

40th Anniversary

Wellbore stability analysis in geothermal well drilling

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Outline

- Introduction
- Wellbore stresses
- Failure criteria
- Stress analysis
- Stress variation
- Wellbore stability
- Discussion
- Conclusions

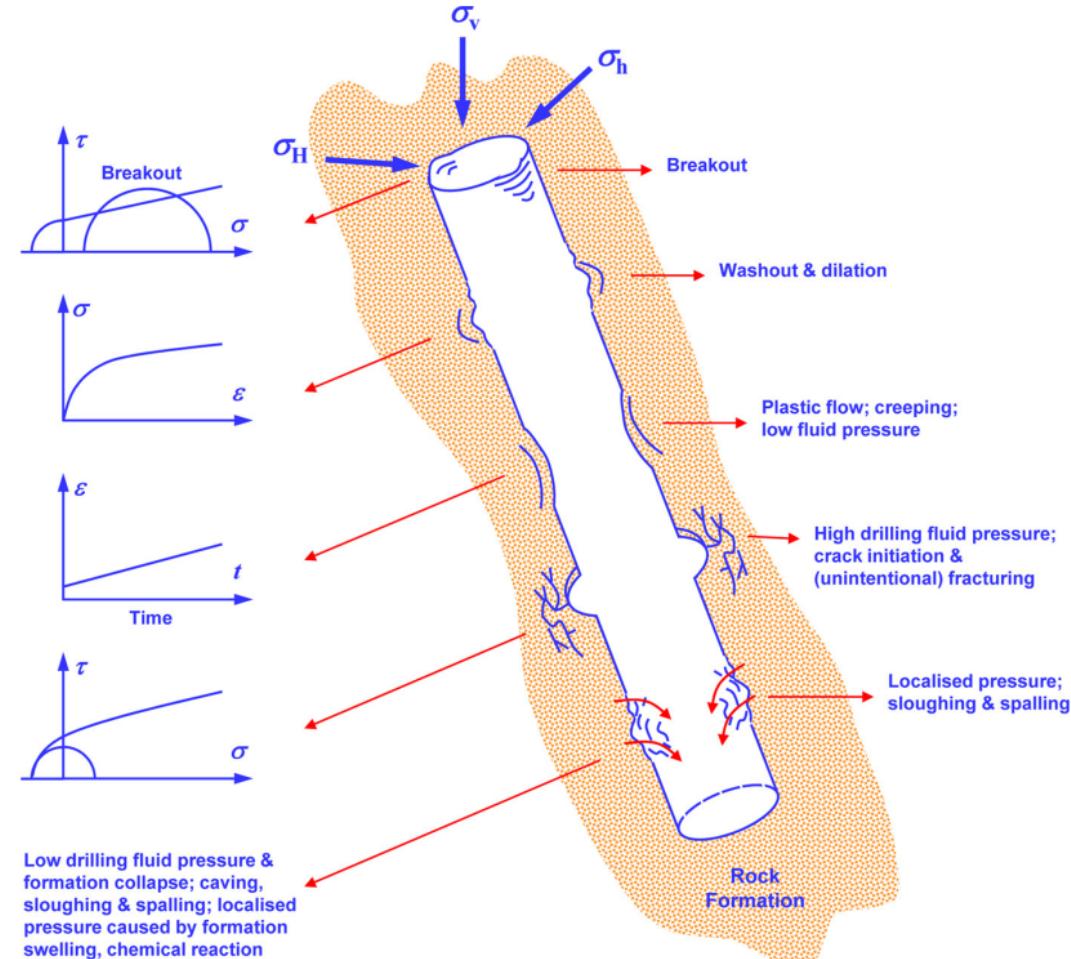
Introduction

- Olkaria field- Kenya rift system part of the EARS
- High temperature field
 - above 200°C at 1000 m depth
- Well drilling - significant cost in geothermal projects
- Drilling practices
 - timely well delivery
- Cost implication of geothermal projects
- Drilling challenges
 - extension of time
 - increased cost



