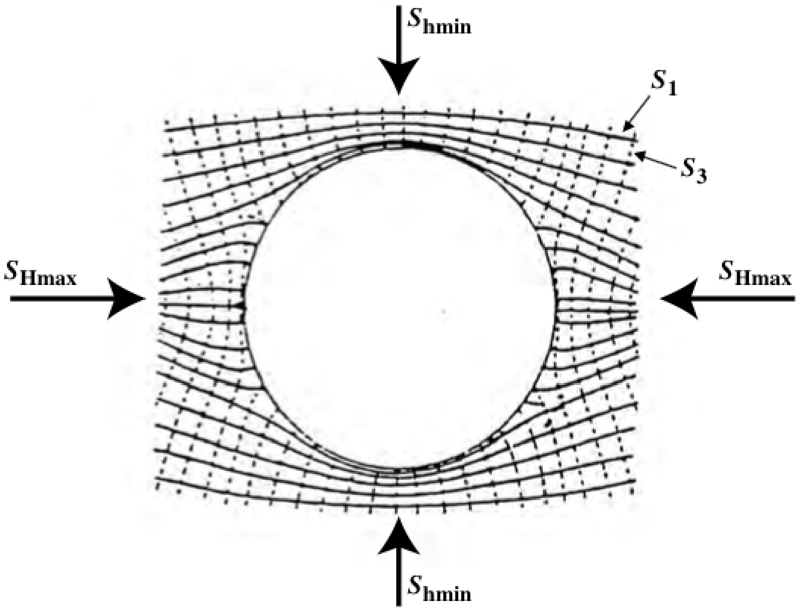
Compressive and tensile failure in vertical wells

Stress around circular cavity



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Kirsch solution

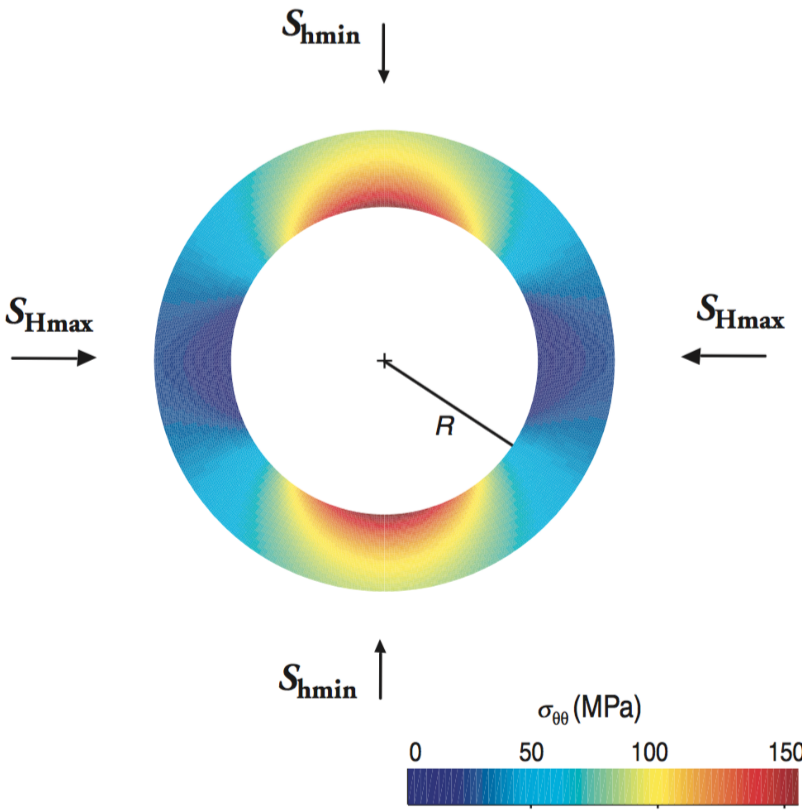
$$\sigma_{rr} = \frac{\sigma_{Hmax} + \sigma_{hmin}}{2}\left(1 - \frac{a^2}{r^2}\right) + \frac{\sigma_{Hmax} - \sigma_{hmin}}{2}\left(1 - 4\frac{a^2}{r^2} + 3\frac{a^4}{r^4}\right)\cos 2\theta + (P_w - P_p)\,\Bigg($$

$$\sigma_{\theta\theta} = \frac{\sigma_{Hmax} + \sigma_{hmin}}{2}\left(1 + \frac{a^2}{r^2}\right) - \frac{\sigma_{Hmax} - \sigma_{hmin}}{2}\left(1 + 3\frac{a^4}{r^4}\right)\cos 2\theta - (P_w - P_p)\left(\frac{a^2}{r^2}\right)$$

$$\sigma_{r\theta} = \frac{\sigma_{Hmax} - \sigma_{hmin}}{2}\left(1 + 2\frac{a^2}{r^2} - 3\frac{a^4}{r^4}\right) - \sin 2\theta$$

$$\sigma_{zz} = \sigma_v - 2\nu(\sigma_{Hmax} - \sigma_{hmin})\left(\frac{a^2}{r^2}\right)\cos 2\theta$$

Example



$$
\begin{aligned}
S_{Hmax} &= 90\text{MPa} \\
S_v &= 88.2\text{MPa} \\
S_{hmin} &= 51.5\text{MPa} \\
P_p &= 31.5\text{MPa} \\
P_w &= 31.5\text{MPa}
\end{aligned}
$$

