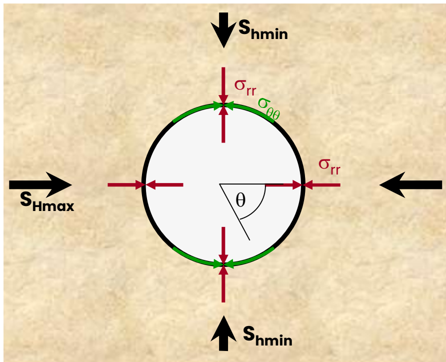
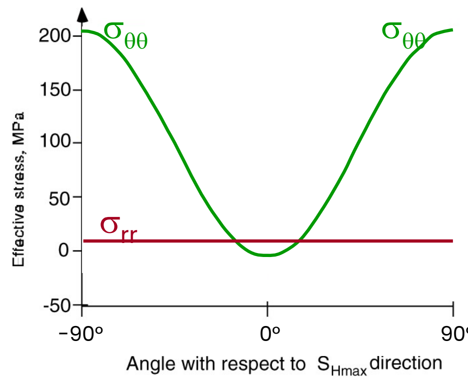
Breakouts that are less than 90 degrees will tend to deepen, but not widen. If the breakout is greater than 90 degrees then the wellbore will not have enough arch support and the breakout will grow wider over time, eventually spanning the entire wellbore and causing a washout.

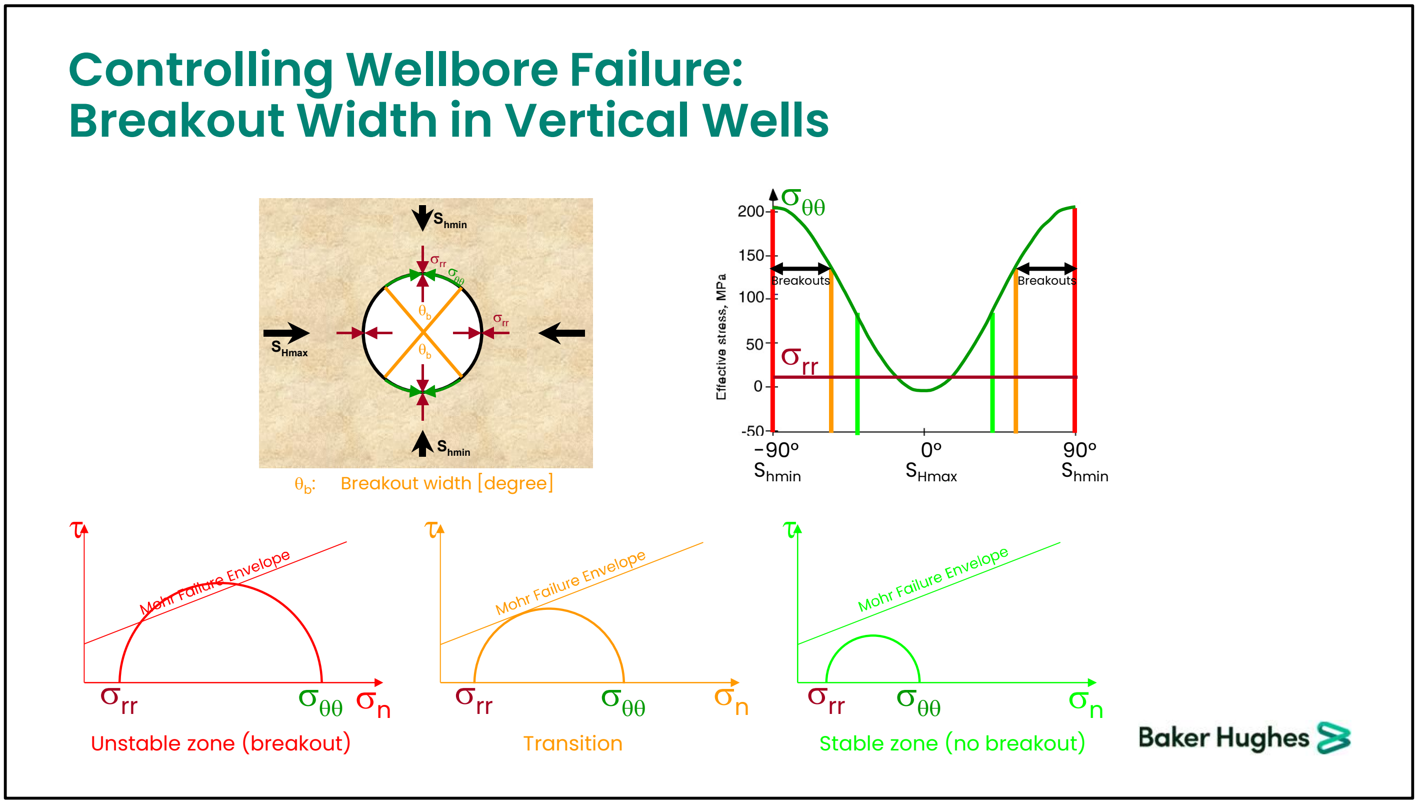
Controlling Wellbore Failure: Stress Concentration Around Vertical Wells





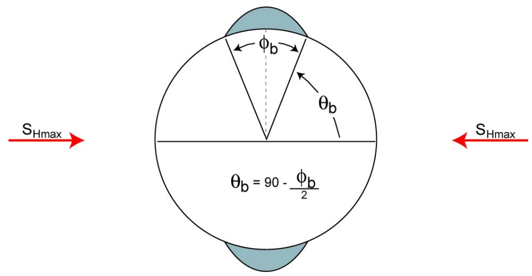
S_{Hmax}:	Maximum horizontal stress
S_{hmin}:	Minimum horizontal stress
$\sigma_{\theta\theta}$:	Circumferential stress
σ_{rr}:	Radial stress
θ:	Circumference angle

The stresses around the wellbore wall are described by a radial stress acting perpendicular to the wellbore wall at all points, and a “hoop” stress acting tangent to the wellbore wall at all points. The radial stress does not vary around the well. The circumferential stress varies around the wellbore wall and is typically measured at an angle from the orientation of the maximum horizontal stress.



Where the difference between the hoop stress and the radial stress is greatest, the breakouts will form if the Mohr circle exceeds the failure envelope for the rock being drilled. As the position around the wellbore changes from the Shmin direction, the difference between the hoop stress and the radial stress is reduced. At some point the Mohr circle is just in contact with the failure envelope. This point represents the limit of the breakout. The total breakout width can be seen by taking the total angular difference between the red and the orange lines. At positions around the wellbore closer to the maximum horizontal stress the Mohr circle becomes too small to cause any failure.

Estimation of SHmax Magnitude From Breakout Width (In Vertical Wells)

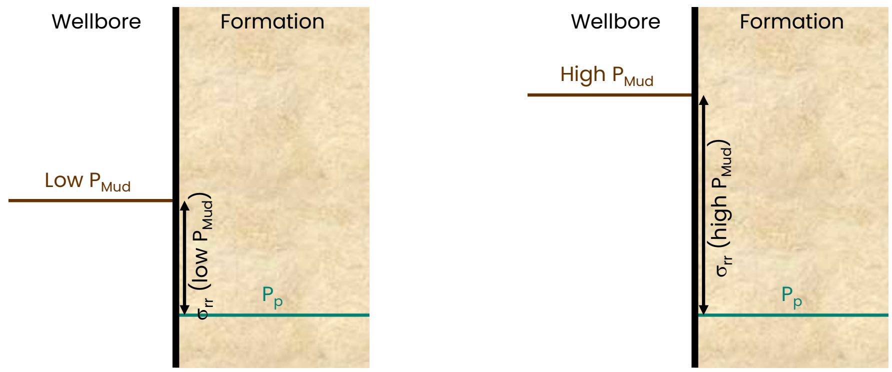


$$\sigma_{\theta\theta} = S_{h\min} + S_{H\max} - 2\left(S_{H\max} - S_{h\min}\right)\cos 2\theta_b - P_p - P_{Mud} - \sigma^{\Delta T} = C_{eff}$$

$$S_{H\max} = \frac{\left(C_{eff} + P_p + P_{Mud} + \sigma^{\Delta T}\right) - S_{h\min}\left(1 + 2\cos 2\theta_b\right)}{1 - 2\cos 2\theta_b}$$

The breakout width is related to the stress applied to the rock. Larger breakout widths are expected in higher stress environments.

Controlling Wellbore Failure: Influence of Mud Weight on Breakout



An increase in mud weight increases σ_{rr}, which is the pressure the mud exerts on the wellbore wall.

(Assumes perfect seal between wellbore pressure and formation pressure)

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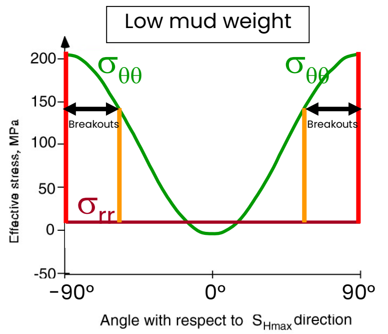
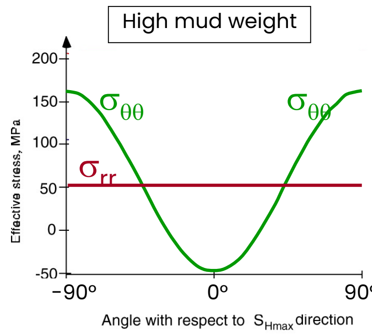
Increasing mud weight increases the radial stress at the wellbore wall. Because an increase in radial stress reduces the difference between the hoop stress and the radial stress, the compressive stresses acting at the wellbore wall are reduced.

Controlling Wellbore Failure: Influence of Mud Weight on Breakout





- An increase in mud weight increases σ_{rr}, and at the same time reduces the circumferential stress ($\sigma_{\theta\theta}$).
- As a result the breakout width decreases with increasing mud weight.