Wellbore stresses

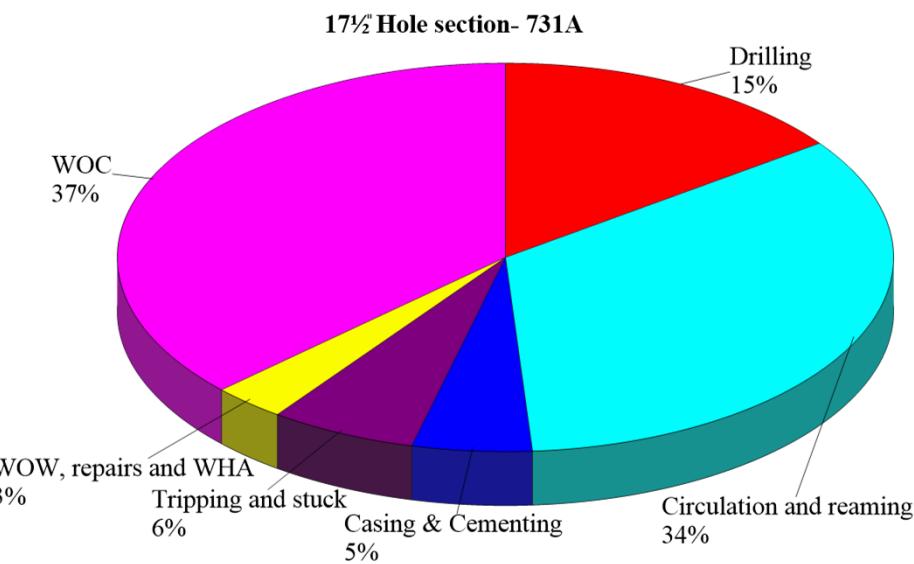
- Drilling-formation balance
 - Material removal
 - Drilling fluid
- Wellbore wall-new surface
 - Stress field alignment
 - Converge and diverge
- Instability
 - Chemical-dispersion
 - Mechanical-breakout or fracturing
- Compressive-convergence
 - Collapse
- Tensile-divergence
 - Fracture



Various forms of wellbore instabilities (Aadnoy & Looyeh, 2011)

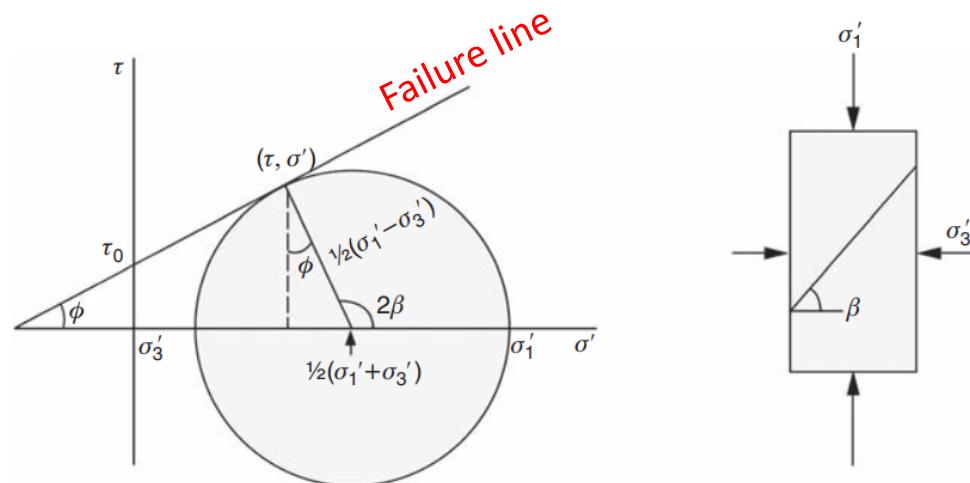
Instability effects

- Stuck drill string
 - Time lost
 - Material
 - Tool and equipment
- Loss of drilling circulation
 - Extra material required
- Tight spot
 - Reaming
 - Slow down drilling progress
- Caving
 - Reaming
 - Circulation
- Collapse
 - Loss in hole
 - Cementing
 - Abandonment
- Side tracking
 - Time
 - Specialized equipment

