Geomechanical Model, Leigh Creek, South Australia

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Contents

Glossary

Acronym	Description
B	Biot's Factor
BO	Borehole Breakout
BOW	Borehole Breakout Width
Cal	Caliper
CF	Coefficient Of Internal Friction
DDR	Daily Drilling Report
DFIT	Diagnostic Fracture Injection Test
E, E_{Dyn}, E_{Stat}	Young's Modulus, dynamic, static
ε_{Hmax}	Strain in σ_{Hmax}
ε_{hmin}	Strain in σ_{hmin}
FA	Friction Angle
GR	Gamma Ray
ISIP	Initial Shut In Pressure
LOT	Leak off Test
MD	Measured Depth
MPa	Mega pascal
MW	Mud weight
ν	Poisson's Ratio
NF	Normal Faulting
Por Sat	Saturated Porosity'
P_p	Pore pressure
ppg	Pounds Per Gallon
PR	Poisson's Ratio

Acronym	Description
psi	Pounds Per Square Inch
R	Reverse Faulting
Resis	Resistivity
RHO	Density
SG	Specific Gravity
S_{Hmax}	Maximum Horizontal Stress
S_{hmin}	Minimum Horizontal Stress
Sig1'	Major effective stress (SHmax')
Sig2'	Minor effective stress (Shmin')
SigV'	Vertical effective stress (Sv')
SR	Sinistral Reverse
SS	Strike Slip
σ_v	Vertical stress
Tect1 strain	Strain in SHmax direction
Tect2 strain	Strain in Shmin direction
TF	Thrust Faulting
TS	Strike Slip
TVDGL	True Vertical Depth from Ground Level
TVDml	True Vertical Depth from Mud Line
UCS	Uniaxial Cohesive Strength
Vp	Compressional Velocity
Vs	Shear velocity
m	Meters
g/cm^3	Gram Per Cubic Centimetre

1. Summary

Summary

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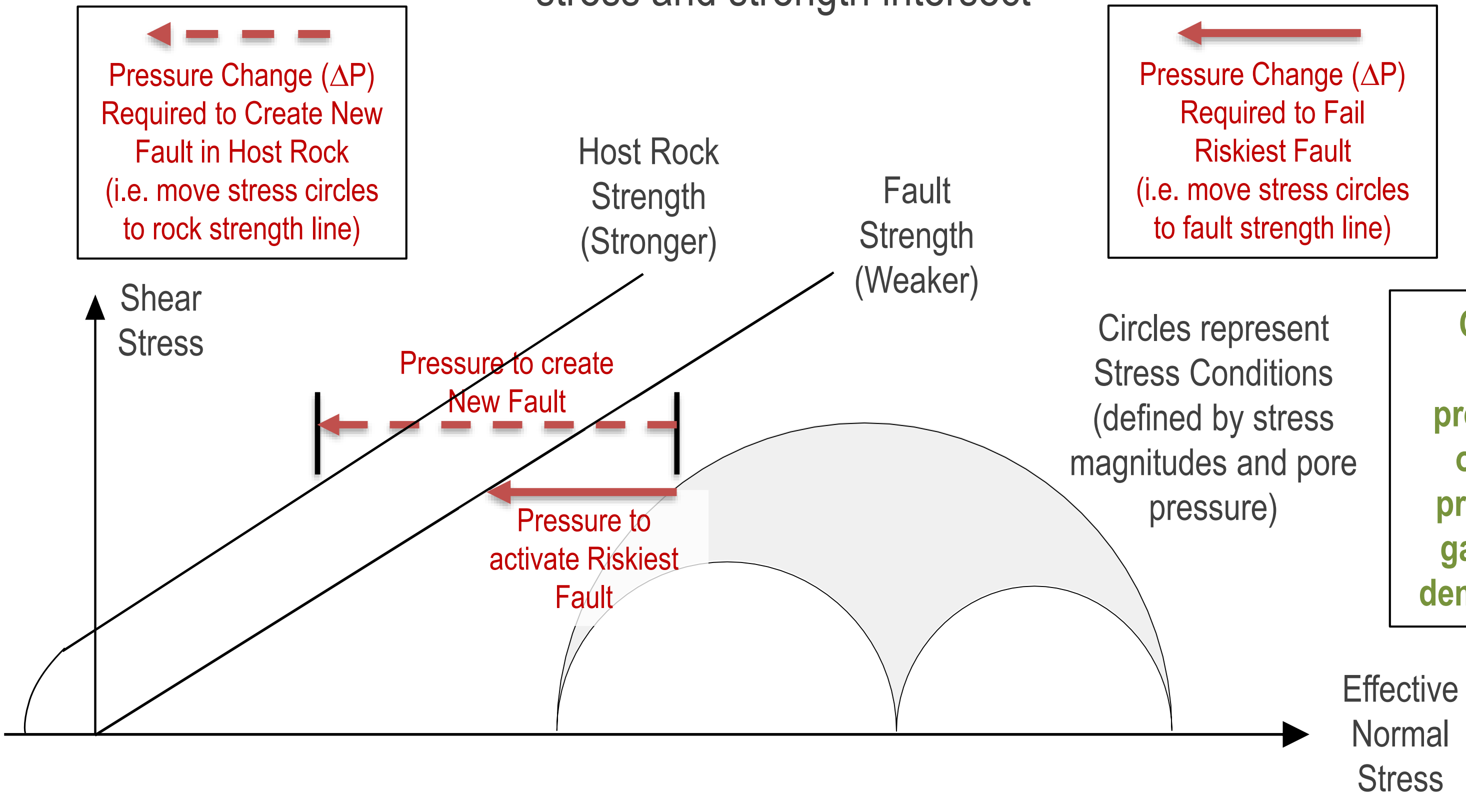
- **Problem:** What is the risk of reactivating existing faults/fractures and creating new faults/fractures within the overburden at the Leigh Creek Energy Coal Gasification demonstration site under operating conditions?
- **Scientific Proposition:** What is the likelihood that operating pressures will create or activate the highest risk fault orientation?
- **Approach:** Determine stress conditions and assess worst case scenario (conservative model)
  - What pressure will create a fault?
  - What pressure will reactivate critically oriented (riskiest) fault?
- **Method:** What is balance between stresses acting on faults and their strength?
  - Construct 1D geomechanical model
  - Assume rock and fault strength
  - Determine pressure change to induce failure and compare with operating pressures for gasification demonstration
  - Pressure change determined using Mohr Diagrams

Summary

- **Mohr Diagrams:** Illustrate the relationship between stress and strength – failure occurs where stress and strength intersect

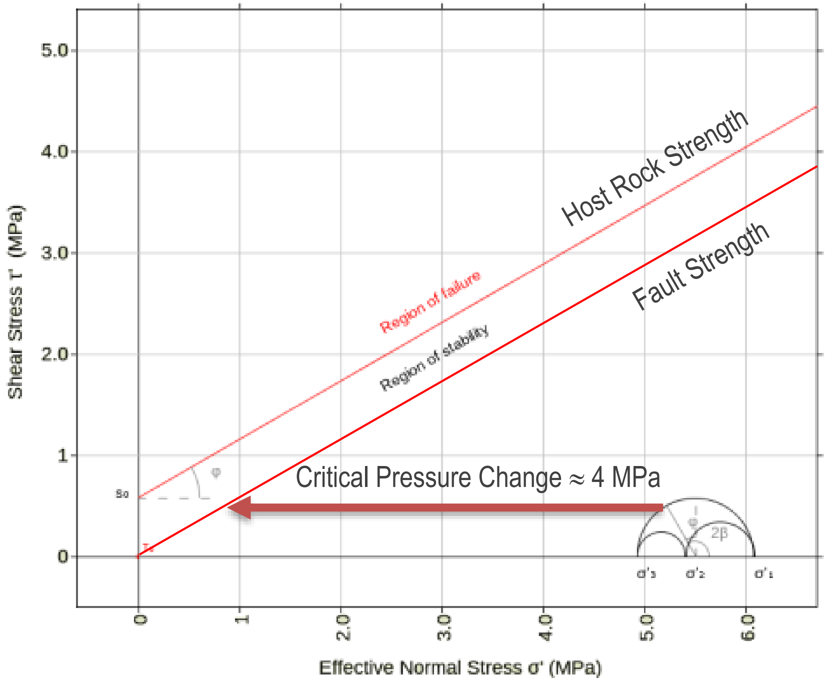


Compare critical pressures to operating pressure for gasification demonstration

Summary

- **Causes of uncertainty**
  - Poor DFIT (Diagnostic Fracture Injection test – affects Shmin calibration point)
  - No shear velocity data (Vs) – affects stress magnitudes
  - Variable overcoring results – affects stress magnitudes via uncertain calibration of strength and elastic properties
  - Regional vs. local stress orientation indicators – stress orientation
  - Faults and fractures from Leigh Creek mapping database (< 200m from surface) – uncertain fault distribution
- **Implementation to accommodate uncertainty**
  - Assess using multiple stress models to accommodate range of uncertain values
    - Expected Case
    - Strike Slip Case
    - Overcoring Case
  - Assess alternative stress orientations
- **Impact of stress modelling uncertainty on conclusions**
  - Stress Magnitudes – Minor
  - Stress Orientation – Minor
  - Fault Orientation and Location – Minor
  - Thermal Alteration of Strengths – Intermediate? Will faults become weaker with increased temperatures?

Summary



- Considering all models, critical pressure change to reactivate riskiest fault orientation is 4.25 MPa (43 bar) at 500m depth within overburden.
- Pressure overhead will increase with underbalanced operating pressures.
- All stress models predict compressional stress regime from surface to at least 70m depth.
- Critically oriented fault in compressional regime is sub-horizontal - bedding surfaces are likely features to be reactivated before inclined faults in these intervals.

TVDGL = 500.0 m, PP = 4.99 MPa, Shmin = 9.92 MPa, SHmax = 10.40 MPa, Sv = 11.08 MPa, SHmax Ori. = 50°N, Lithology = Mudstone

2. Executive Summary

Executive Summary

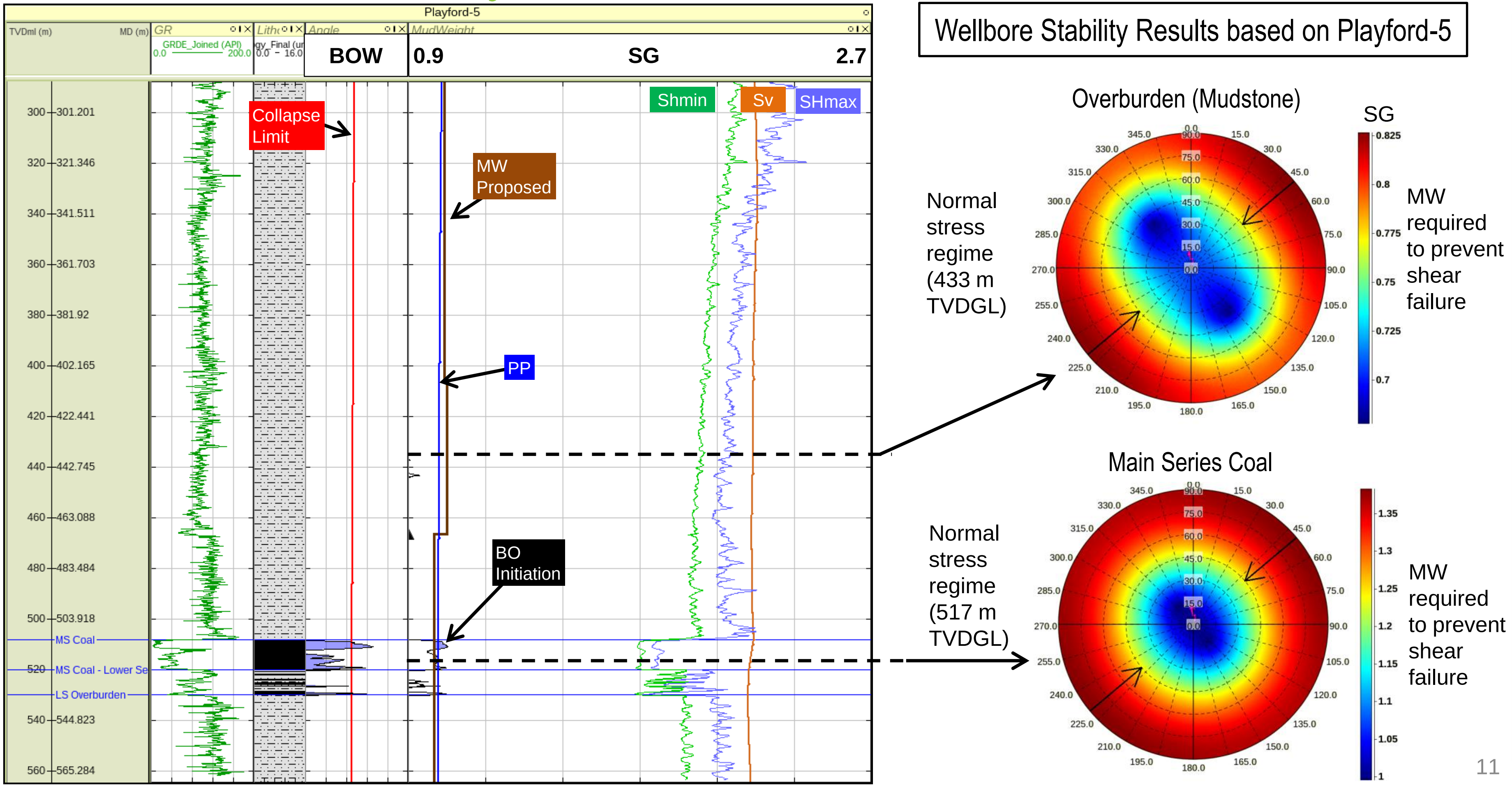
The Energy Resources Division of the Department of The Premier and Cabinet (DPC) requested Ikon Science (Ikon) to develop a present day static geomechanical model for the Leigh Creek Mine area utilising the data set from the Playford-5 well and additional information provided by Flinders Mining, including The Leigh Creek Mine Closure Plan. The static geomechanical model is used to provide input on various stress related issues that may affect the in-situ gasification (ISG) demonstration project such as wellbore stability, fault reactivation and structural permeability.

Rock mechanics tests and DFIT data indicates that the overburden section is strong and a normal stress regime (Shmin < SHmax < Sv) is dominant (Expected Case). An additional stress model was examined due to regional information suggesting that other stress regimes are prevalent in the Flinders Ranges. The alternative stress model has a strike-slip stress regime (Shmin < Sv < SHmax) in the overburden section. A normal stress regime is predicted in the Main Series Coal no matter which of the two stress regime cases occur in the overburden section.

Wellbore failure (borehole breakouts) were only observed in the coal lithology on the image log from Playford-5. A maximum horizontal stress orientation of 50^{o}N was used in this study based on the breakouts. However, a regional SHmax orientation of ~90^{o}N cannot be ruled out. A good match is achieved between the observed wellbore failure, or lack of failure, and the modelled wellbore failure when using a Mohr-Coulomb failure criterion.

The geomechanical model indicates that wellbore stability should not be an issue in the overburden section for both the normal stress regime scenario (Expected Case) and the alternative strike-slip stress regime scenario. In both scenarios, the MW required to prevent breakout initiation is below 1.0 SG for all wellbore trajectories. The coal lithology displays the highest risk for wellbore stability related issues. Horizontal wells in a normal stress regime require higher MWs to prevent breakout initiation than required for vertical wells. Thus, the risk of wellbore failure is predicted to be higher in horizontal wells drilled through the coal lithology. Direct strength measurements are not available for the coal lithology, which increases the uncertainty in the predicted MWs required to prevent breakout initiation and wellbore collapse in the coal lithology. Wellbore failure is predicted to initiate on the side of the wellbore for the coal lithology in horizontal wells.

