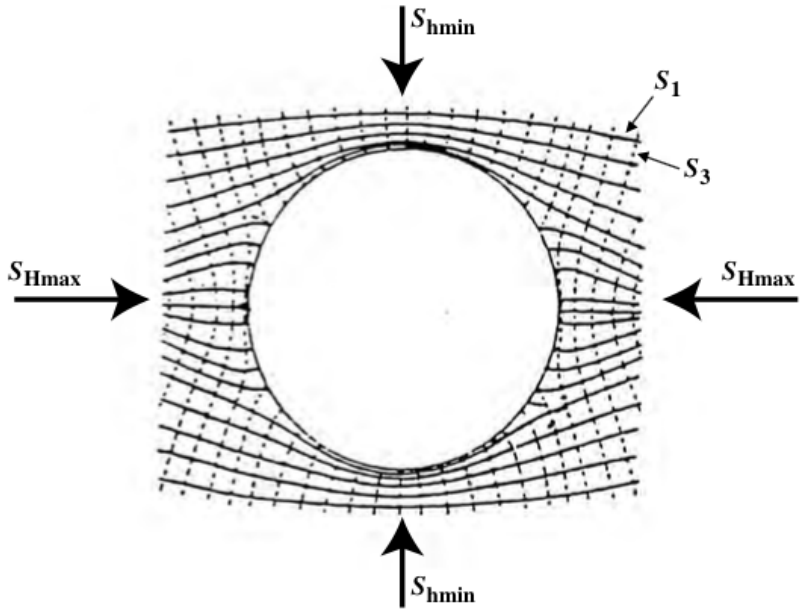
Compressive and tensile failure in vertical wells

Stress around circular cavity



 Zoback, *Reservoir Geomechanics* (Fig. 6.1, pp. 169)

Kirsch solution

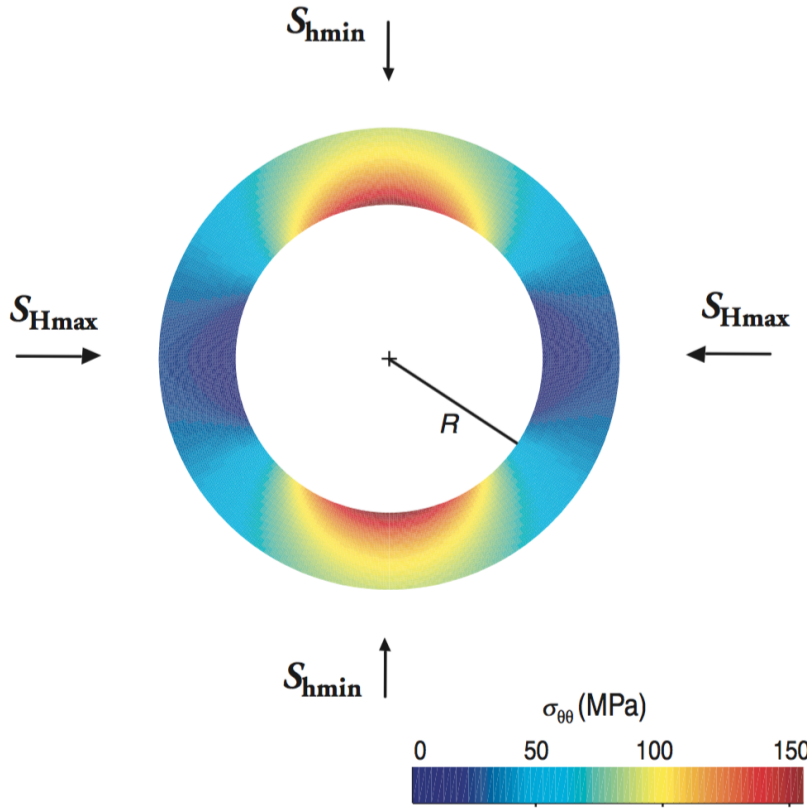
$$\sigma_{rr} = \frac{\sigma_{Hmax} + \sigma_{hmin}}{2}\left(1 - \frac{a^2}{r^2}\right) + \frac{\sigma_{Hmax} - \sigma_{hmin}}{2}\left(1 - 4\frac{a^2}{r^2} + 3\frac{a^4}{r^4}\right)\cos 2\theta + (P_w - P_p)\left(\frac{a^2}{r^2}\right)$$

