Well Logging Principles and Applications
G9947 - Seminar in Marine Geophysics
Spring 2008

In situ STRESS estimation
Why do we care about in situ stress?
Wellbore (& foundation) stability

\[ S_H = \text{max. Horizontal stress} \]
\[ S_h = \text{min. horizontal stress} \]
\[ S_v = \text{vertical stress} \]
Sources of in situ stress information:

1. Earthquake focal mechanisms
2. Wellbore breakouts*
3. Hydrofracturing*
4. Elastic-wave anisotropy*
5. Overcoring* / doorstoppers
6. Quaternary fault slip
7. Alignment of volcanoes

* borehole methods
Overcoring - in situ stress relief
Hydrofracturing
Hydrofracturing

\[ P_b = T + 3S_{H_{\text{min}}} - S_{H_{\text{max}}} - P, \]

where \( T \) is the tensile strength of the rock and \( P \) is the static pore pressure in the rock surrounding the borehole. As \( T \) and \( P \) can be determined independently, Equation (1) allows \( S_{H_{\text{max}}} \) to be determined. Assuming that one of the principal stresses is oriented vertically, the third principal stress can be estimated from \( S_v = \rho g H \), where \( \rho \) is the average density, \( g \) is gravity, and \( H \) is the depth to the interval that is isolated by packers.
Wellbore Breakouts

**Schematic of Photograph**
- Original borehole shape
- Hole ovalisation caused by pieces of wellbore wall spalling off
- Zones of failure that have not spalled off
- Conjugate shear failure planes
Wellbore Breakouts

\[ S_c = S_H + S_h - 2(S_H - S_h)\cos 2\Theta_b - \Delta P_b \]

\[ \tau_0 = S_c, \text{ at } \Theta_b = \pi/2 - \Phi_b \]
Effects of $\Delta S_H$ and friction

- $S_H' = 10$ MPa, $S_H = 15$ MPa
- $S_H' = 10$ MPa, $S_H = 20$ MPa
- $S_H' = 10$ MPa, $S_H = 30$ MPa

$\mu = 0.5$ and $\mu = 1.0$

Effect of Borehole Pressure

- $\Delta P = 0$
- $\Delta P = 2.5$ MPa
- $\Delta P = -2.5$ MPa

Breakout shapes under successive episodes of failure.
4-arm caliper tool

\[ P1AZ = \text{HAZI} + \arctan\left(\frac{\tan RB}{\cos \text{DEVI}}\right) \]

(a) In gauge hole
(b) Breakout
(c) Washout
(d) Key seat

Caliper increase

Depth

Bit size C1

C1

C2
4-arm caliper log

NORTHEAST-SOUTHWEST COMPRESSIVE STRESS IN ALBERTA. EVIDENCE FROM OIL WELLS

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Acoustic Televiwer (BHTV) tool

The BHTV (Borehole Televiewer) is an acoustic tool used in the oil and gas industry for imaging the borehole wall. It consists of a cylinder-shaped transducer that is rotated by a motor and provides images of the borehole's inner surface. The tool is particularly useful for detecting and mapping the formation's internal features, such as fractures or natural breaks, which are crucial for optimizing drilling and well completion procedures.
BHTV breakout image
Resistivity (FMS/FMI) tools

Figure 2.2.27. FMI images over a layered carbonate sequence with at least two distinct planar fracture sets, on dipping towards SSW, the other dipping steeply towards NNE.
Resistivity (LWD) tools

- geoVISION Resistivity (6-3/4)
- Resistivity-at-the-Bit (8-1/4)
- Laterolog, like FMS/FMI
LWD Breakout images

e.g. Nankai trough

shallow  medium  deep
LWD Breakout orientation

e.g. Oregon Margin
Breakouts and Fractures
(present-day stress)  (paleo-stress)
e.g. Gulf of Mexico
Breakouts and Fractures
(present-day stress)    (paleo-stress)
e.g. Newark Basin
Breakouts and Fractures
(present-day stress)  (paleo-stress)
e.g. Newark Basin

Core fractures

Core vs BHTV
Breakouts and Fractures
(present-day stress)   (paleo-stress)
e.g. Newark Basin

Martinsville

Breakouts - 90°

Nursery Road
Breakouts, EQs, and Fractures

e.g. Newark Basin
Elastic wave anisotropy

- Wave propagate faster when the direction of particle motion is parallel to the direction of greatest stiffness.
- The “fast” shear wave will travel in the direction of maximum horizontal stress.
Stress-induced anisotropy - ?

Winkler et al. (1998)
Stress-induced dispersion

Vs dispersion

$V_{fast}$ crossover

![Graphs showing velocity vs frequency under different stress conditions.](image-url)
Cross-dipole Vs logging
Stress-induced anisotropy

Rotated dipole waveforms

Dispersion crossovers
Stress-induced anisotropy

e.g. Kane Fracture Zone
Stress-induced anisotropy

e.g. Kane Fracture Zone
Stress-induced anisotropy
e.g. San Andreas Fault
Stress-induced anisotropy

e.g. San Andreas Fault

No Breakouts, high Anisotropy

⇒ Stress relief zones