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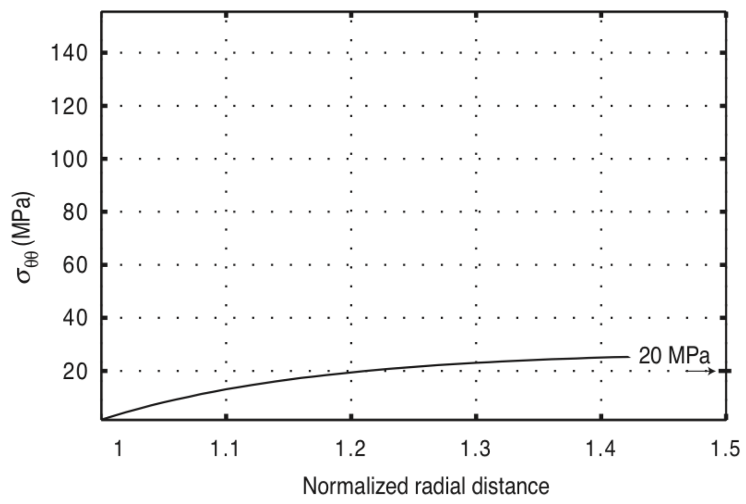
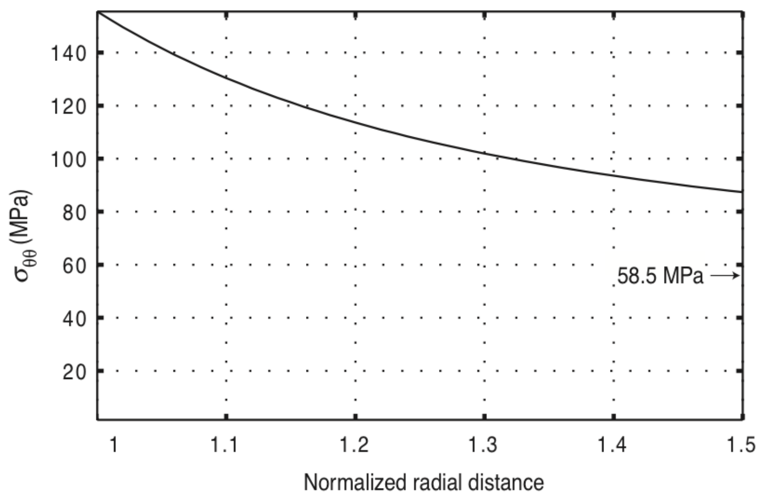


Along azimuth of S_{hmin}



Along azimuth of S_{Hmax}

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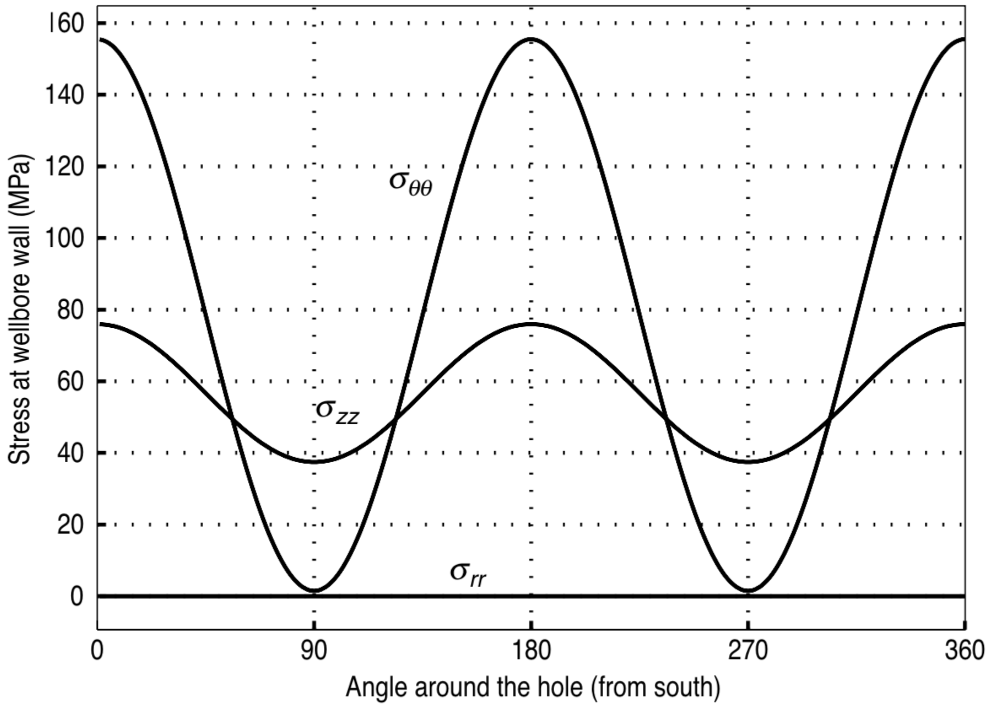
Variation of wellbore stresses



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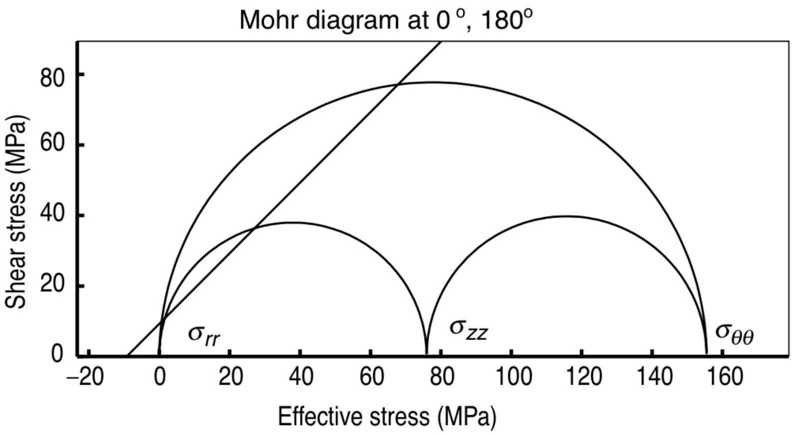
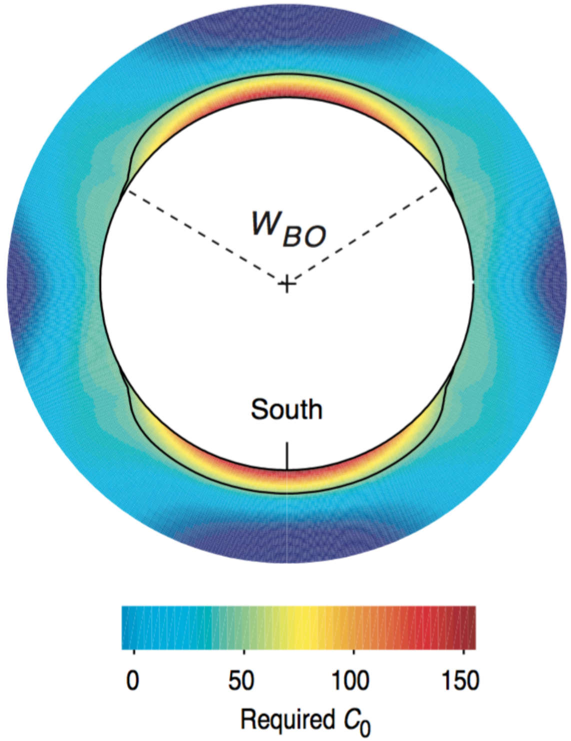
Wellbore breakout region