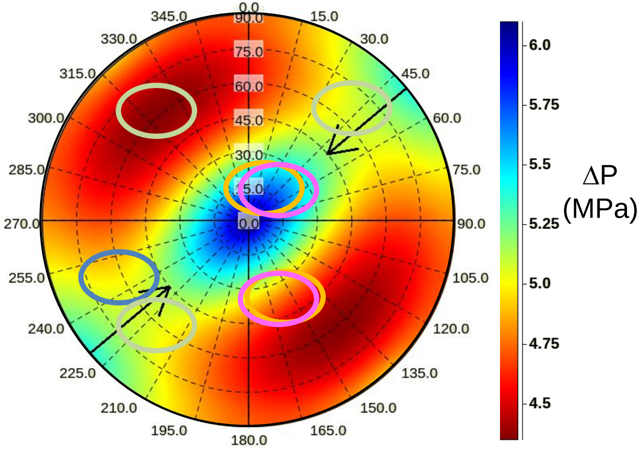
Executive Summary



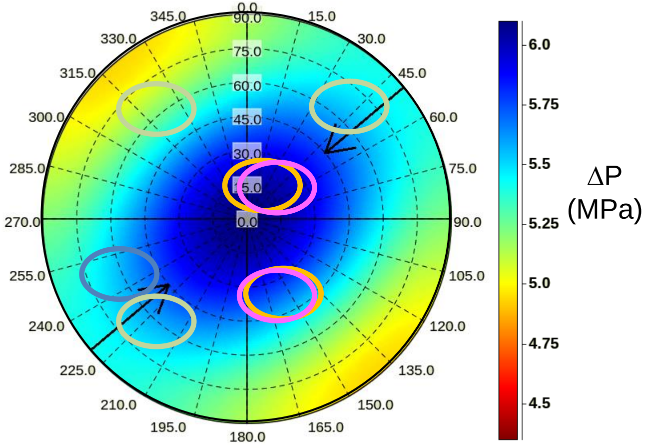
Executive Summary

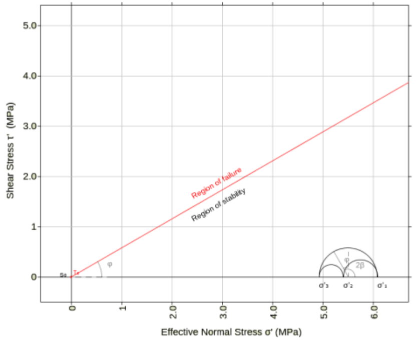
TVDGL = 500.0 m, PP = 4.99 MPa, Shmin = 9.92 MPa, SHmax = 10.40 MPa, Sv = 11.08 MPa, SHmax Ori. = 50ºN, Lithology = Mudstone

CF = 30º, Cohesion = 0 MPa



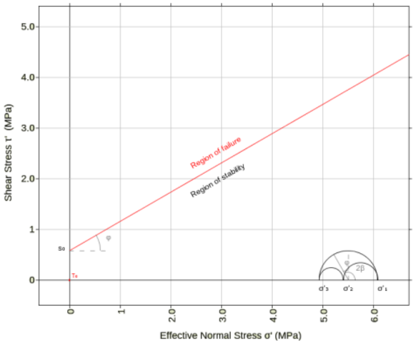
CF = 30º, Cohesion = 0.58 MPa





Faults
Joints
Bedding
Shears

CF = Coefficient of internal friction



The fault reactivation/structural permeability assessment of the overburden directly above the Main Series Coal (normal stress regime) indicates that faults/fractures striking towards 15º-80º and 195º-260º with a dip angle of 45º-75º have the highest likelihood of being reactivated/open and provide conduits to fluid flow based on a SHmax orientation of 50º and a normal stress regime. The faults/fractures would most likely open in shear failure.

Fracture planes plotted as poles to planes. Main structural trends extracted from the Leigh Creek pit mapping database indicated by ellipses.

Executive Summary

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Implications for in-situ gasification (ISG) demonstration project

The Leigh Creek ISG Demonstration will be a dynamic system with high temperatures and variable pressures. These changing conditions cannot be fully assessed using a static geomechanical model with uncertainties. The following implications derived from this analysis are based on the initial conditions of the site. Therefore, a fully coupled thermal poro-elastic numerical model, or equivalent, is recommended to understand the dynamic changes in stability, flow and containment across the life of the system.

Wellbore stability analysis indicates that the Main Series Coals are susceptible to breakout and this risk is elevated with increasing wellbore deviation. The required MW to prevent breakout for horizontal wells deviated in the Shmin direction (NW-SE) is slightly less than the SHmax direction. Given that the operating pressure is expected to be <1.0 S.G., compressive failure of the coal is expected. Failure is expected to initiate on the side of the wellbore and is predicted to extend around the majority of the wellbore at the proposed low operating pressures. Additional calibration data and modelling is required to provide a more accurate prediction of coal failure response.

Each stress case is characterized by a stress transition from extension at depth in the reservoir through strike-slip within the overburden to reverse at the surface, however, the depths at which these transitions occur varies between each case. The transition from a strike-slip to a reverse regime corresponds with a rotation of the critical surface reactivation orientation from sub-vertical to sub-horizontal. In the context of the Leigh Creek Energy Demonstration Project, this implies that any surface that is reactivated due to changed pressure and stress conditions adjacent to the gasification chamber is likely to be the steeper dipping faults and or joints. Any vertically propagating structural element is likely to be retarded or rotated by the reverse stress environment where sub-horizontal features (bedding) would be preferentially reactivated unless activating pressure is significant enough to continue propagate to surface..

The Expected Stress Case implies a 250 m reverse stress regime to surface and the Overcoring Stress Case implies 70 m reverse stress regime to surface implying both models indicate conditions conducive to sub-vertical surface reactivation and fault/fracture creation.

Executive Summary

Recommendations to Reduce Model Uncertainty

- Acquiring shear velocity (Vs) data is advised in order to reduce the uncertainty in the rock elastic properties. This will in turn assist to reduce the uncertainty in the horizontal stress magnitudes.
- Acquiring additional DFIT tests in the overburden, underburden and Main Series Coal would reduce the uncertainty in Shmin magnitude.
- Image logs should be recorded as they can provide a direct indication of geomechanical failure in wellbores and can be used to better calibrate geomechanical models and to determine horizontal stress orientation.
- Rock mechanics tests (UCS and Triaxial tests) would assist in further calibrating the log-derived rock strength estimates. In particular the coal lithology requires rock mechanics tests in order to reduce the uncertainty in the wellbore stability results for the Main Series Coal.
- Triaxial tests are important in order to establish the correct dynamic to static relationship for the elastic properties. Improving the constraint on the elastic properties will reduce the uncertainty in both the rock strength and stress models. Triaxial tests will also provide vital calibration for the friction angle. Additional calibration of the rock strength model, particularly the UCS strength, would assist in reducing the uncertainty in other geomechanical model input parameters, such as the minimum horizontal and maximum horizontal stresses.

3. Introduction and Background

Introduction

The Energy Resources Division of the Department of The Premier and Cabinet (DPC) has requested Ikon Science (Ikon) to develop a present day geomechanical model for the Leigh Creek Mine area utilising the data set from the Playford-5 well and additional information provided by Flinders Mining, including The Leigh Creek Mine Closure Plan. This model will be used to provide input on various stress related issues that may affect the in-situ gasification (ISG) demonstration project proposed by Leigh Creek Energy and help inform the draft Environmental Impact Report (EIR) of likely risks.

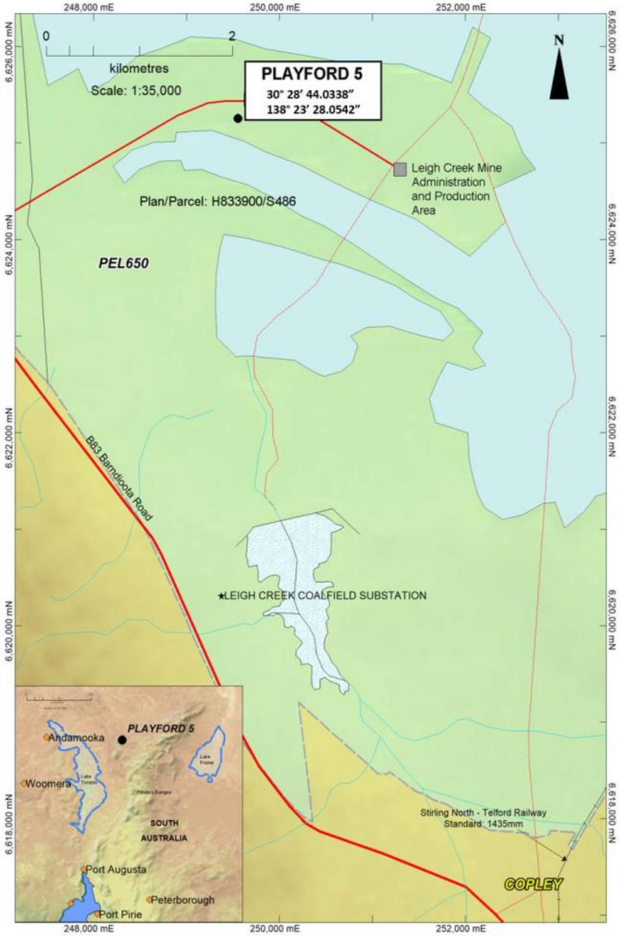
Objectives for this study are to build and utilise a log based 1D geomechanical model using the Playford-5 dataset and address the following items:

- Understand the variable distribution of stresses in the subsurface relative to the planed ISG operations;
- Determine optimal wellbore orientations that minimise the instability of highly deviated wellbores and consider the orientation of the planned ISG facilities in this context;
- Evaluate the relative geomechanical permeability of local structural elements within the changing horizons of interest, and;
- Consider the relative risk of fault orientations that may be susceptible to leakage and pose a risk to the viability of the project.

Introduction

These objectives will be achieved with the following scope of work:

- Televiewer image log interpretation to identify stress related deformation and define natural fracture populations.
- Construct 1D geomechanical models utilising the Playford-5 dataset.
- Assess relative stability of potential wellbore trajectories (vertical and highly deviated trajectories in a range of azimuth directions).
- Assess structural permeability of natural fracture populations and any other known structural elements in the area (faults).
- Document these results and discuss in the context of the planned ISG operations at the Leigh Creek Mine.
- Make recommendations for additional data items to be acquired as part of the current drilling program in order to improve the Environmental Impact Report.



4. Drilling History Review

Drilling History Review

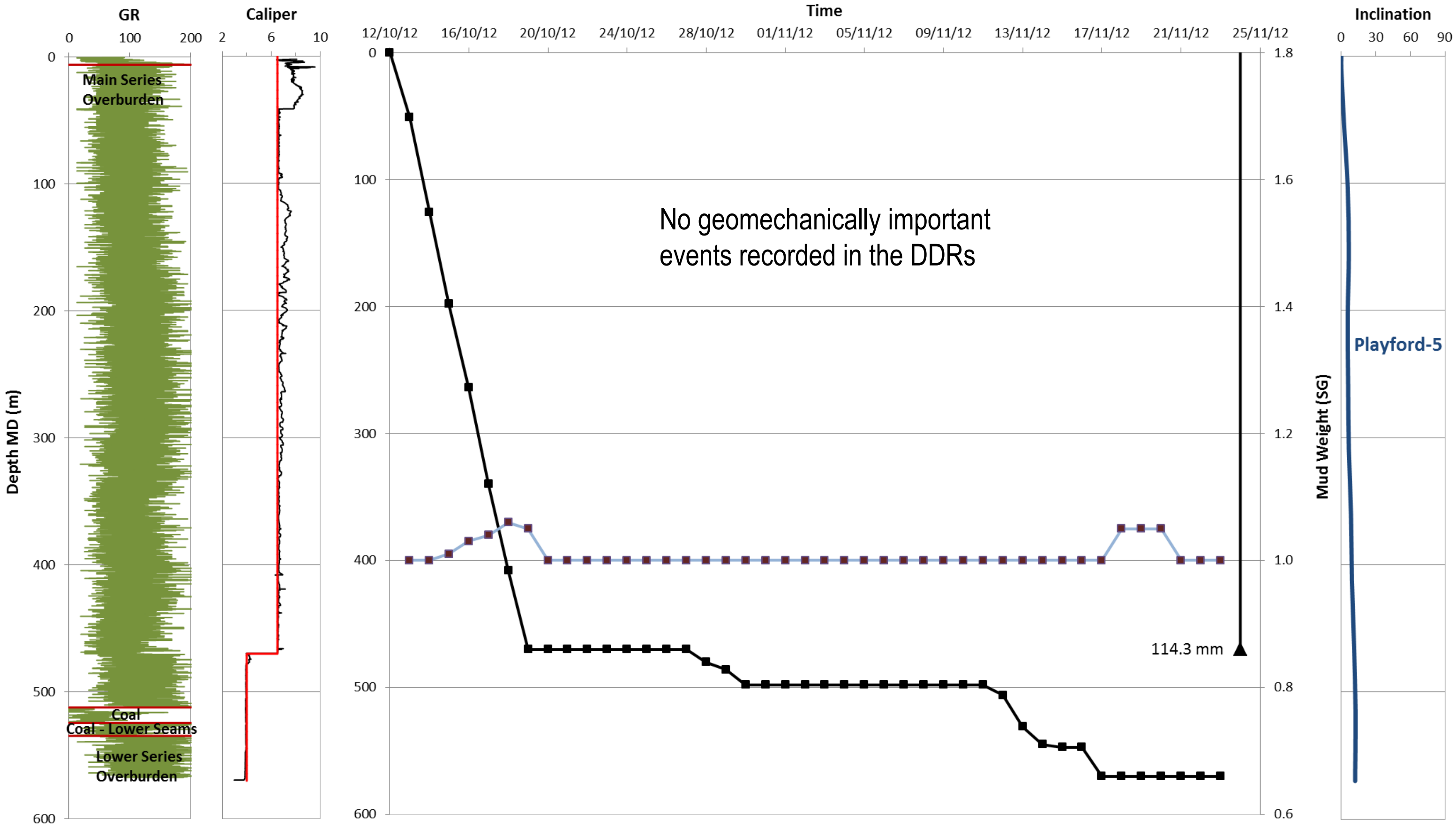
A detailed drilling history review was conducted for the Playford-5 well with the depth versus time plots displayed in the following slide. The drilling history review is used to identify geomechanically significant events or data that assists in calibrating the geomechanical models.

No significant geomechanical relevant events were encountered when drilling the Playford-5 well. The well was drilled using a rotary mud system with a PCD bit (165 mm) from the surface to 470 m. From 470 m to 570 m (TD) the well was drilled using a diamond core (96 mm bit size). The maximum deviation was 12^{o} at TD of the well.

The caliper log indicates some enlargement above 300 m, which might indicate wellbore failure. However, no wellbore failure was observed on the image log over this section. Wellbore failure was only observed in the Main Series Coal on the image log.

The mud weight (MW) in the 165 mm hole section increased from 1.0 SG to 1.05 SG at TD of the section. A MW of 1.0 SG was used for the 96 mm hole section.