⇒ Collapse mud weight maintains breakout width below a critical size (90 degrees in vertical wells)

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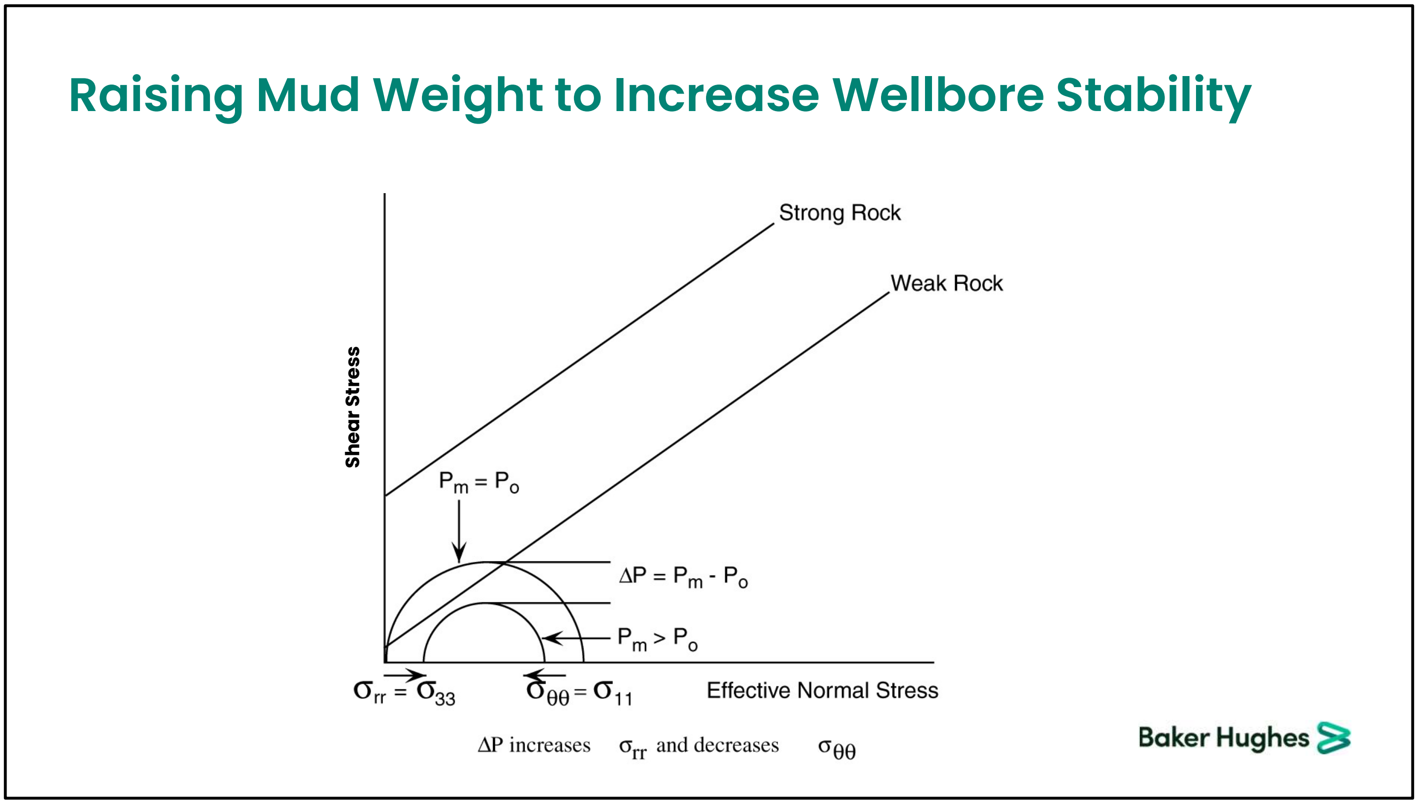
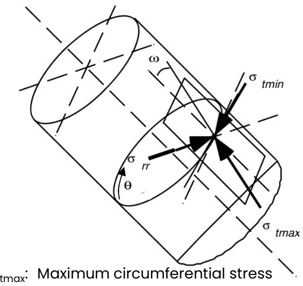
The mud weight also reduces the hoop stress around the wellbore at the same time the radial stress is increased. The result is that breakout width decreases with increasing mud weight.

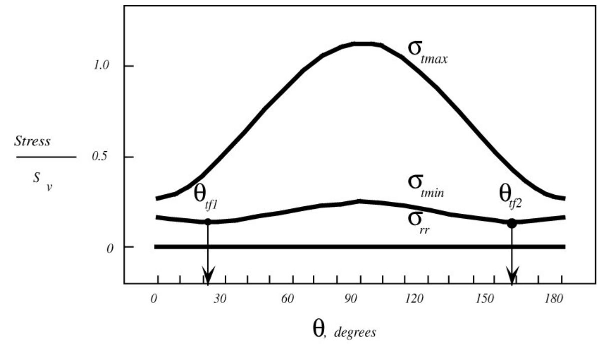


The effect of increasing mud weight is to increase the radial stress while reducing the hoop stress at the wellbore wall. The result is that the Mohr circle shrinks and weak rocks are stabilized.

Principal Stresses in an Arbitrarily Oriented Wellbore



σ_{tmax}: Maximum circumferential stress
σ_{tmin}: Minimum circumferential stress
σ_{rr}: Radial stress
θ: Circumference angle
ω: Angle between σ_{tmax} and borehole axis



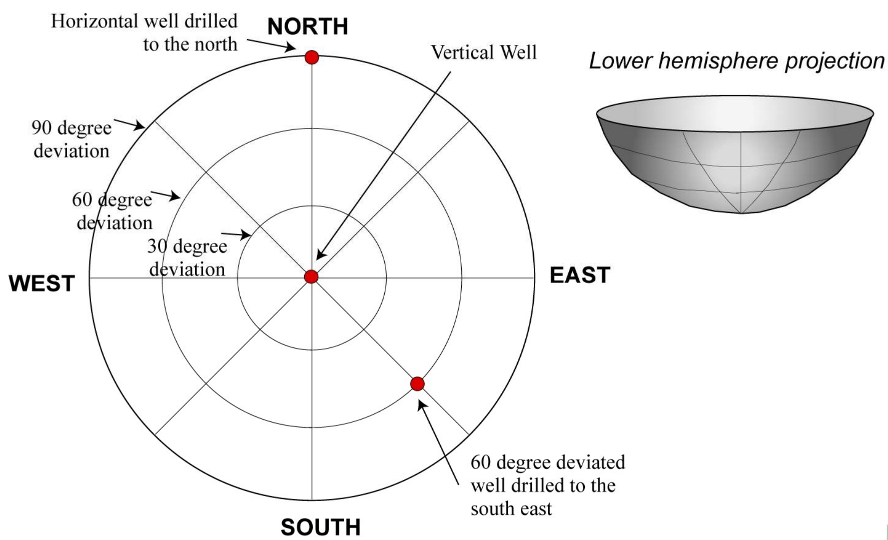
The allowable breakout for maintaining wellbore stability is limited to 90˚ in a vertical well, and 30˚ in a horizontal well. The allowable failure is varied linearly between 90˚ and 30˚ for wells deviated between horizontal and vertical.

Horizontal wells are not necessarily any less stable than vertical wells. However, deviated and horizontal wells are harder to clean. Therefore, the allowable failure in deviated and horizontal wells is reduced.

Baker Hughes

Stress concentration around a deviated wellbore depends on the orientation of the well in the stress field and the magnitudes of the stresses acting on the wellbore. In a deviated well the position of the failure around the well constrains both the stress orientation and the stress magnitude.

Representing Drilling Trajectories



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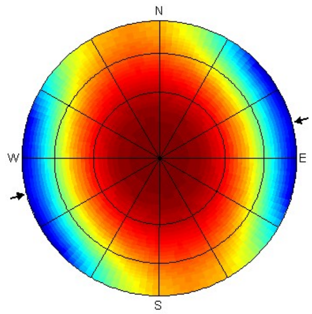
Many of the outputs of the Baker Hughes geomechanics software display wellbore stability on a “Lower Hemisphere Stereo Plot.” The view is looking down into a hemisphere. This plot enables you to see a 2-D display of all possible wellbore trajectories. For example, a vertical well is represented at the direct center of the diagram. As you go farther out from the center, the wells are more inclined. The outer circle represents perfectly horizontal wells, drilled at 90 degrees. The interior of the hemisphere is typically colored to represent various drilling parameters, such as mud weight required to maintain wellbore stability.