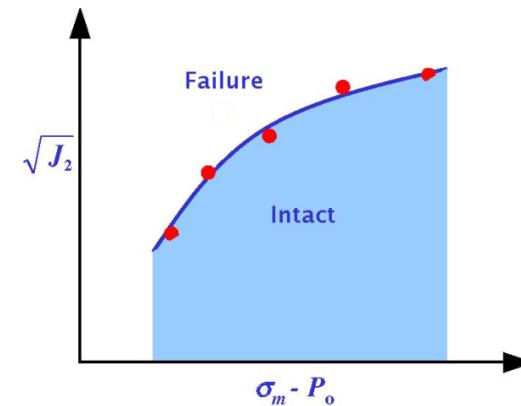


Failure criteria

- Stress- strain relation
 - Response to applied force- external loading
- Pressure and stress
 - Deformation in elastic solid
- Failure criteria
 - Behaviour and stresses involved
 - Collapse, creep, fracture,
- Mohr-coulomb criterion
 - Failure envelop
 - Maximum and minimum stress
- Von mises
 - Stress invariants
- Hoek-brown
 - Uniaxial compressive strength (UCS)
 - Geological strength index (GSI)



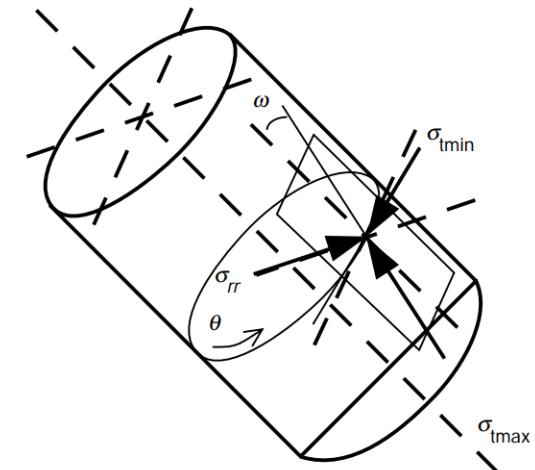
Mohr-Coulomb failure criterion (Mitchell & Miska, 2011)



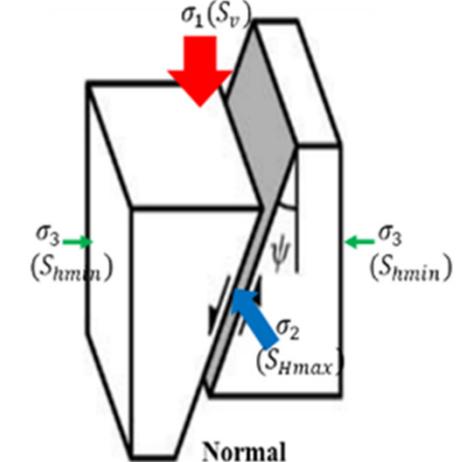
Von mises criteria (Aadnoy & Looyeh, 2011)

Stress analysis

- Field stress- Normal faulting
 - Overburden maximum
 - Minimum- perpendicular to faulting direction
- Formation pressure-pore pressure
- Rock properties
 - Density, Poisson's ratio
- Well data- direction and azimuth
- Stress equation- transformation to well orientation
 - Hoop- tangential $\sigma_{\theta max} = \frac{1}{2} \left(\sigma_{zz} + \sigma_{\theta\theta} \pm \sqrt{(\sigma_{zz} - \sigma_{\theta\theta})^2 + 4\tau_{\theta z}^2} \right)$
 - Radial $\sigma_r = \Delta P = (P_f - P_p)$
 - Vertical $\sigma_{zz} = \sigma_v - 2\vartheta(\sigma_{Hmax} - \sigma_{hmin})\cos 2\theta - P_p - \sigma^{\Delta T}$