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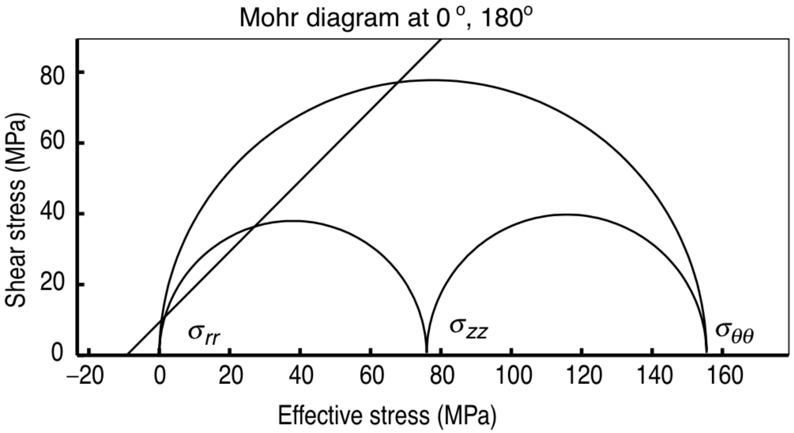
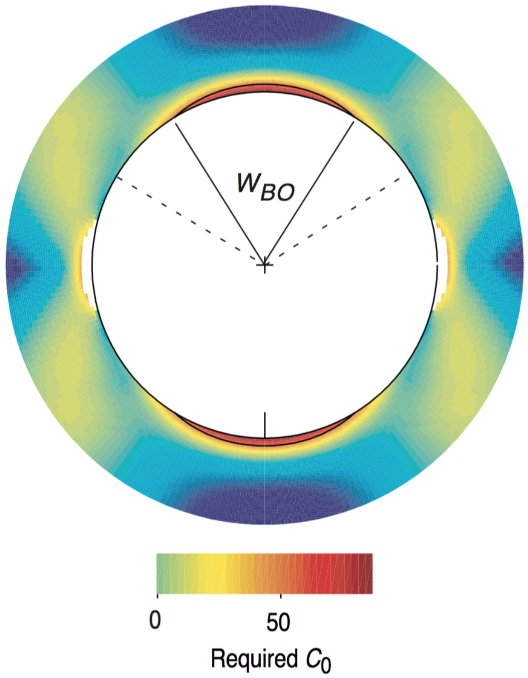
Mudweight stabilization

As ΔP increases, $\sigma_{\theta\theta}$ decreases and σ_{rr} increases.





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Breakouts as indicators of far-field stresses

Simplify Kirsch equations at wellbore wall $a = r$, so

$$\sigma_{rr} = (P_w - P_p) = \Delta P$$
$$\sigma_{\theta\theta} = \sigma_{Hmax} + \sigma_{hmin} - 2(\sigma_{Hmax} - \sigma_{hmin}) \cos 2\theta - \Delta P$$
$$\sigma_{zz} = \sigma_v - 2\nu(\sigma_{Hmax} - \sigma_{hmin}) \cos 2\theta$$

$\sigma_{\theta\theta}$ has min at 0° and 180°

$$\sigma_{\theta\theta}^{min} = 3\sigma_{Hmin} - \sigma_{Hmax} - \Delta P$$

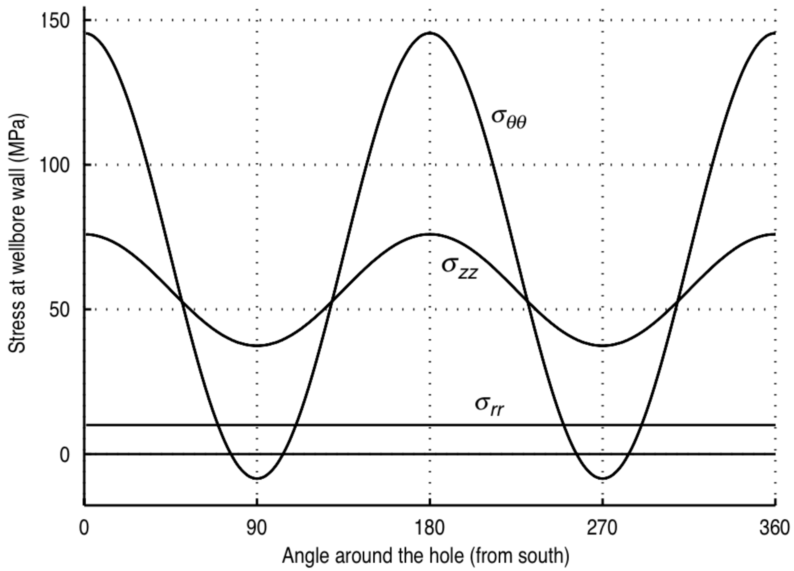
$\sigma_{\theta\theta}$ has min at 90° and 270°, so

$$\sigma_{\theta\theta}^{max} = 3\sigma_{Hmax} - \sigma_{hmin} - \Delta P$$

so

$$\sigma_{\theta\theta}^{max} - \sigma_{\theta\theta}^{min} = 4(\sigma_{Hmax} - \sigma_{hmin})$$

