Wellbore Stability: Special Considerations for the Marcellus Shale**

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Abstract

Wellbore stability problems such as tight hole, pack-off, stuck pipe, inflow, and lost circulation are most commonly associated with conventional reservoirs but also occur in unconventional reservoirs. Prevention of wellbore instability saves time and money and can often be achieved by deriving a field-specific geomechanical model to inform the drilling recommendations. A basic geomechanical model consists of an understanding of the pore pressure, vertical stress, orientation and magnitude of the horizontal stresses and the rock properties, though, of course, there are additional complexities that sometimes need to be considered.

We will use a generalized Marcellus Shale example to illustrate some special considerations regarding wellbore stability in unconventional reservoirs. First, as many areas of the Marcellus have fissile shale bedding, we investigate how much additional mud weight is required to prevent excessive wellbore collapse when weak bedding planes are present. We show that in some cases, the mud weight required to control shear failure is high enough to cause pre-existing fractures and faults to slip, which can cause additional mud to invade the formation. In such cases, if mud invasion cannot be prevented through the use of lost circulation materials, raising the mud weight can actually exacerbate the instability. We also examine the feasibility of underbalanced drilling and the effect of model uncertainties on our predictions.

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Wellbore Stability:
Special Considerations for the Marcellus Shale

Marcellus and Utica Point Pleasant Geosciences Technology Workshop

17 – 19 June 2014, Pittsburgh, Pennsylvania

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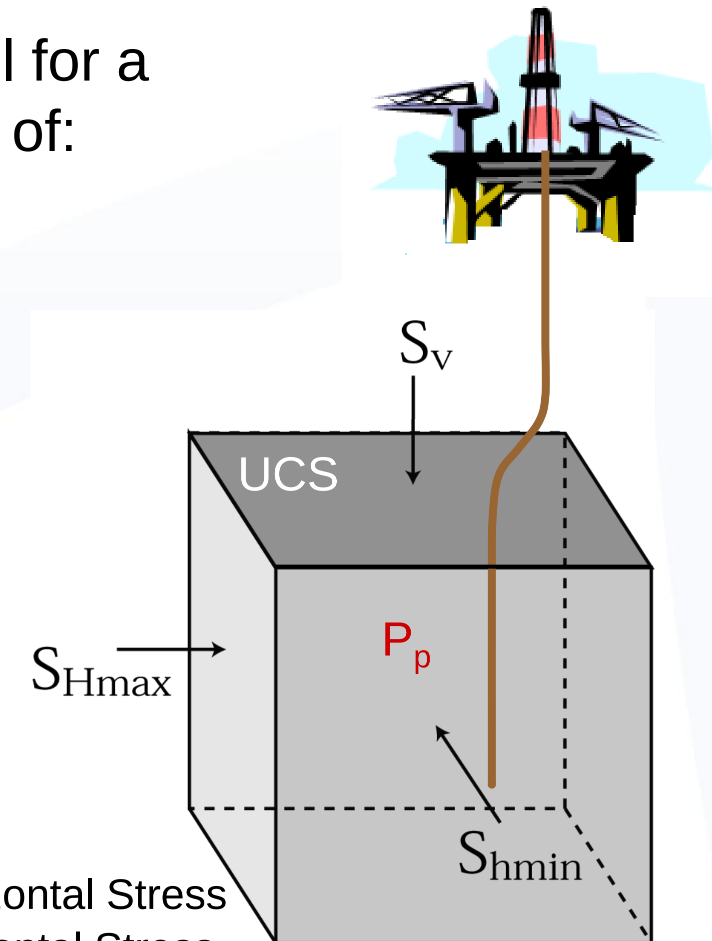
Presentation Outline

- Overview of geomechanics
- Characteristics & challenges of the Marcellus Shale
- Common drilling problems & cavings shapes
- Marcellus Shale: generalized example
  - Effect of weak bedding on required mud weight
  - Slip of bedding and fractures
  - Slip of multiple planes of weakness
  - Mud invasion
  - Underbalanced drilling
  - Effect of model uncertainties on the predictions
- Discussion points

OVERVIEW OF GEOMECHANICS

Foundation of the Geomechanical Model
The Principal Stress Tensor

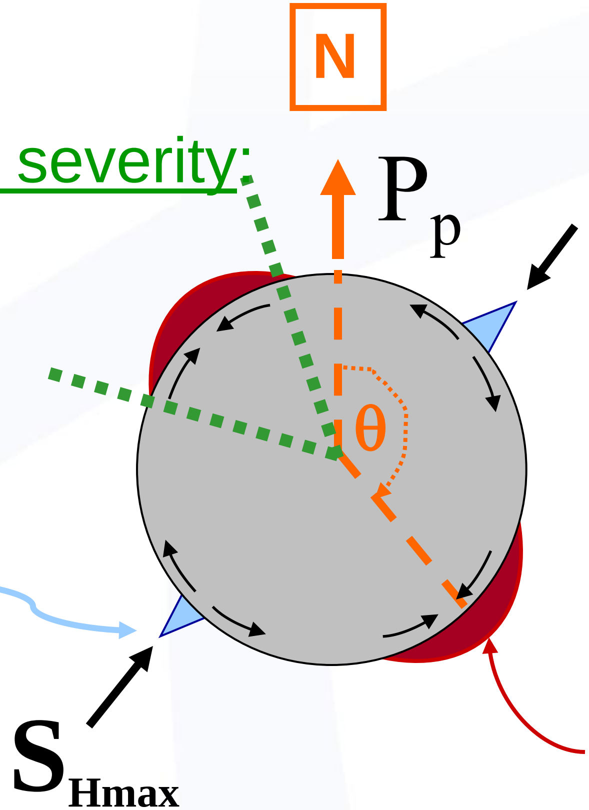
- Description of a geomechanical model for a reservoir involves detailed knowledge of:
  - In situ stress orientations
  - In situ stress magnitudes
  - Pore pressure
  - Rock mechanical properties
- Other considerations:
  - Mud chemistry
  - Weak bedding planes
  - Fractures
  - Thermal effects



S_v – Vertical Stress
S_{Hmax} – Maximum Horizontal Stress
S_{hmin} – Minimum Horizontal Stress
P_p – Pore Pressure
UCS – Unconfined Compressive Rock Strength
Rock Properties – Cohesion, Friction, Elastic Moduli

Observations of Borehole Failure to Constrain the Stress State

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



Breakout width/failure severity:

- Stress magnitudes
- Rock strength

Breakout azimuth:

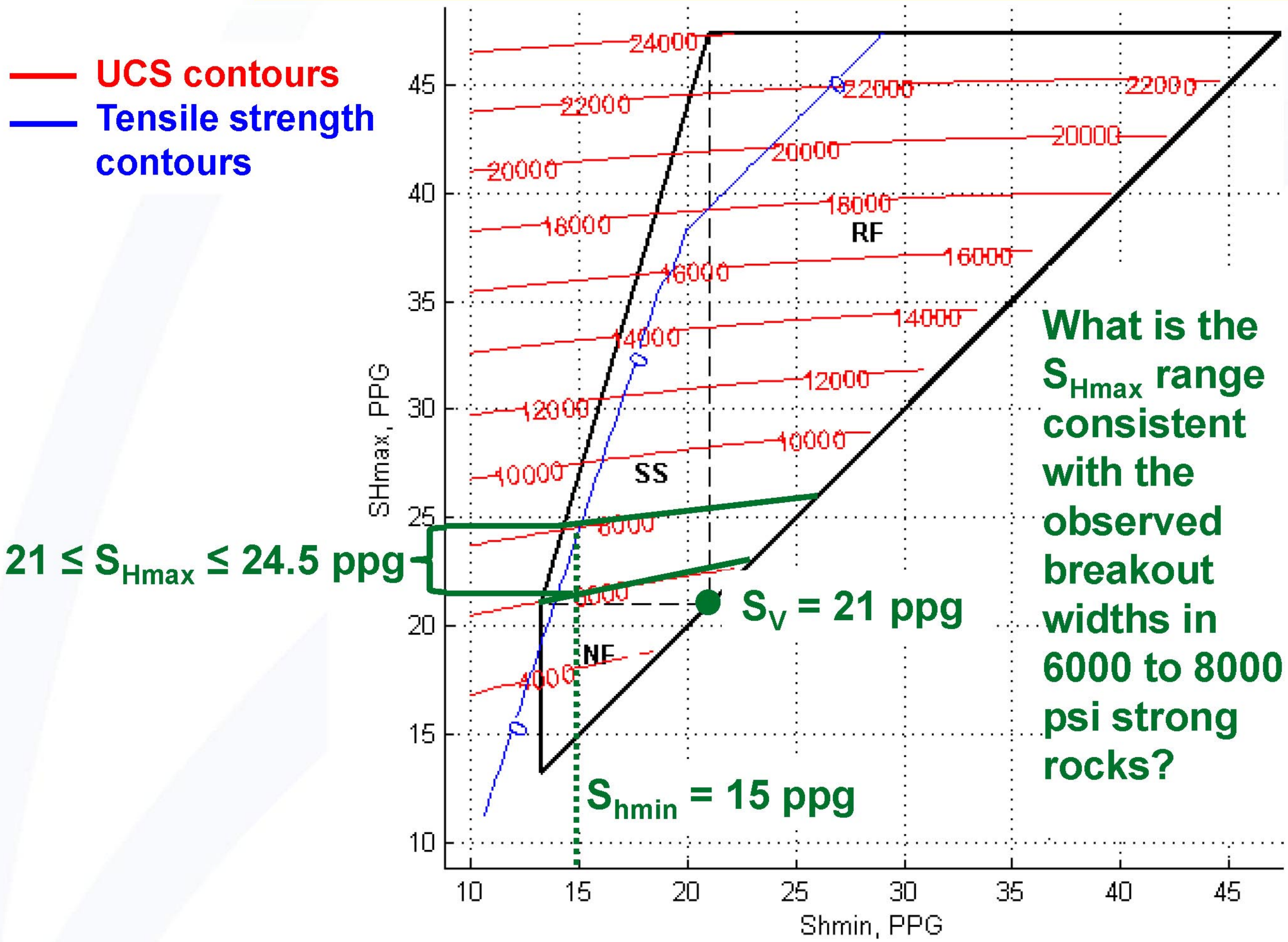
- Stress orientation

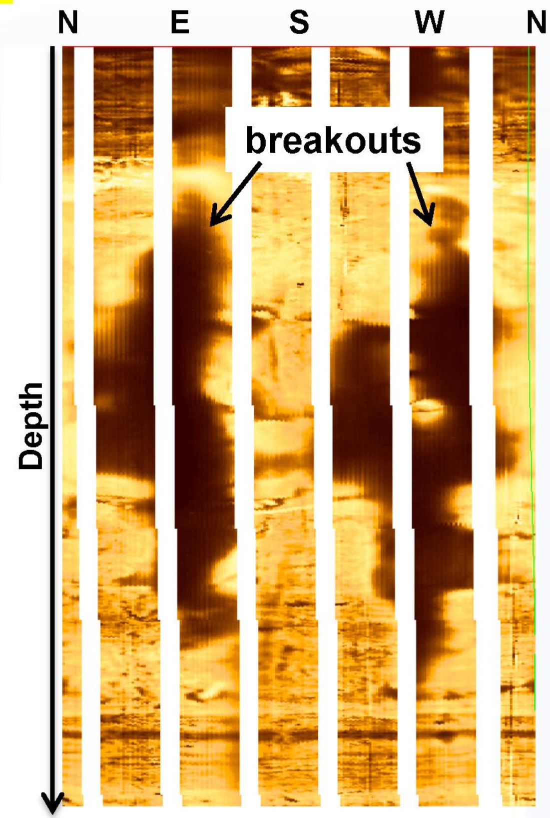
Tension:
Hydraulic fractures and tensile wall fractures

Compression:
Breakouts

Constraining Stresses with GMI•SFIB^{TM}

Combining Information About the Earth With Observations of Wellbore Failure to Constrain Stress Magnitudes





CHARACTERISTICS & CHALLENGES OF THE MARCELLUS SHALE

What is Special about the Marcellus?

- Current stress regime can be normal ($S_V > S_{Hmax} > S_{hmin}$) or strike-slip ($S_{Hmax} > S_V > S_{hmin}$) faulting
- S_{Hmax} orientation is approximately NE-SW
- Local variations in pore pressure and magnitude of S_{Hmax}
- Vertical wells often air drilled or drilled underbalanced
- Underbalanced drilling is less common in horizontals but sometimes possible
- Difficulty sometimes experienced drilling deviated and horizontal well sections
- Possible weak bedding effect
- Fractures and joints further complicate things

Challenges in the Marcellus

- Pore pressure is difficult to determine
- Rocks tend to be strong, but there are high uncertainties in rock strength – appropriate triaxial strength tests would help reduce uncertainties
- May encounter weak bedding and/or fractures in build or horizontal wells
  - Watch for tabular or blocky cavings
  - Too high mud weight can penetrate into bedding and/or fractures making problems worse
- All wellbore instability is time-dependent but once mud invasion occurs it is difficult to stop and failure may worsen significantly with time

COMMON DRILLING PROBLEMS & CAVINGS SHAPES

Common Drilling Problems & Cavings Shapes When Weak Planes Are Present

Blocky Cavings – Evidence of Fractures

Platy Cavings – Evidence of Weak Bedding

These cavings shapes will dominate

Drilling problems are likely to include tight hole, pack-off, stuck pipe and lost circulation.

