Real Stress Distributions through Sedimentary Strata and Implications for Reservoir Development and Potential Gas and Coal Development Strategies

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Main Means of Rock Stress Measurement

• Overcoring
• Hydrofracturing
• Borehole Breakout Analysis
• Slotting
• Indirect Means
  Kaiser Effect
  Post Elastic Strain Recovery
Overcoring

• Most direct system

• Requires, elastic though not necessarily linearly elastic response

• This means that failure of the borehole wall is a problem, ie if major stress is above $\frac{1}{4}$ to $\frac{1}{3}$ of UCS breakout may occur
Overcore devices

• Glued devices
  – Doorstoppers
  – Leeman Triaxial Cell
  – CSIRO HI Cell

• Mechanical Devices
  – USBM deformation gauge
  – Sigra IST tool
Hydrofracture

- Practically a biaxial stress measurement technique
- Requires elastic theory to obtain major stress – but can deliver minor stress with failed borehole wall
- Strongly influenced by pre-existing fractures
- If minor stress is perpendicular to hole then there is a problem
Hydrofracture Plot of Total Test Sequence

Hydrofracture plot of total test sequence
Fracture Trace on Impression Packer
Problems with Hydrofracturing for Stress Measurement

- Packer pressure must exceed fluid pressure

  therefore

- Packer scaling pressure on hole wall will generally initiate failure

- Fracture opening pressures are flow rate dependent

- Need to use controlled pressure rise not flow to see fracture initiation
IMPRESSION OF FRACTURE INITIATED BY PACKER STRESS
Hydrofracturing may still be useful

• When someone asks you to measure stress after the hole is drilled
• To establish a minimum stress from closure
• As part of diagnostic fracture injection testing when the closure phase is used for permeability measurement
  – Though the analysis for permeability leaves a bit to be desired
Acoustic scan showing breakout
Borehole Breakout

• Primarily Biaxial stress direction indicator
• May be analysed for stress value if you know the UCS of the rock and the minimum stress (from hydrofracture closure)
• Relations between sonic logs and UCS not adequately reliable for quantitative analysis of breakout
Sigra IST system

• Quick biaxial overcore system
  – 100 m hole overcore in 1 ½ hours
  – 500 m hole overcore in 2 ½ hours
  – 800 m hole overcore in 3 ½ hours

• Used primarily with HQ wireline coring system

• Mostly used in vertical holes

• Capable of operation to 1500 m vertical depth
Sigra Stress Measurement Tool
In-Situ Stress Measurement Tool

**STEP 1**
Breaking last core run

**STEP 2**
Drilling the counterbore

**STEP 3**
Drilling the pilot hole

**STEP 4**
Setting the tool
IN-SITU STRESS MEASUREMENT TOOL

STEP 5: Pulling back the rods for a compass reading
STEP 6: Overcoring
STEP 7: Pulling the core and tool
STEP 8: Extracting the data
IST tool in core
IST tool out of core
Full tool trace
Overcore Detail
Useful Features

- 1 x 6 pin set solution
- 6 x 5 pin set solution
- 15 x 4 pin set solution
- 20 x 3 pin set solution – do not use as no redundancy
- Can handle minor breakout or fracture problems – just ignore pin result
<table>
<thead>
<tr>
<th>Hole Reference</th>
<th>Sigra In-situ Stress Test (IST) Reference</th>
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<tbody>
<tr>
<td>Date of Test</td>
<td></td>
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<tr>
<td>Material Description</td>
<td>Sandstone</td>
</tr>
<tr>
<td>Depth of Run</td>
<td>709.13 m</td>
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<tr>
<td>Young's Modulus</td>
<td>15,083 MPa</td>
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<tr>
<td>Poisson's Ratio</td>
<td>0.14</td>
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<tr>
<td>Unconfined Compressive Strength, UCS</td>
<td>74.60 MPa</td>
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<tr>
<td>Mean Effective Stress</td>
<td>16.02 MPa</td>
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<tr>
<td>Deviatoric Stress</td>
<td>4.80 MPa</td>
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<tr>
<td>Angle of Principal Effective Stress</td>
<td>23.08 Degrees from Magnetic North</td>
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<td>RMS Error</td>
<td>1.80 %</td>
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<tr>
<td>Maximum Principal Effective Stress</td>
<td>20.82 MPa</td>
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<tr>
<td>Minimum Principal Effective Stress</td>
<td>11.22 MPa</td>
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<td>Ratio of Maximum Effective Stress over UCS</td>
<td>0.28</td>
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<tr>
<td>Horizontal Effective Stress due to Self-weight</td>
<td>1.70 MPa</td>
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<tr>
<td>Maximum Tectonic Stress</td>
<td>19.12 MPa</td>
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<tr>
<td>Minimum Tectonic Stress</td>
<td>9.51 MPa</td>
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<tr>
<td>Maximum Tectonic Strain</td>
<td>1.18E-03</td>
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<tr>
<td>Minimum Tectonic Strain</td>
<td>0.456E-04</td>
</tr>
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</table>
IST Used in multiple rock types