Tensile induced fractures



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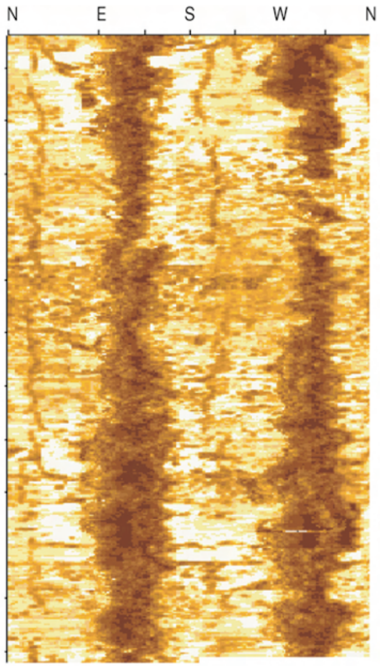
Safe drilling mud window

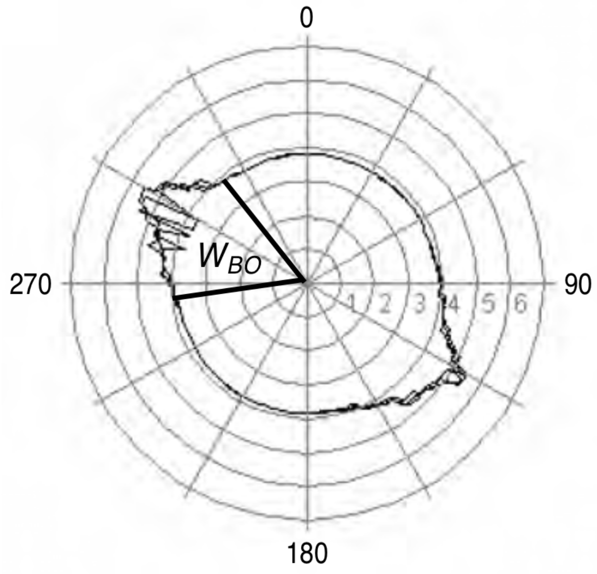
- **Mud weight too low**
  - Breakouts
- **Mud weight too high**
  - Tensile induced fractures leading to lost circulation

Imaging breakouts



Ultrasonic *P*-wave

Electrical resistivity



Breakout cross-section

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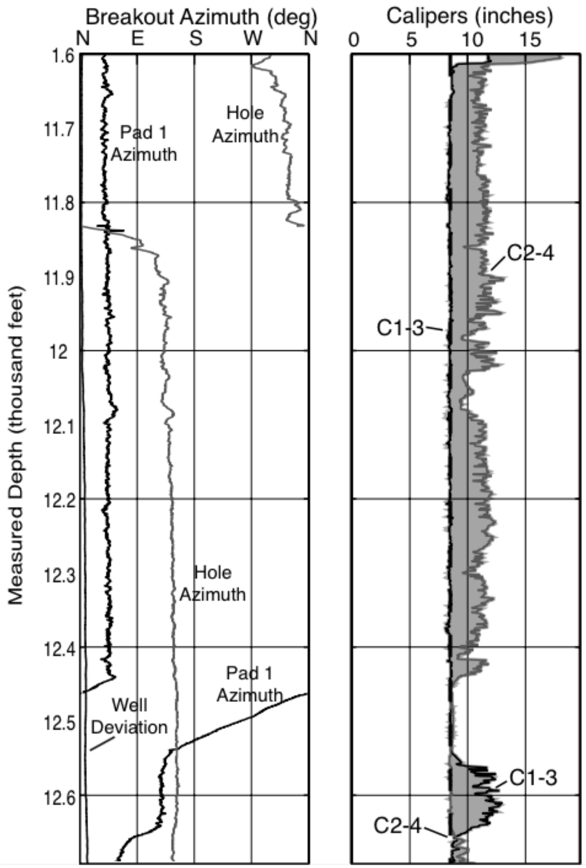
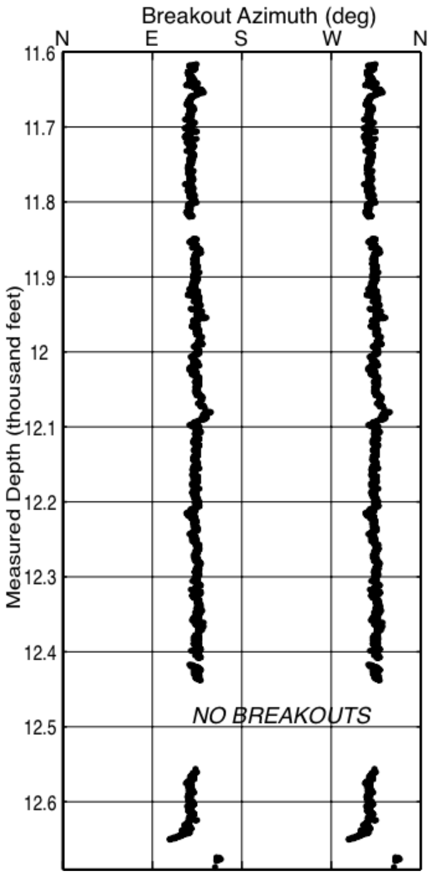
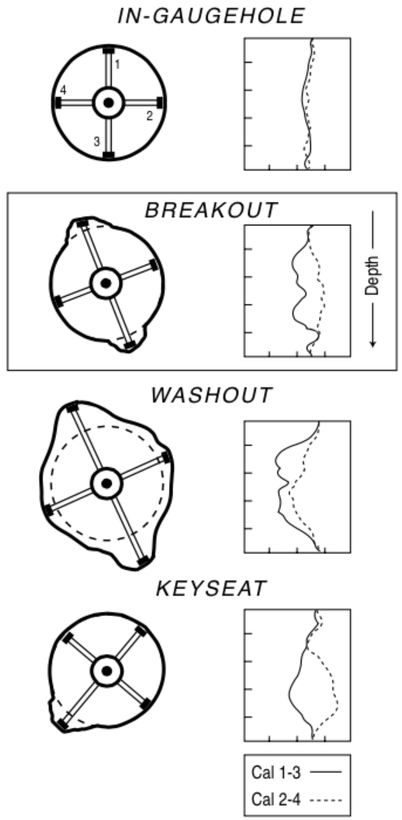
Four-arm caliper data