MARCELLUS SHALE: GENERALIZED EXAMPLE

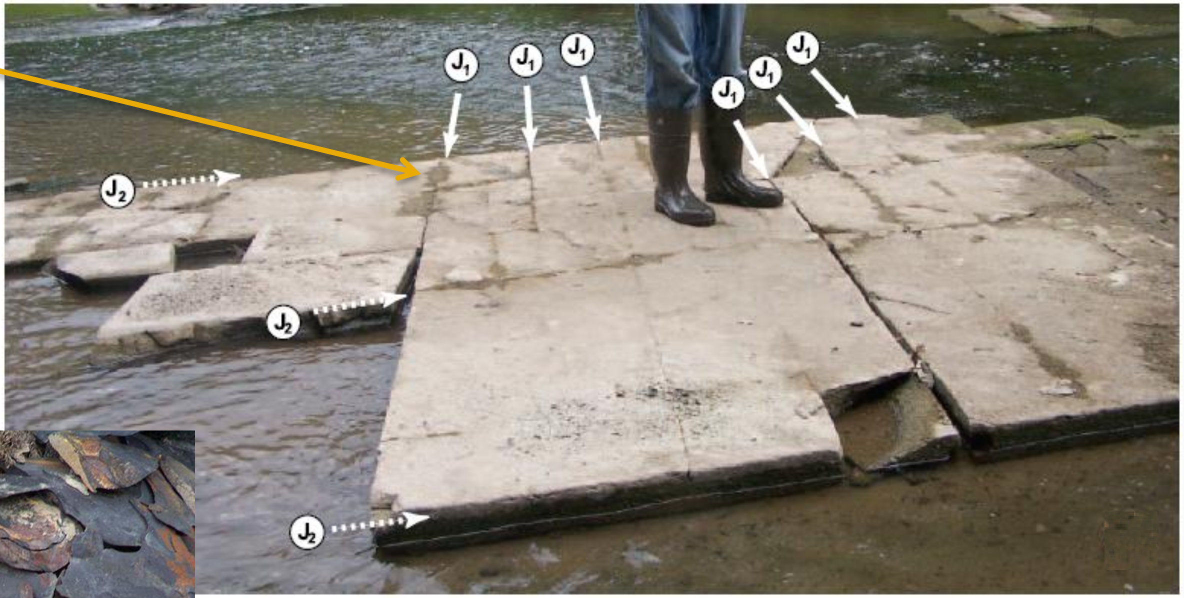
Marcellus Shale: Generalized Example Details

Parameter	Value	Unit
Depth	8000	ft
S_V	22	ppg
S_{hmin}	16	ppg
S_{Hmax}	23	ppg
S_{Hmax} azimuth	60	degrees
P_r (pore pressure)	11	ppg
UCS	8000	psi
Well azimuth	150	degrees
Well deviation	89	degrees
α (Biot's coefficient)	0.6	unitless
ν (Poisson's ratio)	0.3	unitless
μ (Internal friction coefficient)	0.7	unitless

- Slight overpressure
- Strike-slip faulting stress regime ($S_{Hmax} > S_V > S_{hmin}$)
- Horizontal weak beds are assumed to be present
- Vertical J1 and J2 joints sets are assumed to be present parallel and perpendicular to the direction of S_{hmax}

Joints and Bedding in the Marcellus

J1 joints are typically parallel or sub-parallel to S_{Hmax} orientation (~N-E); J2 joints can be orthogonal or at an angle. J1 joints are more closely spaced.



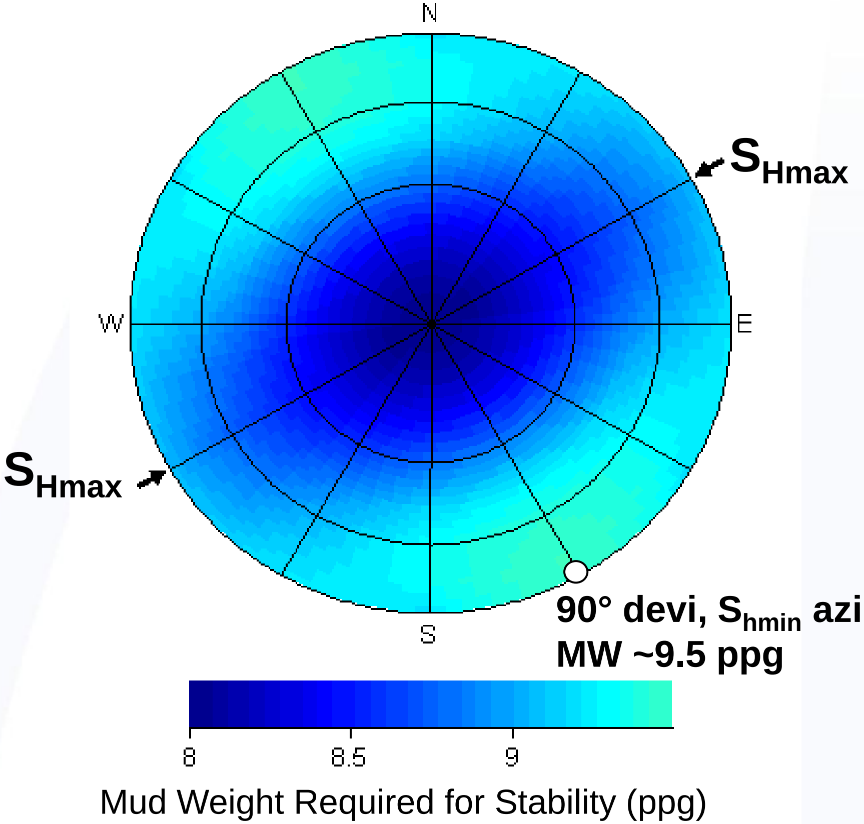
From: Engelder, T., Lash, G.G. and Uzcátegui, R.S.: "Joint sets that enhance production from Middle and Upper Devonian gas shales of the Appalachian Basin," *AAPG Bulletin*, (July 2009), 857-899).

Pieces below exposed Marcellus shale in Marcellus, NY, evidence the fissile nature of the shale at this location.

