Techniques for Stress Field Constraints from Boreholes

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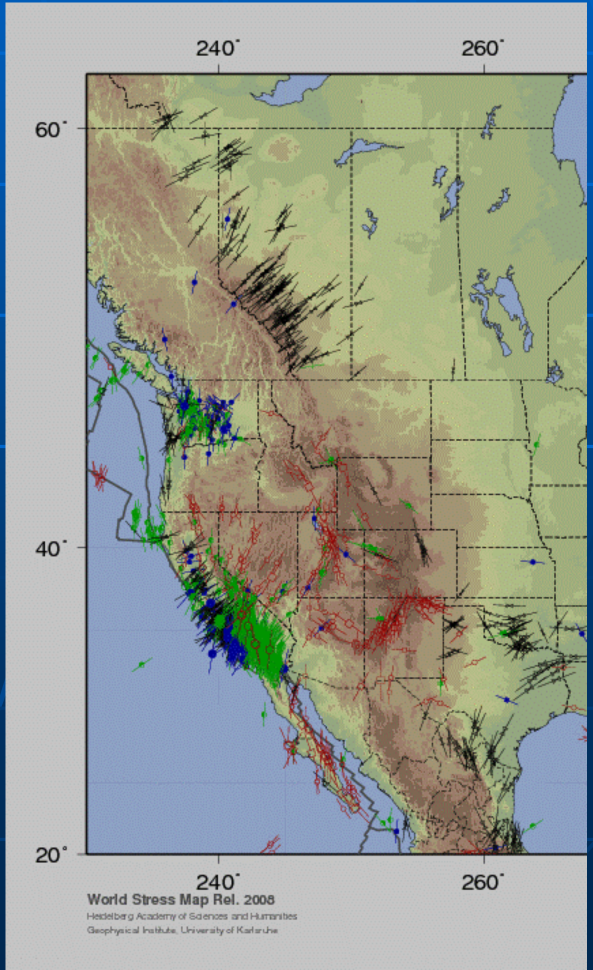
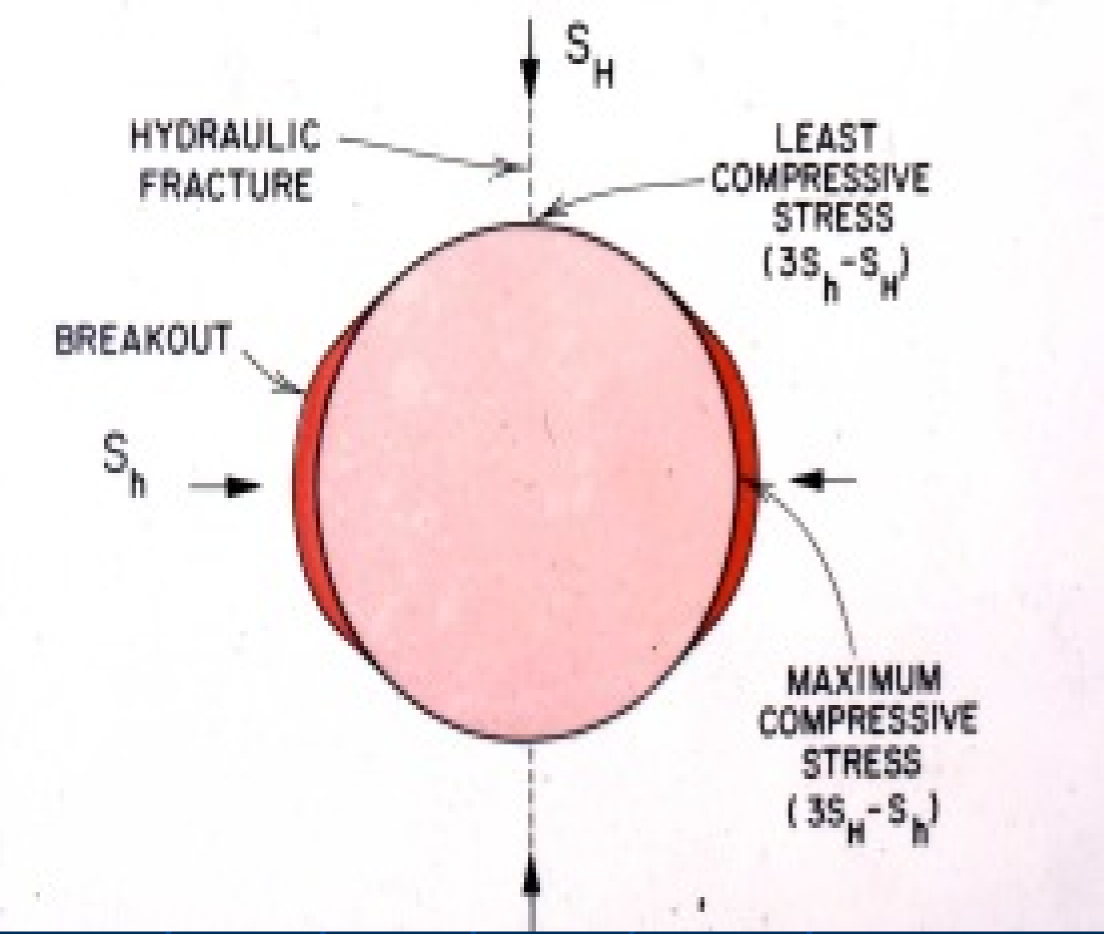


Directions of principal stresses

In vertical wells:
Assume a simple orientation of the stress field: Sv. SH and Sh

- Use orientations of borehole breakouts
- Use orientations of drilling induced hydraulic fractures
- Use orientations of hydraulic fractures deliberately produced in a packed off interval



Elastic equations for stresses around a cylindrical hole (Kirsch, 1898)