Well Trajectories



Pad B

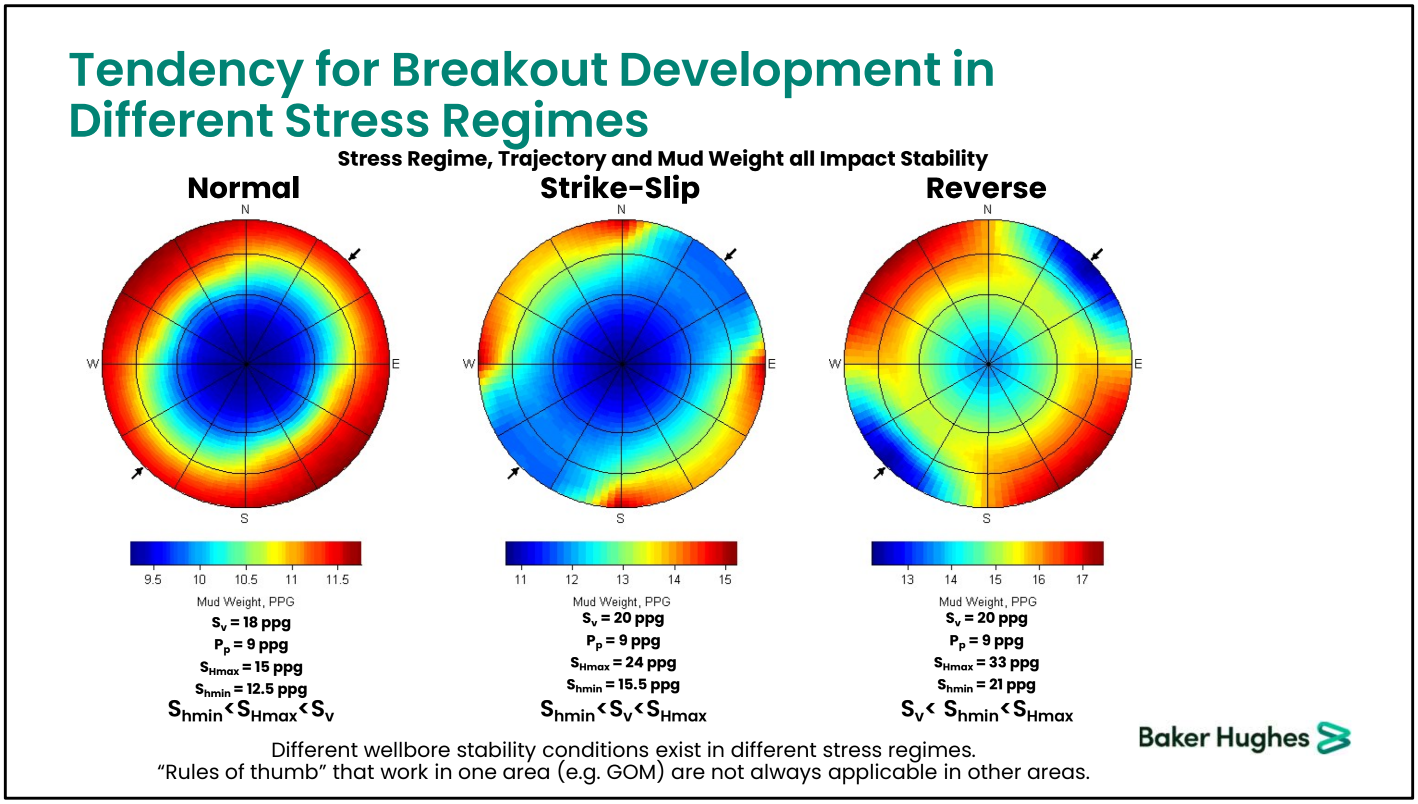
Target

Pad A

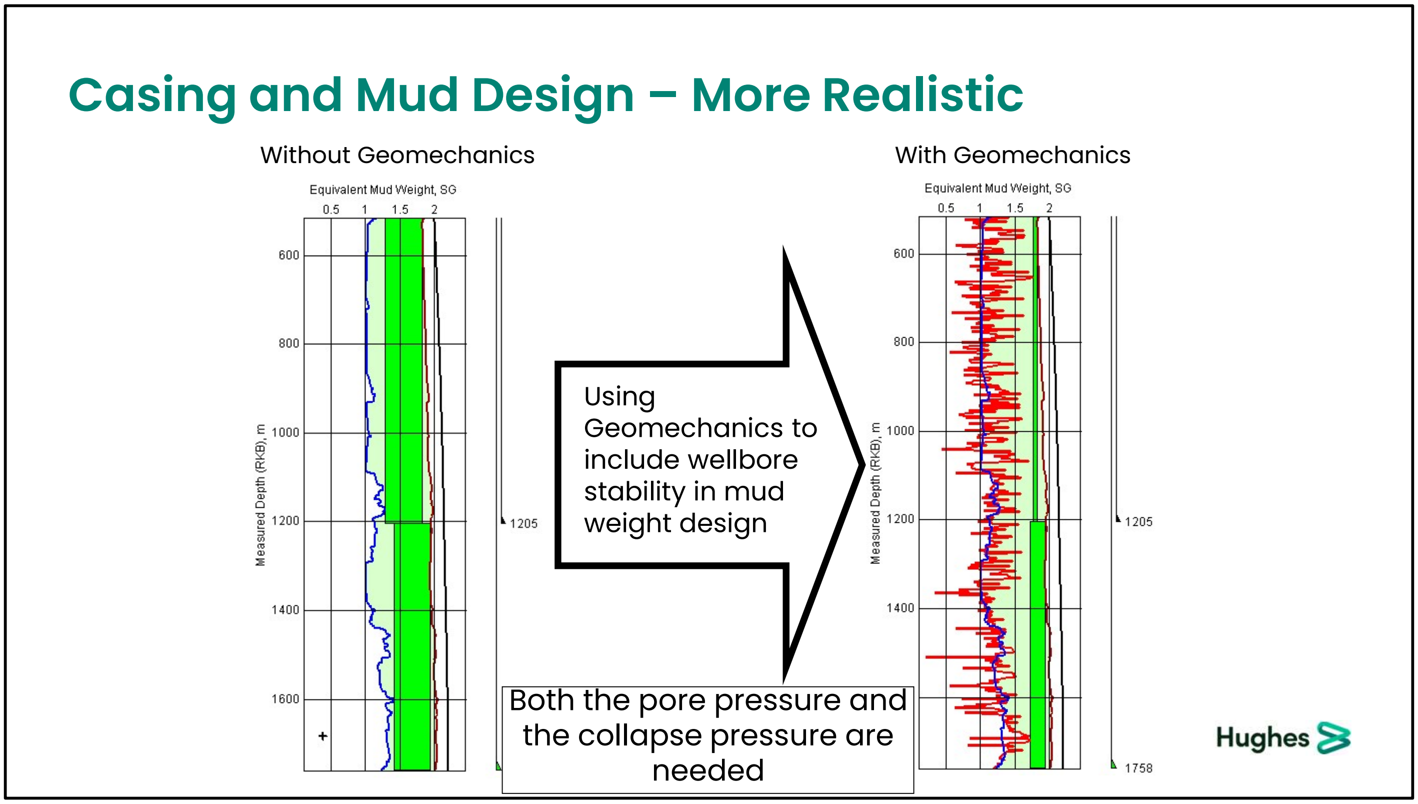
From which pad should you drill to maximize the probability of successfully reaching the target?

Pad C

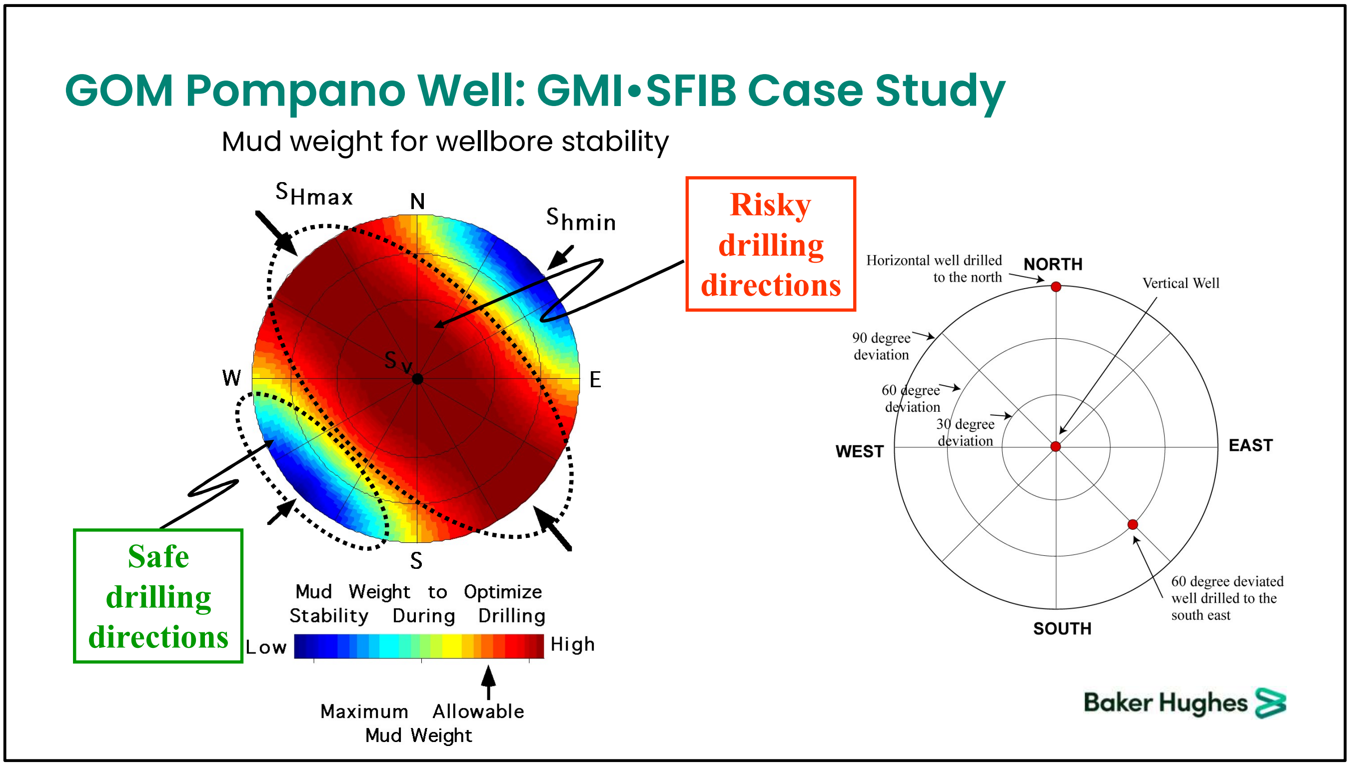
Baker Hughes



The optimal drilling direction for maintaining stability may change in different stress regimes. Because stresses change continuously throughout the earth, the plots shown also change colors continuously from extensional normal faulting regimes to more compressive strike-slip and reverse faulting stress regimes. For example, the optimal orientation for maintaining stability in the normal faulting stress regime may be a vertical well. There little azimuthal difference in required mud weight for deviated wells. In the strike-slip faulting stress regime shown the optimal orientation is still vertical, but horizontal wells drilled in the direction of the maximum horizontal stress will help to minimize the mud weight. In the reverse faulting stress regime shown, the optimal orientation is a horizontal well drilled toward the maximum horizontal stress. **This highlights the importance of knowing the orientation, relative magnitudes, and absolute magnitudes of all three principal stresses.**



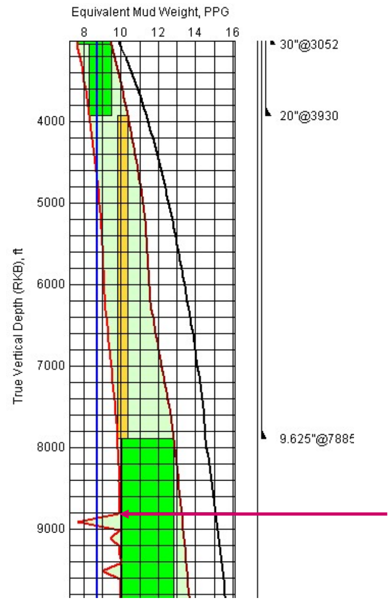
With a traditional pore pressure/Frac gradient approach, casing strings are set with the lower bound as pore pressure (plus some safety factor) and the upper bound as frac gradient. With a geomechanical approach, the lower bound is the maximum of pore pressure or wellbore collapse (red line), and the upper bound can be least principal stress or fracture gradient. Additional mud window can be accessed by choosing preferable drilling directions and deviations. It is not uncommon to be able to design a well with at least one less casing string as compared to traditional methods.



The colors in the stereographic projection indicate parameters such as mud weights, failure width or rock strength. This example shows maximum allowable mud weight.

In general, hot colors are associated with higher risk and blue colors represent drilling directions with low risk. In this particular case, the plot shows that it is highly risky to drill a vertical well (contrary to many rules of thumb and common sense) and relatively safe to drill deviated wells to the northeast or southwest with inclinations greater than 45 degrees. Wells in these directions could be drilled with the lowest mud weights, and still remain stable.