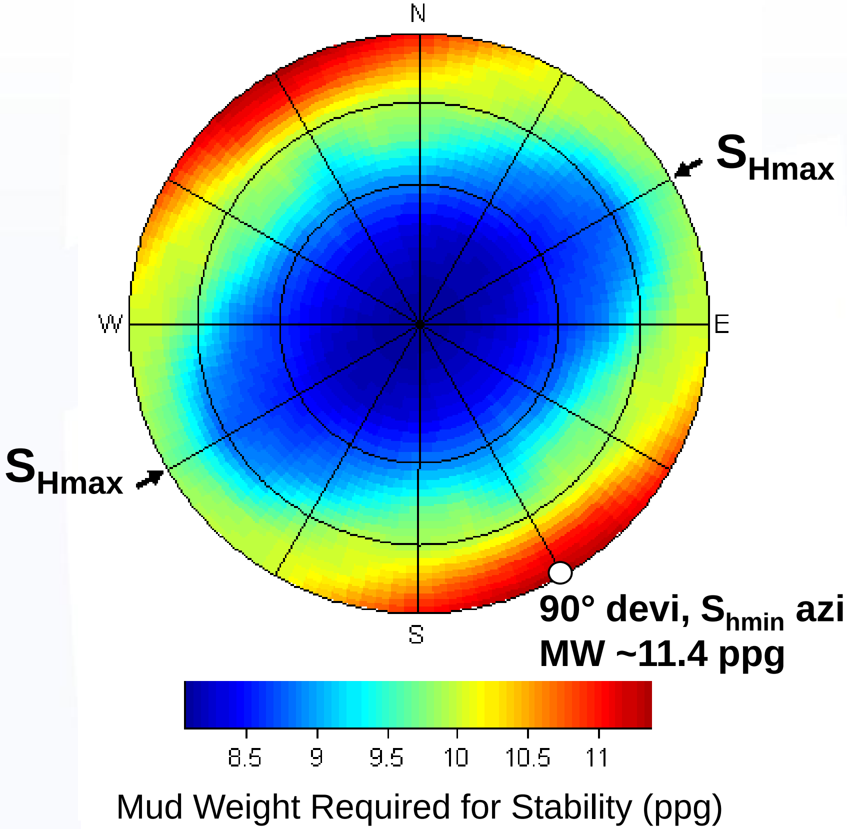
From: http://en.wikipedia.org/wiki/File:MarcellusShaleCloseUp.jpg (Author Lvklock).

Effect of Weak Bedding on Mud Weight Required for Wellbore Stability

No Weak Bedding



Weak Bedding

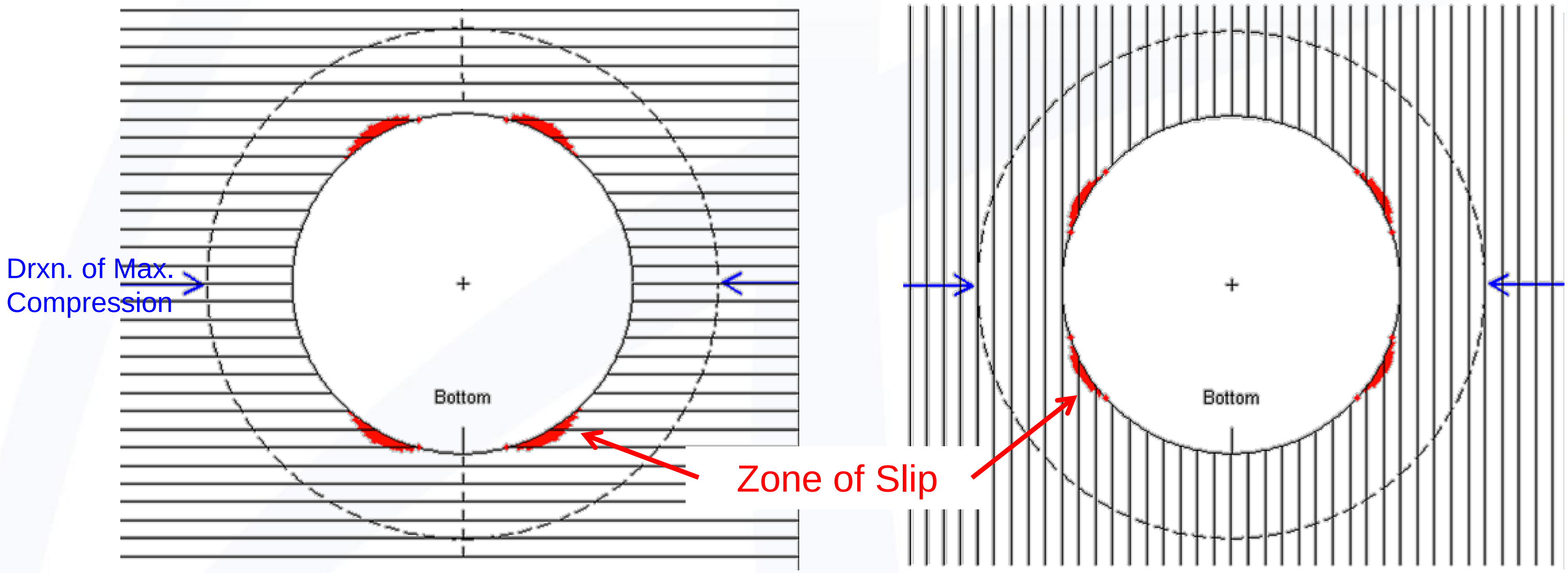


The mud weight required to maintain stability significantly increases if weak beds are added to the model (compare left and right plots). Drilling perpendicular to S_{Hmax} (white circle) will require the highest mud weight to ensure wellbore stability.

Slip of Bedding and Fractures: Cohesion Exists

Showing a lateral well drilled in the direction of S_{hmin}, drilled with 11.4 ppg MW. We will follow this example throughout the presentation.

Slip of Bedding | **Slip of J2 Joints**

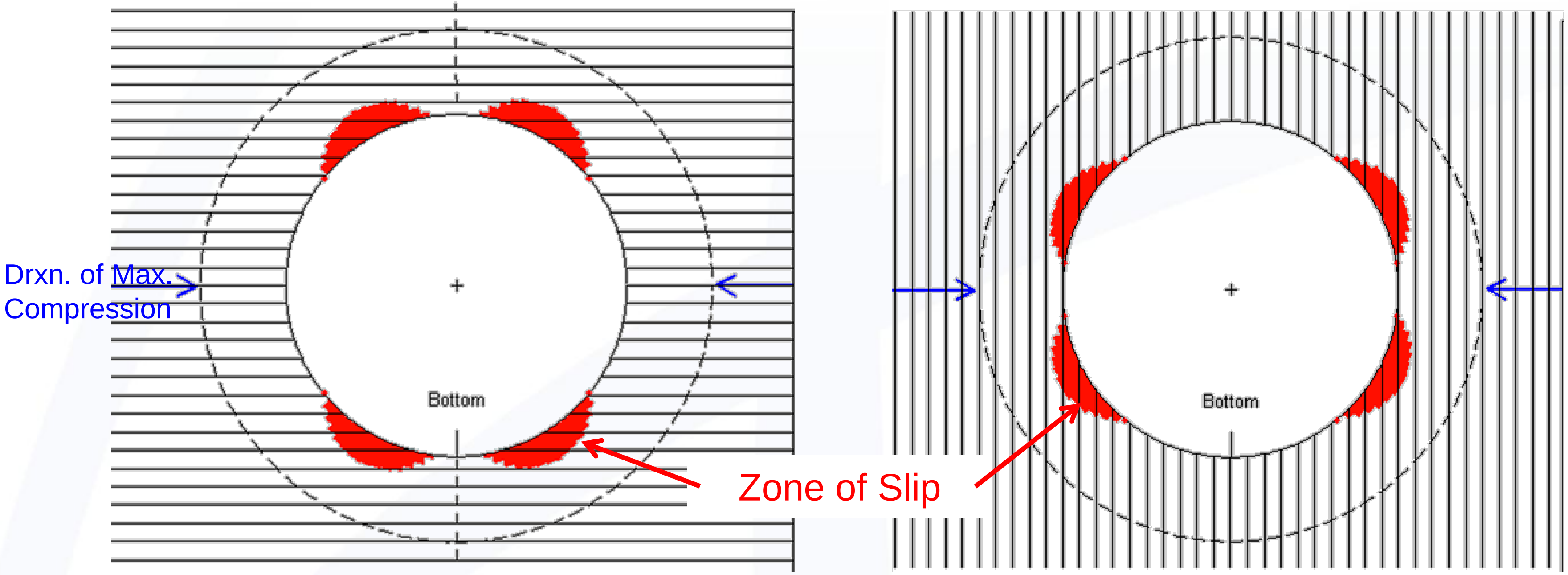


Bedding slip occurs on the top and bottom of the wellbore
Dip=0; Dip azi=0; Cohesion=800 psi; Sliding friction=0.6