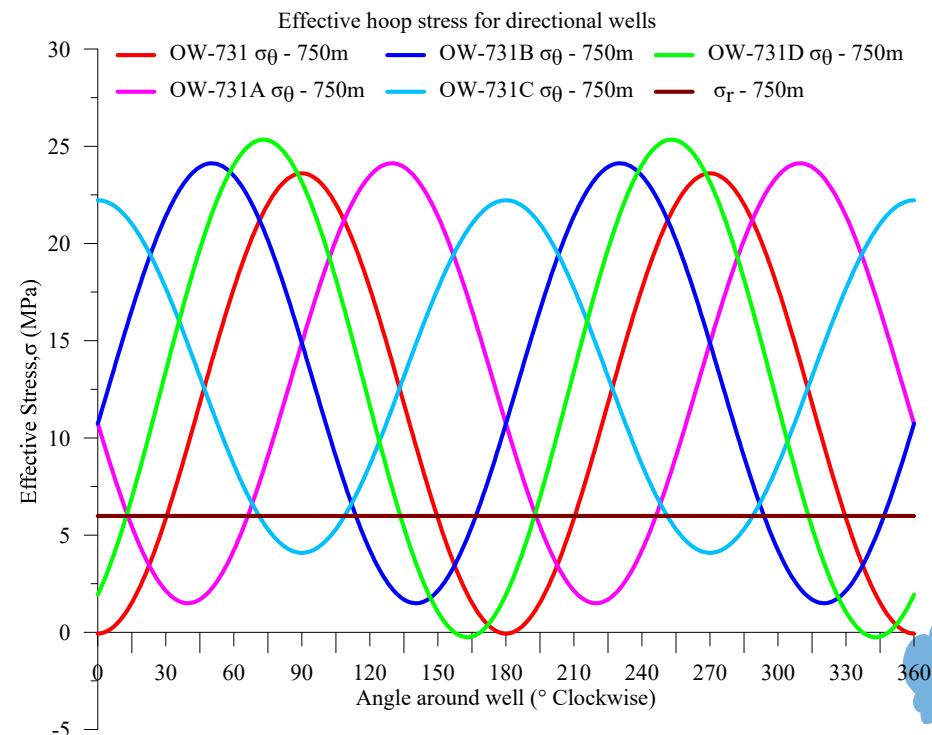
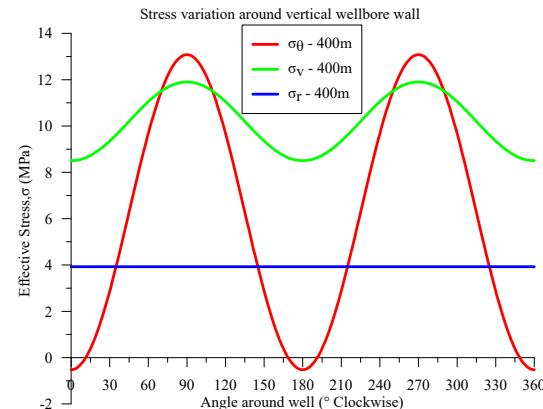
Stress at inclined borehole wall (Zoback, 2010)



Stress orientation (Fjær et al., 2008)