480

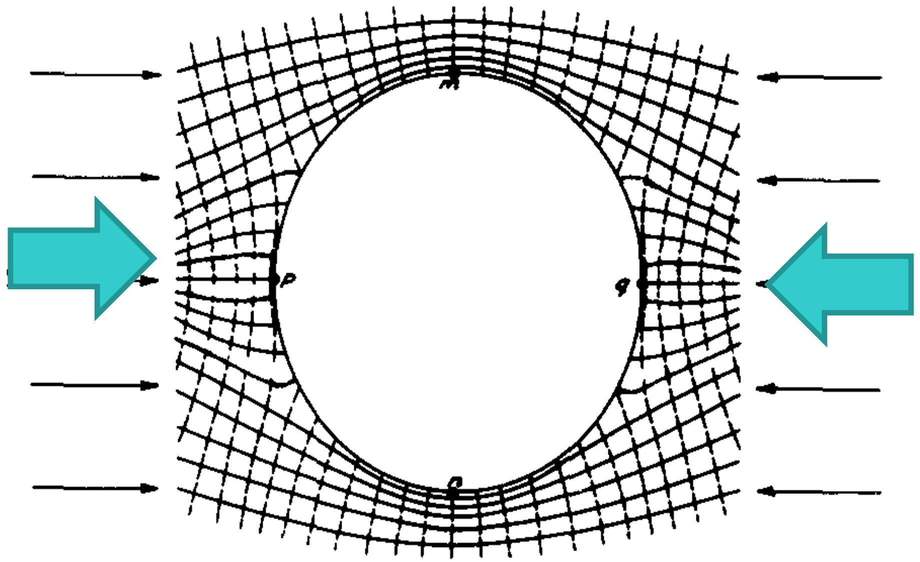


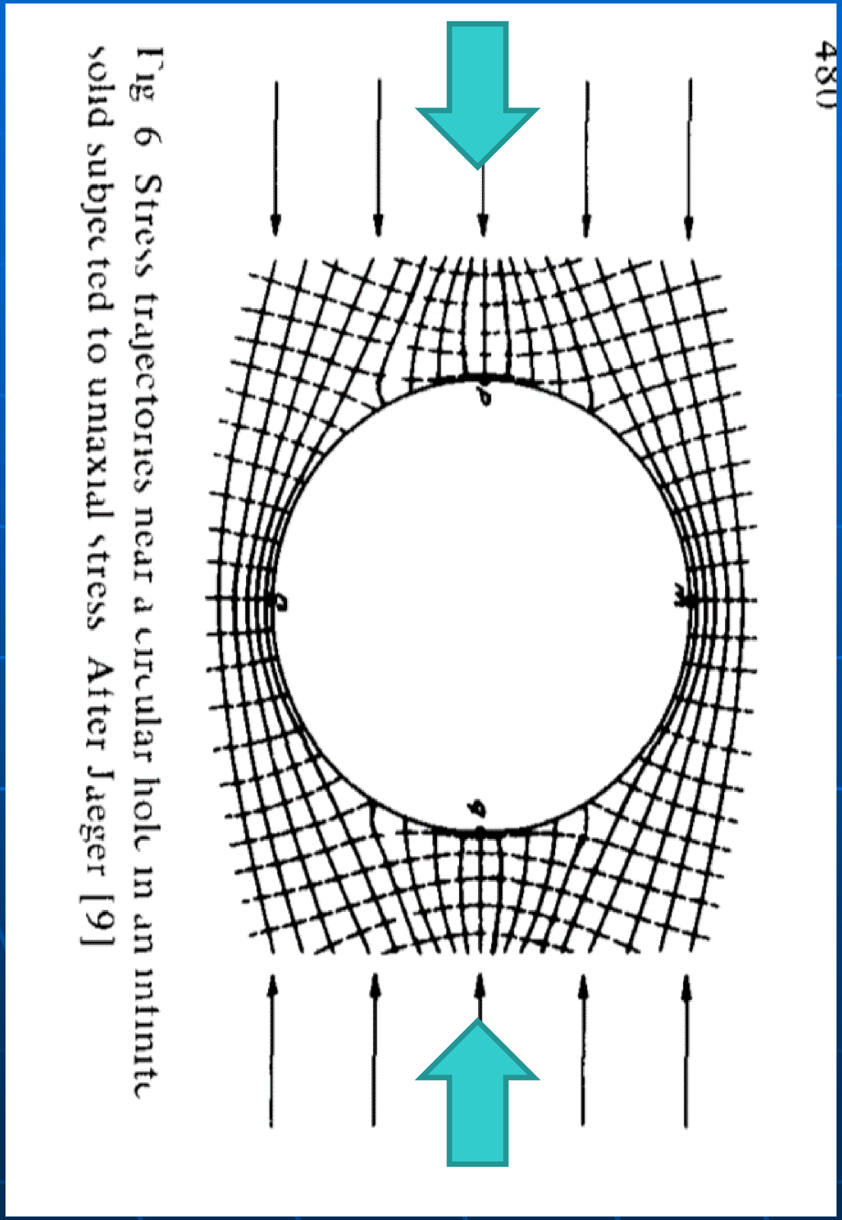
Fig 6 Stress trajectories near a circular hole in an infinite solid subjected to uniaxial stress After Jaeger [9]

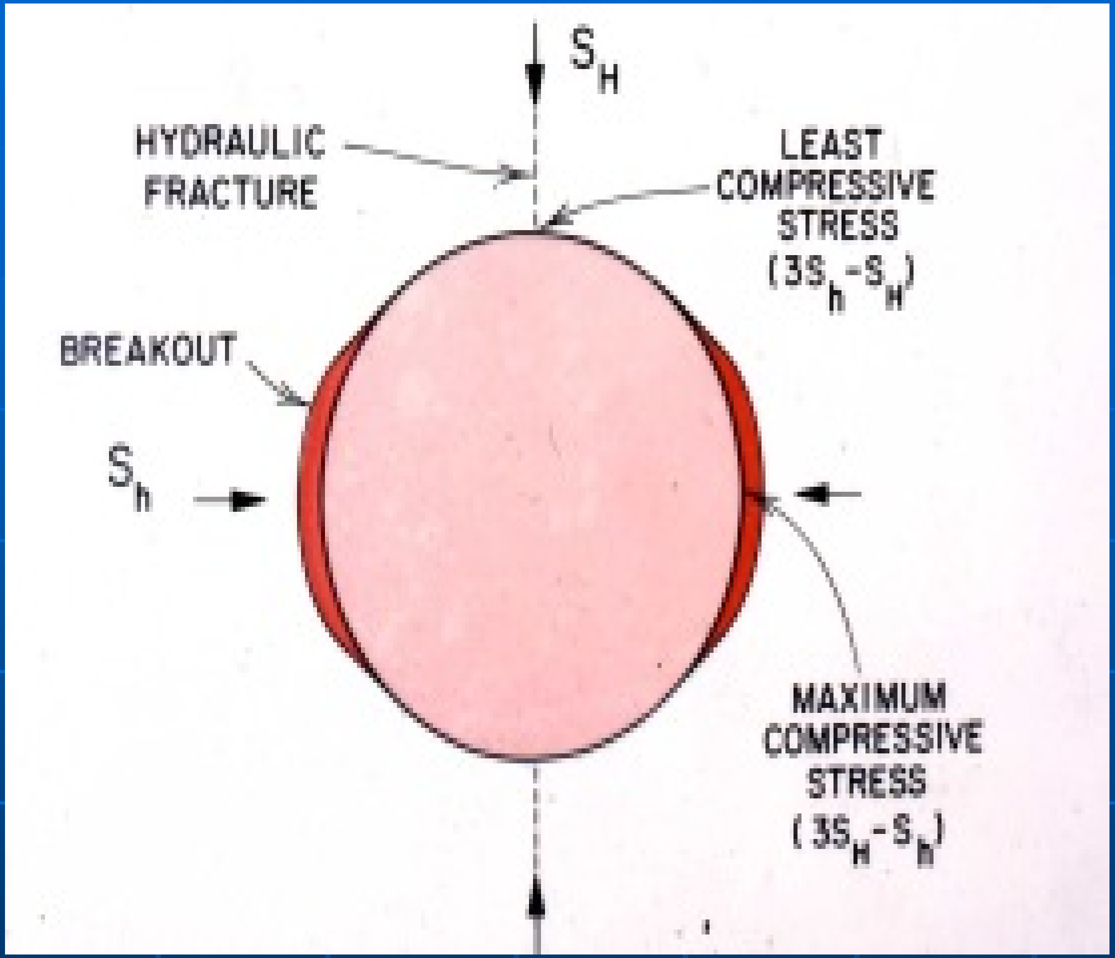
Stress trajectories closer together = more compressive

Stress trajectories farther apart = more tensile

Stress trajectories are perpendicular to free surface since it cannot support shear stress

Uniaxial stress





Stress trajectories closer together = more compressive

Stress trajectories farther apart = more tensile

Shapes of Breakouts

- Zoback, Mark D.; Moos, Daniel; Mastin, Larry; and Anderson, Roger N., "Well Bore Breakouts and in Situ Stress" (1985).
- These shapes are from Borehole Televiewer