Case Study - Mud Window and Casing Design of Previous Well

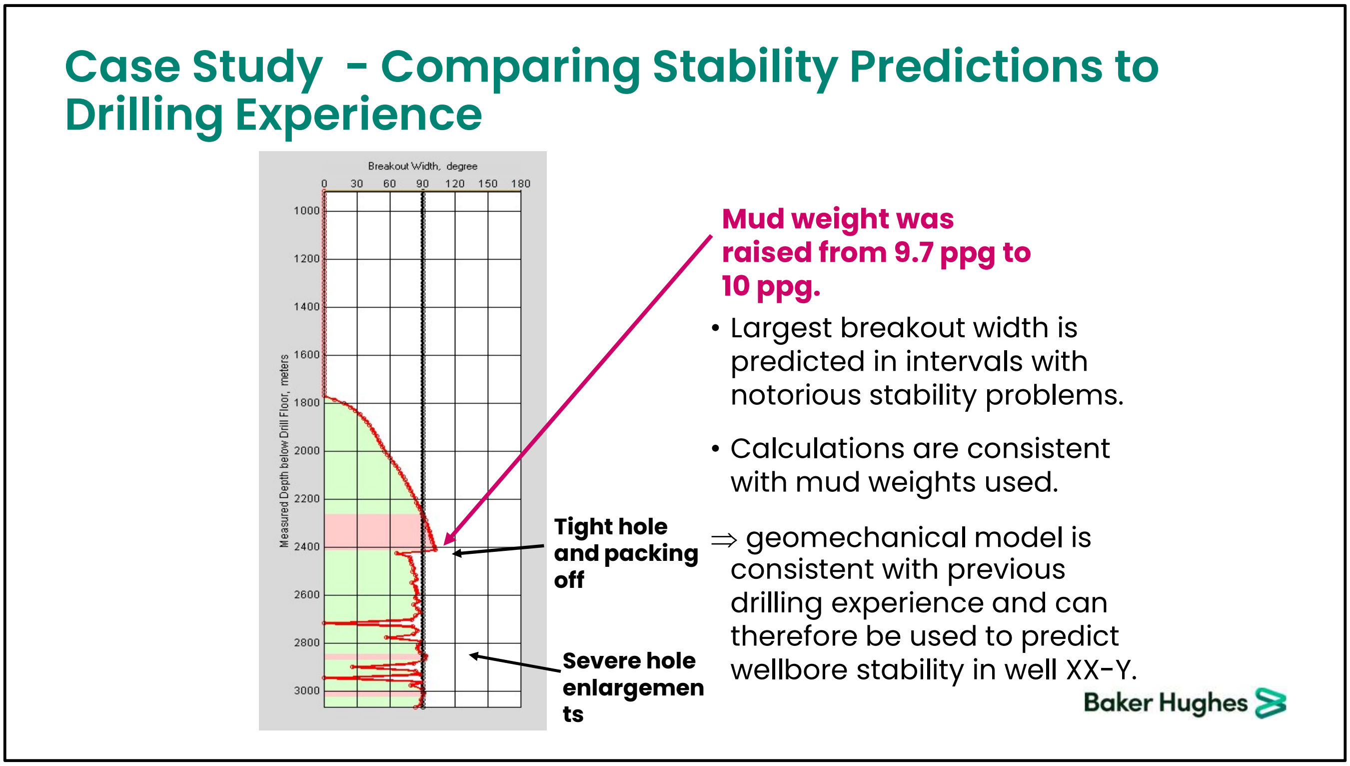


Mud window not sufficient to push 9 5/8 inch casing down to the reservoir

Baker Hughes

At the heart of the problem in the previously drilled wells was the narrow mud window in the intermediate section. The 20” casing was not set deep enough on the initial wells to allow the mud weight to be raised sufficiently to control the unstable shale interval. This required setting pipe to isolate the shale before entering the reservoir. To effect a large completion for the development program, we needed to eliminate this string of casing without risking losses or stuck pipe in the reservoir. By understanding the geomechanical model, we can push the surface casing to the depth necessary to give us control of the shales in the intermediate hole section.

Blue line is pore pressure
Red line is collapse
Brown is fracture
Black is overburden.
Light green area is area between pore pressure & fracture
Dark green and orange boxes are possible mud weight window for section.

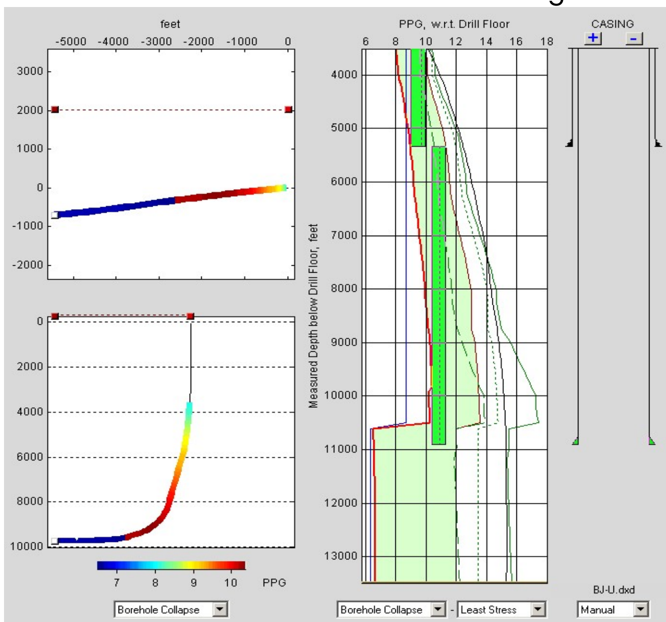


The geomechanical model built must also reflect the actual drilling experience encountered. The area of instability is where the breakout width exceeded 90 degrees. Here the model does predict the actual experience of the well, therefore it can be used to predict results for wells of different azimuths and deviations.

The calculations shown in this slide are based on an initial geomechanical model, which is based on limited data availability from the previously drilled wells. Nevertheless, the match of the model predictions with the actual drilling experience indicates that the initial model is adequate, despite large inherent uncertainties.

Case Study - Wellbore Stability in Main Hole of XX-Y

Predictions for first new well based on initial geomechanical model

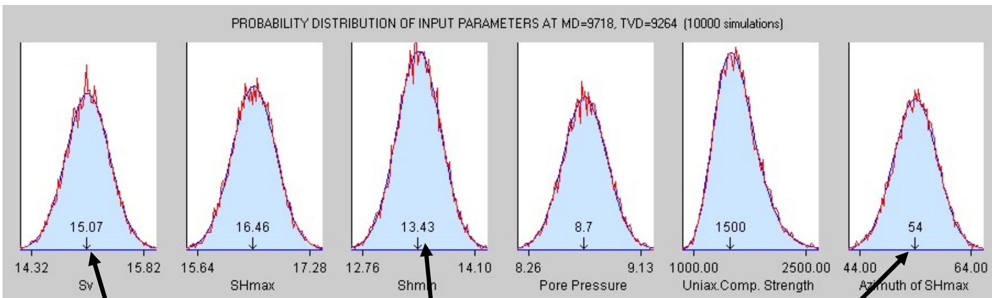


The planned casing program should allow a sufficient mud window in both the pilot and main holes.

Enterprise’s well design involved omitting and intermediate casing string, i.e.. 30” x 13-3/8” x 9-5/8” at top reservoir. For the first well, we predicted that the well could be stable without the intermediate string of casing if the surface casing is pushed to 1700 m. In this case it should be possible to reach the reservoir without intermediate casing. Note here that directional profile, casing depths etc were generated by Enterprise using Compass and sent to us in Wellbore Planner format, thereby easing greatly the data transfer burden. The color coded directional plot is a useful tool during operations - it allowed us to weight up the mud whilst drilling ahead.

Case Study - 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

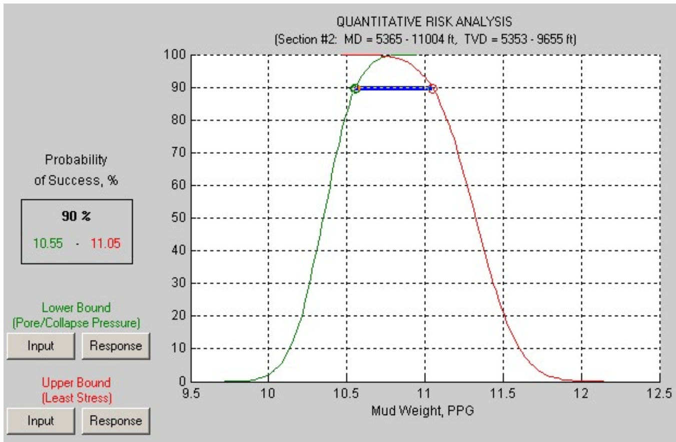
Large uncertainty due to lack of reliable leak off tests

Well constrained by wellbore failure observations from image log

Baker Hughes

We used the ranges of data as input, and then got an output that incorporates the uncertainty of the input data into a risk adjusted outcome. We compute the risk for a range of input parameters, and output the results in terms of a likelihood of success, where success is defined as keeping the width of wellbore breakouts less than a predefined value. The parameters and their variation are shown above. It can be seen that most parameters have a large uncertainty, because the amount of data available before drilling the new wells was limited.

Case Study - QRA – Chance of Successful Drilling



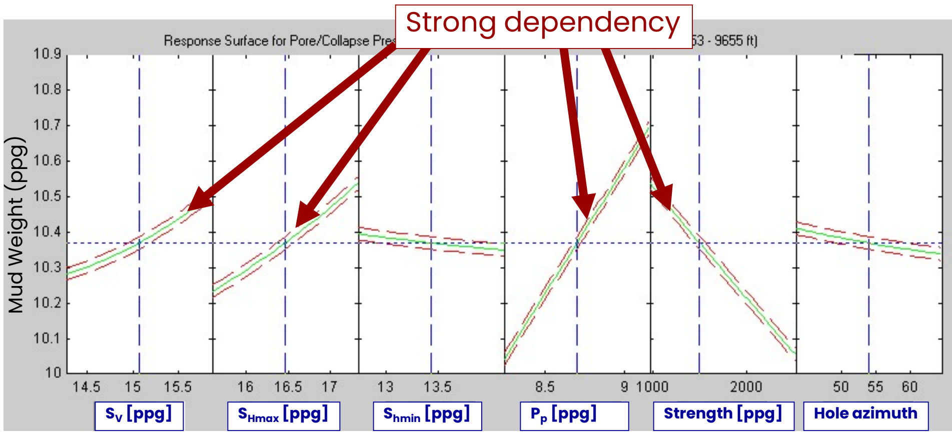
Collapse Pressure
Fracture Gradient

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

Baker Hughes

We computed the risk for the uncertainty range of input parameters shown on the previous slide, and output the results in terms of a likelihood of success. Success is defined as keeping the width of wellbore breakouts less than a predefined value (green line), and preventing circulation losses (red line). In this example, we obtain a probability of success (drilling the hole section with a minimal amount of hole problems) of 90% if the bottom hole pressure is maintained between 10.6 and 11 ppg. In other words a static mud weight of 10.6 ppg will provide a 90% of the uncertainty in the data.

Case Study - QRA - Sensitivity Analysis

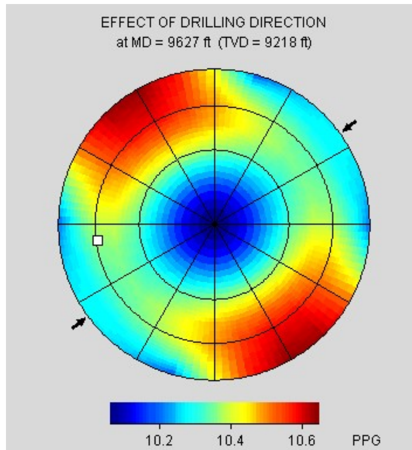


Predictions depend on better knowledge of S_{Hmax}, P_p, rock strength, and S_v.