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

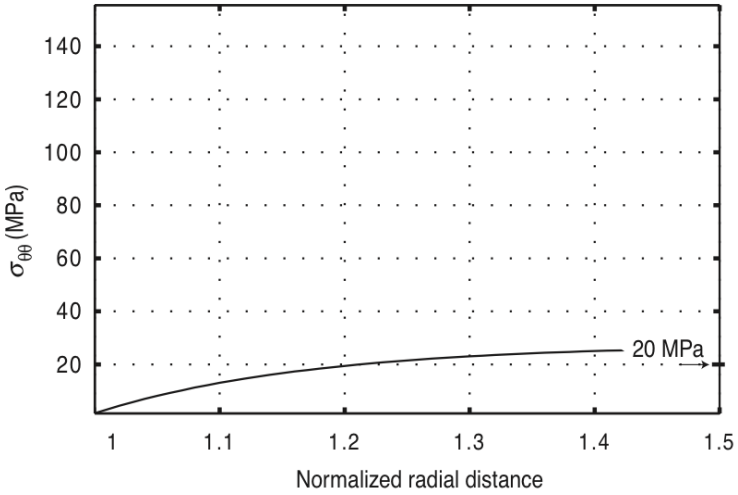
$$\sigma_{r\theta} = \frac{\sigma_{Hmax} - \sigma_{hmin}}{2}\left(1 + 2\frac{a^2}{r^2} - 3\frac{a^4}{r^4}\right) - \sin 2\theta$$