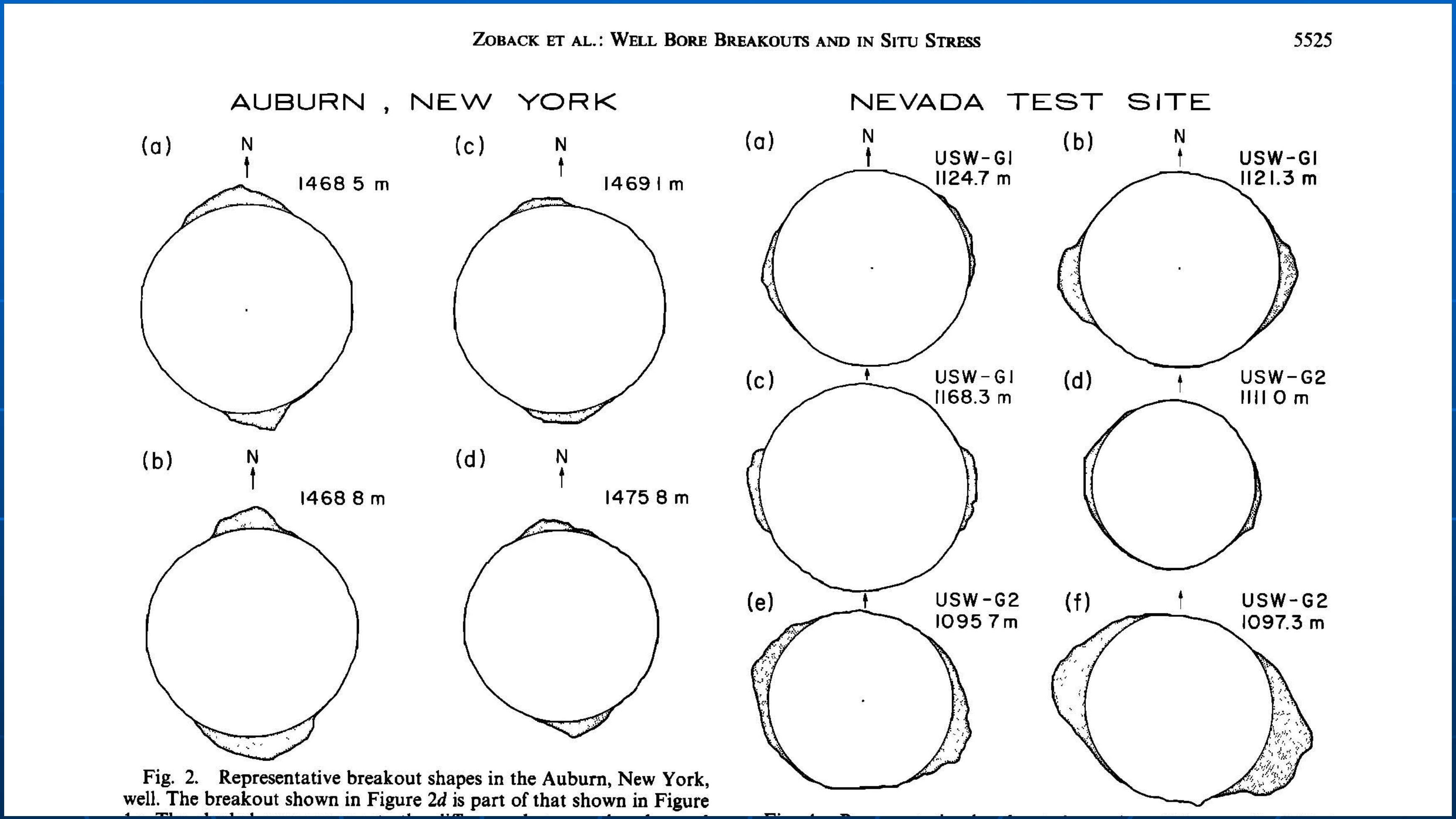


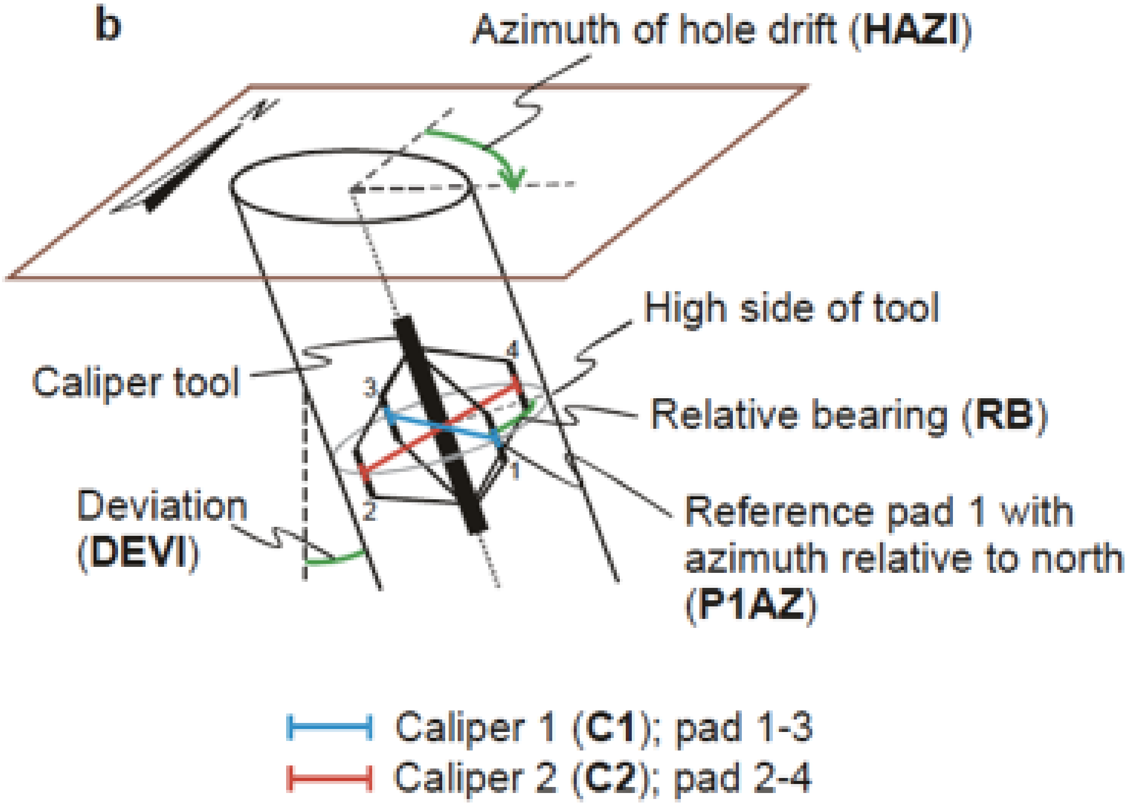
Fig. 2. Representative breakout shapes in the Auburn, New York, well. The breakout shown in Figure 2d is part of that shown in Figure

Not all wells have breakouts! A difference in magnitude of SH and Sh is needed.

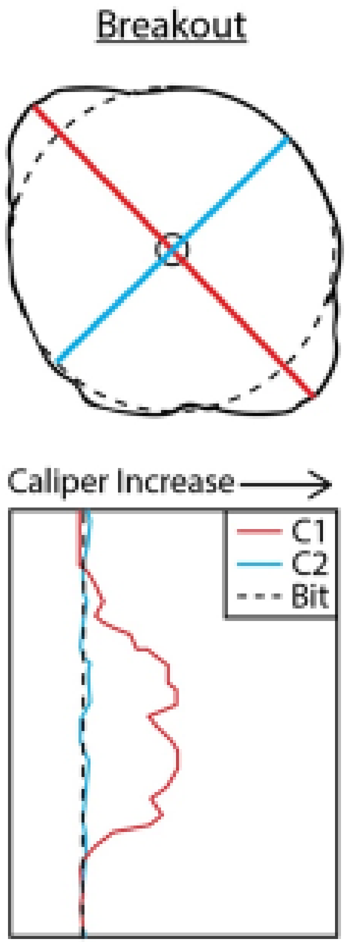
How do we image the directions?