Drilling History Review – Playford-5



5. Geomechanical Analysis of Playford-5

Lithology

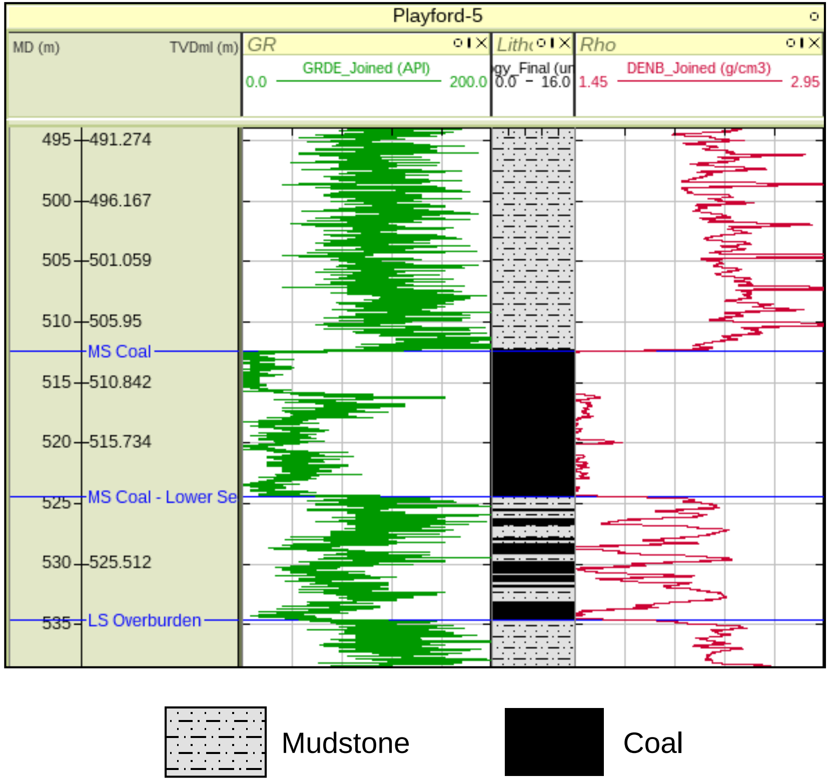
The lithology was divided into mudstone and coal in order to develop the geomechanical model.

The lithology breakdown was undertaken using the appropriate cut-off of values of the RHO log as listed below.

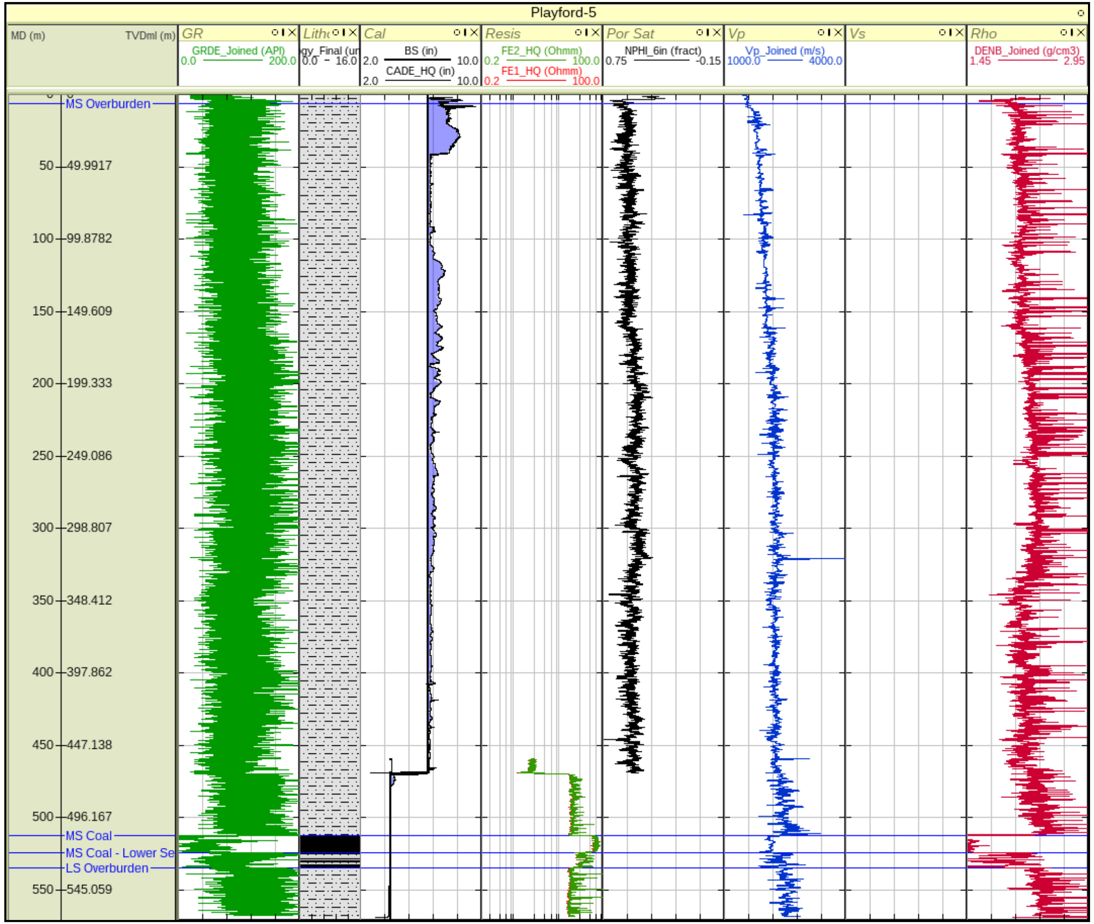
Lithology cut off

RHO < 2 g/cm^3 - Coal

RHO ≥ 2 g/cm^3 - Mudstone



Log Data – Playford-5



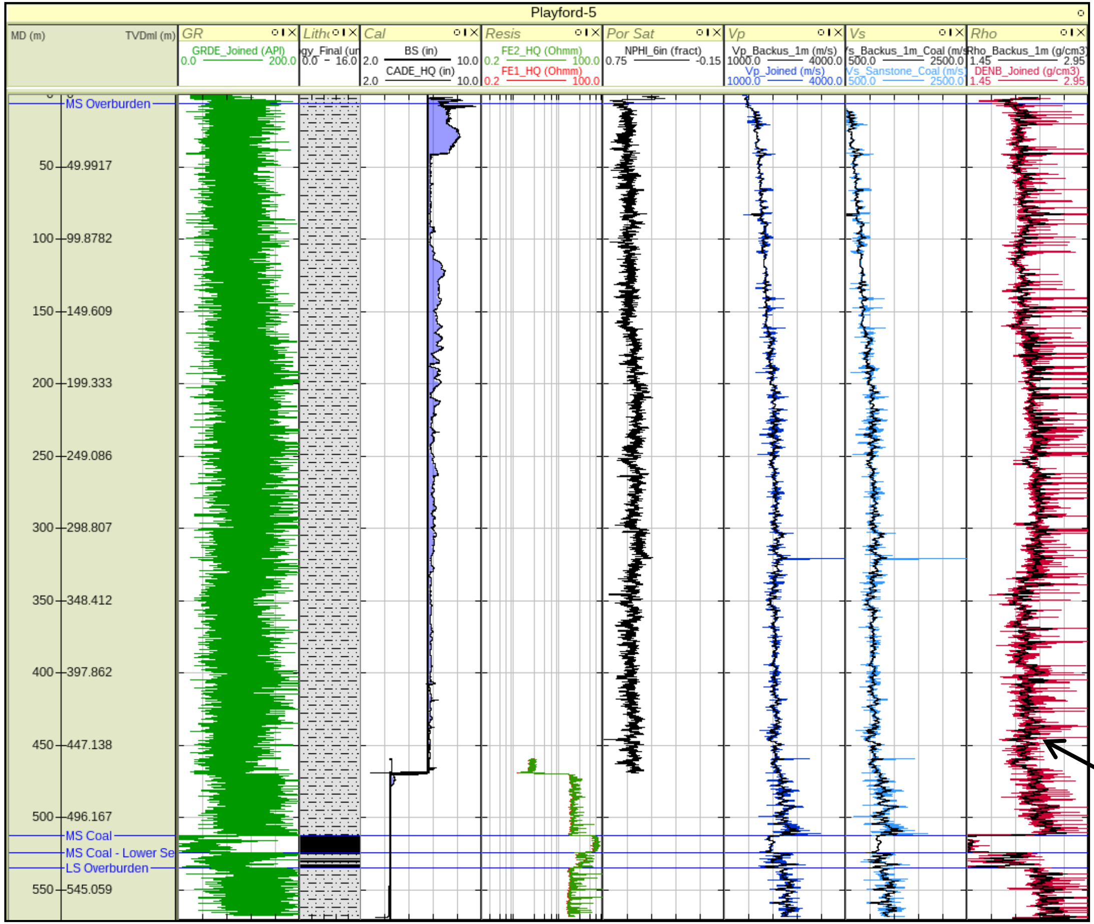
Rho and Vp data were available for the 6 ½" & 4" hole sections of Playford-5. Vs data was not available. As a result a model Vs was calculated based on the following Greenberg Castagna (1992) relationship.

$$Vs = 0.80416 * Vp - 0.85588$$

The above relationship was chosen as it produced the closest match to the Poisson's Ratio data from the rock mechanics tests.

Actual Log Data
Playford-5

Log Data – Playford-5



A Backus filter was applied to the Vp, Vs and Rho logs with a 1 m window in order to reduce the spikes in the data. The 1 m average logs were used to build the geomechanical model.

Final Vp, Vs & Rho logs displayed in black

Rock Properties – Playford-5

Uniaxial rock mechanics tests were undertaken by Sigra Pty Ltd on core plugs from the Playford-5 well. The following results were used to calibrate the log-based rock mechanical properties.

Ref	Depth m	RHO g/cm³	E MPa	PR	UCS MPa
133.036	482	2.214	3014.4	0.249	22.3
345.022	492	2.246	3201.4	0.307	20.1
348.022	505	2.194	3895.7	0.337	25.3
352.022	546	2.147	3442.9	0.342	19.3

Rock Properties – Elastic Moduli

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The dynamic Poisson's Ratio and Young's Modulus were generated via standard rock physics relationships using the Vp, Vs and Rho data from the well.

Poisson's Ratio

$$\nu = \frac{(Vp/Vs)^2 - 2}{2 \times (Vp/Vs)^2 - 1}$$

Young's Modulus

$$E_{DYN} = \rho \times (1 + \nu) \times Vs^2$$

For the purposes of this study the Young's Modulus(E_{DYN}) is converted to the static Young's Modulus (E_{STAT}) according to the following equation based on rock mechanics test data.

$$E_{STAT} = 0.352 \times (E_{DYN})$$

The static value for the Poisson's Ratio was assumed to equal the dynamic value. This is the standard approach in geomechanics studies due to the nature of the Poisson's Ratio from the rock mechanics tests.

Rock Properties – UCS

The UCS was calculated based on the following formulas. The mudstone lithology formula was scaled to match the UCS results from the rock mechanics tests. The Coal lithology formula was scaled based on the predicted wellbore failure after calibrating the horizontal stress magnitudes.

UCS for all **Mudstone** lithology (Eq.18 Chang et al., 2006):

$$UCS = \left(7.22 \times \mathrm{E}^{0.712}\right)^{1.08}$$

Scaling factor

UCS in MPa
E in MPa

UCS for **Coal** lithology (from Bradford et al., 1998):

$$UCS = 1.1 \times [2.8 \times 4.1089 \times \mathrm{E}]$$

Scaling factor

UCS in MPa
E in MPa

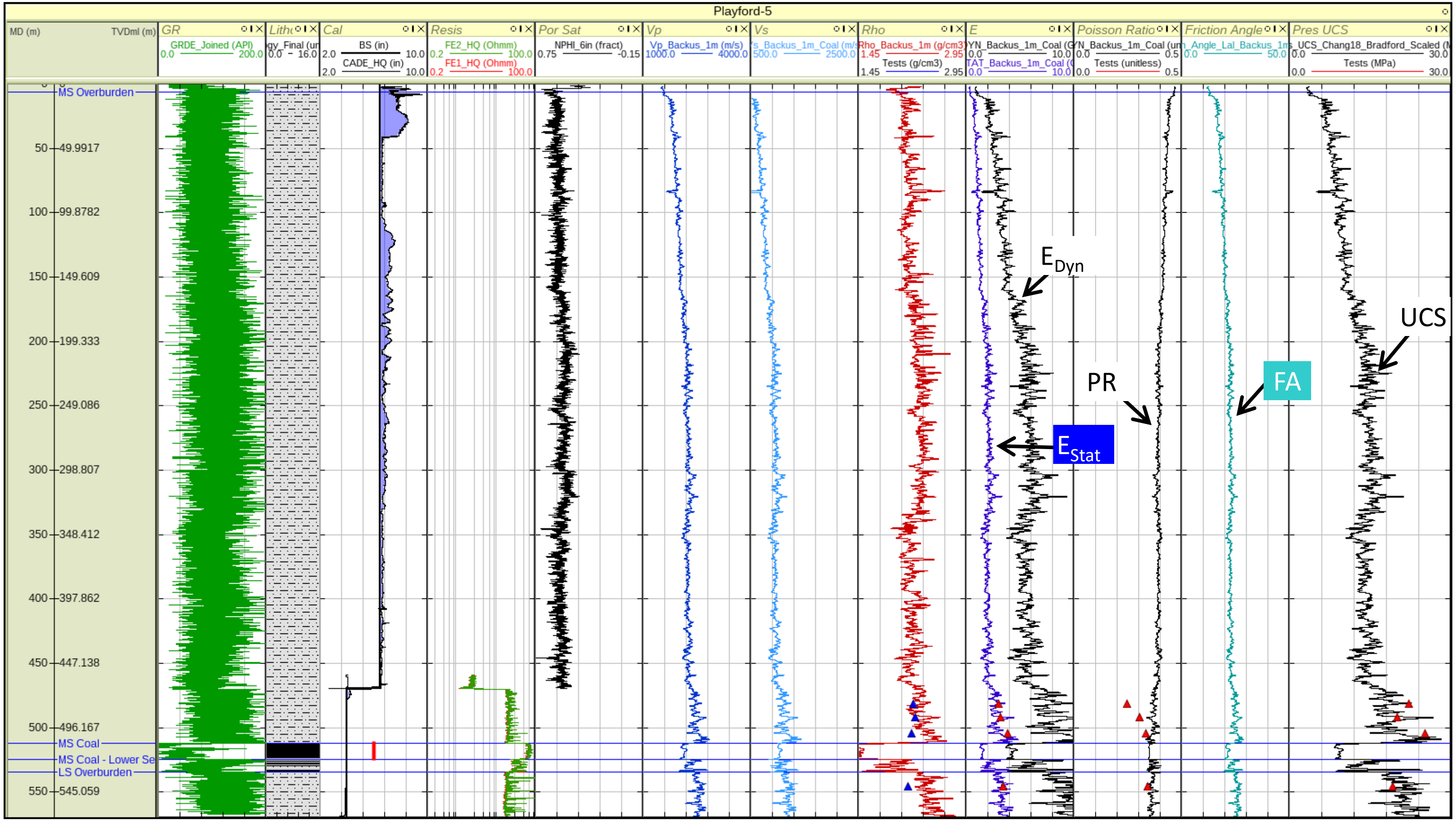
Rock Properties – Friction Angle

The friction angle was calculated using the Lal (1999) shale method, according to:

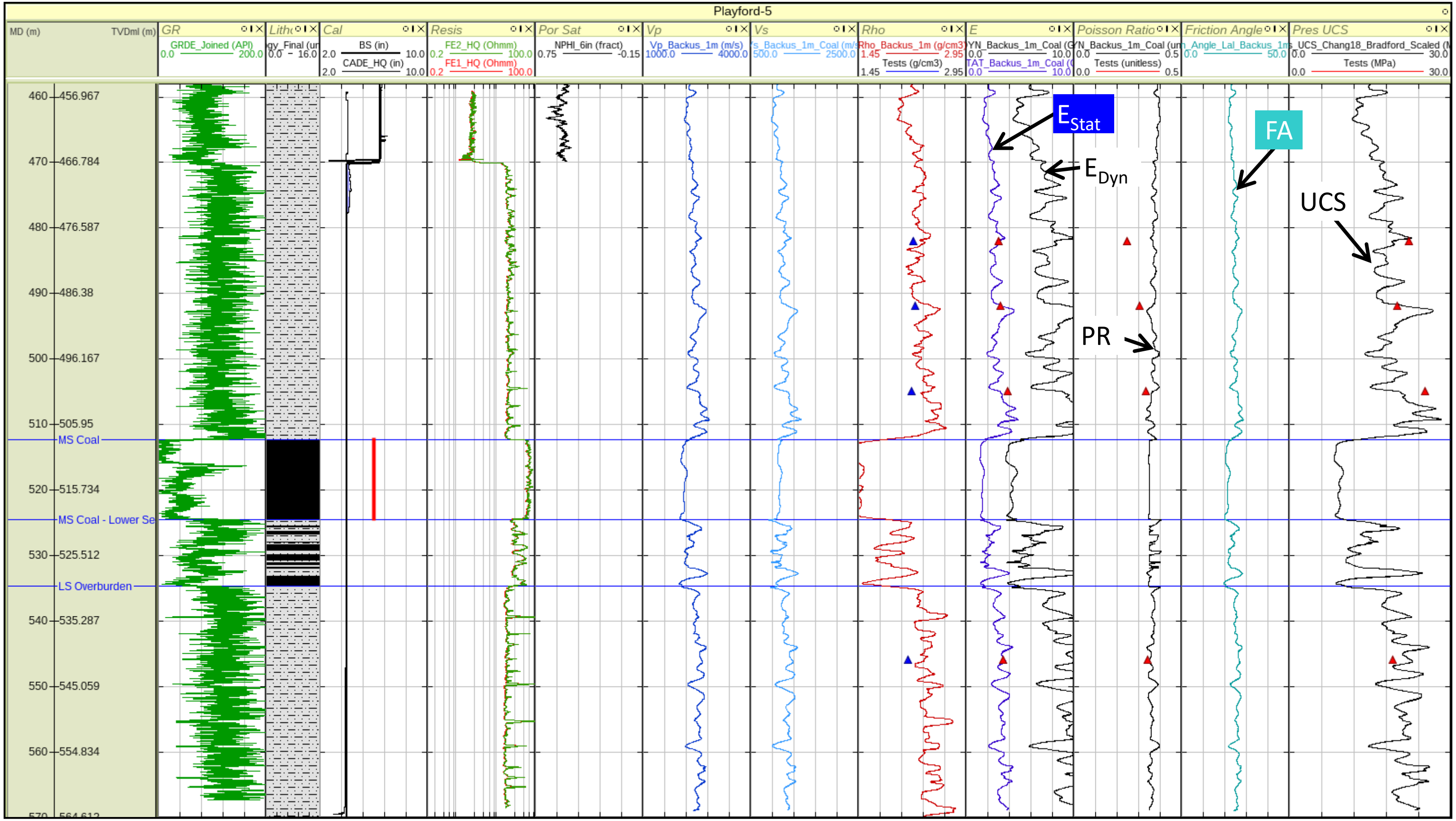
$$FA = asin\left(\frac{(Vp - 1000)}{(Vp + 1000)}\right)$$

Friction angle from rock mechanics test data was not available in order to calibrate the log-based friction angle. The following slide displays a summary of the rock properties for the Playford-5 well.

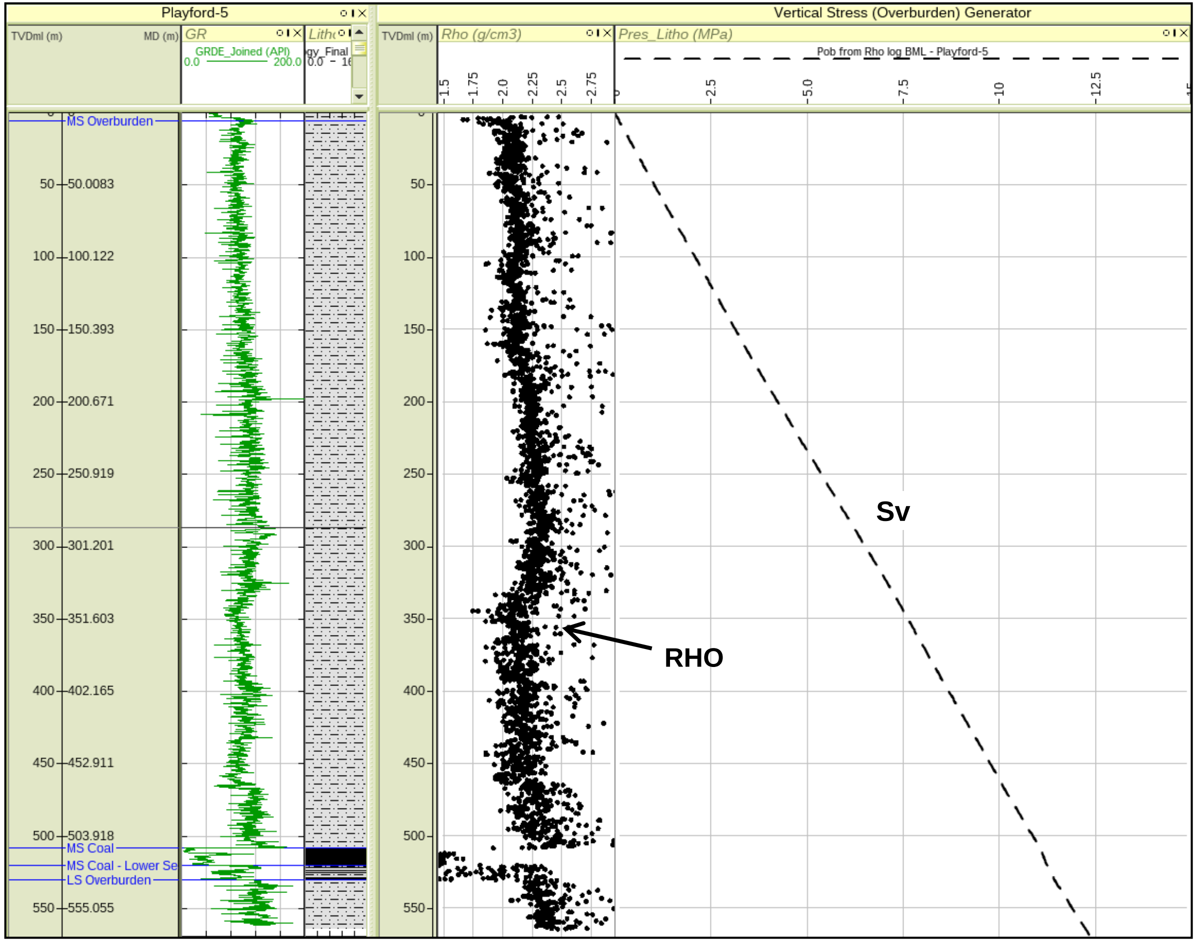
Rock Properties – Playford-5



Rock Properties – Playford-5



Vertical Stress



Density data was recorded from close to the surface to TD of the well.

The vertical stress was calculated by integrating density data from the surface to the depth of interest.

$$S_v = \int_0^z \rho_b(z) g . dz$$

Maximum Horizontal Stress Orientation

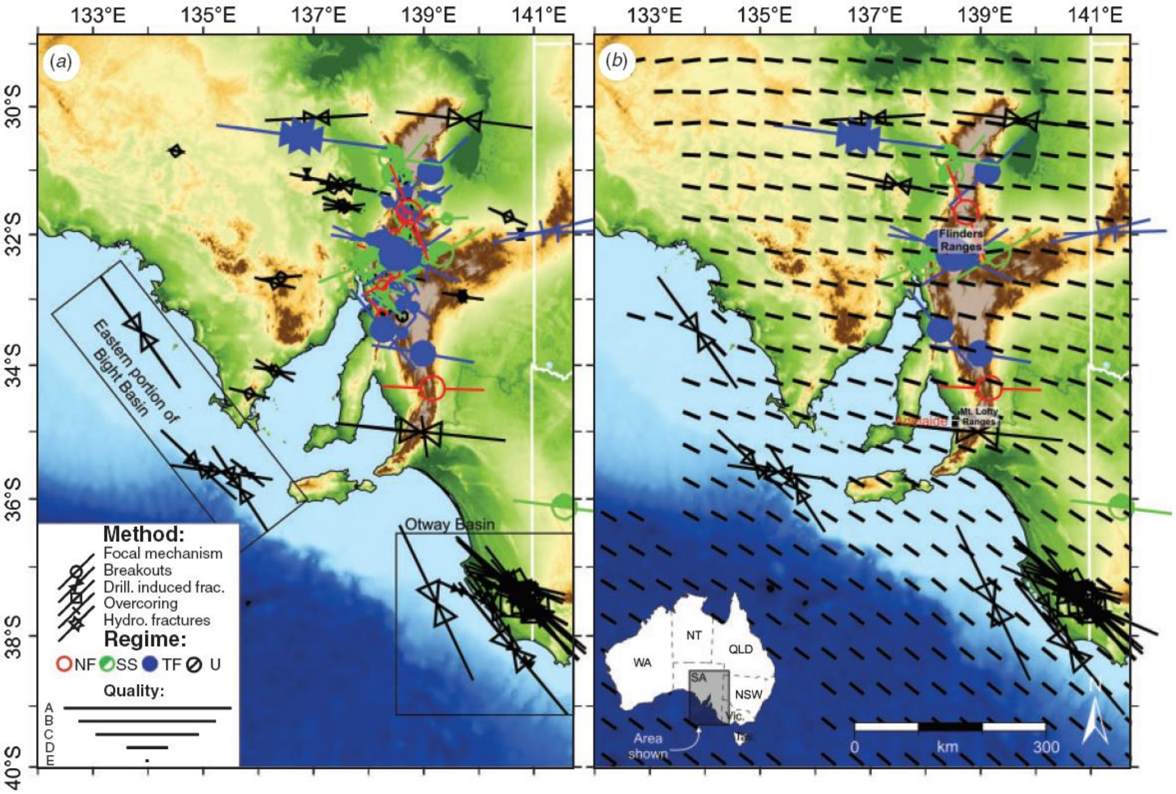
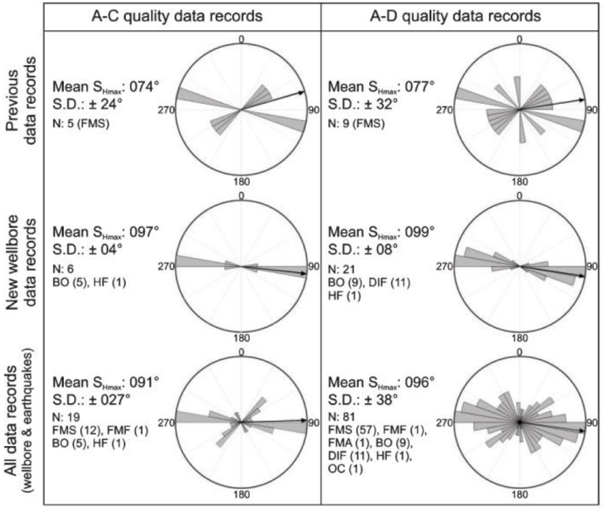


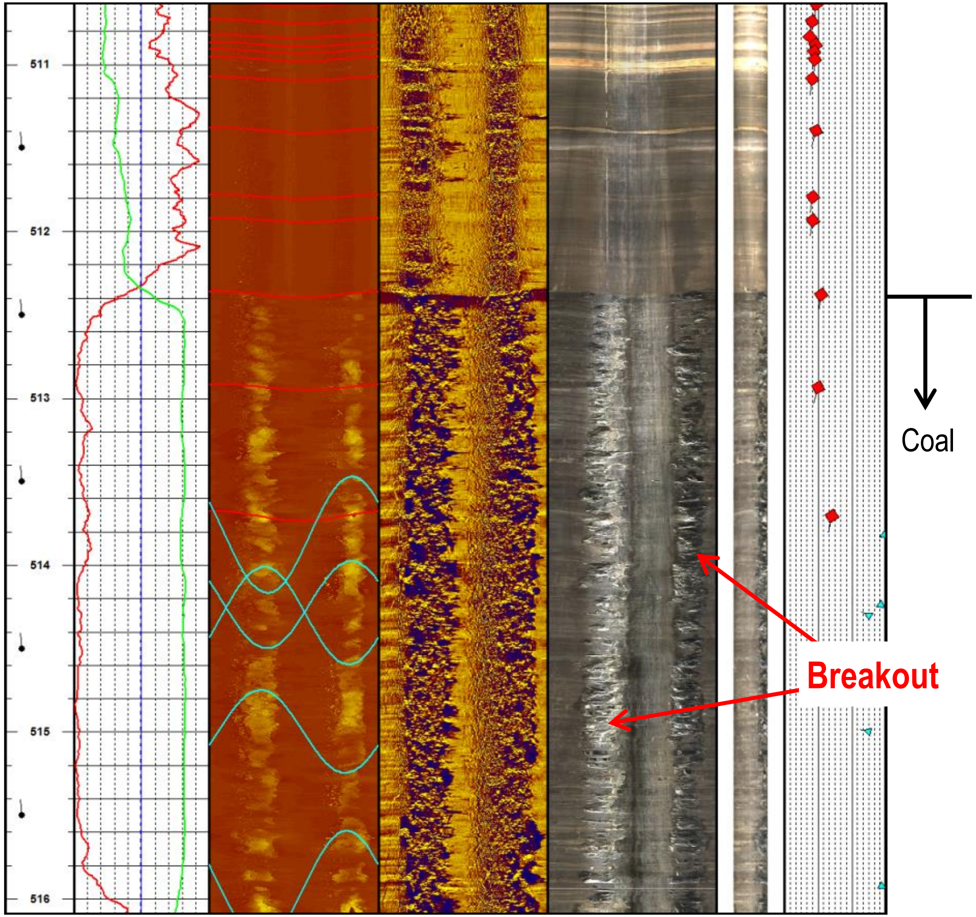
Fig. 7. (*a*) The present-day stress map of the Flinders and Mount Lofty Ranges based on 102 (A–E) quality S_{Hmax} data records. The legend is similar to Figure 2. (*b*) The smoothed stress pattern of South Australia including Flinders and Mount Lofty Ranges, South Australian Otway Basin and eastern parts of the Bight Basin. The smoothed map is based on A–C quality data records in this region and all the newly compiled stress data of the Australian continent (Rajabi et al., 2015). Black lines show azimuthal orientation of the S_{Hmax}.

Regional stress orientation data from Rajabi, 2016 for the Flinders and Mt Lofty Ranges.