Caliper data



Breakout indication



Examples of variations

Thermal effects on wellbore stress

Strongly time dependent

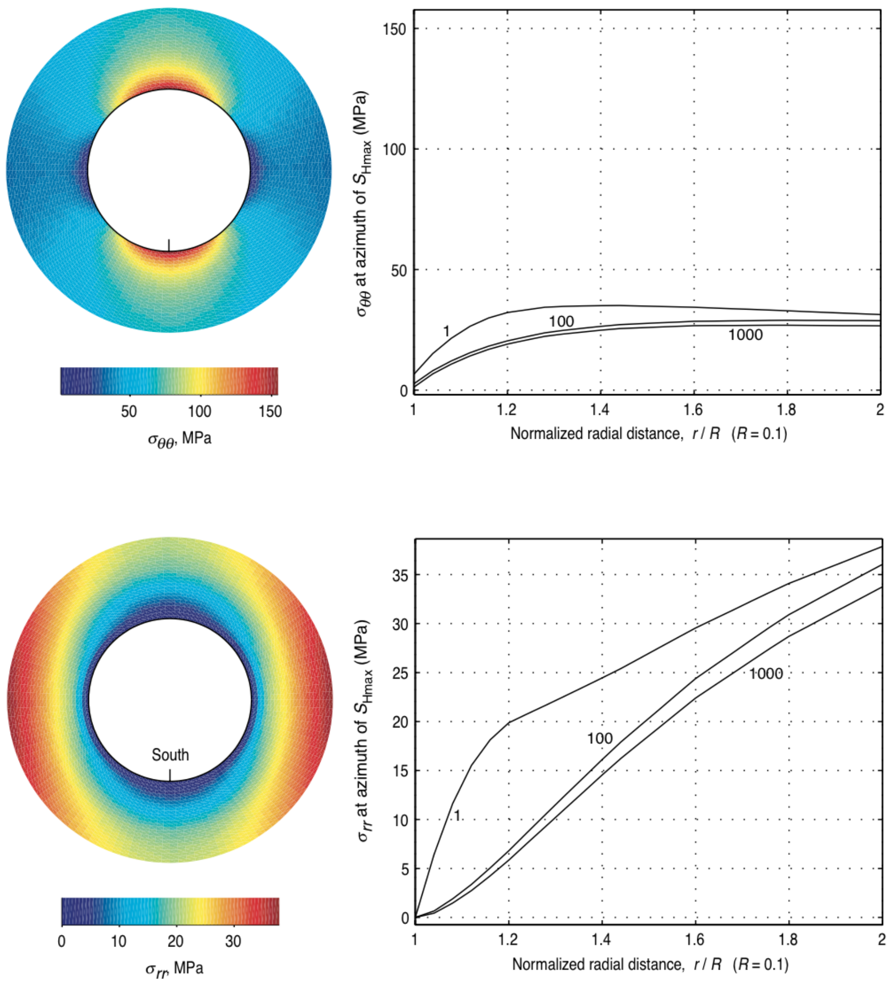
$$\frac{\partial T}{\partial t} = \alpha_T \nabla^2 T$$

$\alpha \rightarrow$ strongly dependenent of the silica content of the rock.

Under steady-state conditions,

$$\Delta\sigma_{\theta\theta}^{T} = \frac{\alpha_T E \Delta T}{1 - \nu}$$

Time-temperature effects



$\Delta T = 25^\circ$ C

$\Delta P = 6$ MPa

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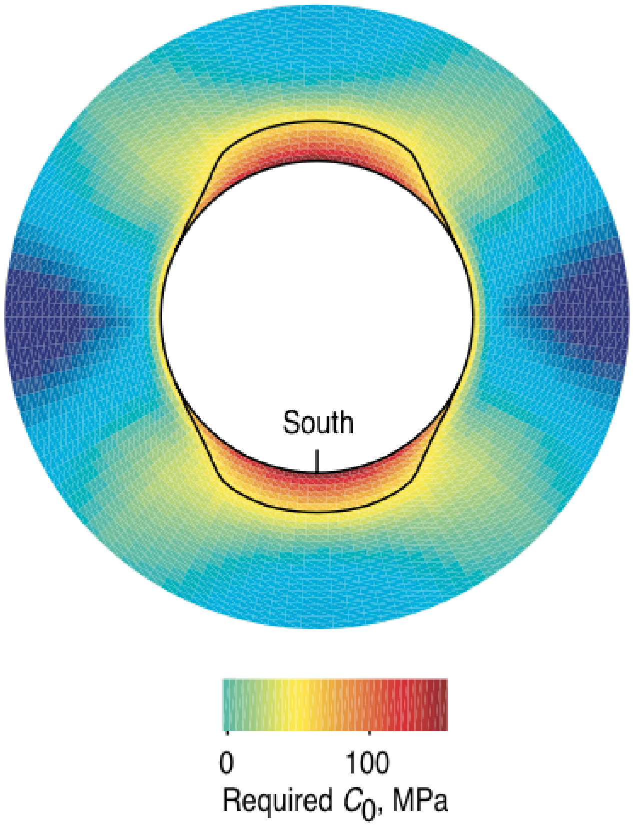
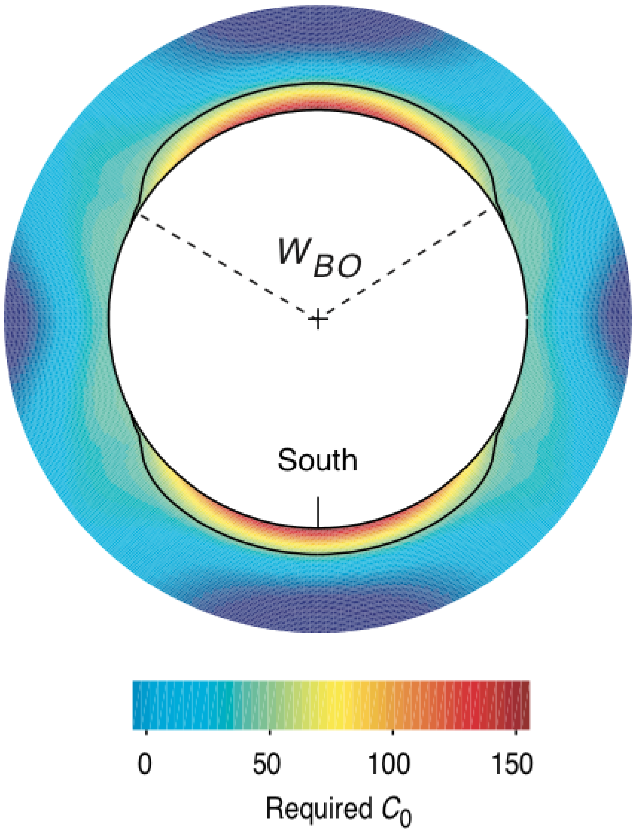
Stability through cooling?