1. Borehole Breakout Identification:
4-arm Caliper Tool

Plumb and Hickman (1985)



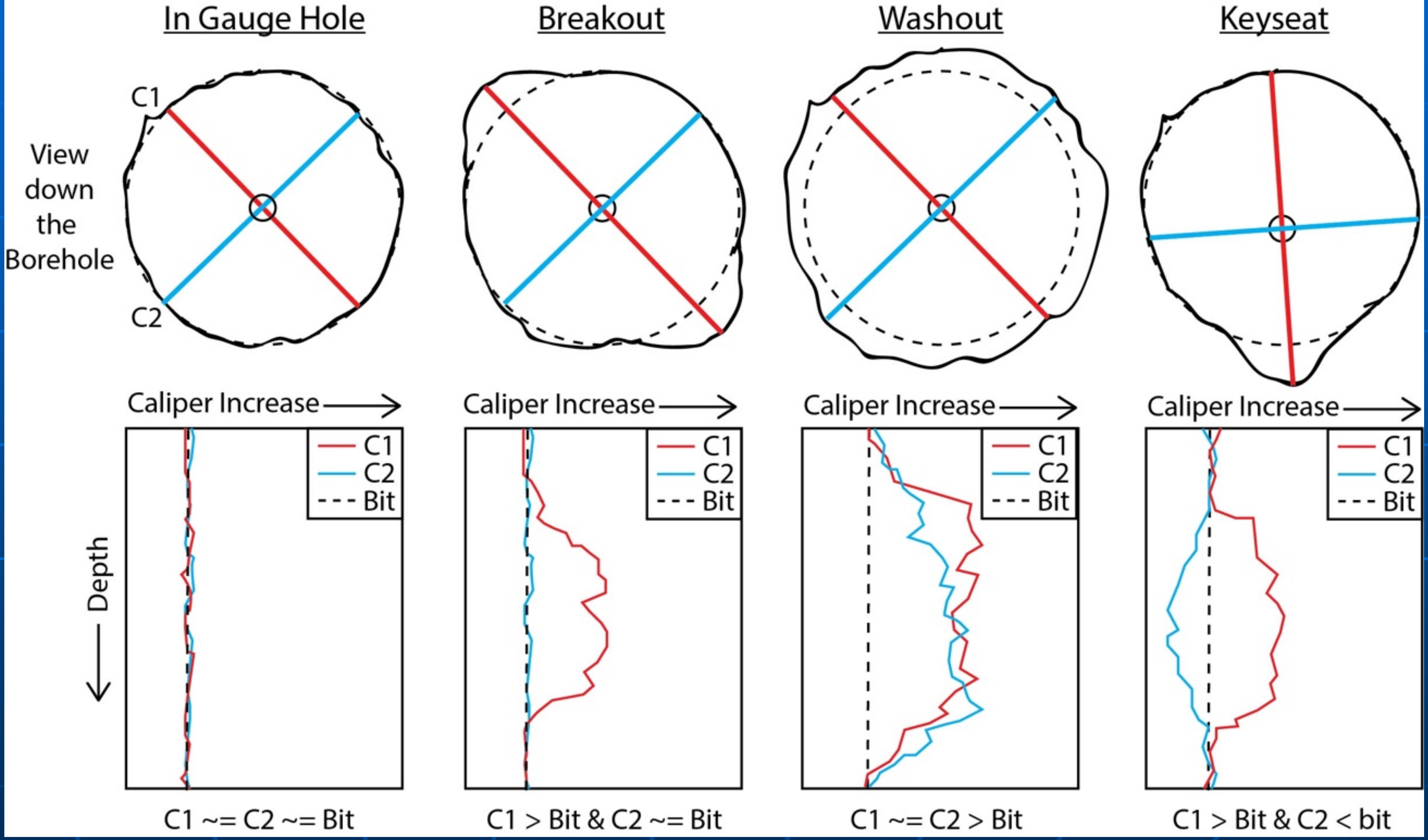
Reinecker et al. (2003)



C1 > Bit & C2 ~= Bit

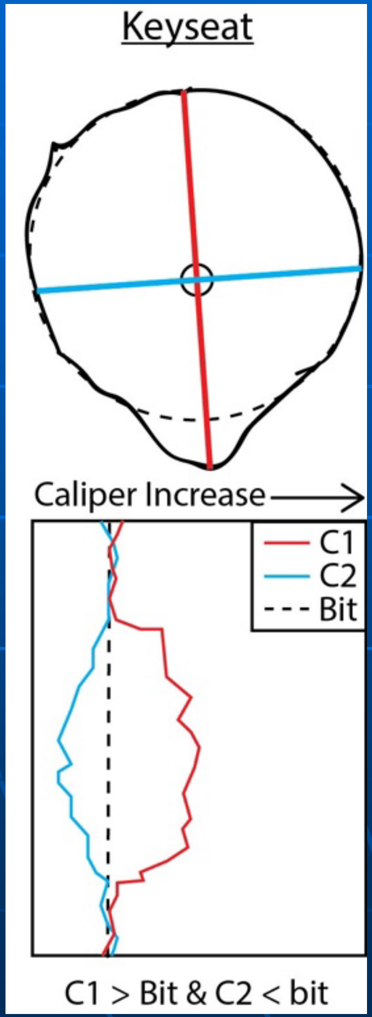
1. Borehole Breakout Identification: Breakout Selection Criteria

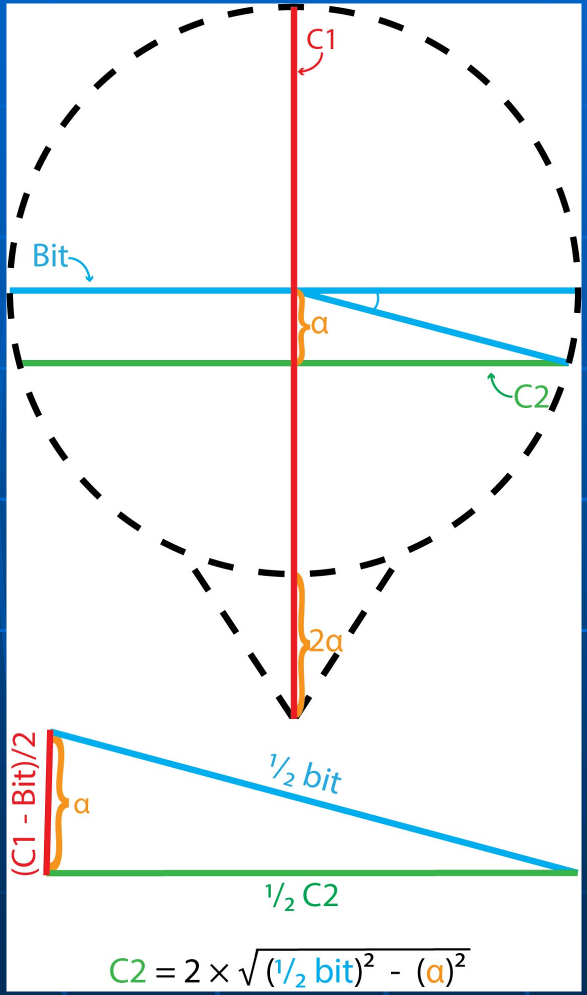
1. Tool rotation ceases
2. Calipers at least 5% different from one another
3. Smaller caliper close to bit size
4. Keyseat Criterion
5. Breakouts length > 3 m or > 1m at Holly