The average SHmax orientation based on the A-C quality data is approximately east-west (091°).



Maximum Horizontal Stress Orientation



An acoustic log was acquired in both hole sections, while an optical image log was acquired in the 4” hole section of Playford-5.

Borehole breakouts are observed only in the coal section. The average SHmax orientation was interpreted as 050^o. This is consistent with the average SHmax orientation from the four overcoring tests (053^o).

The SHmax orientation is approximately 40^o different from the regional SHmax orientation. This could be a result of local structural influences or the nearby Leigh Creek coal mine.

A value of 050^o was used for the SHmax orientation in this study. The regional SHmax orientation was examined as part of the uncertainty analysis.

Horizontal Stress Magnitudes

The two equations below, termed the poro-elastic strain equations, are typically used by Ikon to estimate the horizontal stress magnitudes. The poro-elastic strain equations are commonly used throughout the petroleum industry, but require appropriate calibration and reliable input parameters. The Shmin magnitude is typically calibrated to good quality LOT values or ideally closure pressure from mini-frac test results. The SHmax magnitude is calibrated against the presence or absence of wellbore failure (e.g. borehole breakouts or drilling-induced fractures). Overcoring was undertaken in the 4” hole section of Playford-5, which has provides an estimate for the magnitude of Shmin, SHmax and Sv. In addition, two DFIT tests were conducted in the nearby Playford-2 well. Summary tables are provided on the following slides.

$$\sigma_{h\min} = \frac{\nu}{1-\nu}(\sigma_V - B \cdot P_P) + \frac{E}{1-\nu^2} \cdot \varepsilon_{h\min} + \frac{E\nu}{1-\nu^2} \cdot \varepsilon_{H\max} + B \cdot P_P$$

$$\sigma_{H\max} = \frac{\nu}{1-\nu}(\sigma_V - B \cdot P_P) + \frac{E}{1-\nu^2} \cdot \varepsilon_{H\max} + \frac{E\nu}{1-\nu^2} \cdot \varepsilon_{h\min} + B \cdot P_P$$

Component from vertical load
ν

Tectonic component
E

B = Biot’s Factor

E = Young’s Modulus

ν = Poisson’s Ratio

P_p = Pore pressure

σ_v = Vertical stress

ε_{hmin} = Strain in σ_{hmin}

ε_{Hmax} = Strain in σ_{Hmax}

Horizontal Stress Magnitudes

The following overcoring data was undertaken in the Playford-5 well. Uncertainty exists in the reliability of overcoring results to give an accurate estimate of the far-field stresses (Shmin, SHmax, Sv). For example, the Sv from the overcoring tests does not match the Sv calculated from the density log. Furthermore, the Shmin magnitude from the overcoring is not consistent with the Shmin magnitude from the DFIT test. As a result, the overcoring tests were only used to provide an alternative horizontal stress model.

Run No.	Tool No.	Depth (m)	Sig1' (MPa)	Sig2' (MPa)	SigV' (MPa)	Tect1 strain	Tect2 strain	Angle degree
133	36	482	3.38	3.05	7.57	479.8	342.9	49.2
345	22	492	3.69	3.16	7.72	388.5	170.8	32.2
348	22	505	4.33	3.22	7.93	405.4	24.3	76
352	22	546	4.59	3.47	8.57	456.3	20.1	55.9

Biot's Vertical = 0.8

Biot's Horizontal = 0.6

Sig1' = Major effective stress (SHmax')

Sig2' = Minor effective stress (Shmin')

SigV' = Vertical effective stress (Sv')

Tect1 strain = Strain in SHmax direction

Tect2 strain = Strain in Shmin direction

Angle degree = Maximum horizontal stress orientation

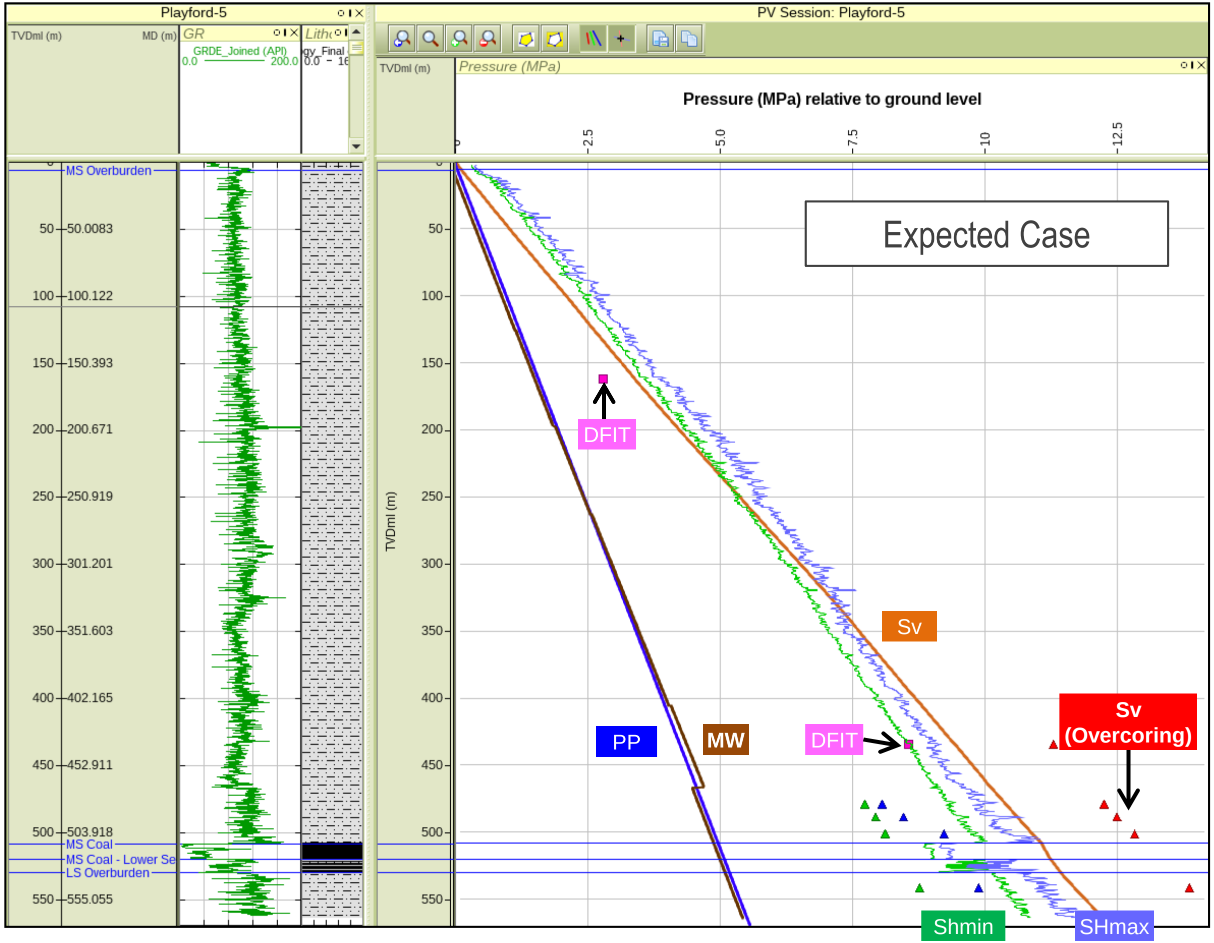
Horizontal Stress Magnitudes

The following DFIT data was recently acquired in the nearby Playford-2 well. Analysis of the DFIT tests were undertaken by Ray Johnson from Unconventional Reservoir Solutions and used to calibrate the stress model where the data is deemed to be reliable. A high uncertainty exists in the results of DFIT-2 due to the unusual pressure response, which could indicate that the packers have induced a shear fracture with the result not an indication of the Shmin magnitude (pers. comm. Ray Johnson and DFIT Evaluations Playford-2 (Injections 8 & 9), 18 Dec 2017). As a result, only the reliable result from DFIT-1 was used to calibrated the Shmin magnitude. The fracture closure pressure is preferred over the overcoring results to estimate the Shmin magnitude, since it is measuring the stress directly and not strain.

	Top Depth (m)	Bottom Depth (m)	Mid Depth (m)	Reservoir Pressure (psi)	Breakdown Pressure (psi)	ISIP (psi)	Closure Pressure (psi)
DFIT-1	571	577	574	611	1654	651	1258
DFIT-2	187	193	190	-	659	423	420

	Top Depth (m)	Bottom Depth (m)	Mid Depth (m)	Reservoir Pressure (MPa)	Breakdown Pressure (MPa)	ISIP (MPa)	Closure Pressure (MPa)
DFIT-1	571	577	574	4.21	11.40	4.49	8.67
DFIT-2	187	193	190	-	4.54	2.92	2.90

Stress and Pore Pressure Model (psi)



Expected Case stress and pore pressure model for the Playford-5 well based on the DFIT data.

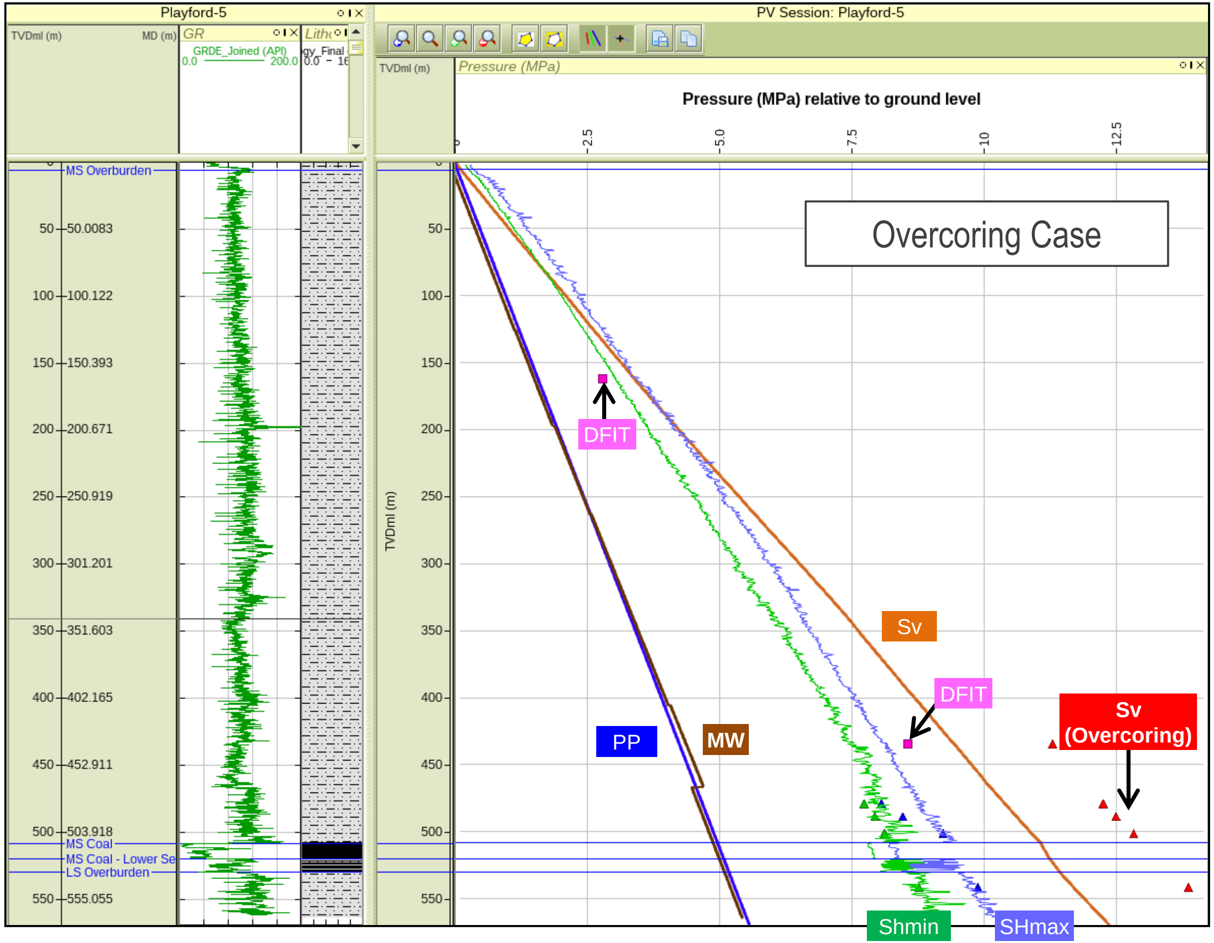
Hydrostatic pore pressure assumed using a gradient of 1 g/cm^3.

The stress model uses the following parameters (Biot's = 1.0, εhmin = 0.0002, εHmax = 0.0005) in order to match the horizontal stress data from the DFIT at 434 m (TVDGL).

A reverse stress regime (Sv < Shmin < SHmax) is predicted at the surface that then transitions to a strike-slip stress regime (Shmin < Sv < SHmax) and finally to a normal stress regime (Shmin < SHmax < Sv) below 340 m (TVDGL).

Stress and Pore Pressure Model (psi)

ikon Science

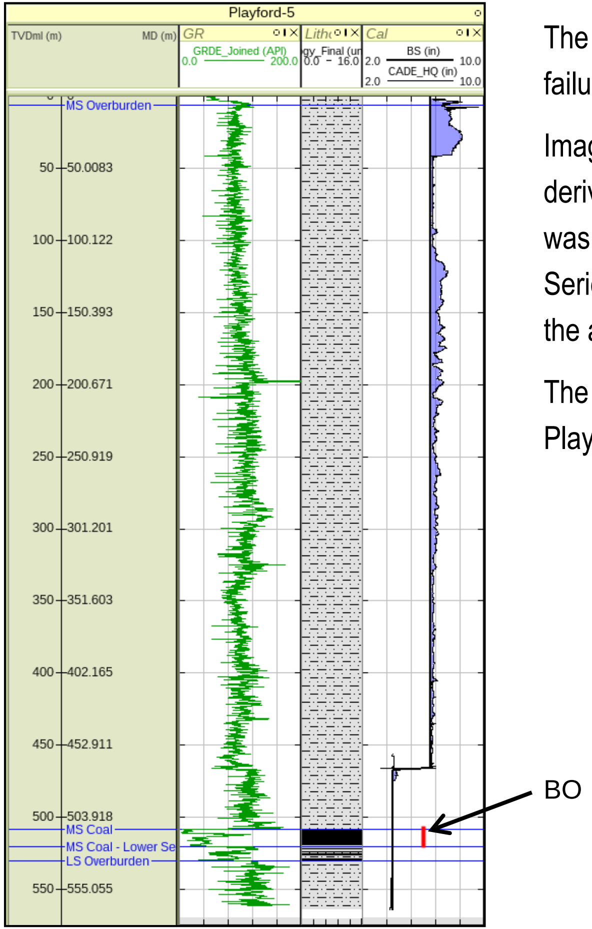


An alternative stress model was develop using the overcoring data as calibration. The stress model uses the following parameters (Biot's = 0.7, $\varepsilon hmin$ = 0.000, $\varepsilon Hmax$ = 0.0004) in order to match the horizontal stress data.

A reverse stress regime (Sv < Shmin < SHmax) is predicted at the surface that then transitions to a strike-slip stress regime (Shmin < Sv < SHmax) and finally to a normal stress regime (Shmin < SHmax < Sv) below 200 m (TVDGL).

The previously displayed Expected Case is the preferred stress model.