Cooling



Reference

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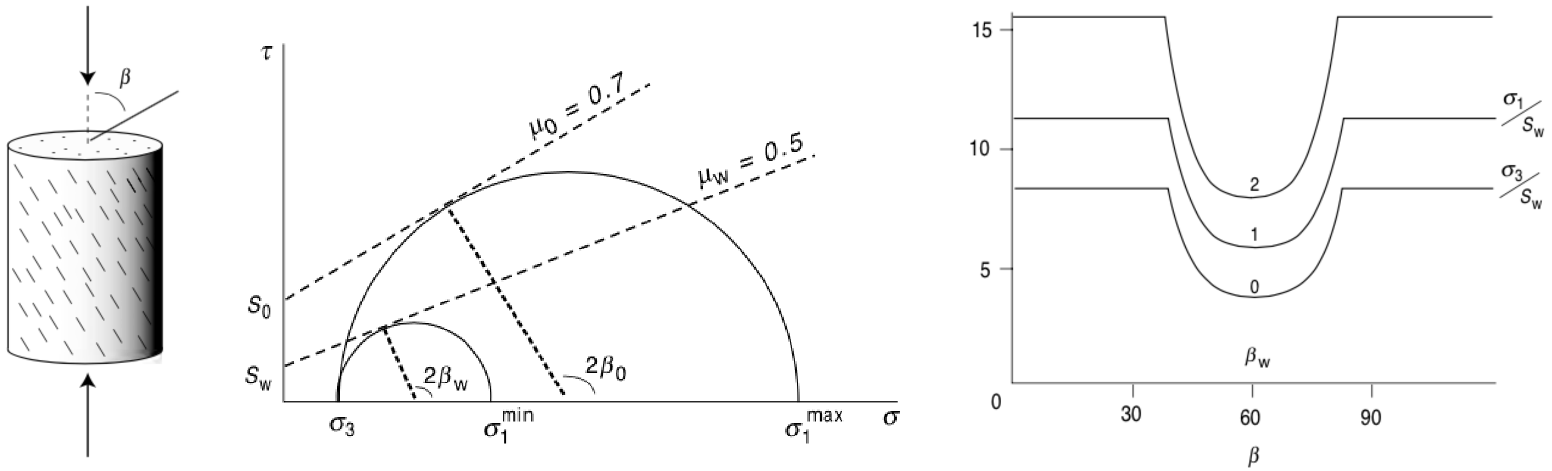
Rock strength anisotropy



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

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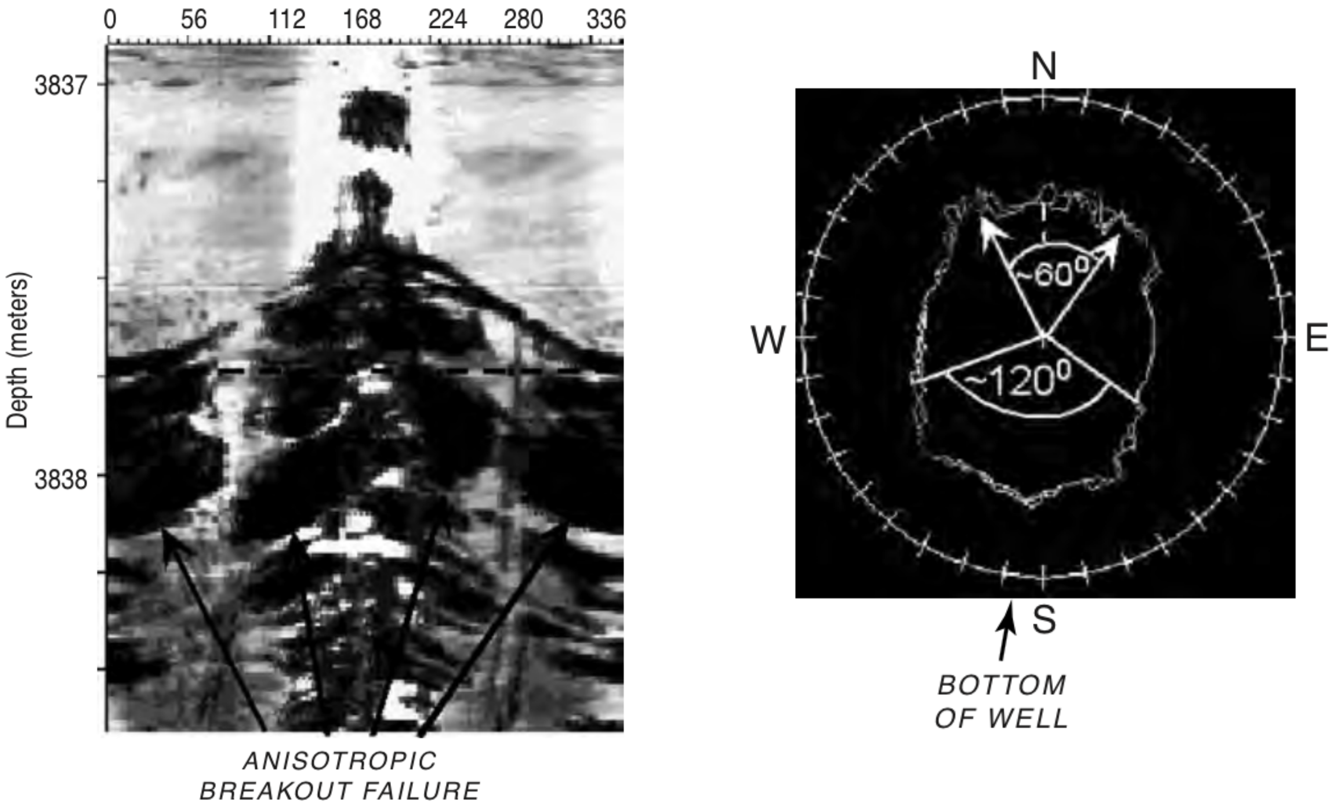
Rock strength anisotropy effects on breakouts