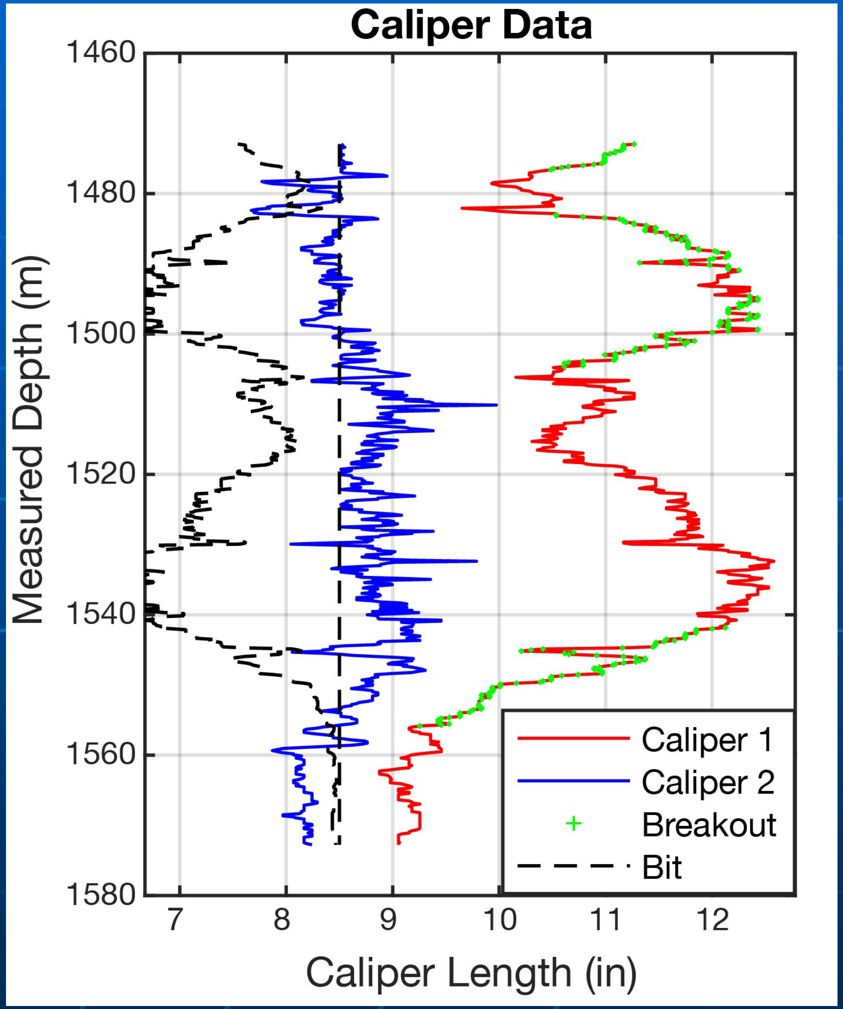


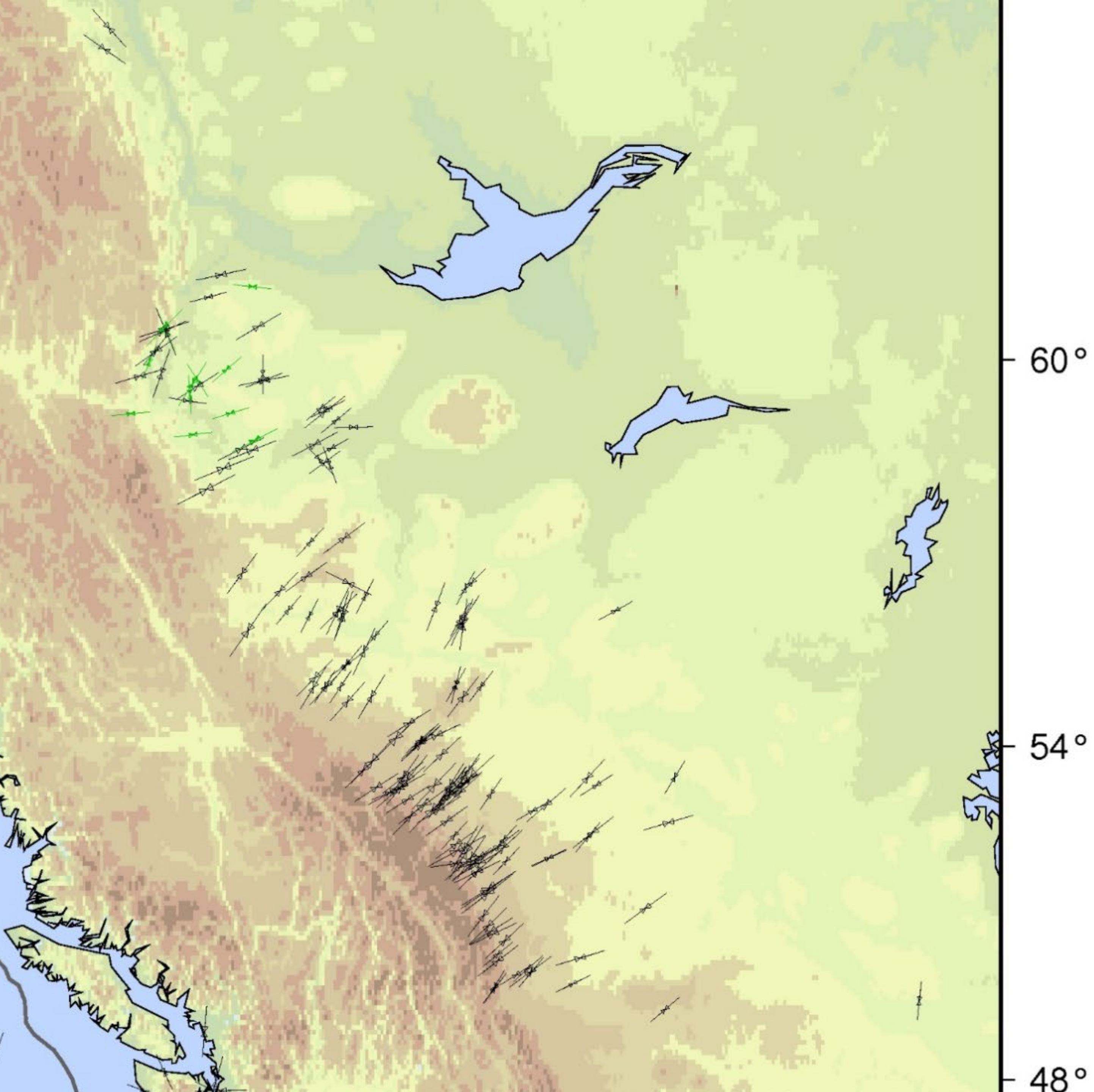
Sketch based on Reinecker et al. (2003)

1. Borehole Breakout Identification: Keyseat Criterion









Heidbach, Oliver; Rajabi, Mojtaba; Reiter, Karsten; Ziegler, Moritz; WSM Team (2016): World Stress Map Database Release 2016. GFZ Data Services. doi.org/10.5880/WSM.2016.001