• Very weak rock with UCS of 4 MPa – Crinum Colliery

• Very hard rock with UCS of 280 MPa and stiffness of 80 GPa at Burdekin Falls Dam Spillway
Tectonic Strain

• Sedimentary rocks have stiffness that varies layer by layer
• Stresses vary with stiffness
• Tectonic strain is the strain that is required to develop the measured stress
• The general rule is that tectonic stresses are fairly even through sedimentary sequences. There are exceptions
Layered Sedimentary Strata with Varying Stiffness and Poisson’s Ratio

Major and Minor Stress (MPa) and Tectonic Strain Through a Typical Sedimentary Sequence
Major Stress and Tectonic Strain
Major Stress
RED
Tectonic Strain
BLACK
Tectonic Strain Origins

- Major plate tectonic loading
- Local folding
- Local stress relief through faulting
Faults Relieve Stress

- Normal Faulting – Major vertical stress
- Reverse Faulting – Minor vertical stress existed through failed strata
- Slip-Strike Faulting – Major and minor principal stresses horizontal
- Mixed fault types – changing stress regime
Some stress situation are quite simple. Reverse faults limiting stress. Single phase of loading?
Other stress distributions are much more complex. Multi-phase loading...
Coal Seams are Weak and May Shear in the Plane of the Seam

• Not uncommonly reverse faults may migrate into the seam and continue within the seam as a shear band that may extend for several kilometres.

• German Creek Seam

• Northern Ishikari Coal Field, Hokkaido

• D6 seam Karaganda Basin, Kazakhstan

• In-seam drilling becomes impossible
Prediction of Stresses

• If we can identify the tectonic strain regime then we can calculate the stresses through all of the strata based on:

  • Tectonic strain
  • Depth of burial
  • Stiffness of strata
Stiffness of Strata

- Preferably obtained from direct core testing
- May be more reliably obtained than UCS data from sonic logs
- Has huge implications for horizontal stress
- Coals have special behaviours
Young’s Modulus of Coal
Stress in Coal

• Use Tectonic Strain

• Use real coal modulus – varies with confining stress

• Check with hydrofracture for minor stress
Stress Around Holes

• If initial major effective stress => 2-3 x UCS strength failure around boreholes will occur
• This gets worse as fluid pressure is lowered and effective stress rises
• The hole is flushed by production fluids which remove broken material
• Sand / Fines production continues
Hydrofracture for Gas Production from Coals

• Fracture is propped open so it will not collapse
• Cannot hydrofracture from in-seam as borehole stability generally precludes this
• Casing cannot be left in seam as it prevents future mining
• Drill adjacent to the seam, case, cement, perforate and fracture into the seam
Drainage times Vs frac spacing for 15 to 3 cu.m/tonne methane
Borehole Location

• Preferably in the floor of the seam so as not to damage the roof for future mining
• In strata where the minor stress is horizontal so that the fracture propagates vertically – this depends on tectonic strain and stiffness of the strata
• Borehole is drilled to cross the direction of major stress (implications for hole stability)
The Importance of Stress Path

• The effective stress in coals changes with drainage due to lowering fluid pressure and due to the effects of shrinkage

• Which effect dominates?

• This is important as coal permeability is a function of effective stress.
The Effect of Stress

The permeability of cleated coals is controlled by stress.

General equation for permeability variation with stress

\[
\log k = \log k_0 - \frac{\Delta \sigma_{\text{eff}}}{b}
\]

\(b\) is the stress change that causes one order of magnitude change in permeability.
Horizontal Strains Vs Sorption Pressure

Shrinkage Samples with Langmuir Fit

- Gas Pressure kPa
- Strain με
High shrinkage, moderate sorption pressure
Low Sorption Pressure
Thank You for listening to a small part of what we do

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