J2 joints slip on the sides of the wellbore
Dip=90; Dip azi=60; Cohesion=800 psi; Sliding friction=0.6

Slip of Bedding and Fractures: Post-slip, No Cohesion Exists

Slip of Bedding | **Slip of J2 Joints**



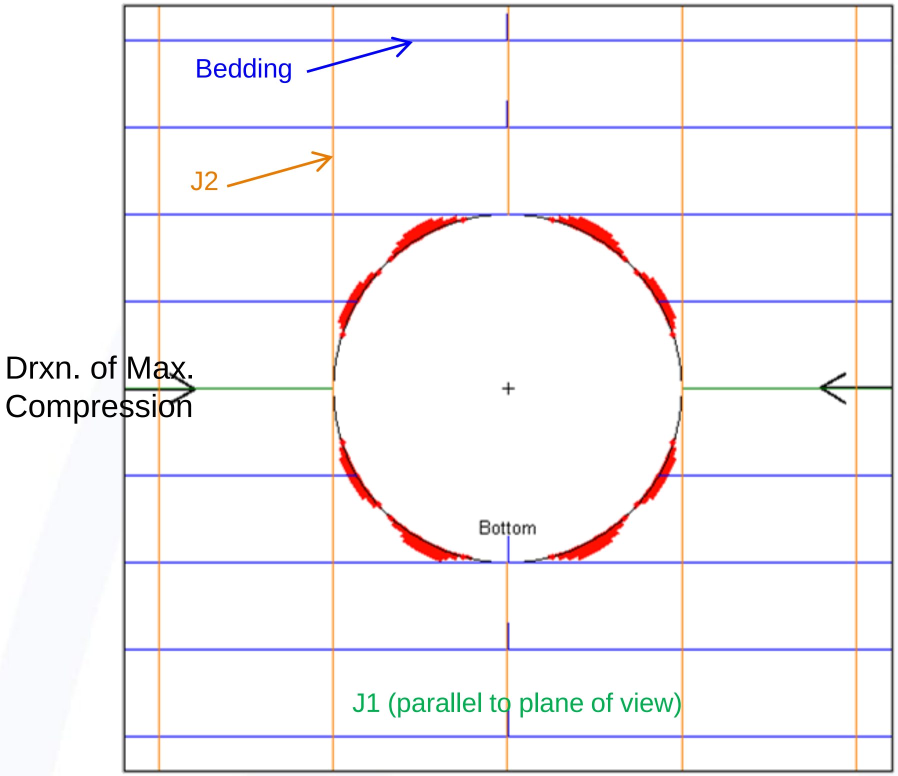
Bedding slip occurs on the top and bottom of the wellbore
Dip=0; aziDip=0; Cohesion=0; Sliding friction=0.6

J2 joints slip on the sides of the wellbore
Dip=90; aziDip=60; Cohesion=0; Sliding friction=0.6

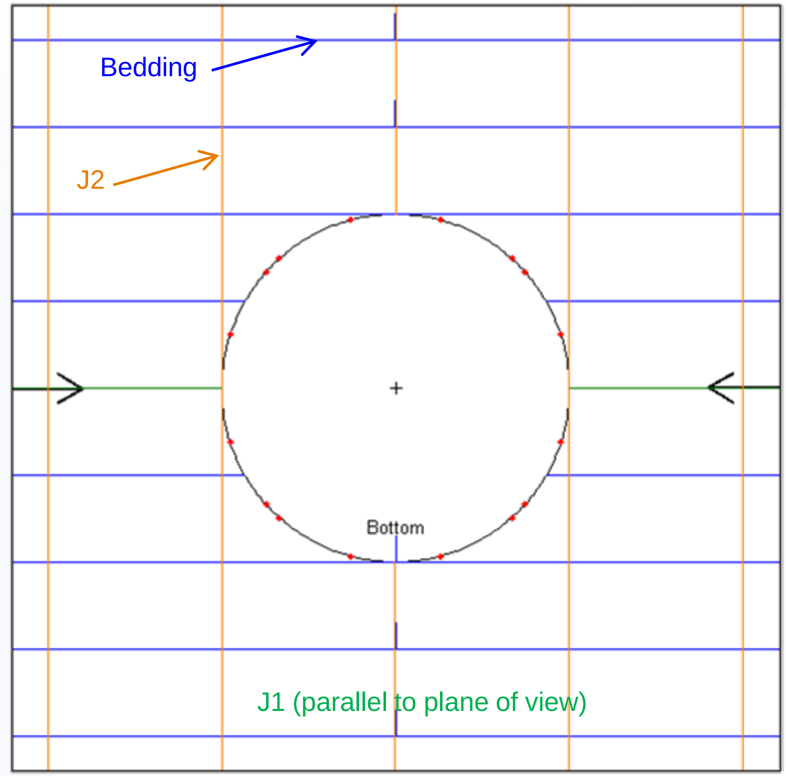
Additional slip occurs after initial slip reduces cohesion to zero.