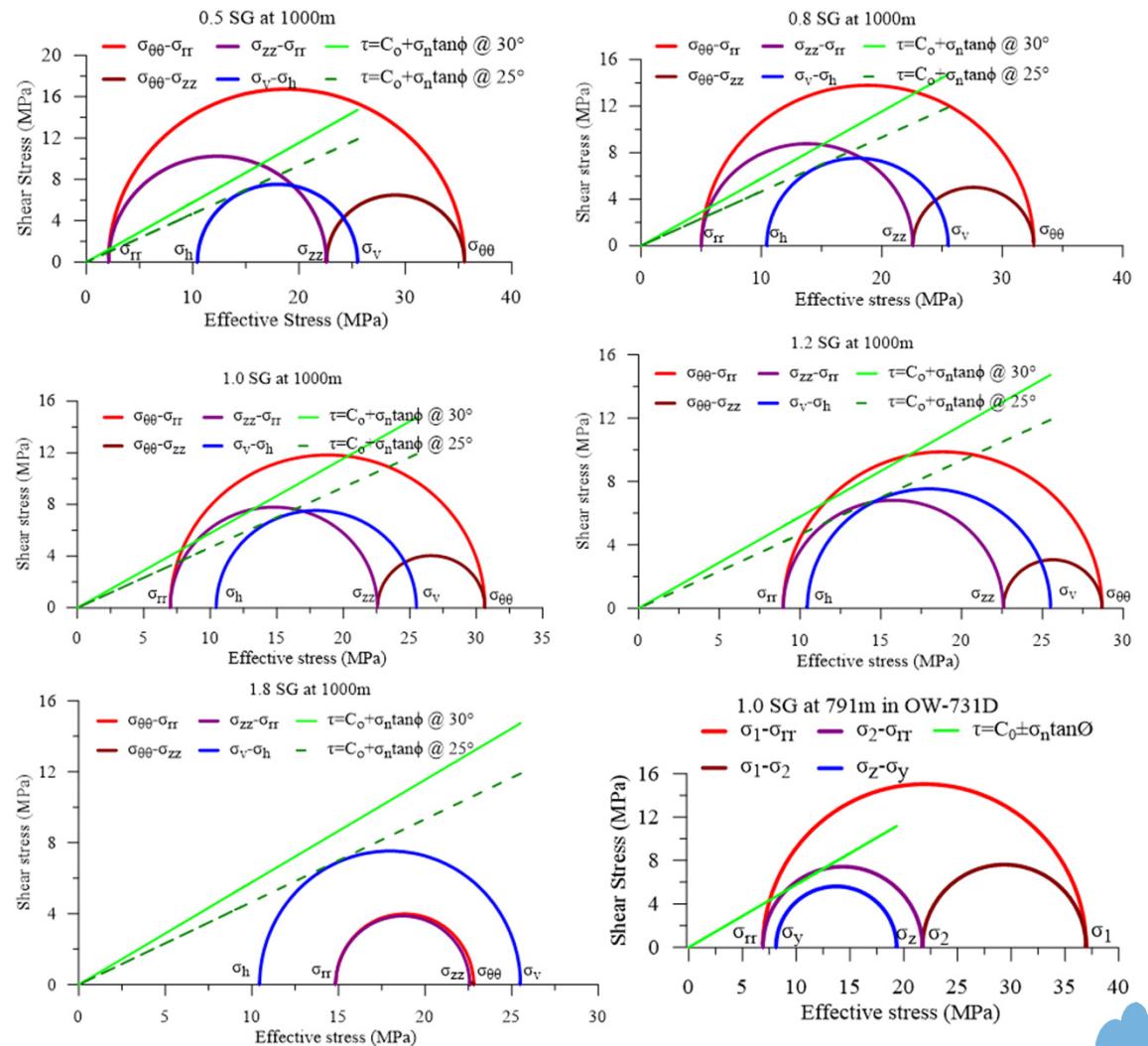
Wellbore stability

- Stress variation with angle
 - High amplitude- stress magnified at the wall
 - Directional well variation with azimuth
- Different drilling fluid density
 - Variation of radial stress
- Olkaria wells OW-731
 - Vertical
 - Directional - inclination 20°
 - Azimuth A-135°, B-225°, C-270° and D-200°



Discussion

- Mohr-coulomb analysis at 1000 m
- Stability improves with density increase
 - Tensile stress possibility
 - Loss of circulation
- Less wall support with reduced fluid density
 - Compressive stress-shear failure
 - Wellbore collapse
 - Creep



Conclusion

- Instability in geothermal well drilling
 - Loss of circulation
 - Collapse
- Slowing drilling progress and well cost
 - Stress analysis- loading forces
- Well design
 - Direction
 - Possible problem zones

Thank you