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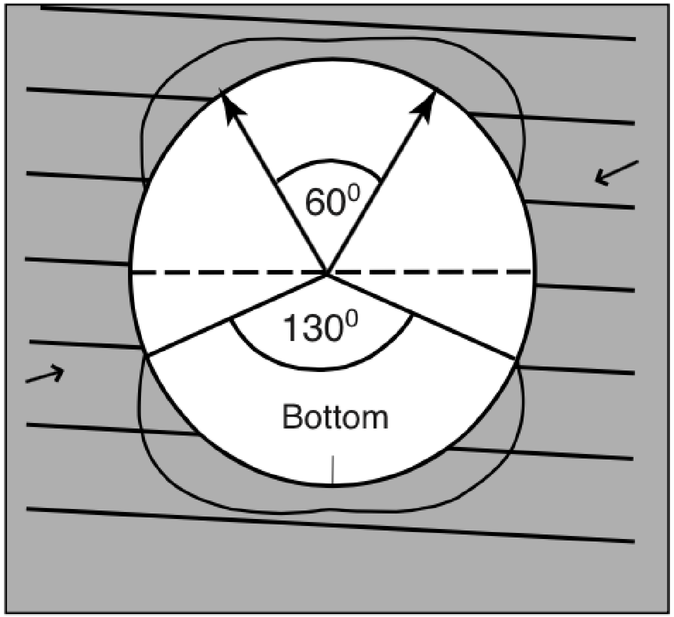
Two mechanisms

- Stresses exceed intact rock strength
- Stresses activate slip on weak bedding planes



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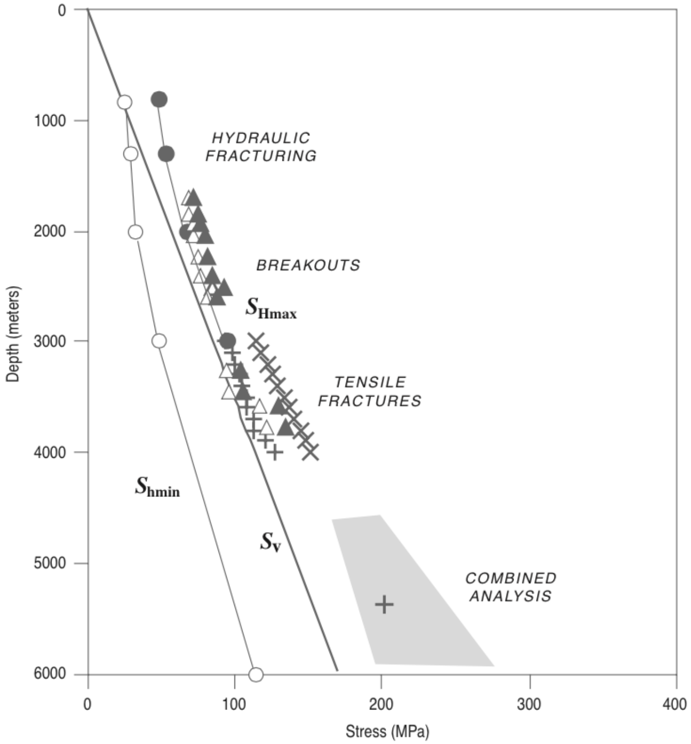
Chemical effects

- Water Activity ($A_w \sim \frac{1}{\text{salinity}}$) can to increased pore pressure

S_{Hmax} from breakout data

$$S_{Hmax} = \frac{(C_0 + 2P_p + \Delta P + \Delta\sigma^T) - S_{hmin}(1 + 2\cos(\pi - w_{bo}))}{1 - 2\cos(\pi - w_{bo})}$$

Example



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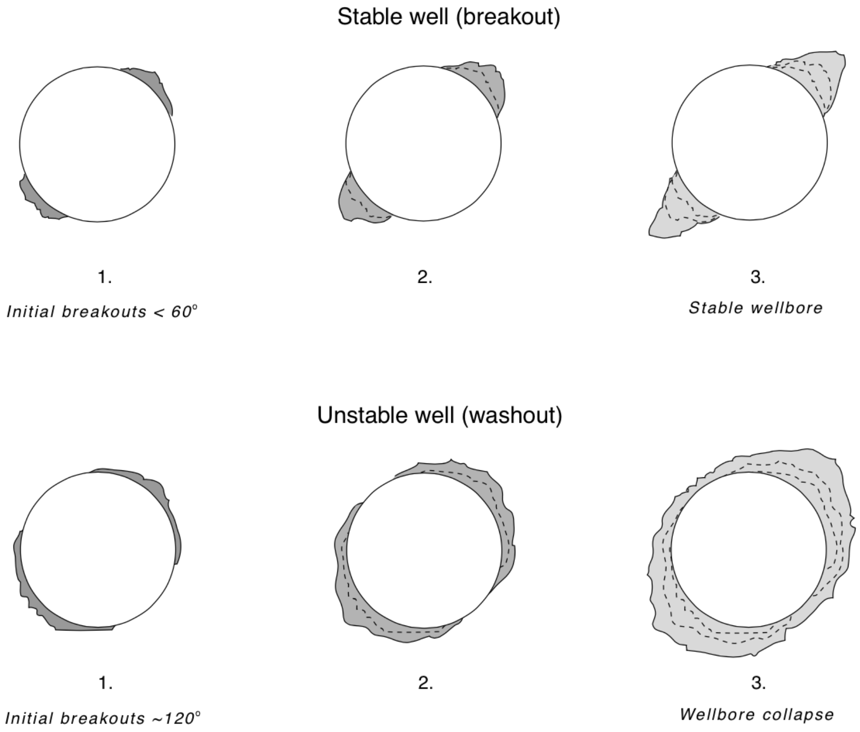
Wellbore stability