Slip of Multiple Planes of Weakness: Cohesion Exists

1 Slipping Plane, 800 psi Cohesion



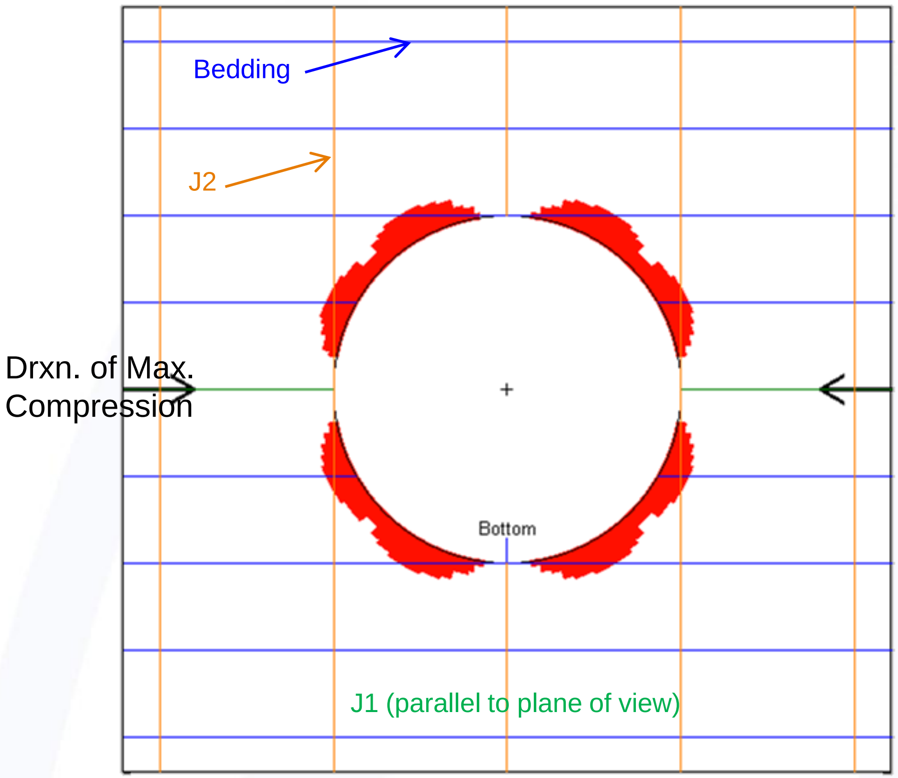
2 Slipping Planes, 800 psi Cohesion



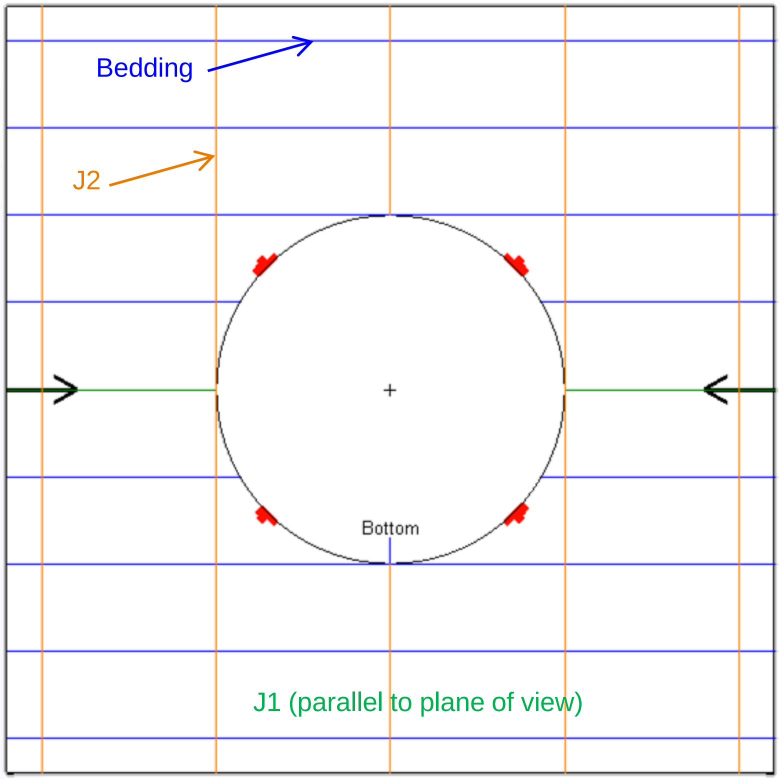
J2 joint set and bedding are slipping, but when only one plane of weakness slips, the rock within that zone is unlikely to wash out and fall into the hole. These plots show that J1 joints are unlikely to slip.

Slip of Multiple Planes of Weakness: Post-slip, No Cohesion Exists

1 Slipping Plane, 0 psi Cohesion

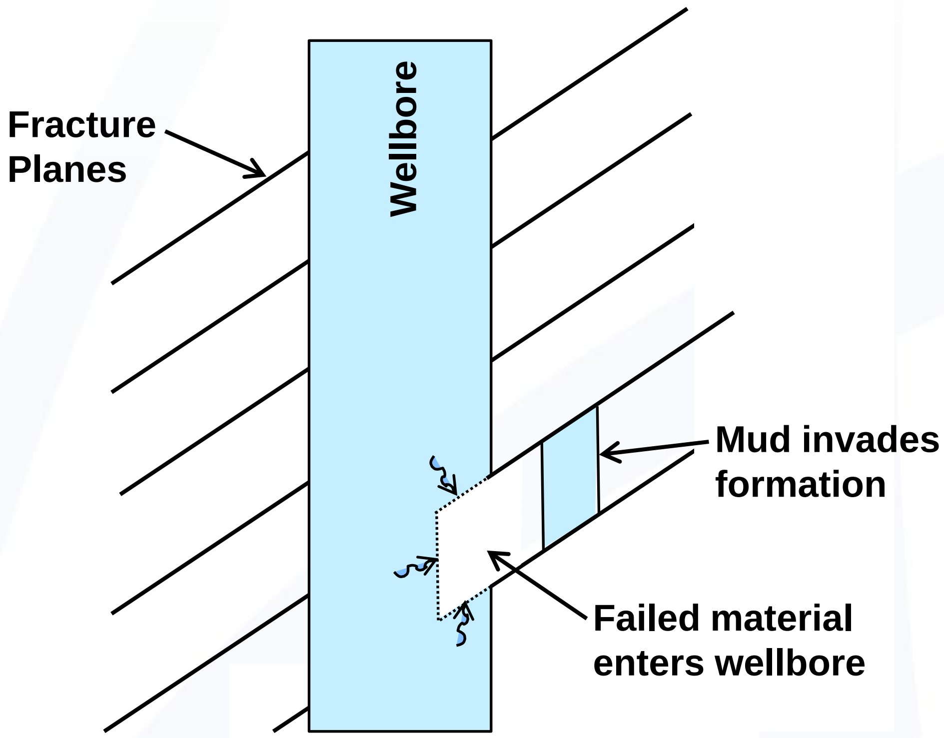


2 Slipping Planes, 0 psi Cohesion



Slip of bedding AND joints (2 planes of weakness) is expected when cohesion is 0 psi. Cohesion drops to 0 psi after slip has occurred, so failure of two planes is expected, though the total amount of failed material is small and is not likely to cause drilling problems.