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

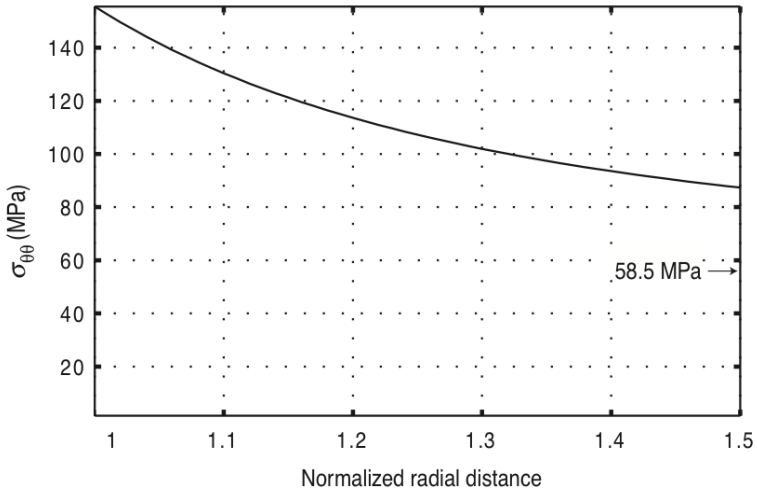
Example



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

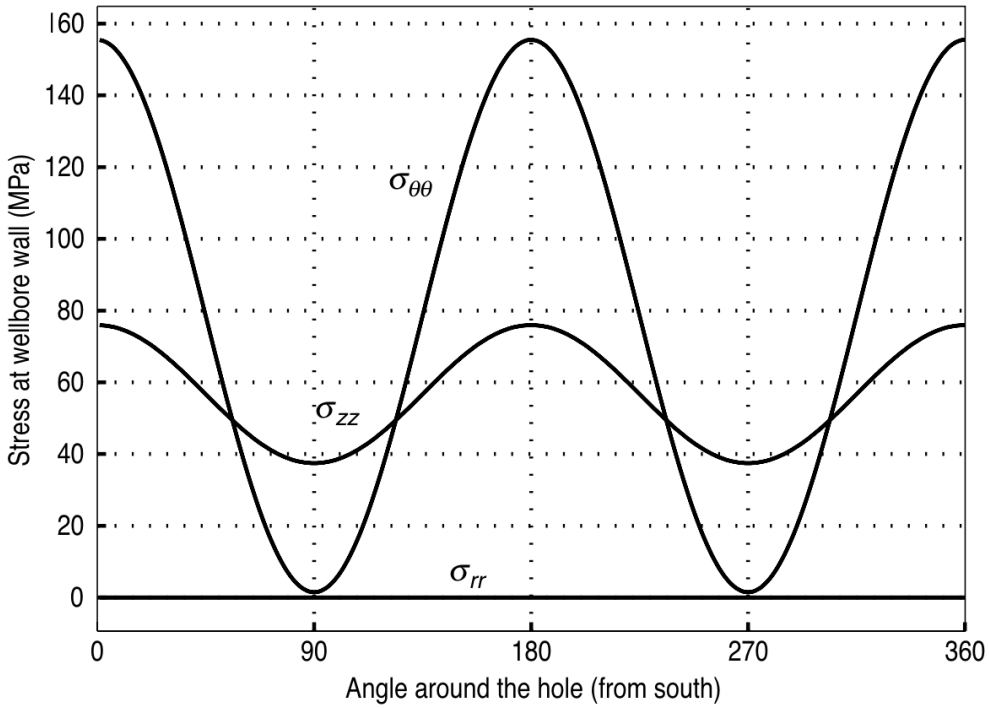


Along azimuth of S_{hmin}



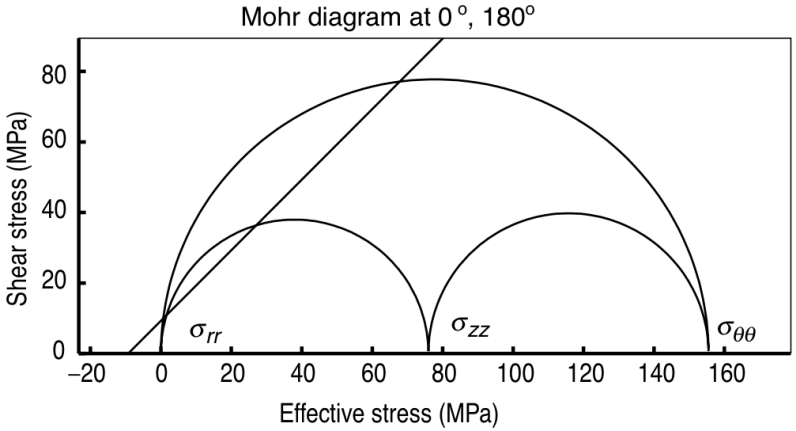
Along azimuth of S_{Hmax}

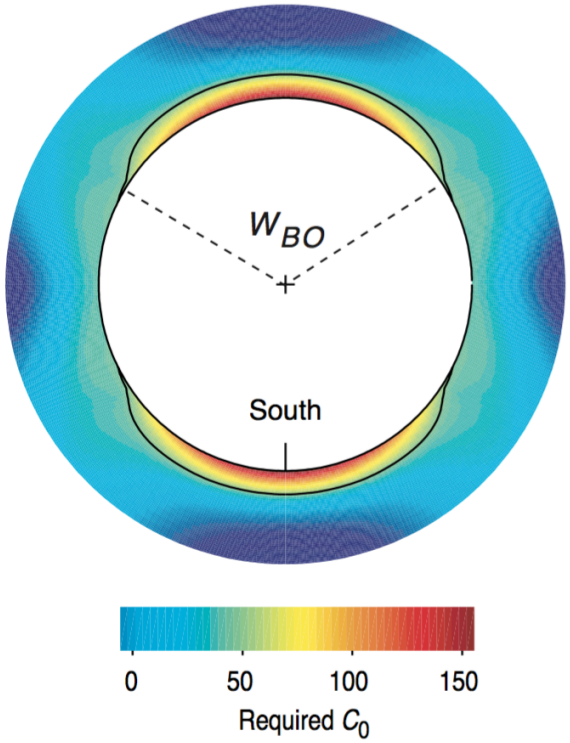
Variation of wellbore stresses



 Zoback, *Reservoir Geomechanics* (Fig. 6.3a, pp. 173)