Geomechanical Model Calibration

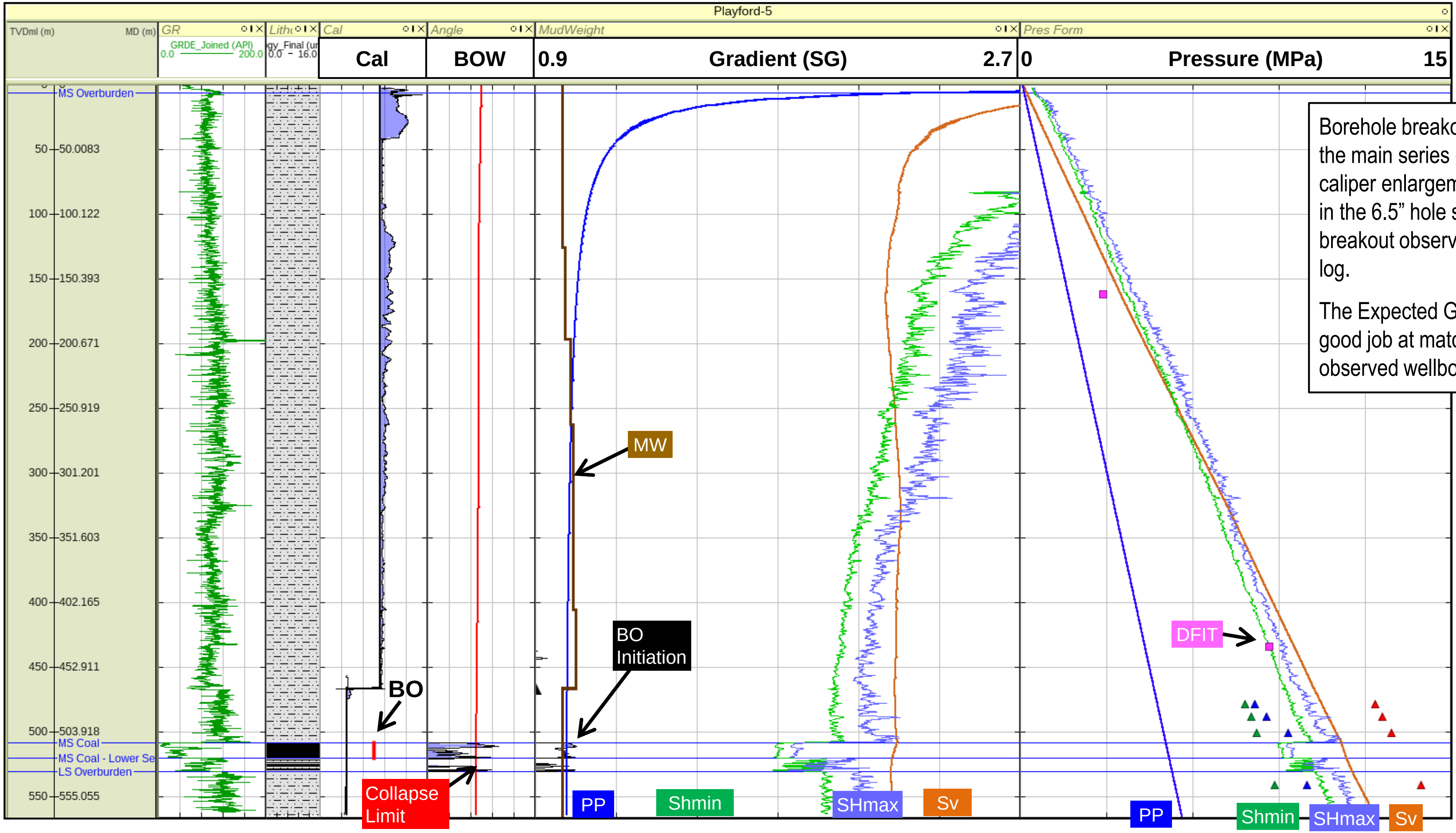


The geomechanical model was calibrated by attempting to match the presence or absence of wellbore failure in the Playford-5 well.

Image logs provide the best source of data in order to observe and distinguish the geomechanically derived wellbore failure. An acoustic log was acquired in both hole sections, while an optical image log was acquired in the 4" hole section of Playford-5. Borehole breakouts are observed only in the Main Series Coal. Despite the caliper enlargement in the upper section, no wellbore failure was observed on the acoustic image log.

The following slides display the overall fit between the predicted and observed wellbore failure for the Playford-5 well in terms of SG (TVDml reference).

GM Model Calibration – Playford-5 – Expected Case



Borehole breakout is observed in the main series coal. Some caliper enlargement is observed in the 6.5" hole section, but no breakout observed on the image log.

The Expected GM model does a good job at matching the observed wellbore failure.

GM Model Uncertainty

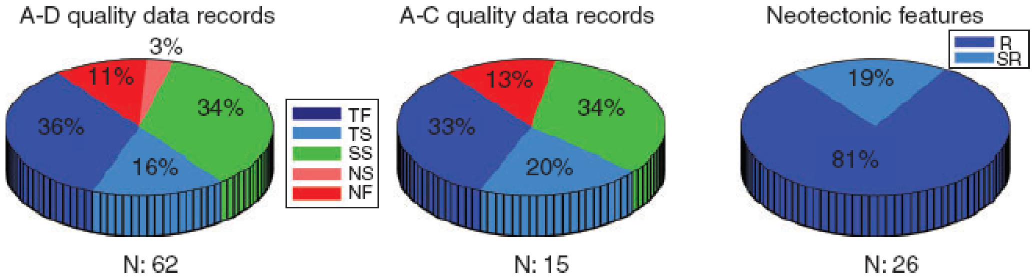
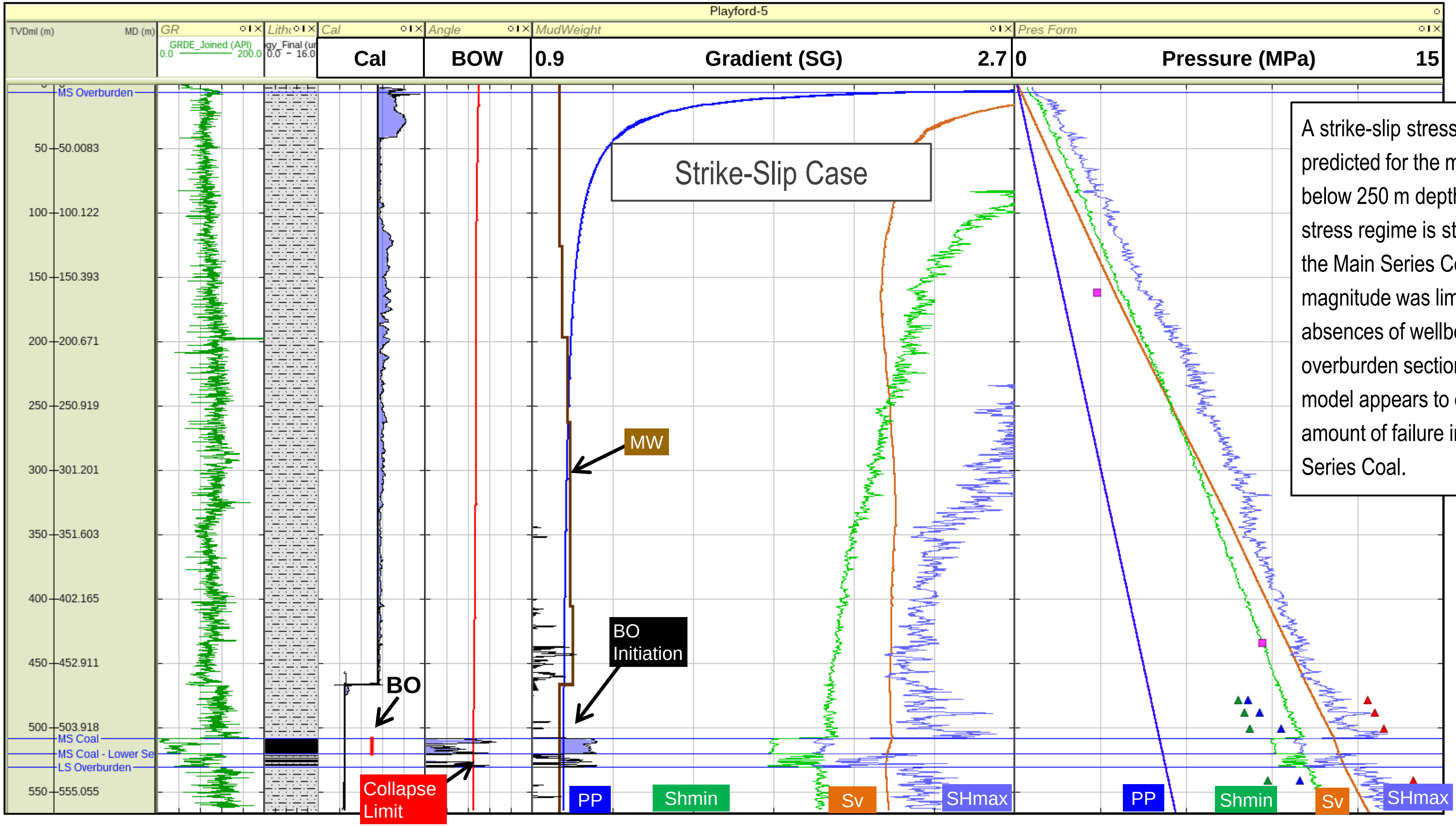


Fig. 9. Distribution of tectonic stress regime in the Flinders and Mount Lofty Ranges based on our stress data compilation for A–D quality (left) and A–C quality data records (middle). Our database reveals that the majority of the stress data indicate a thrust faulting stress regime (TF) or predominately thrust faulting with minor strike-slip component (TS). In addition, the database also reveals considerable amount of strike-slip (SS) and normal faulting (NF) stress regimes in the Mount Lofty and Flinders Ranges. The right pie chart shows the available neotectonic faults in the neotectonic database of Geoscience Australia (Geoscience Australia, 2016*b*) that are assigned with a stress regime, and indicates a dominant thrust or reverse (R) faulting stress regime. NS, predominately normal faulting with strike-slip component; SR, sinistral reverse.

Uncertainty exists in the SHmax magnitude. The GM model in the previous slide indicates a normal stress regime at the depth of the Main Series Coal. However, regional stress information from Rajabi, 2016 for the Flinders and Mt Lofty Ranges indicates a range of different stress regimes. As a result, the SHmax magnitude was increased while maintaining the same magnitude for Shmin as in the previous GM model.

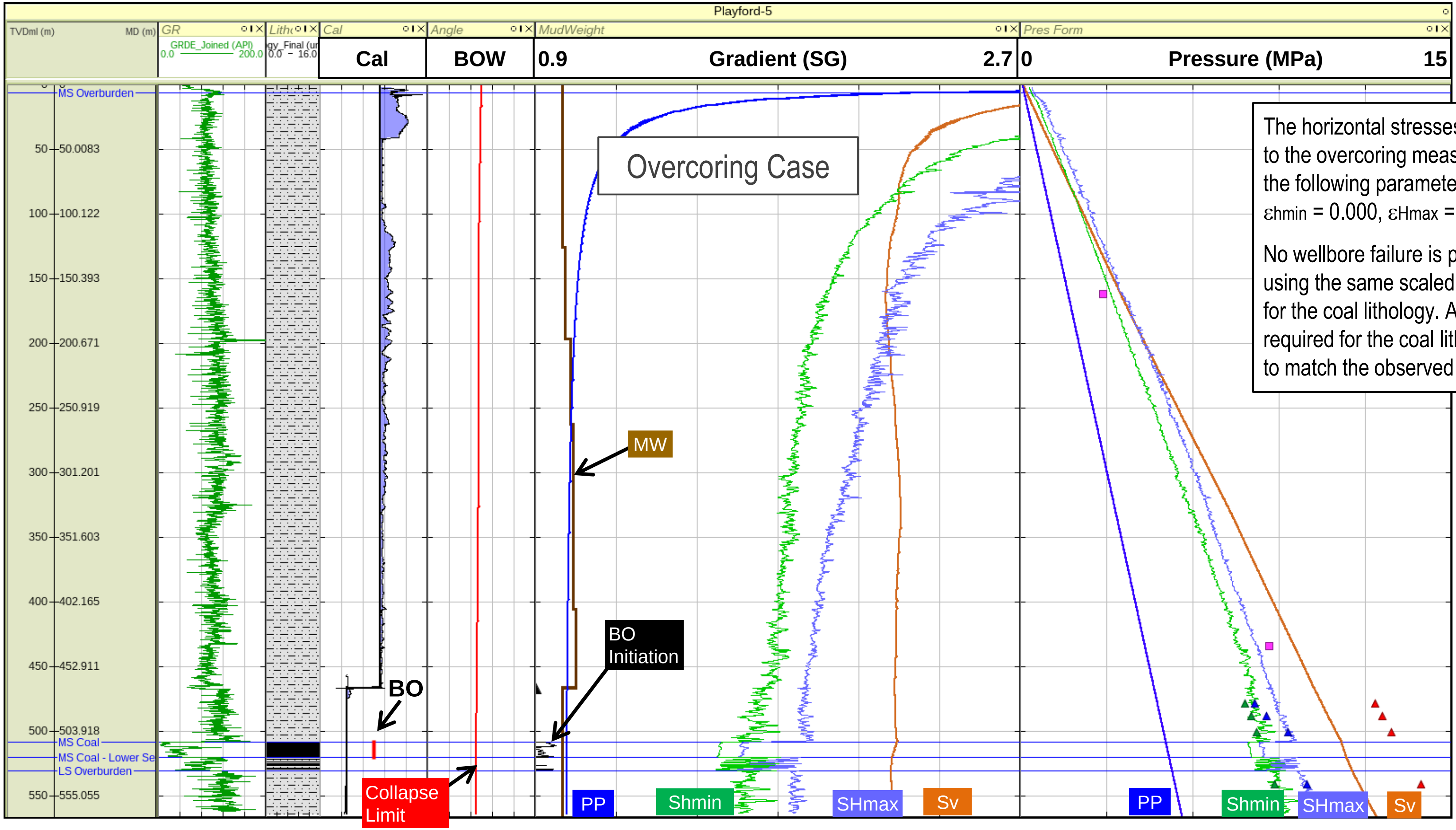
The following slide displays the results of increasing the SHmax magnitude.

GM Model Uncertainty – Strike-Slip Stress Regime



A strike-slip stress regime is predicted for the mudstone section below 250 m depth. A normal stress regime is still predicted for the Main Series Coal. The SHmax magnitude was limited by the absences of wellbore failure in the overburden section. This GM model appears to over-predict the amount of failure in the Main Series Coal.

GM Model Calibration – Playford-5 – Overcoring



The horizontal stresses were matched to the overcoring measurements using the following parameters Biot's = 0.7, εhmin = 0.000, εHmax = 0.0004.

No wellbore failure is predicted when using the same scaled Bradford model for the coal lithology. A lower UCS is required for the coal lithology in order to match the observed wellbore failure.

GM Model Calibration – Discussion

The horizontal stress magnitudes were constrained by data from the deepest DFIT from the Playford-2 well and required the following model parameters, Biot's = 1.0, ε_{hmin} = 0.0002 & ε_{Hmax} = 0.0005 (Expected Case). A good match is achieved between the observed wellbore failure, or lack of failure, and the modelled wellbore failure when using a Mohr-Coulomb failure criterion.