Baker Hughes

The QRA sensitivity, part of the WellCheck software output, shows which variables are having the highest effect on the outcome, which is the mud weight required for stable wells. Strong dependencies are shown for SHmax, the pore pressure, rock strength, and overburden. These are areas of data collection which would be worth investigating in the upcoming drilling campaign.

Case Study - Importance of Drilling Direction



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

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In this figure a vertical well is drilled directly into the center, and each ring outward from the center represents thirty degrees of deviation. The preliminary model indicates that wells drilled to the North East – South West require less mud weight to remain stable. The areas in red may require additional mud weight, and therefore wells in the these directions must be carefully contemplated.

Time-Dependent Wellbore Stability Effects

Chemical Processes in Shale

Osmotic diffusion – flow of water to high salt (lower activity) from low salt (higher activity)

- Changes shale pore pressure
- Effects increase as membrane efficiency increases
- Minimized by balancing activities

Ionic diffusion – flow of ionic species across a non-ideal membrane from high to low concentration

- Weakens shale by ionic substitution
- Changes fluid salinities and species concentrations
- Offsets effects of osmotic diffusion
- Minimized by increasing membrane efficiency

Smectitic Shales

- High content of swelling clays (smectitic also called bentonite or montmorillonite)
- Very high surface area means that these shales are by far the most reactive shales
- Smectites are destroyed by temperature at depth $\Rightarrow$ do not exist below ~6000 m
- Often intact, unfractured

Baker Hughes

Quartz-Illite Shales

- Clays have been changed from smectite and kaolinite to illite and quartz
- Very low surface area, and the deposited silica acts as a cement, also, low porosity
- They are geochemically non-reactive
- The mineral change involves a great deal of shrinkage, leading to intense fracturing
- Fractured shales are almost never reactive (no smectite), are deeper, higher permeability
- Mechanical effects dominate

Baker Hughes

Impact of Chemical Effects on Wellbore Stability

Mody & Hale (1993) model for chemical osmosis:
(Non time-dependent)

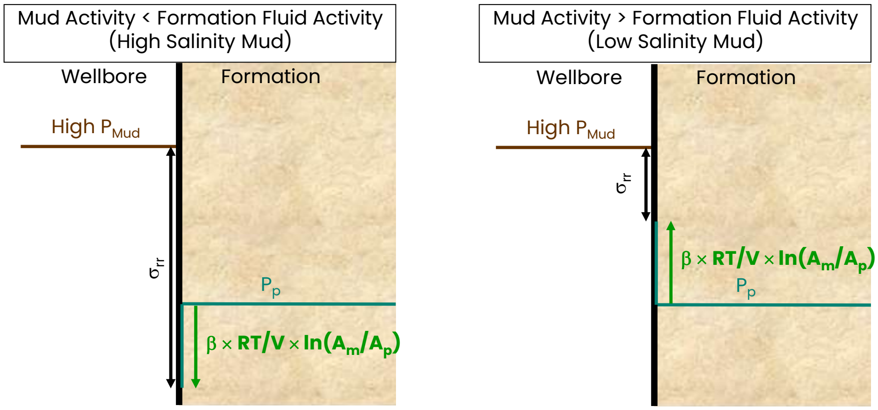
$$P = P_p + \beta \times RT/V \times \ln(A_m/A_p)$$

P:	Near-wellbore pore pressure [MPa]
P_p:	Far-field pore pressure [MPa]
β:	Membrane efficiency [ ], $0 \le \beta \le 1$ (OBM has a membrane efficiency of 1)
R:	Gas constant, = 8.3 [J/(mol x degree Kelvin)]
T:	Absolute temperature [degree Kelvin]
V:	Partial molar volume of water [m^3/mol]
A_m:	Water activity in drilling fluid [ ]
A_p:	Water activity in pore fluid (an activity of 1 corresponds to fresh water) [ ]

- Pore pressure in the near wellbore zone is affected by fluid transport due to differences in water molar free energies of the drilling and pore fluids (chemical osmosis).
- Poroelasticity equations are explicitly correct only for zero time, just after drilling.

Baker Hughes

Illustration of Mody & Hale Model



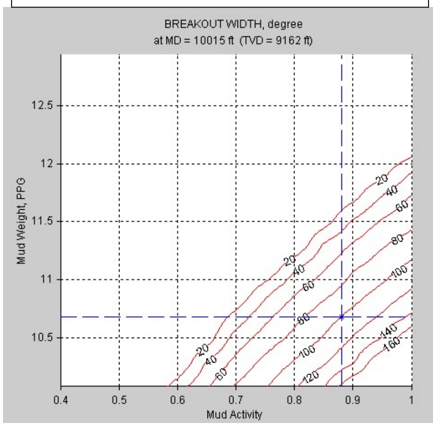
- According to the Mody & Hale model, high salinity mud stabilizes the formation, because chemical osmosis causes a drop in formation pressure (increase in srr) near the wellbore wall.
- Conversely, a low salinity mud destabilizes the formation because chemical osmosis "charges" the formation and srr decreases at the wellbore wall.

Baker Hughes

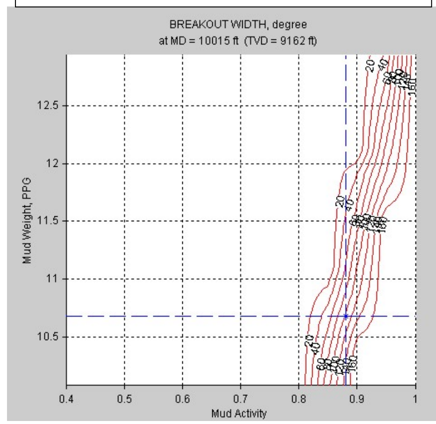
If the mud salinity is higher than the formation then the pore pressure in the near wellbore environment will be reduced and the overbalance between the mud weight and the pore fluids will increase. The increased overbalance will stabilize the formation. If the mud salinity is lower than the formation then the pore pressure in the near wellbore environment will be increased and the overbalance between the mud weight and the pore pressure will be reduced. The reduced overbalance will cause the formation to fail more easily.

Impact of Chemical Effects on Wellbore Stability - Membrane Efficiency

Water based mud
(5-10% membrane efficiency)



Silicate mud
(50-60% membrane efficiency)

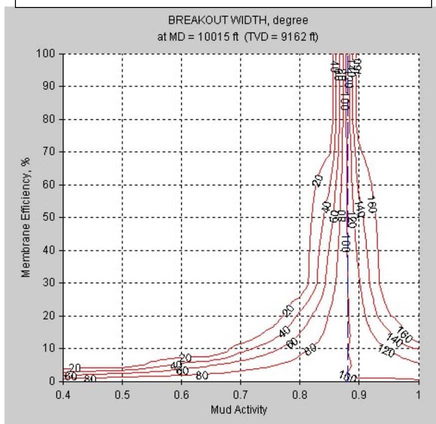


Membrane efficiency is a measure of the mobility of solutes through the shale pore network. Membrane efficiency depends on both shale and mud properties.

Plots showing breakout width (red contours) as a function of mud weight and mud activity. Higher efficiency membranes allow for mud activities that are less well-balanced between the formation and the mud. For a constant mud weight (horizontal blue line), the mud activity needs to be reduced significantly more in a water based mud than in a silicate based mud to eliminate the breakouts.

Impact of Chemical Effects on Wellbore Stability

Fixed Mud Weight of 10.7 ppg

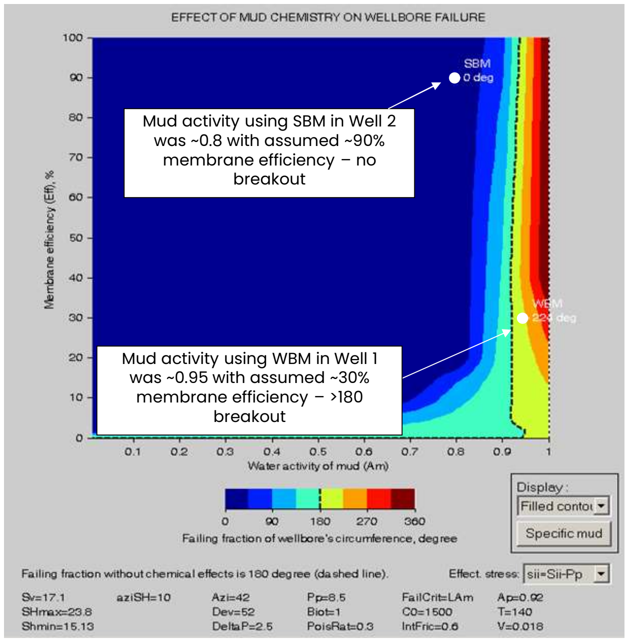


- Pore fluid activity in this case is 0.88
- Lowered mud activity (use of inhibitors) helps to lower the amount of wellbore failure if some membrane efficiency exists.

Baker Hughes

Plot showing breakout width (red contours) versus the membrane efficiency and mud activity for a fixed mud weight and pore fluid activity. Higher membrane efficiency means the chemical properties of the mud do not need to be balanced with the formation as carefully.

Chemical Instability – Case Study Example

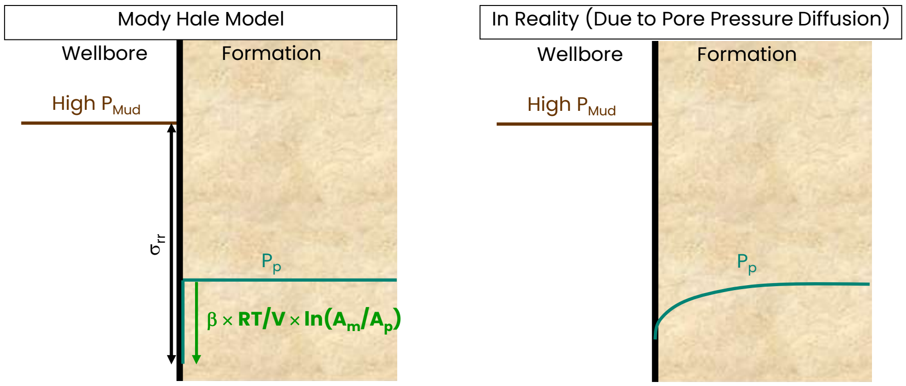


Well 1 used WBM at 11.0 ppg. The model predicts 110° breakout width. This well experienced stuck pipe and pack-off events resulting in the well being side-tracked.

An offset well used the same mud weight, a SBM with ~0.8 activity and ~90% membrane efficiency, and had relatively much better wellbore stability.

Case study offshore Australia investigating the effects of mud chemistry variations on wellbore stability.