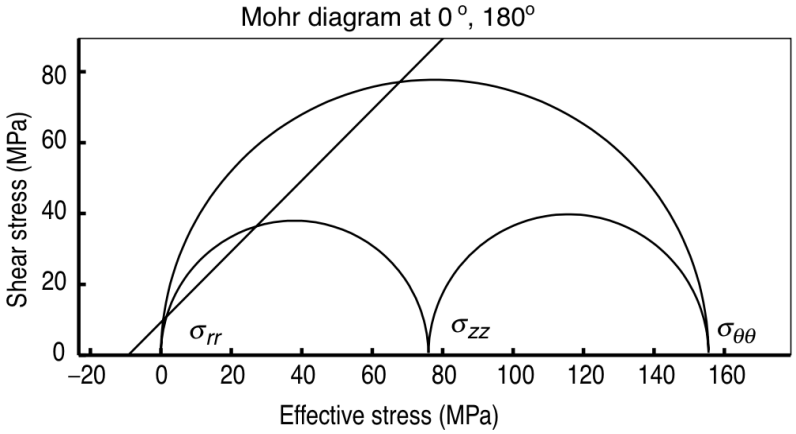
Wellbore breakout region

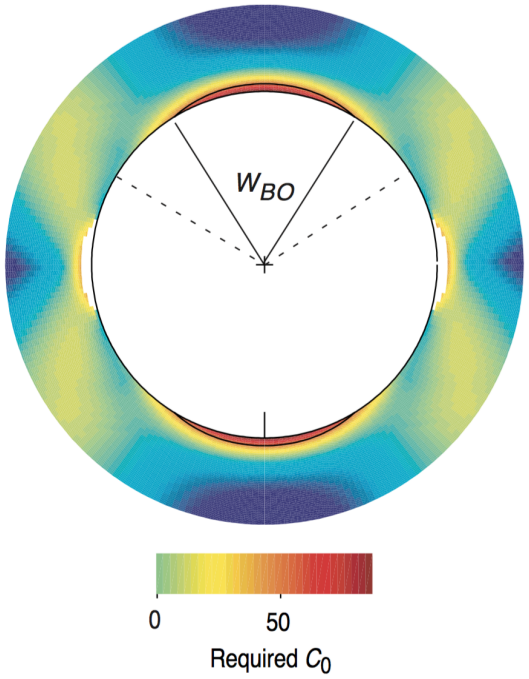




Mudweight stabilization

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





Breakouts as indicators of far-field stresses

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

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

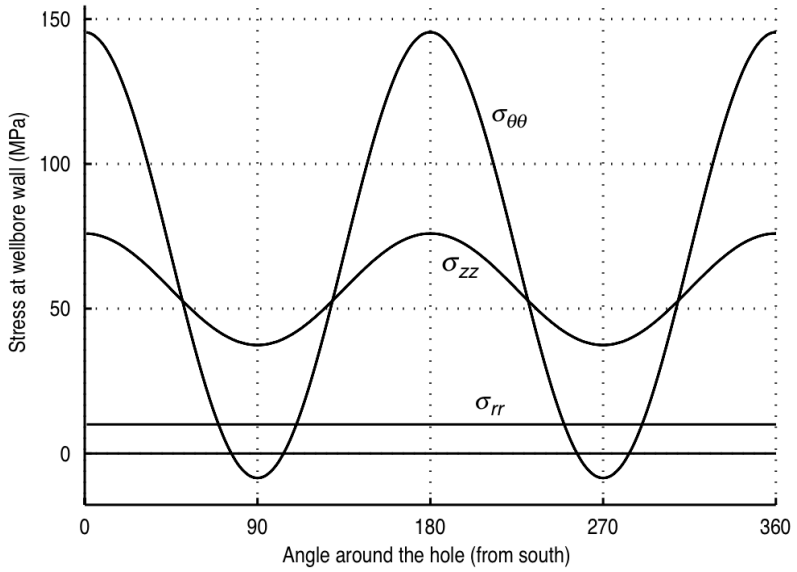
$\sigma_{\theta\theta}$ has min at 0° and 180°