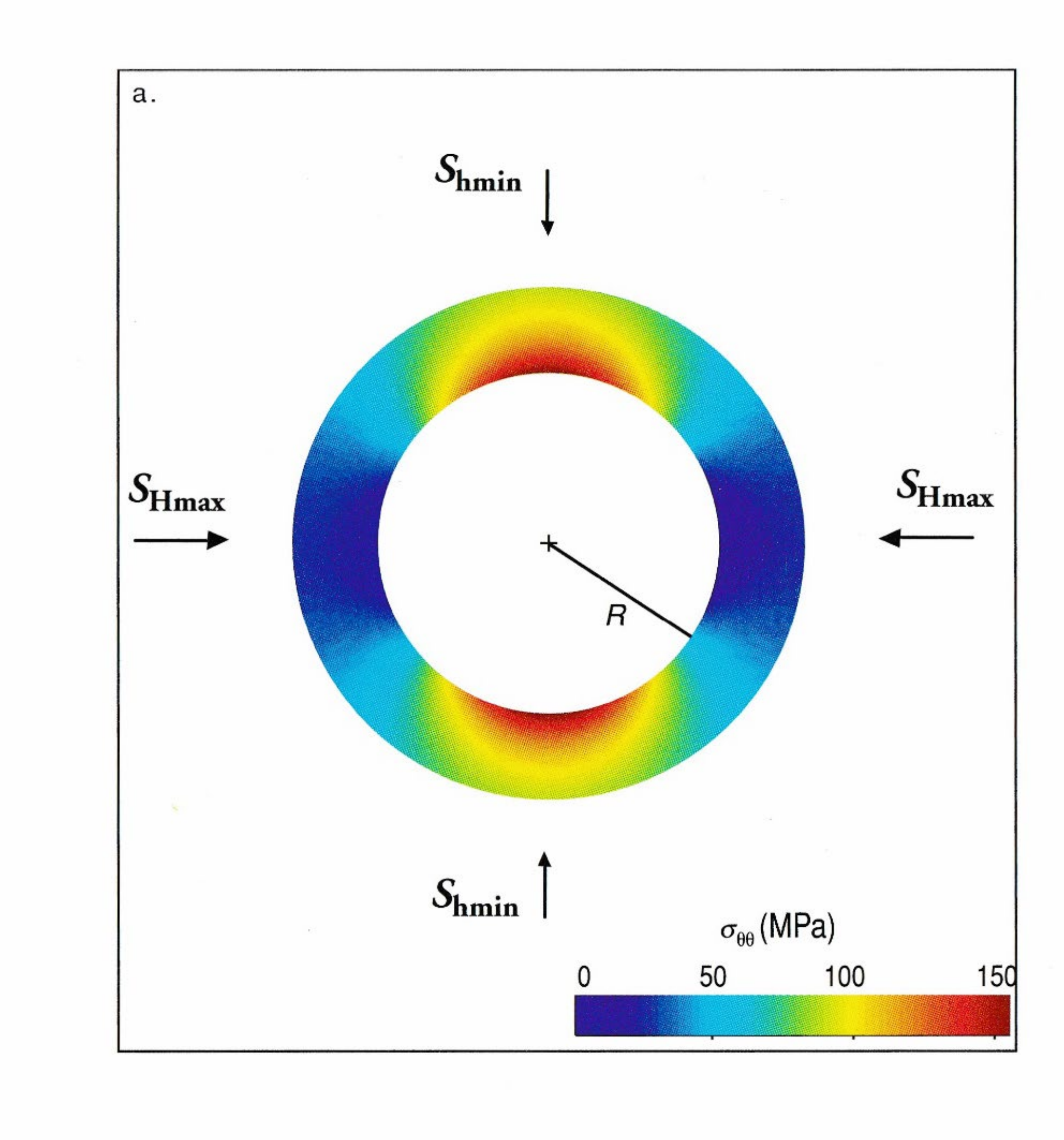
Arrows = SH direction.

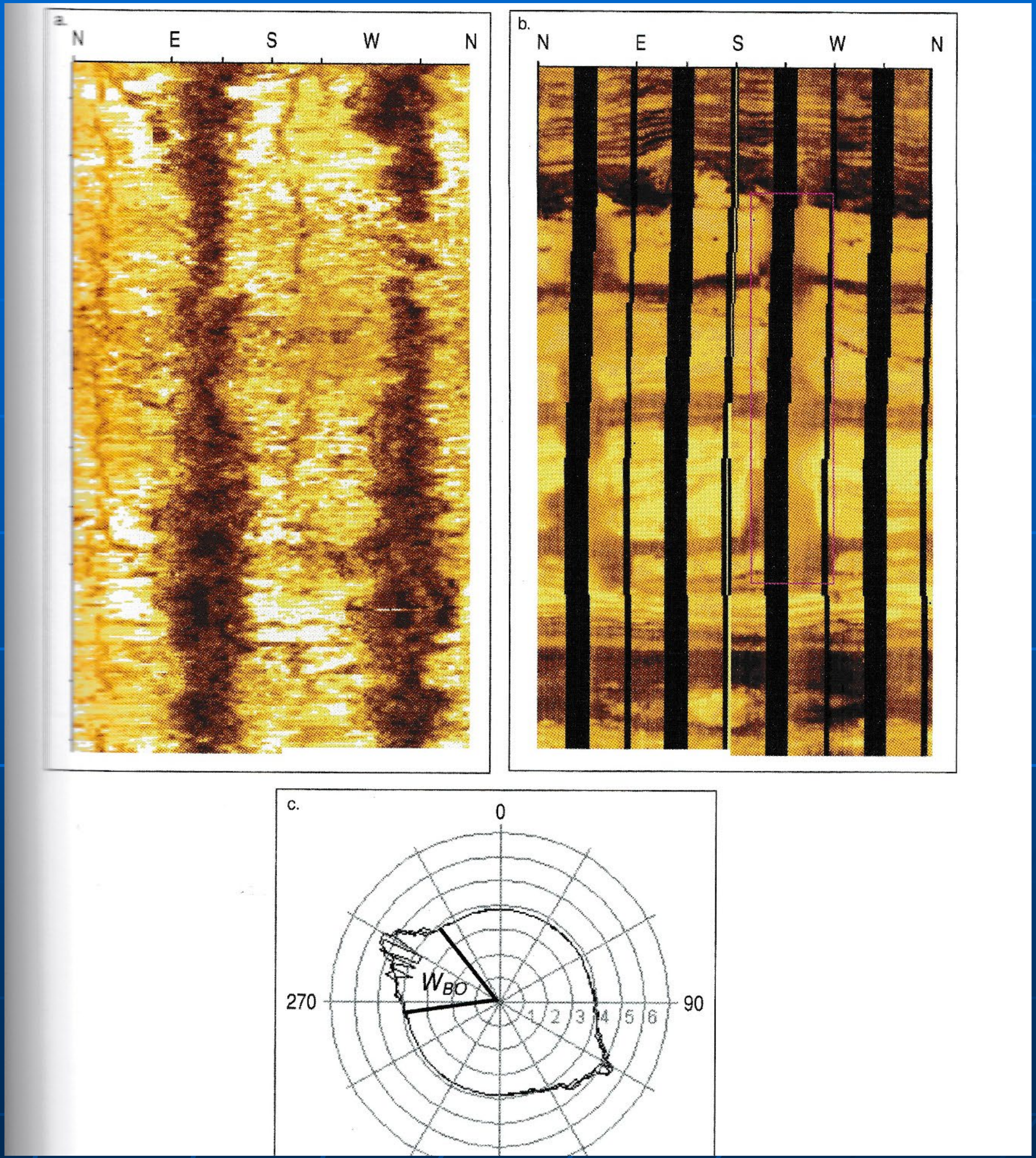
Many regions have relatively consistent SH directions over a large area (e.g., Alberta Basin, Canada).