Shortcomings of Mody & Hale Model



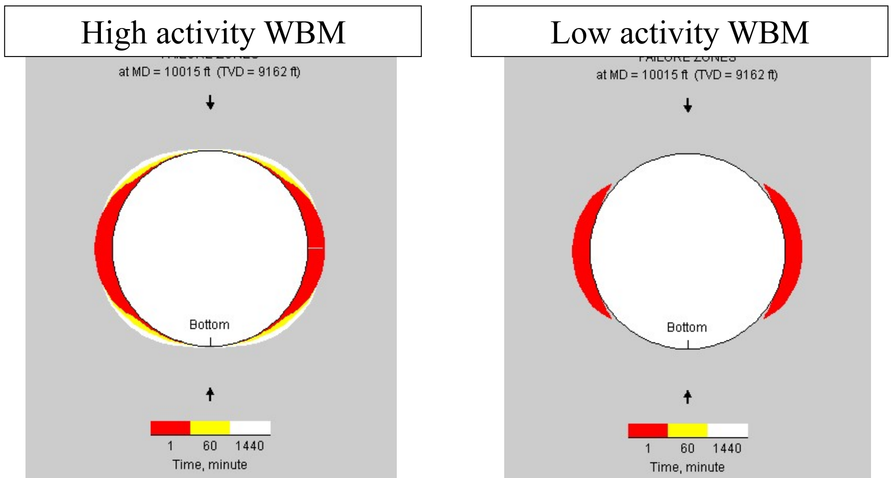
- The Mody Hale model does not include pore pressure diffusion and associated poroelastic effects. More sophisticated models include this effect (e.g. Sherwood & Bailey, 1994). However, input parameters are hard to quantify.
- Changes in physical shale properties are not considered. For example, drying out of shale. In reality, high mud salinity can cause shales to dry out causing them to weaken.)
- The movement of ions is not considered except for membrane efficiency term.

Baker Hughes

The Mody and Hale model for chemical pressure diffusion does not take into account weakening of the shale due to drying out, time dependent effects, diffusion effects, or ion movements. However, models that take these factors into account require a greater number of input parameters that are often difficult to quantify.

Chemical Effects Impact Wellbore Stability - Fully Coupled Chemo–Poroelastic Model

(Sherwood & Bailey, 1994, extended by Ghassemi et al., 1998)



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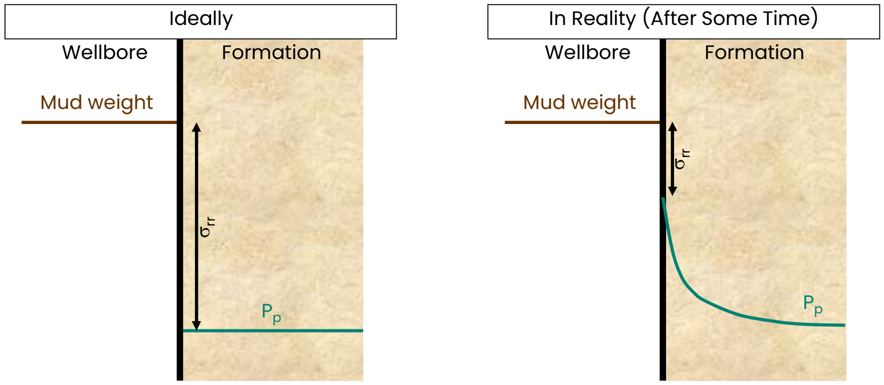
Time dependent pressure diffusion into the formation can cause greater amounts of failure over time. At one minute the failure extends around the red colored areas. Sixty minutes after the formation comes into contact with the drilling fluid the failure extends into the yellow zones, and after 1440 minutes the failure reaches into the white colored zones. In a chemically well-balanced mud system, all of the failure occurs immediately and there are no time-dependent effects.

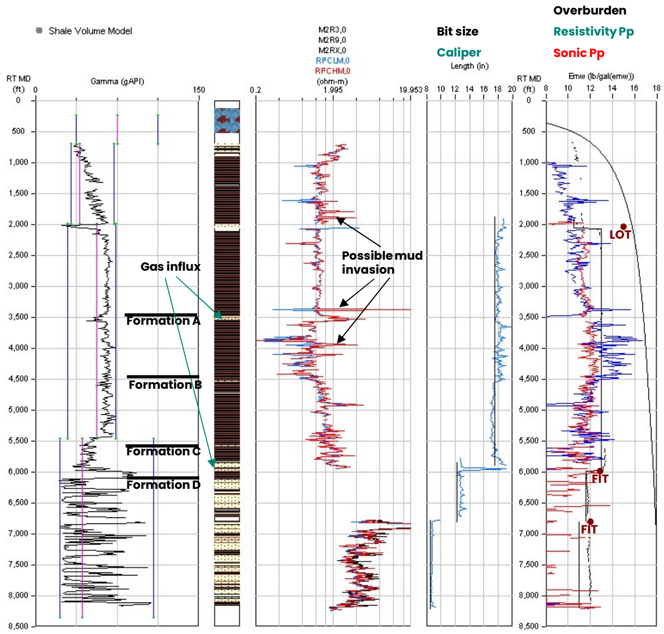
Time-Dependent Wellbore Instability Due to Mud Invasion



- Mud invasion can destabilize a well, because "charging" of the formation reduces σ_{rr}.
- This is especially problematic in fractured shales and near fault zones.
- The development of a mud cake slows down or prevents this effect. High capillary entry pressures in synthetic mud systems also helps to avoid this process.

Baker Hughes

Time-Dependent Wellbore Instability Due to Mud Invasion



Increased resistivity values in the near wellbore indicate possible mud invasion above Formation A.

Mud invasion may explain the observed excess of cavings between 2,000' and 3,000' MD, which were not explained with failure predictions.

Baker Hughes

Mud invasion can sometimes be observed through differences between the near-wellbore resistivity and the far-field resistivity.

OBM vs WBM in Shale

OBM

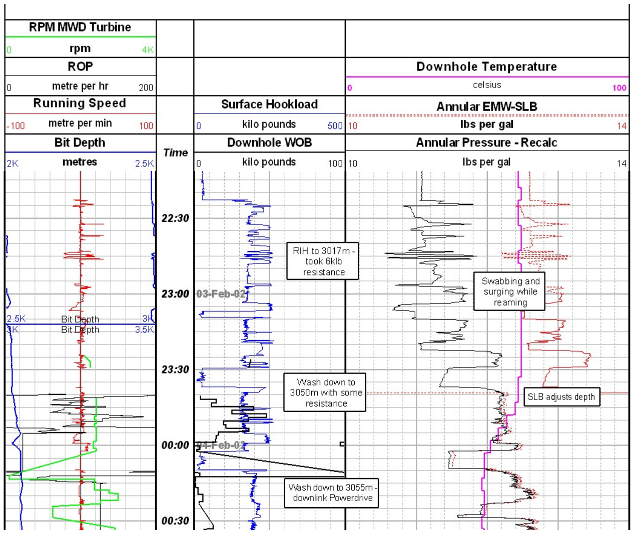
High capillary entry pressure
Little chemical reactivity
Invade fissures and fractures more easily
Expensive

WBM

Fluid invasion into fractures not as easy
Inexpensive
Chemically reactive

Baker Hughes

Time-Dependent Wellbore Instability Due to Dynamic Pressure Changes (Swabbing)



- Swab pressures during tripping out of the well can momentarily reduce σ_{rr}.
- This effect is known to have caused many "time dependent" wellbore stability problems.

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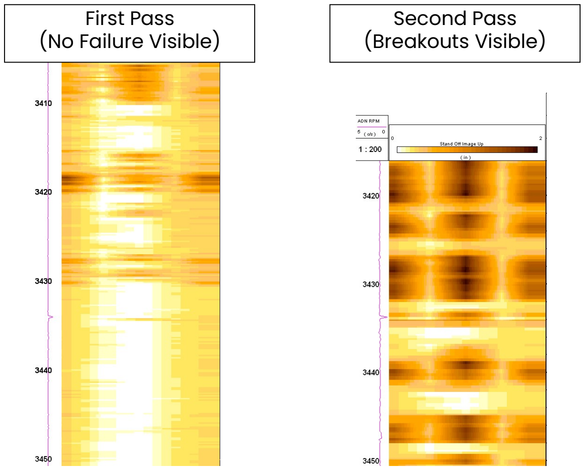
Surge and swab pressures due to movement of the pipe are shown here to be +/- 0.5ppg.

Time-Dependent Wellbore Instability Due to Swabbing

(Ultrasonic Standoff Image – LWD Azimuthal Density Tool)



- Swab pressures during tripping out of the well can momentarily reduce σ_{rr}.
- Breakouts were created while swabbing the well.

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Swabbing the well has induced breakout during a bit trip.

Possible Causes of Time-Dependent Wellbore Failure

- Failure due to chemo-poroelastic effects in shales
  - Can be avoided with proper mud composition (membrane efficiency, mud activity)
- Elevation of near-wellbore pore pressure due to mud pressure invasion (in sands, fractured shales, and rubble zones near salt domes)
  - Proper mud formulation to avoid mud invasion, avoid excessive overbalance
- Formation damage due to dynamic pressure changes
  - Avoid excessive swabbing – annular pressure measurements allow better control of bottom hole pressure changes
- Chemical alteration and weakening of cementation bonds
  - Mud chemistry – lab tests of rock strength as a function of mud exposure can be used to calibrate mud properties
- Activating Slip on Geological Features (see next slides)