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

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

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

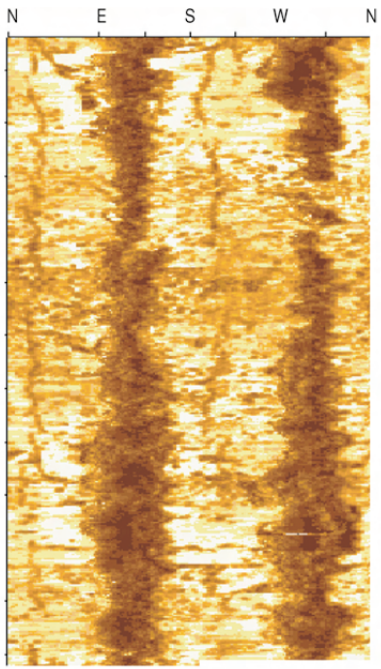
Tensile induced fractures



Safe drilling mud window

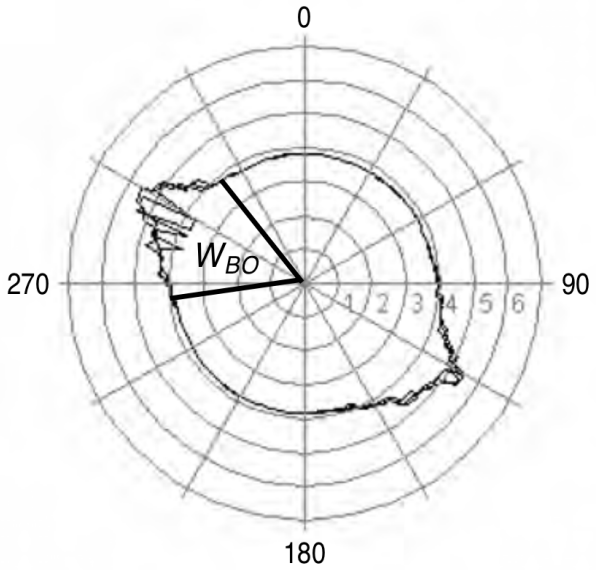
- **Mud weight too low**
  - Breakouts
- **Mud weight too high**
  - Tensile induced fractures leading to lost circulation

Imaging breakouts



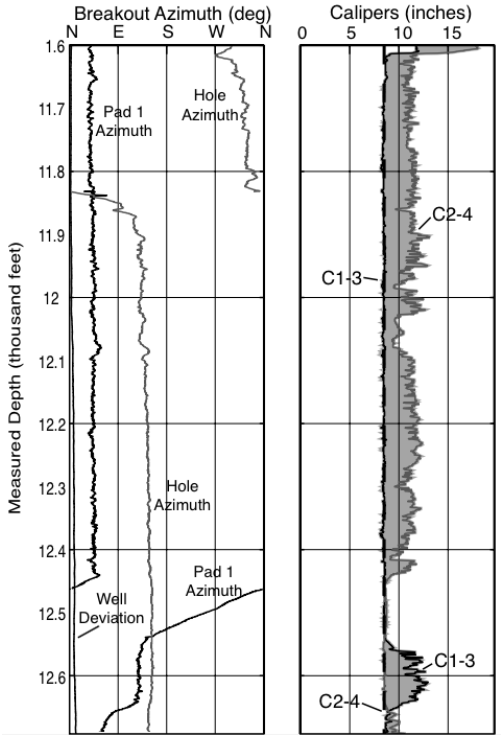
Ultrasonic P-wave

Electrical resistivity

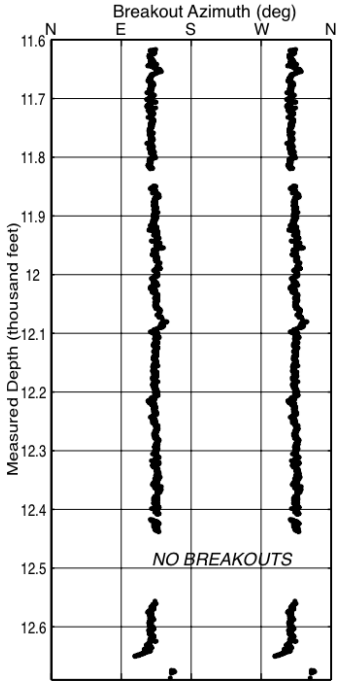


Breakout cross-section

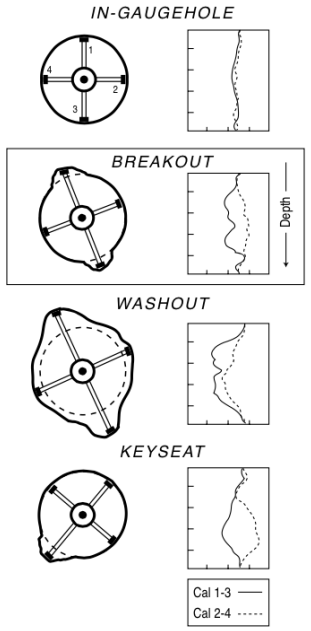
Four-arm caliper data



Caliper data



Breakout indication



Examples of variations