A reverse stress regime (Sv < Shmin < SHmax) is predicted at the surface that then transitions to a strike-slip stress regime (Shmin < Sv < SHmax) and finally to a normal stress regime (Shmin < SHmax < Sv) below 340 m (TVDGL). A maximum horizontal stress orientation of 50^{o}N was used in this study based on image log data from the Playford-5 well. However, a regional SHmax orientation of ~90^{o}N cannot be ruled out.

An additional stress model was examined due to regional information suggesting both other stress regimes are prevalent in the Flinders Ranges. The strain parameters were altered in order to increase the SHmax magnitude, while maintaining a consistent Shmin magnitude with the Expected Case. A strike-slip stress regime (i.e. SHmax > Sv) is possible for the majority of the overburden section, while still matching the absences of observed wellbore failure. However, a normal stress regime is still predicted in the Main Series Coal even if a strike-slip stress regime is present in the over and underburden.

Uncertainty in the geomechanical model can be reduced by undertaking rock mechanics tests on coal lithology and minifrac tests in the overburden, underburden and the Main Series Coal.

6. Generic Wellbore Stability Analysis

Wellbore Stability - Introduction

The following section details wellbore stability predictions based on the Playford-5 well. Rock mechanics test data indicate the overburden is strong with a very low wellbore stability risk. A higher uncertainty exists for the wellbore stability in the coal formation, as rock mechanics test data was not available.

Approach

- Assess lower bound pressure limits for all wellbore orientations within the:
  - Overburden – directly above coal (433 mTVDGL) under Normal and Strike-slip stress conditions
  - Main Coal (517 mTVDGL) under Normal stress conditions (always Normal stress conditions in coal independent of which stress model is used)

Assumptions

- Methodology and calculations pertain to stress concentrations around a circular borehole.
- Concept is about determining upper and lower bound pressures required within the wellbore to prevent two modes of failure.
  - Compressive (shear) failure known as borehole breakout if the pressure is too low
  - Tensile failure known as DITF if the pressure is too high.
- Upper and lower bound limits vary in an unchanging stress field depending on the orientation of the wellbore.
- Upper and lower bound limits vary along the wellbore due to
  - Changing stress conditions
  - Changing wellbore orientation

Wellbore Stability - Introduction

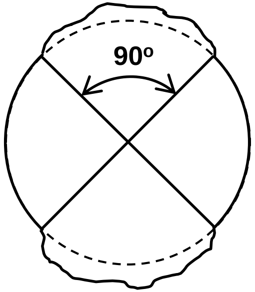
Definitions applicable to this report

Breakout Initiation: Is the pressure (psi) or gradient (PPG) that shear failure will initiate at the wellbore wall if the MW drops below this value. It marks the 0^{o} breakout width (BOW) value.

Collapse Limit: Is the pressure (psi) or gradient (PPG) that the breakout width is 90^{o} for a vertical well and 30^{o} for a horizontal well. Deviated wells scaled based on deviation based on the formula below. A BOW of 90^{o} would indicate that half the wellbore has failed.

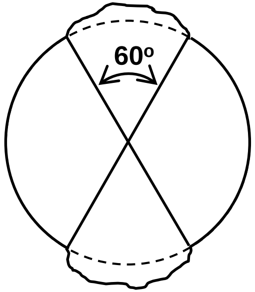
$$Collapse\ limit = 90 - \frac{(90^{\circ} - 30^{\circ}) \times Deviation}{90^{\circ}}$$

Vertical Well



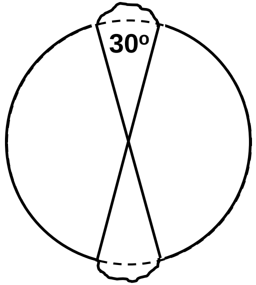
50% of wellbore failed

45º deviated Well



33.33% of wellbore failed

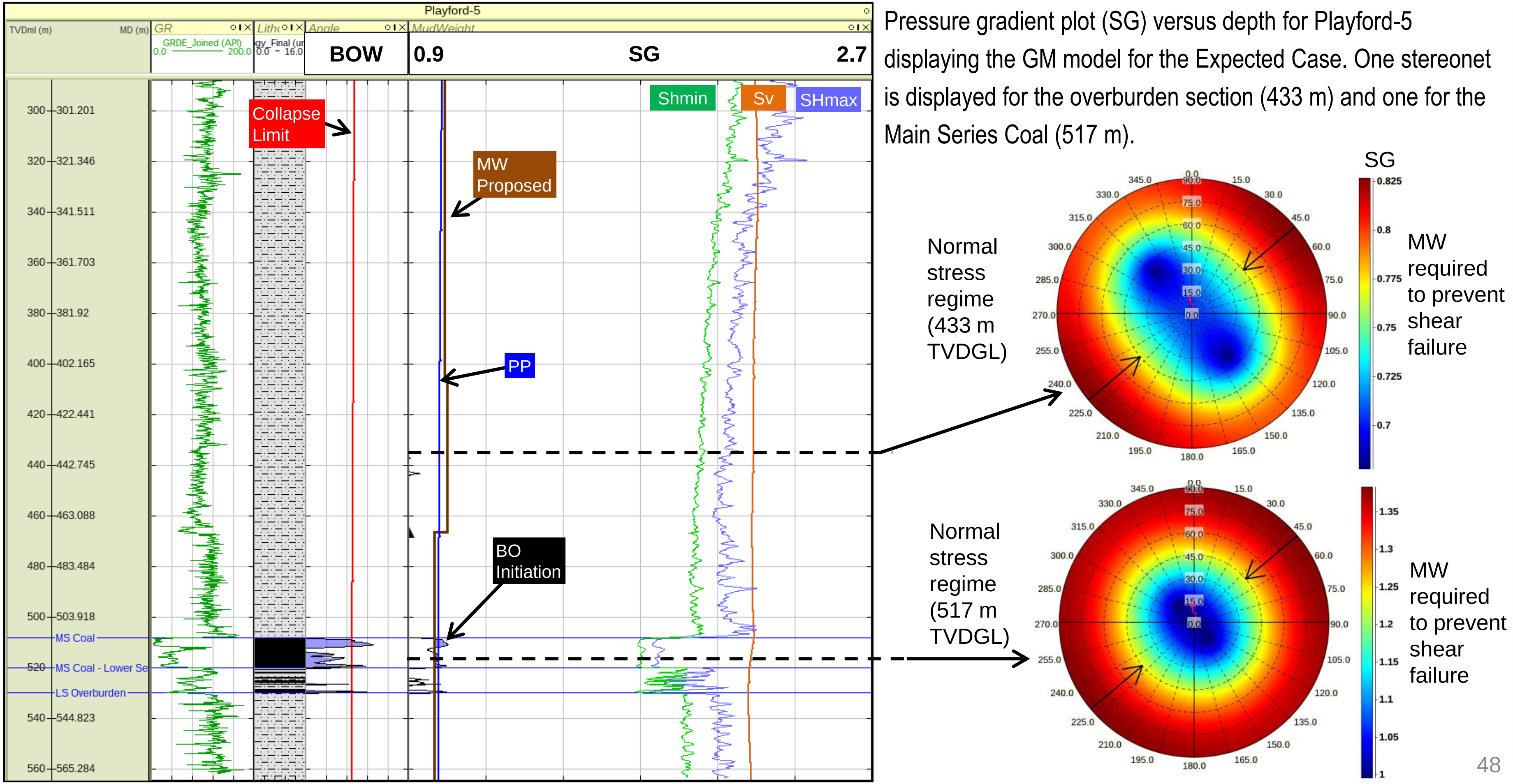
Horizontal Well



16.67% of wellbore failed

WBS Profiles – Based on Playford-5

Pressure gradient plot (SG) versus depth for Playford-5 displaying the GM model for the Expected Case. One stereonet is displayed for the overburden section (433 m) and one for the Main Series Coal (517 m).

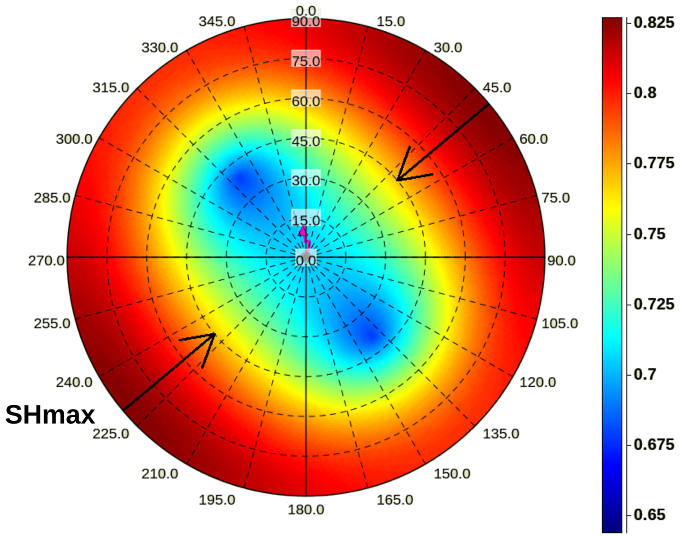


Minimum MW to Prevent Breakout

Normal Stress Regime – 433 m TVDGL (Overburden)

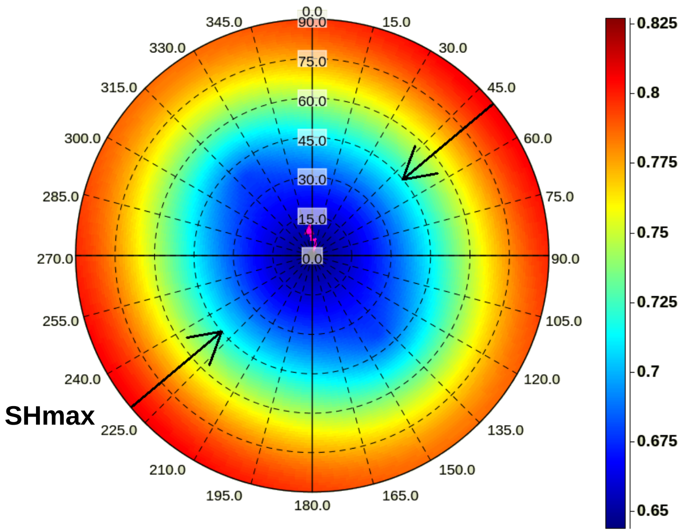
PP = 1.02 SG, Shmin = 2.03 SG, SHmax = 2.13 SG, Sv = 2.24 SG, UCS = 14.2 MPa, FA = 22.7°

Breakout Initiation Gradient



Stereonet displaying MW required to prevent shear failure initiation

Wellbore Collapse Gradient



Stereonet displaying MW required to prevent wellbore collapse based on formula below:

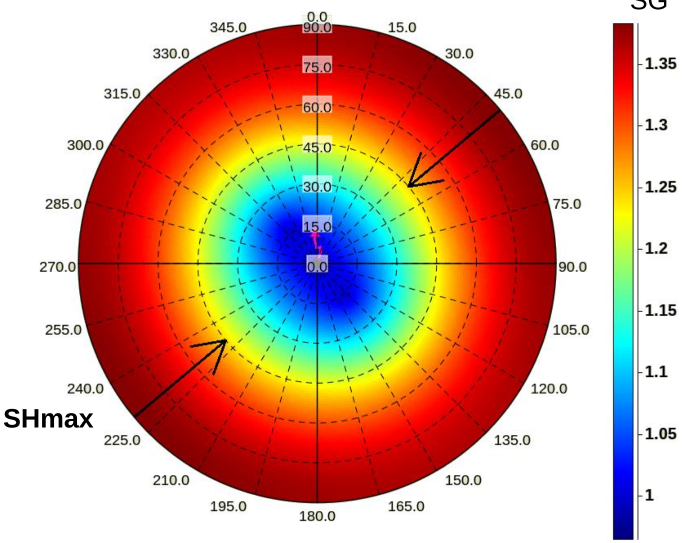
$$\text{Collapse limit} = \frac{90 - (90-30) \times \text{Deviation}}{90}$$

Minimum MW to Prevent Breakout

Normal Stress Regime – 517 m TVDGL (Main Series Coal)

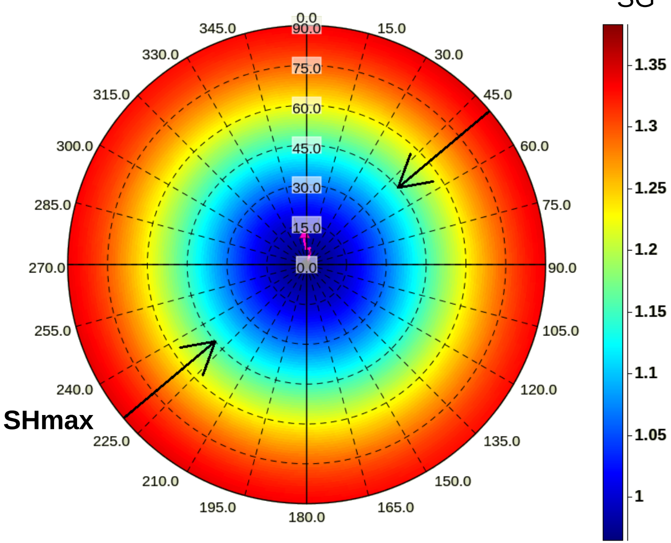
PP = 1.02 SG, Shmin = 1.80 SG, SHmax = 1.86 SG, Sv = 2.23 SG, UCS = 9.02 MPa, FA = 21.1^{o}

Breakout Initiation Gradient



Stereonet displaying MW required to prevent shear failure initiation

Wellbore Collapse Gradient



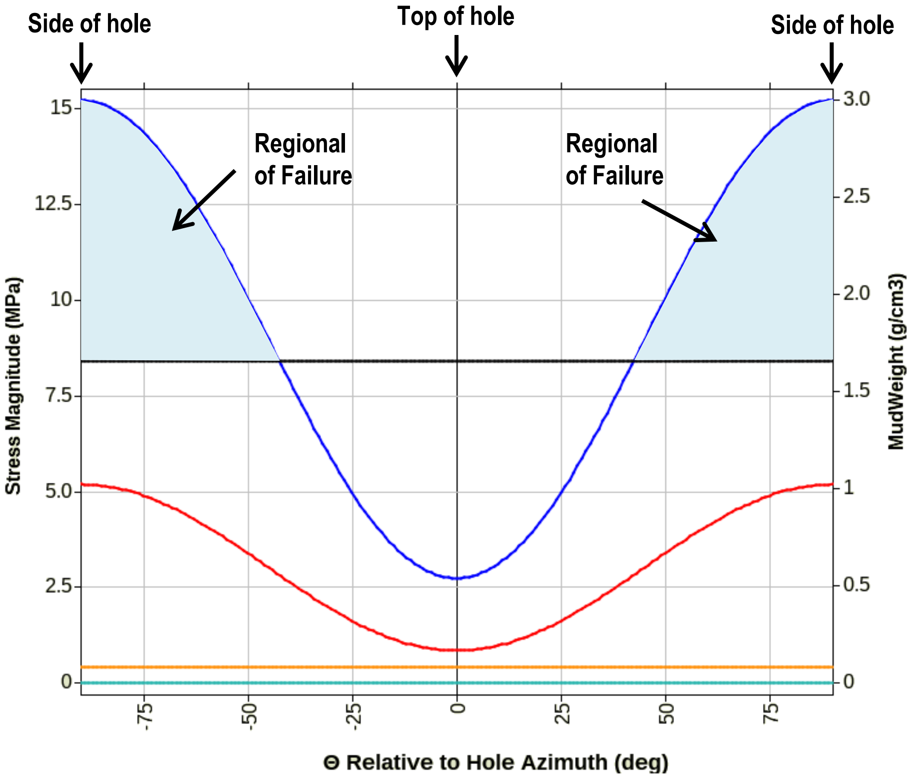
Stereonet displaying MW required to prevent wellbore collapse based on formula below:

$$\text{Collapse limit} = \frac{90 - (90-30) \times \text{Deviation}}{90}$$

Wellbore Stresses in Coal Lithology

Normal Stress Regime – 517 m TVDGL (Main Series Coal)

PP = 1.02 SG, Shmin = 1.80 SG, SHmax = 1.86 SG, Sv = 2.23 SG, UCS = 9.02 MPa, FA = 21.1°



In the coal lithology, a horizontal well, drilled in any azimuth will have wellbore failure that initiates at the side of the wellbore if the MW is too low.