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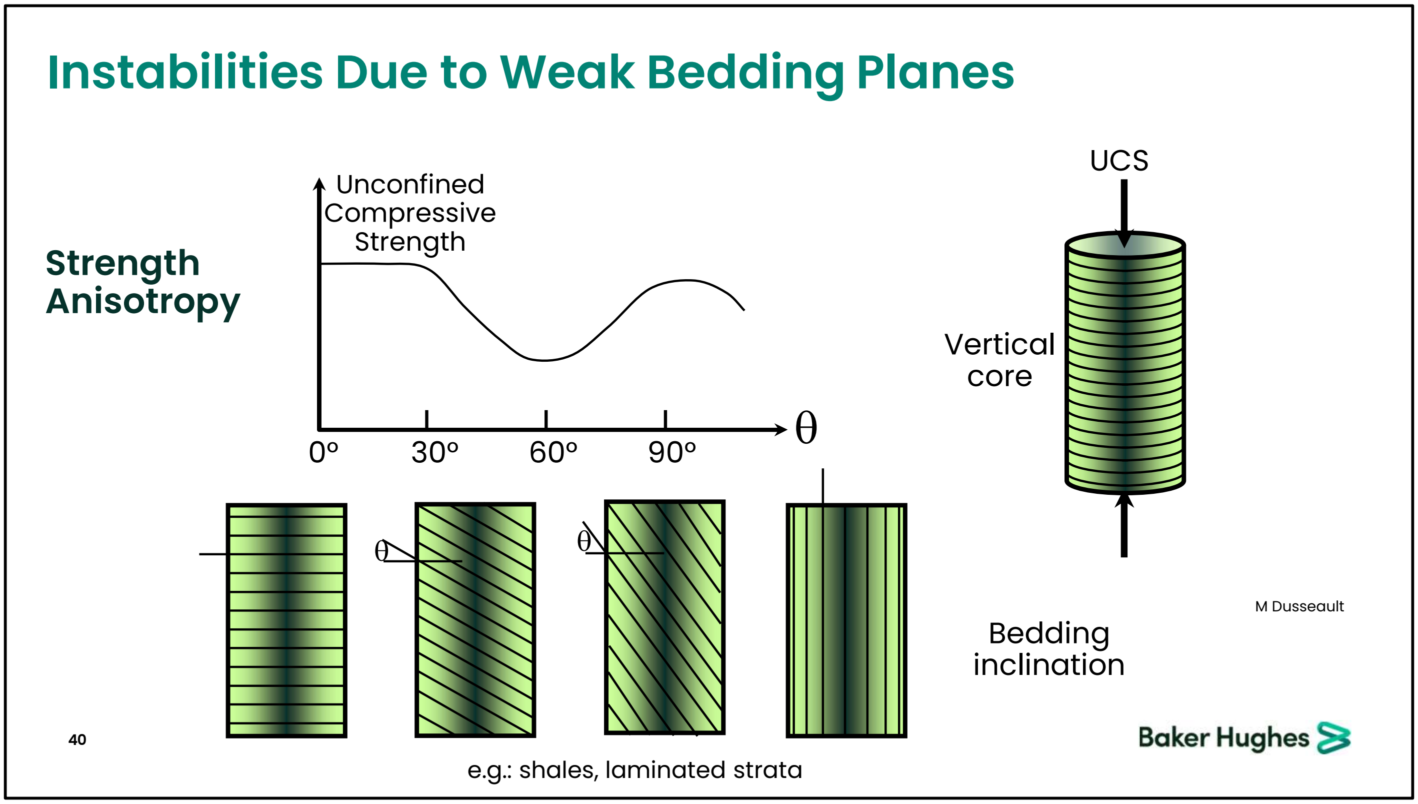
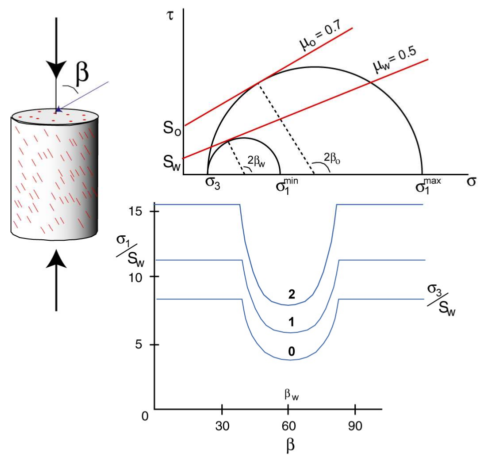


Rock can exhibit different strengths depending on the angle at which stress is applied to the rock. If weak bedding planes or foliations exist in the rock, then these weaknesses can act like pre-existing fractures and allow failure of the rock more readily. Therefore, angle of attack with respect to bedding can have a significant impact on wellbore stability.

Strength Anisotropy

Parallel Planes of Weakness (Bedding/Foliation)



$$\sigma_1 = \sigma_3 + \frac{2(S_w + \mu_w \sigma_3)}{(1 - \mu_w \cot \beta_w)\sin 2\beta}$$

$$\text{if} \quad \tan 2\beta_w = -\frac{1}{\mu_w}$$

$$\sigma_1^{min} = \sigma_3 + 2(S_w + \mu_w \sigma_3)\left[(\mu_w^2 + 1)^{\frac{1}{2}} + \mu_w\right]$$

C_0: Uniaxial compressive strength
S_0: Cohesion of the rock (in the absence of bedding)
S_w: Cohesion on the bedding plane
μ_i: Internal friction coefficient (in the absence of bedding)
μ_w: Friction coefficient on bedding plane
β_0: Angle between σ_1 and the pole of an initiated fracture (in the absence of bedding)
β_w: Angle between σ_1 and the pole of the bedding plane

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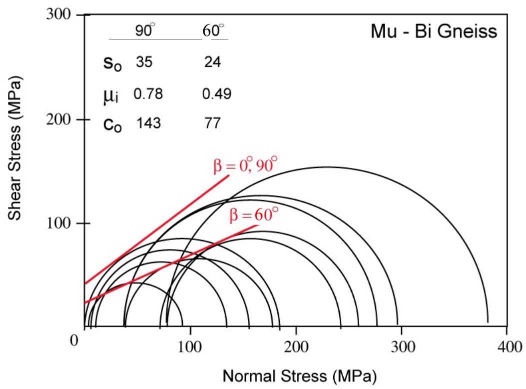
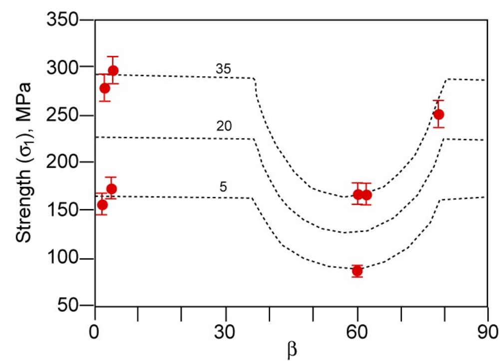
Highly Foliated Gneiss





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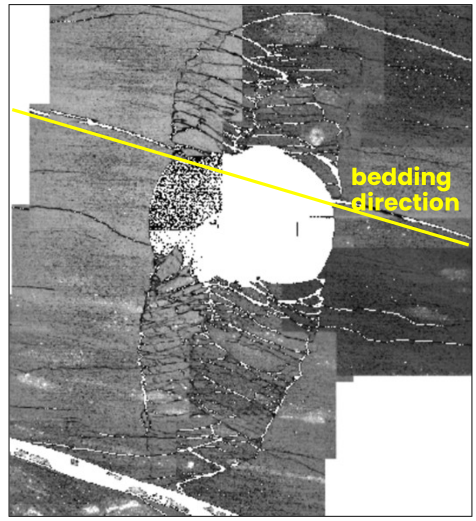
Laboratory measurements of rock strength tested at different angles to a foliated Gneiss (red points) fit well with the theoretical strength of the samples (dotted lines)

Drilling and Bedding Plane Weakness in Shale

- Montage of scanning-electron-microscope image of a laboratory hollow-cylinder test in a fissile Jurassic North Sea shale showing catastrophic hole collapse dominated by failure of bedding planes.
- The large cross-cutting cracks (running from one side of the sample to the other) are thought to be preexisting cracks roughly parallel to the bedding.
- Original hole diameter is 10mm.



Okland and Cook, 1998

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Example of bedding plane weakness in shale where the depth of the breakouts is extreme with respect to the original hole diameter due to the exacerbated failure caused by slip on the bedding planes.

Montage of scanning-electron-microscope image of a laboratory hollow-cylinder test in a fissile Jurassic North Sea shale showing catastrophic hole collapse dominated by failure of bedding planes. The large cross-cutting cracks (running from one side of the sample to the other) are thought to be preexisting cracks roughly parallel to the bedding. Original hole diameter is 10 mm.

Evidence of Geomechanical Problems

- Large volumes of cavings across the shakers
- Operational problems:
  - Tight hole (need to ream constantly)
  - Stuck pipe (fishing)
  - Pack-off
  - Fill on the bottom of the hole
  - Trouble running casing, logging tools, drill string
  - Excessive mud losses

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Things to Do at the Shaker

- Classify as to whether cuttings or cavings
  - Based on size
  - Based on shape and morphological features
- Relate cavings morphology to the type of problem: Fractured rock? High stress? Chemical?
- What is volume of material at the shaker?
  - Only the cuttings? 10% more? 200% more?
- Surges of cavings…
  - Take samples and preserve them
  - Take pictures and movies

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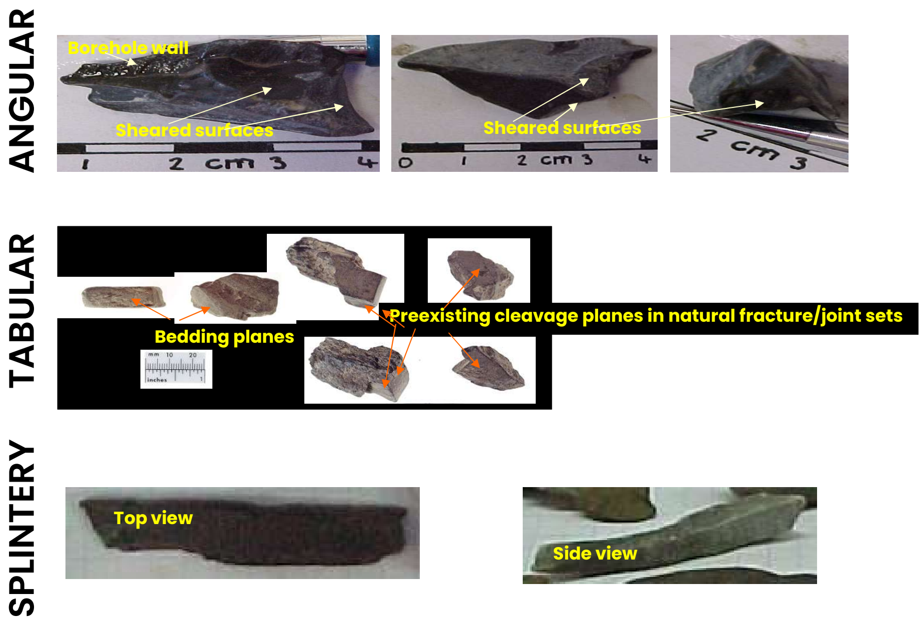
Examination of Cavings



Hughes

M Dusseault

Splintery and angular cavings indicate shear failure of intact rock at the wellbore wall. Blocky, tabular cavings indicate shear failure along preexisting planes of weakness such as bedding planes, cleavage planes or fractures.