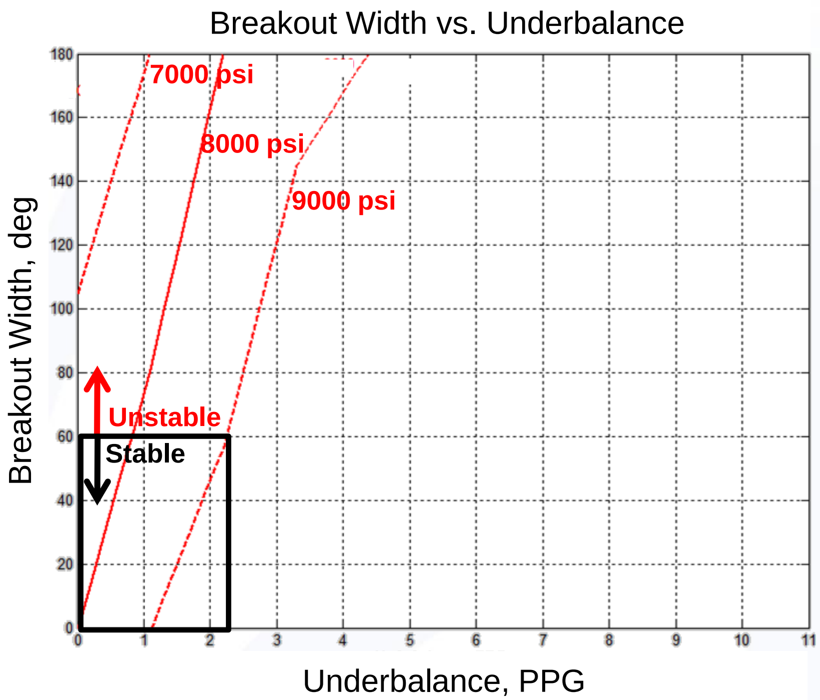
Effects of Mud Invasion Into Rocks With Fractures or Weak Bedding



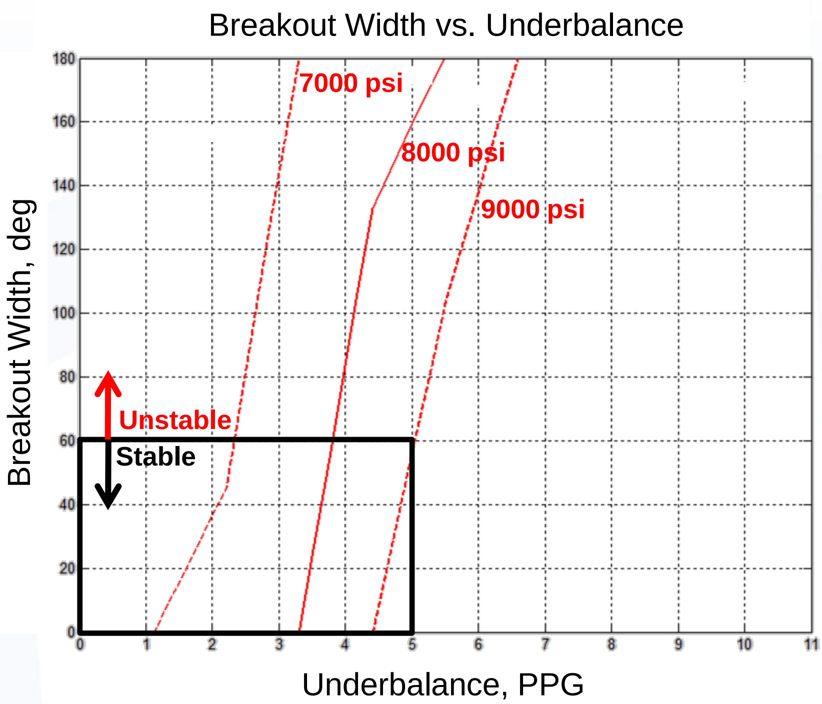
- When mud invasion occurs, mud weights that are too high can lead to borehole collapse and seepage losses.
- If mud invasion causes slip on fracture or fault systems, substantial losses can occur.