This has been known since Cox (1970).

Acoustic image (right) and electrical image (far right) using newer tools; theoretical stress model in color below

From Zoback, Reservoir Geomechanics

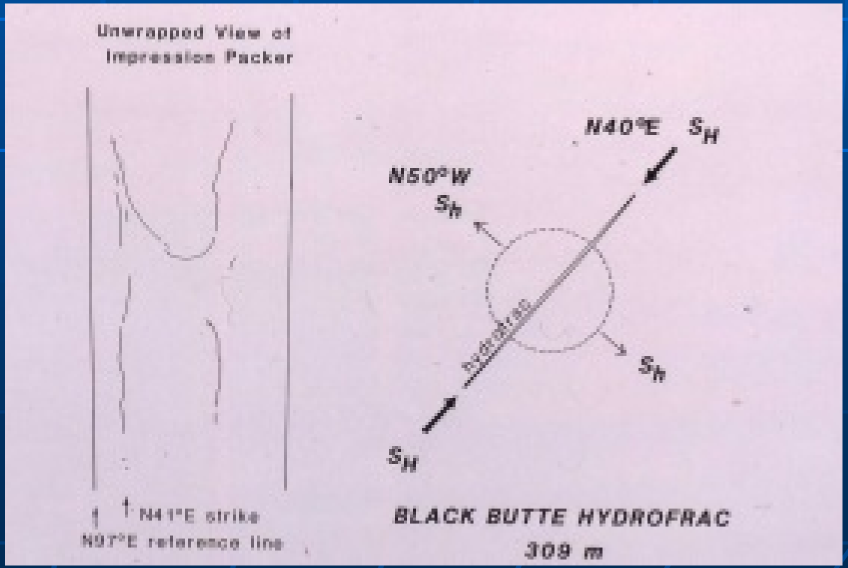




How to get the orientation of a hydraulic fracture? If you can't see it in the acoustic or electrical images:

- Run impression packer to get impression of fracture that formed
- Determine orientation of fracture that formed

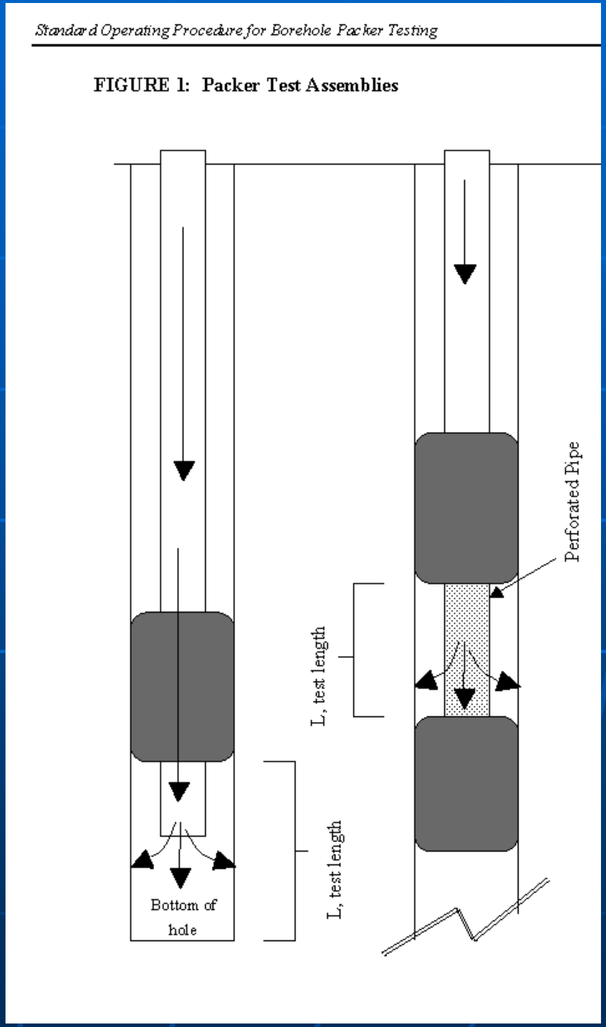
Impression Packer



Magnitudes of principal stresses

A. Directly measure pressure required to open/close a hydraulic fractures of known orientation. This fluid pressure is a measurement of the ***absolute stress*** on this fracture at this location.

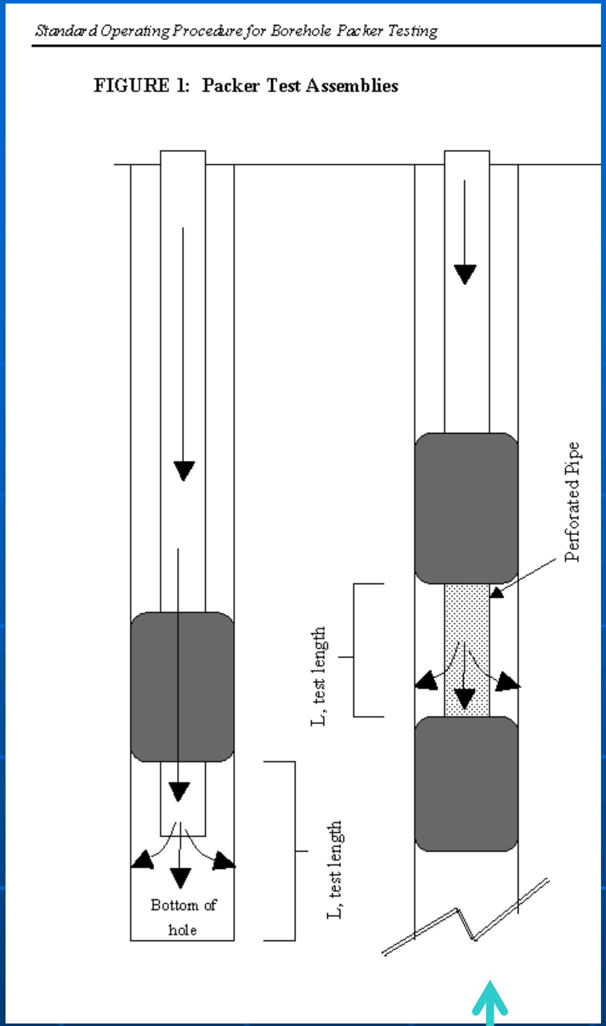
Limited by the depth range of the drill holes



The Hydraulic Fracturing Method (officially in use since 1957)

USGS Drill Rig

Black Butte, Mojave Desert, CA 1987



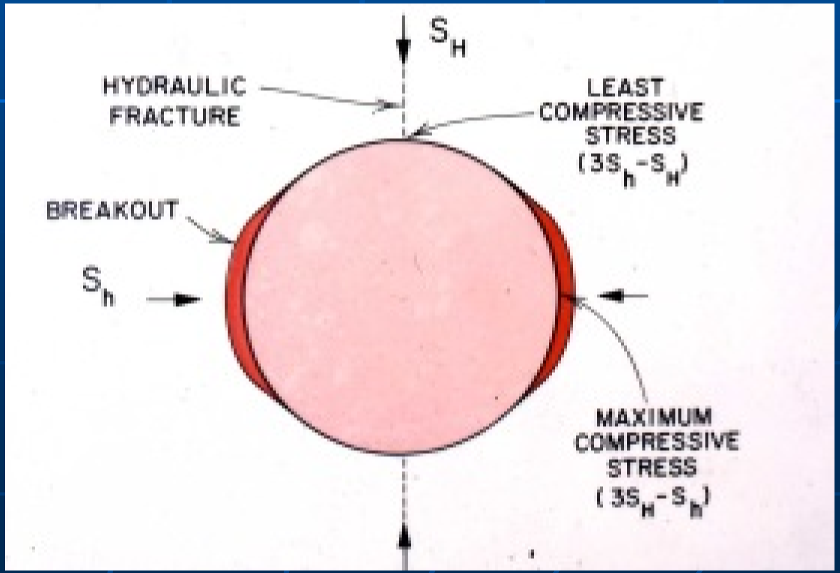
1. Isolate a section of the borehole using a "straddle packer" (two inflatable packers)