Cavings Morphology

- Sheared surfaces are usually visible on drill bit fragments, learn to identify them
- Large curved splinters usually indicate borehole instability sourced chips
- Flat planar features usually indicate failure of naturally fractured shales
- Geochemical alterations on planar surfaces indicate naturally fractured shales

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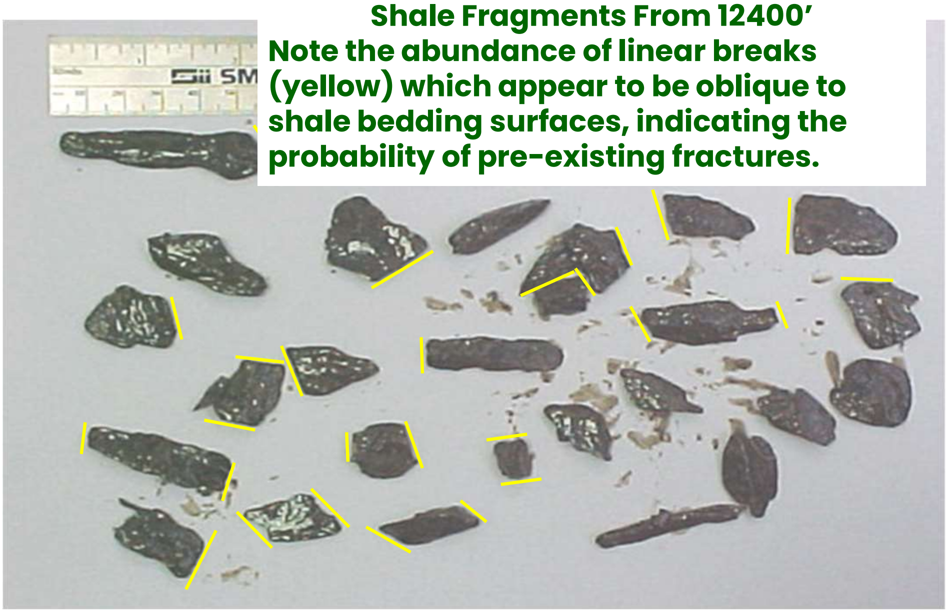
Failure Along Bedding & Natural Fractures

Shale Fragments From 12400’

Note the abundance of linear breaks (yellow) which appear to be oblique to shale bedding surfaces, indicating the probability of pre-existing fractures.



M Dusseault

Baker Hughes

Flat tops and bottoms indicate the shale failed along bedding planes. The flat sides on some samples indicates fractures are also contributing to the sample weakness.

Typical Blocky Cavings - Fractures

Hole
wall
shape

Blocky Cavings

Baker Hughes

M Dusseault

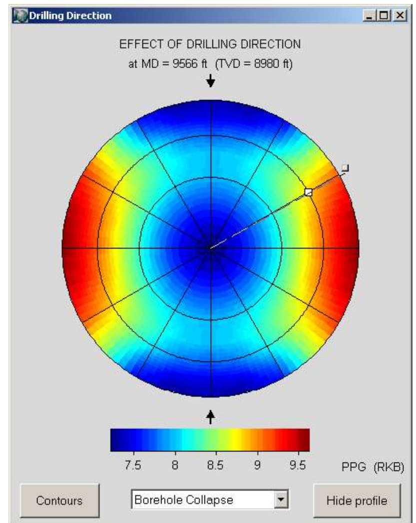
Blocky cavings indicating fractured formations.

Shear Failure (Splintery ‘Pressure’ Cavings)

Failure: Due to stress in massive shales

Mud Type: Oil/Synthetic-based mud or water-based mud

Solution: Raise mud weight, change trajectory



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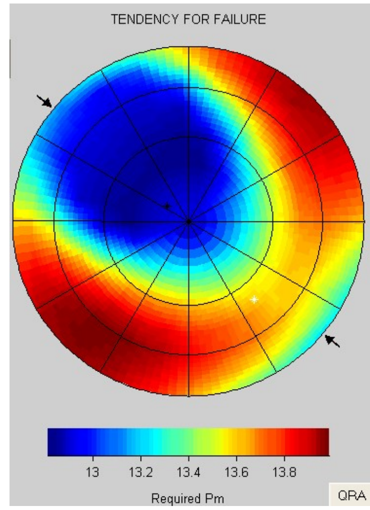
Isotropic wellbore failure due to shear at the wellbore wall results in splintery cavings. The solution is to increase mud weight. Drilling direction can have an impact – the optimal directions usually have a dual symmetry so that, e.g. drilling to the north is the same as drilling to the south.

Platy and Tabular Cavings

Failure: Due to rock strength anisotropy (weakly bedded or fissile)

Mud Type: Oil/Synthetic-based mud may be worse than water-based mud

Solutions: Adjust mud weight, change mud type, prevent mud penetration, increase angle-of-attack to bedding, change trajectory, reduce surging & swabbing



Baker Hughes

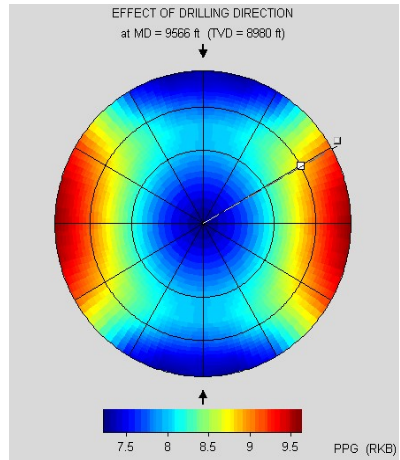
Anisotropic wellbore failure due to shear failure along weak bedding planes or fissile materials results in platy or tabular cavings with flat tops and bottoms. The solution may be to raise or lower the mud weight and/or increase the angle of attack to the bedding. The optimal drilling directions are usually asymmetric so that there is only one general direction that is best, e.g. deviated to the northwest.

Blocky Cavings ('Rubble')

Failure: Due to stress and time-dependent mud penetration into fractures (e.g., fractured rocks, around salt, along faults)

Mud Type: Oil/Synthetic-based mud worse than water-based mud

Solutions: Adjust mud weight, change mud type, prevent mud penetration, reduce surging and swabbing



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Rubble around faults, salt domes, and from fractured formations is difficult to model. A preferred drilling direction may exist, but detailed knowledge of the preferred fracture orientation is necessary. Typically the solution to drilling through these zones is to include LCM in the mud, change the mud type to prevent pressure penetration into the fractures, and changing the mud weight to either give more support to the wellbore wall or reduce the pressure penetration into the fractures.

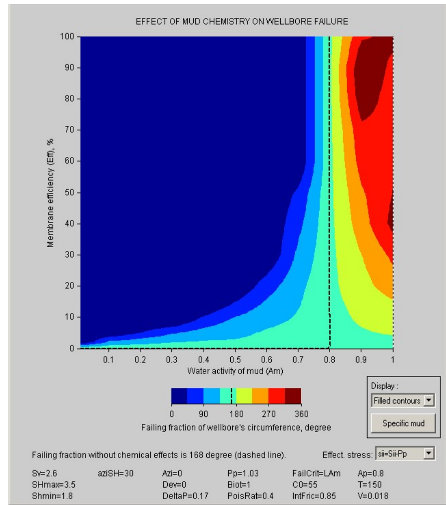
Chemical Wellbore Instability

Shale Specimen After Exposure

Failure: Due to stress and time-dependent swelling and/or water penetration into and out of shale

Mud Type: 'Swelling shales' – water-based mud worse than oil/synthetic-based mud. Osmotic effect – oil/synthetic-based mud worse than water-based mud

Solutions: Raise mud weight, alter mud chemistry, change mud type



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Shale swelling due to chemical effects can lead to excessive cavings and tight hole, and may result in both isotropic and anisotropic wellbore failure. The solution is to raise the mud weight, change the mud salinity to balance with the formation, or change the mud type.

Signs of Geochemical Instability

- Usually only with WBM
- Increase in cavings volume
- Cuttings are mushy and rounded
- Bit balling, BHA balling, increased ECD
- Gradual continued increase in torque
- Tight hole
- Changes in mud system properties, rheology, solids content and type…

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Effects of Poor Mud Chemistry

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Severe gumbo attacks caused material to ball up at the bit, resulting in stuck pipe both inside the hole and inside the casing. The drill string pulled apart when trying to get out of the hole. The picture here shows the result of an explosive charge used to free the drill string. The gumbo also suspended the failed material and cuttings in large chunks that caused pack off and made hole cleaning extremely difficult.

Problems in Drilling Salt

- Salt can seriously deteriorate mud function
  - Contaminates non-salt WBM, lowers cake, etc.
- Salt squeezes rapidly into the hole
  - BHA stuck in hole during POOH
  - Can’t get to TD during RIH
- Salt can dissolve excessively: washouts
  - Poor mud velocity and hole cleaning
  - Mud rings, pack offs, etc.

⇒Can lead to casing and cementing problems

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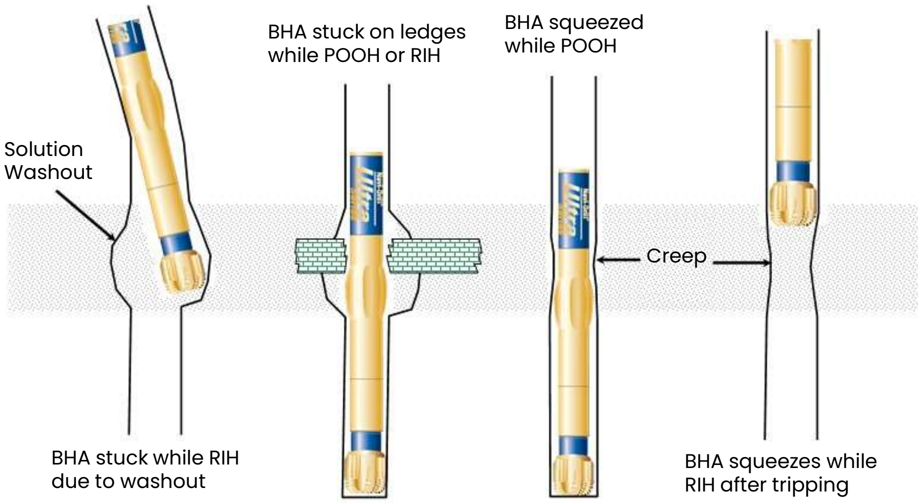
Common Drilling Problems in Creeping Materials



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Characteristics of Salt

Salt is highly soluble

Salt is a viscoplastic substance

Creeps continuously under shear stress

Thermally activated creep rate $d\varepsilon/dt = f(T)$

Stress state in situ is isotropic ($\sigma 1 = \sigma 2 = \sigma 3$)

Generally, in the salt, σsalt ~ σv (vertical)

Impermeable (k < 10-10 Darcy, pure salt)

Salt strata may have thick insoluble layers (e.g. anhydrites, carbonates in bedded salts)

Structural complexity near salt diapirism (stresses, fracturing, flank shear zones…)

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What Can Be Done to Control Creeping Material?

There are three ways to control creeping materials:

1. Use a high mud weight so that the rate of creep is reduced. Reduced differential stresses slow the creep rate.
2. Control the aqueous phase saturation to control the dissolution rate (salt only):
   - Slightly undersaturated WBM gives slow dissolution, counteracting borehole closure.
   - If OBM, or material other than salt, mud weight is roughly equal to the vertical stress to avoid squeeze.
3. Cool the mud aggressively to reduce creep rate (has other benefits on shallower formations). Cooler rocks creep more slowly, and are harder to fracture.

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