Stability of Underbalanced Drilling

Failure ¼" into the wellbore wall

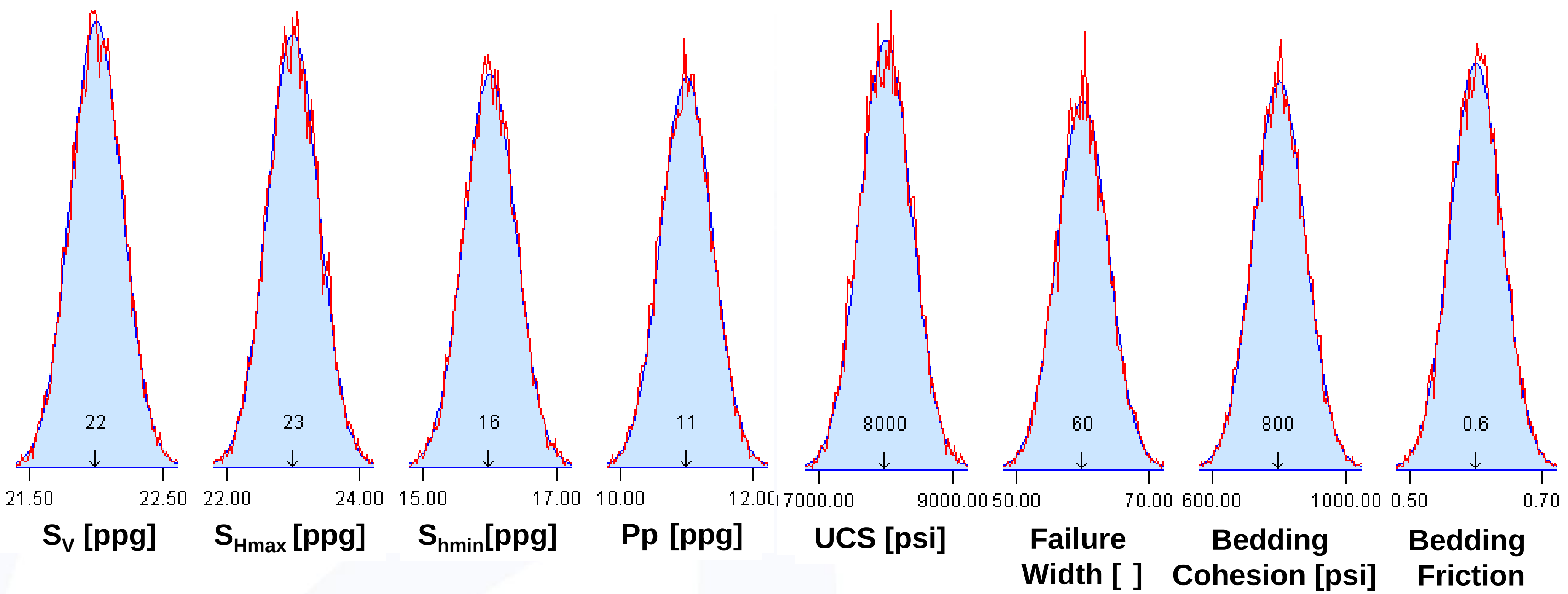


Failure ½" into the wellbore wall



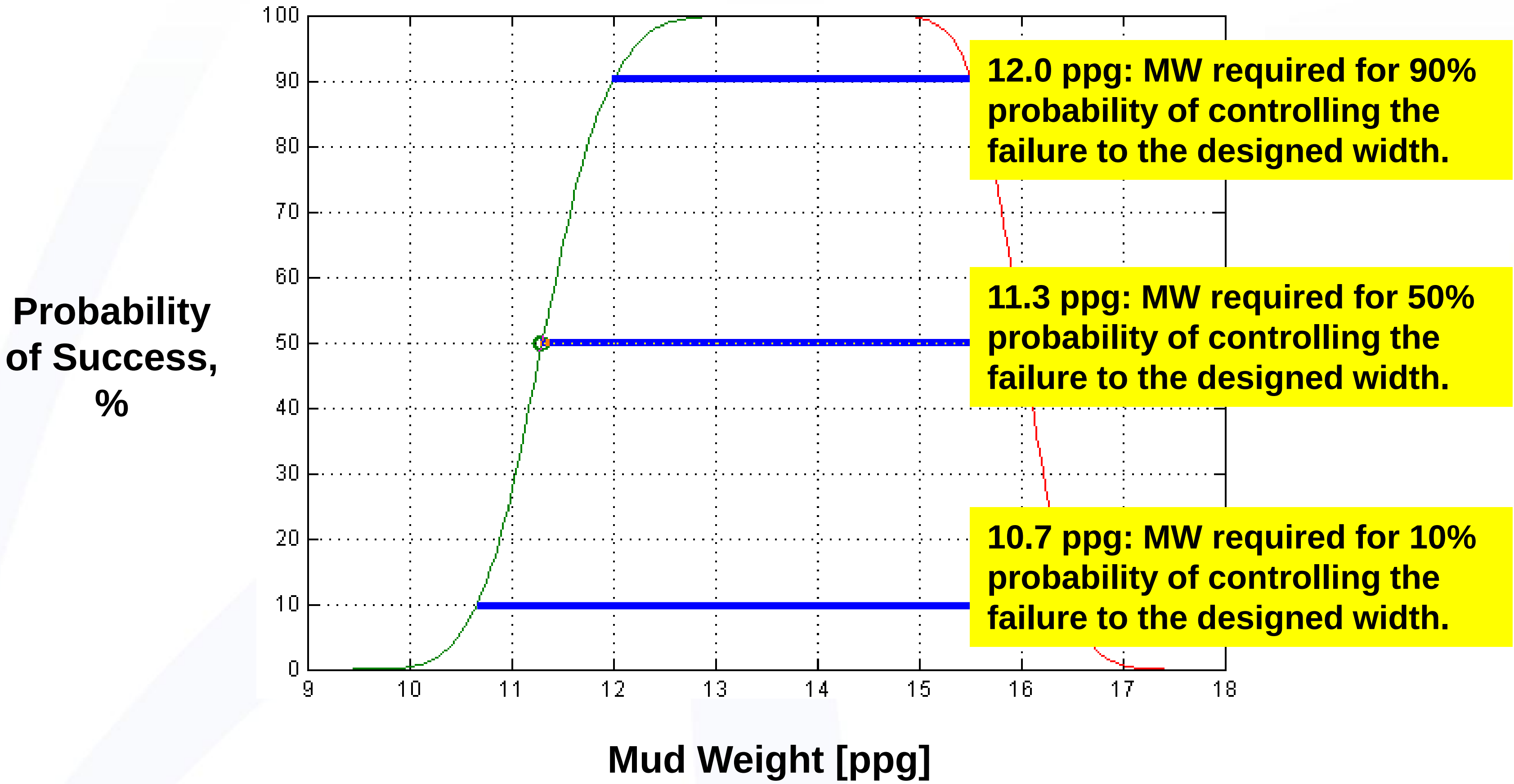
- The failure stabilizes at some distance into the formation.
- Some amount of underbalance may be acceptable, even in the lateral section.
- Underbalanced drilling minimized the risk of mud invasion.

Quantitative Risk Analysis (QRA): Probability Distribution of Input Data

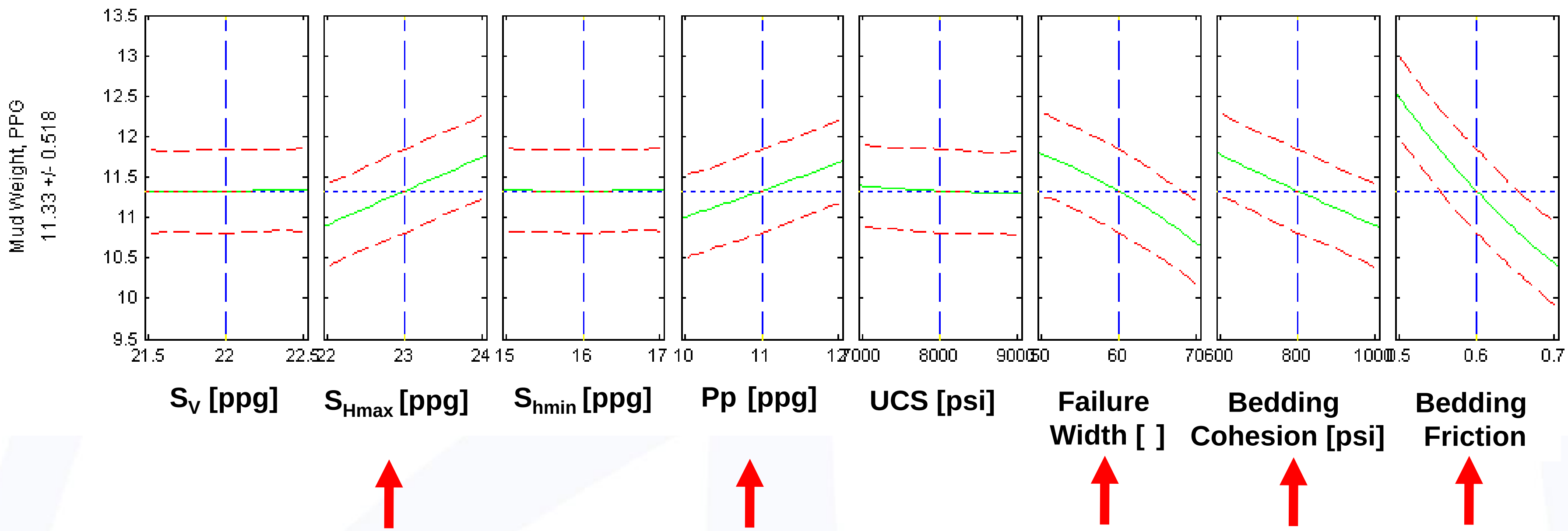


Input parameters are varied to determine the impact of each parameter on the recommended mud weight and to help prioritize data collection recommendations.

Quantitative Risk Analysis (QRA): Probability of Success



Quantitative Risk Analysis (QRA): Sensitivity for Borehole Collapse



The most sensitive parameters to the model are allowable failure width, bedding cohesion and bedding friction. S_{Hmax} magnitude and pore pressure are of secondary importance.

99% Confidence mud weight window

Most likely predicted mud weight

Discussion Points

- What are the best indicators of the presence of fractures and/or weak bedding while drilling?
- What are some common solutions when weak bedding is encountered?
  - Do these solutions make sense if the target itself or the interval directly above the target is weakly bedded?
- What if joints and/or other natural fractures are present?
- What are some of risks of underbalanced drilling?
- Can the presence and strength character of natural fractures and fissile beds be predicted?
- How can we reduce model uncertainties?