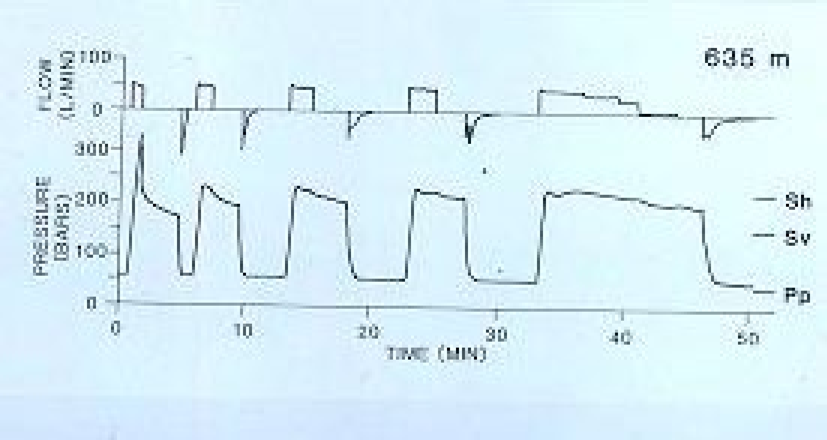
2. Inject fluid under high pressure into this section of the borehole

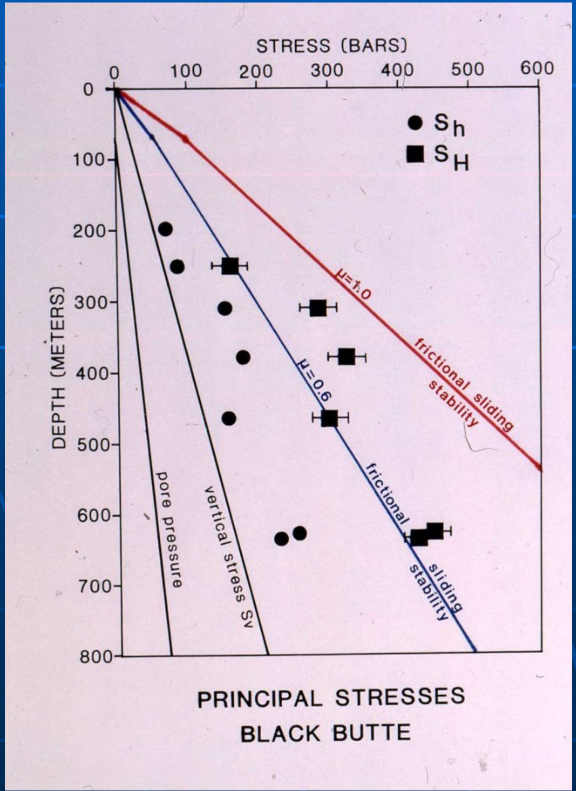
3. When pressure is high enough it will fracture the borehole wall and a fracture will extend out away from the borehole **The fracture should be perpendicular to Sh min.**

Packers in borehole

Cross section of borehole







FLOW TESTS

- Measure fluid flow (top curve, left)
- Measure fluid pressure in interval between the packers (bottom curve on the left)

Curves show when fluid is going into fracture and coming out of fracture. The pressure at which the fracture closes = "shut-in pressure" = magnitude of S_h.

Hydrofrac equation:
$P_{breakdown} = 3S_h - S_H + T - P_{pore}$

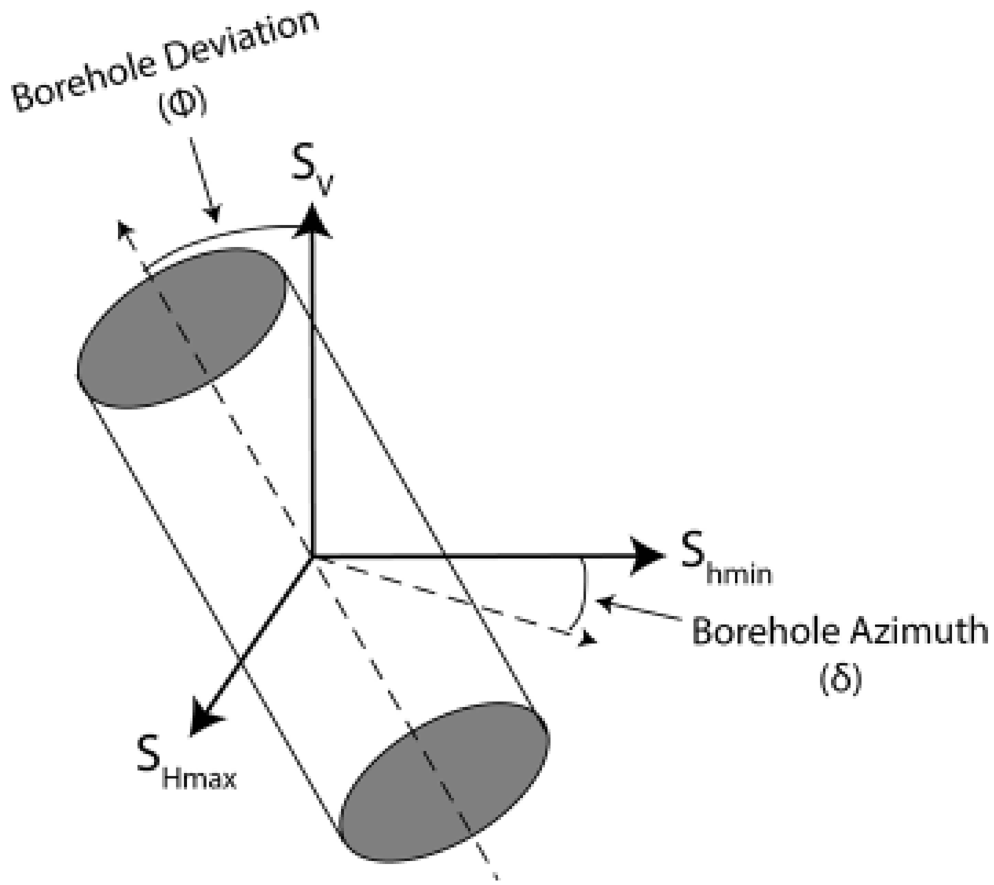
We can derive the magnitude of SH from Sh if we have a good breakdown pressure, and estimates of Tensile Strength T, and pore pressure P_{pore}.

Stress vs. depth plot (left) shows whether faults are close to slipping

Figures from Stock & Healy, 1988, J. Geophys. Res.

Borehole Breakouts and Stress: Deviated Wellbores

- Wellbore <u>not</u> parallel to vertical principal stress
- Breakout orientation depends on:
  - Orientations and relative magnitudes of all 3 principal stress components
  - Orientation of the wellbore itself
- Can constrain orientations and relative magnitudes of all three principal stress components



Based on Zajac (1997)

Assumptions for using deviated wells

The stress tensor is not changing over short distances.

Wells drilled in different directions from the same drilling platform are subject to the same stress field and can be inverted together to yield a complete stress tensor.

(Check this by evaluating the consistency in breakout orientations for different wells that are subparallel to each other in 3D.)