Defining a "stable" wellbore



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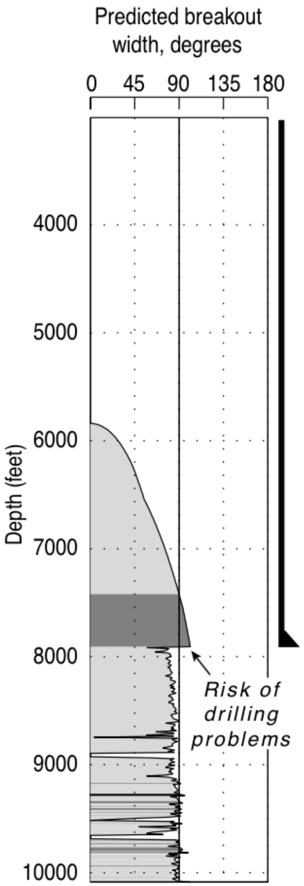
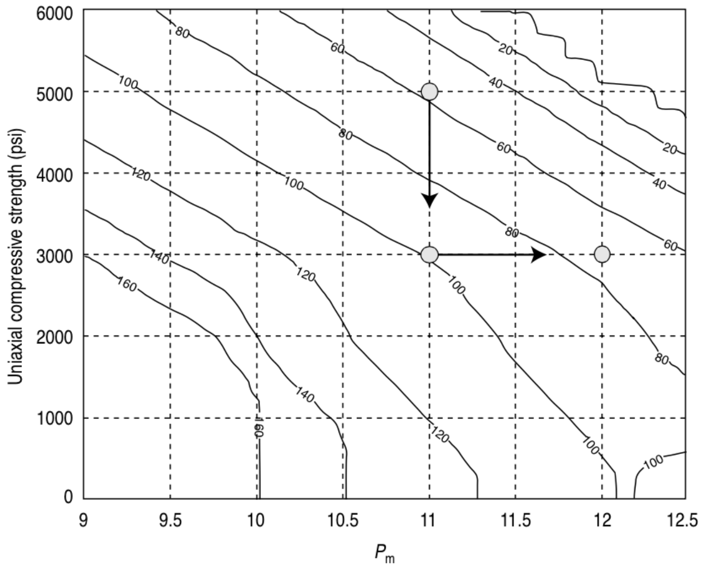
Emperical model: Maximum 90˚ breakouts





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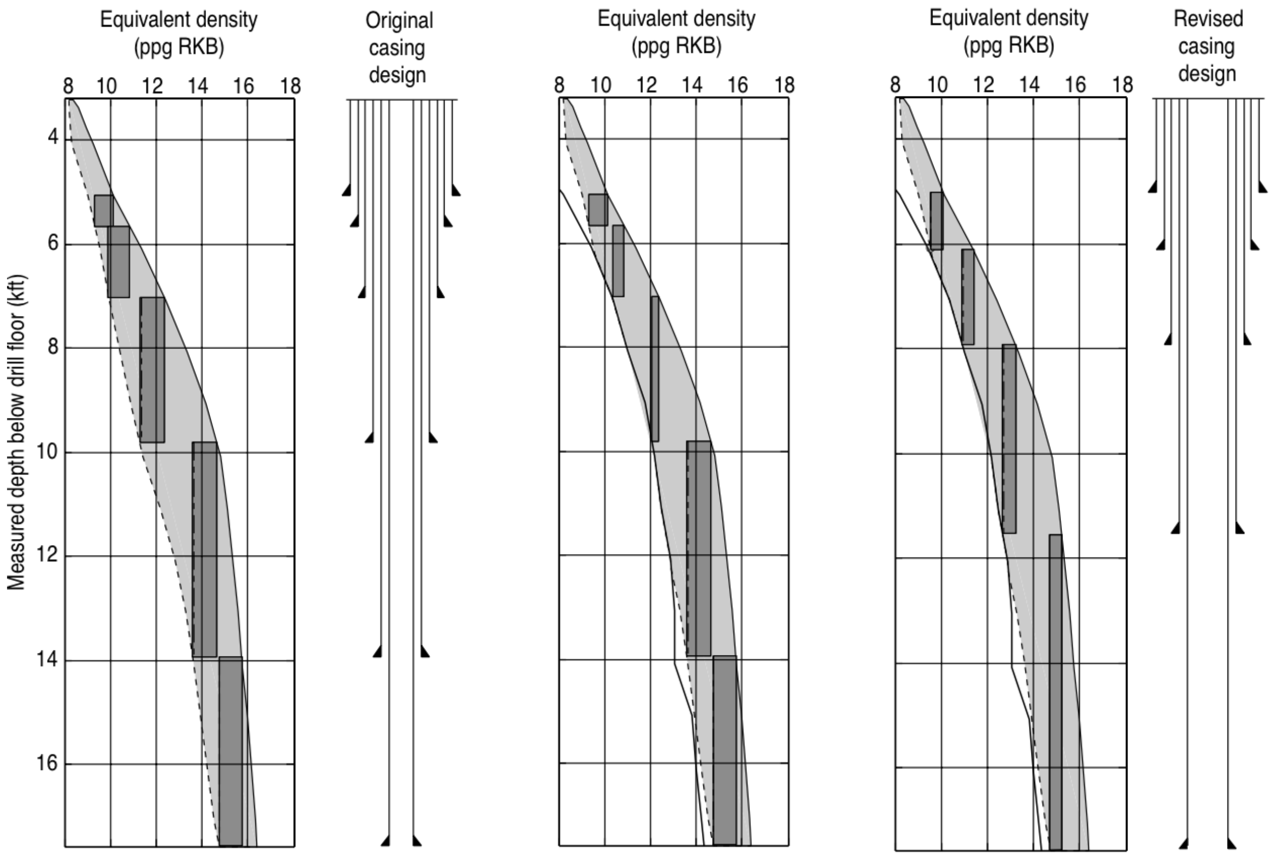
Comprehensive model

i.e. why your studying geomechanics



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