The example to the left is for a horizontal wellbore (deviation 90°) drilled towards the north using a MW of 1.1 SG. Failure is predicted if the Circumferential Effective Stress exceeds the Effective Compressive Failure Stress.

Axial Effective Stress

Circumferential Effective Stress

Radial Stress

Effective Compressive Failure Stress

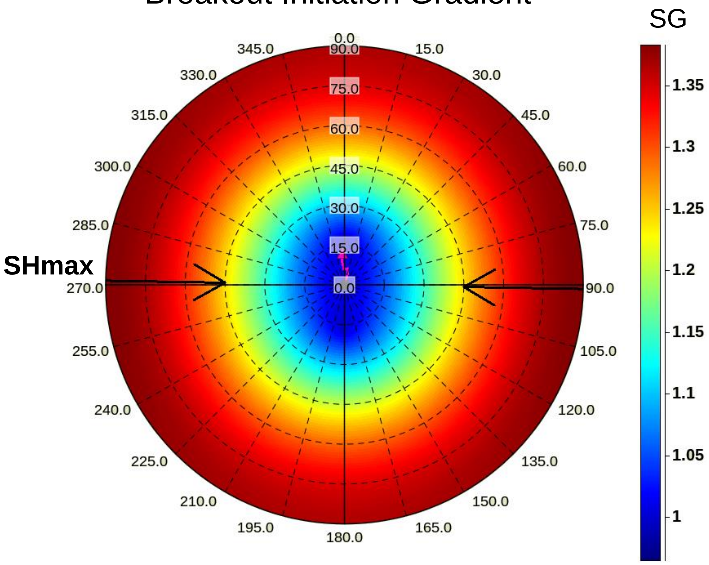
Tensile Strength

Minimum MW to Prevent Breakout – Regional SHmax Ori.

Normal Stress Regime – 517 m TVDGL (Main Series Coal)

PP = 1.02 SG, Shmin = 1.80 SG, SHmax = 1.86 SG, Sv = 2.23 SG, UCS = 9.02 MPa, FA = 21.1°

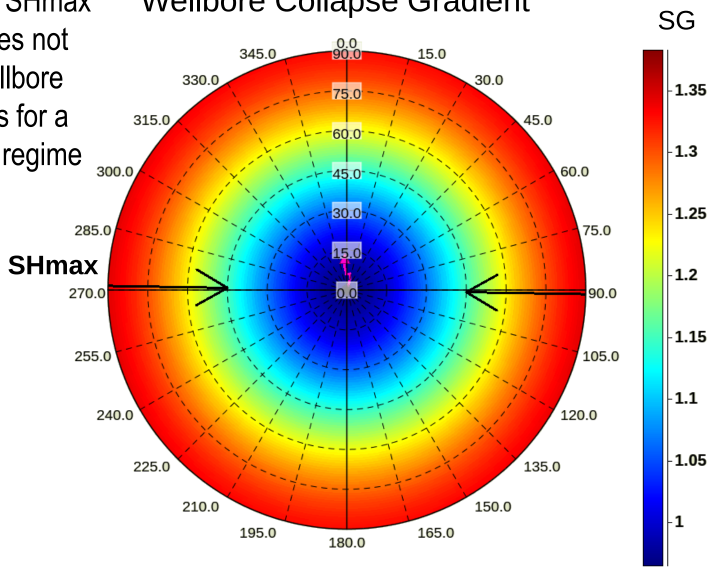
Breakout Initiation Gradient



Stereonet displaying MW required to prevent shear failure initiation

Uncertainty in SHmax orientation does not impact the wellbore stability results for a normal stress regime

Wellbore Collapse Gradient



Stereonet displaying MW required to prevent wellbore collapse based on formula below:

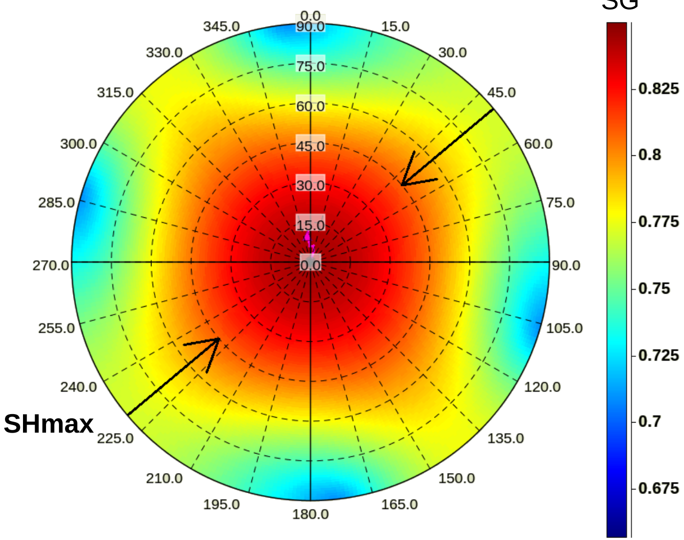
$$\text{Collapse limit} = \frac{90 - (90-30) \times \text{Deviation}}{90}$$

Minimum MW to Prevent Breakout – Strike-Slip Regime

Strike-Slip Stress Regime – 430 m TVDGL (Overburden)

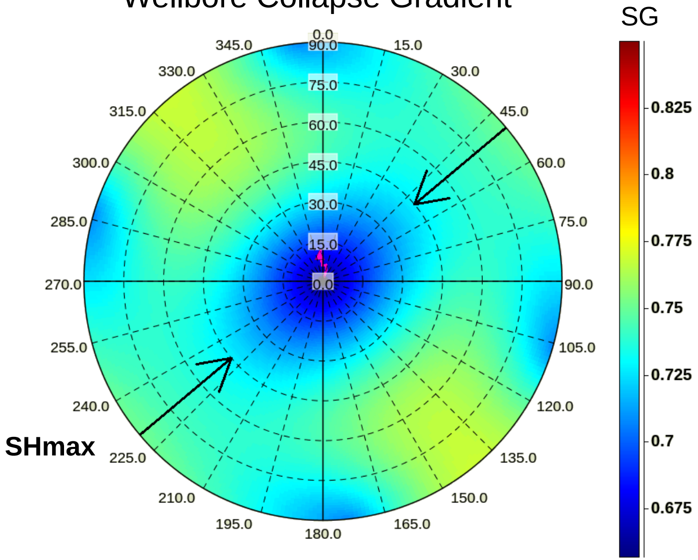
PP = 1.02 SG, Shmin = 2.04 SG, SHmax = 2.34 SG, Sv = 2.24 SG, UCS = 14.89 MPa, FA = 22.9^{o}

Breakout Initiation Gradient



Stereonet displaying MW required to prevent shear failure initiation

Wellbore Collapse Gradient



Stereonet displaying MW required to prevent wellbore collapse based on formula below:

$$\text{Collapse limit} = \frac{90 - (90-30) \times \text{Deviation}}{90}$$

Summary

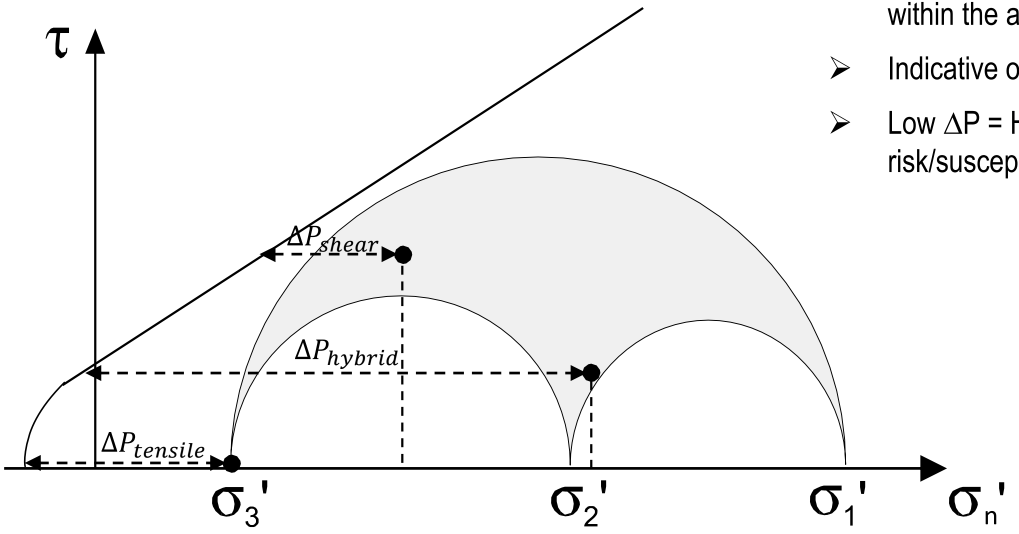
- **Overburden Wellbore Stability**
  - The Playford-5 geomechancial model indicates that wellbore stability should not be an issue in the overburden section for both the normal stress regime scenario (Expected Case) and the alternative strike-slip stress regime scenario. In both scenarios, the MW required to prevent breakout initiation is below 1.0 SG for all wellbore trajectories.
  - Under all stress scenarios (Strike-Slip and Normal stress conditions) the minimum pressure gradient (mudweight) required to prevent borehole breakout (shear failure) in any wellbore orientation is 0.85 S.G. (Pp = 1.02 S.G.)
- **Main Coal Wellbore Stability**
  - Under Normal stress conditions the minimum pressure gradient (mudweight) required to prevent borehole breakout (shear failure) in any wellbore orientation is 1.375 S.G. (Pp = 1.02 S.G.)
  - Horizontal wells in a normal stress regime require higher MWs to prevent breakout initiation than required for vertical wells. Thus, the risk of wellbore failure is predicted to be higher in horizontal wells drilled through the coal lithology. Direct strength measurements are not available for the coal lithology, which increases the uncertainty in the predicted MWs required to prevent breakout initiation and wellbore collapse in the coal lithology.
  - Shear failure is expected to occur on the sides of the wellbore independent of lateral deviation direction rather than the top/bottom of the wellbore under conditions with insufficient wellbore pressure.
  - The range of possible SHmax orientations has a greater impact within a strike-slip stress regime. However, the strike-slip stress regime scenario for the Playford-5 well predicts a low risk of wellbore failure for all wellbore trajectories. Consequently, the uncertainty in the SHmax orientation has no meaningful impact on the wellbore stability results.

7. Fault Reactivation & Structural Permeability

Structural Permeability Analysis

The following structural permeability assessment was based on the calibrated geomechanical model developed for the Playford-5 well in the previous section and analysis of structural elements of the Leigh Creek Coal mine were provided by Dr Gavin Springbett (G & S Resources).

Structural permeability was assessed using the ΔP approach, which can accommodate, shear, tensile and hybrid failure mechanisms. The ΔP approach assess the change in pore pressure required for failure to occur on any plane with a particular strike and dip (e.g. fault, fracture or bedding plane). Planes that plot "closer" to the failure envelope (i.e. low ΔP) on a Mohr diagram are considered more likely to be open and provide conduits for fluid flow.



- ΔP measures "how far from failure" a fracture/fault plane is within the applied stress field
- Indicative of mode of failure and measuring a risk of failure
- Low ΔP = High risk/susceptibility for failure; High ΔP = High risk/susceptibility

$$\Delta P_{shear} = \sigma_n' + \left(\frac{2T - \tau}{\mu}\right)$$

$$\Delta P_{hybrid} = \sigma_n' - \left(\frac{4T^2 - \tau^2}{4T}\right)$$

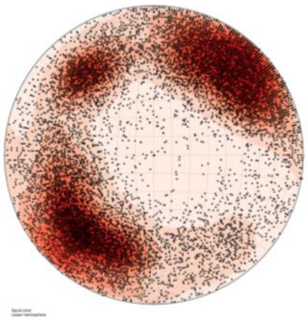
$$\Delta P_{tensile} = \sigma_3' + T$$

Mildren et al (2005)

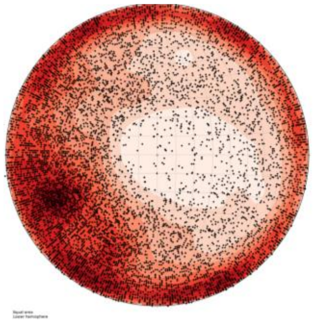
Structural Permeability Analysis

- All structural measurements were extracted from the Leigh Creek pit mapping database, collated in line with structure type (viz. faults, bedding, joints and shears).
- The data is historical and was primarily collected in the 1980's and early 1990's (especially the fault, bedding and shear measurements).
- The data sets are significant (faults ~13K individual measurements, joints ~10K and bedding ~5.5K).
- All measurements were observed at depths less than 200m.
- All structural elements are plotted as lower hemisphere poles-to-planes.

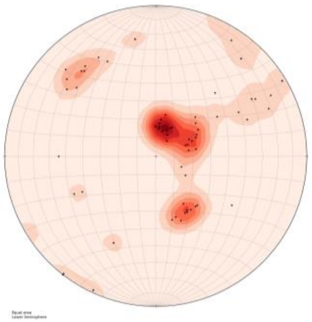
Faults



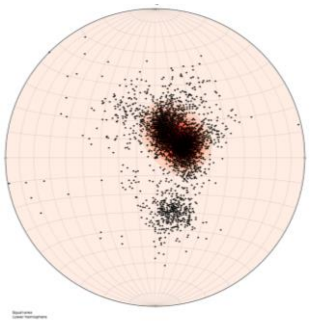
Joints



Shears



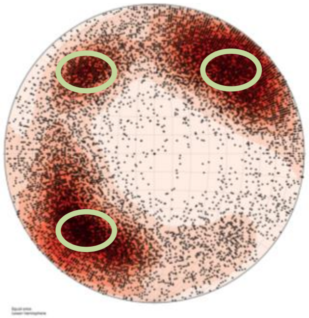
Bedding



Structural Permeability Analysis

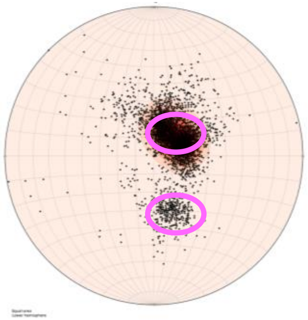
Faults Joints
Bedding Shears

Faults



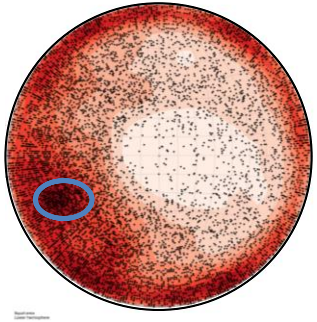
- Conjugate set of NW-SE striking faults dipping 60-70° to the NE and SW.
- Secondary NE-SW striking population dipping 50-60° to the SE

Bedding



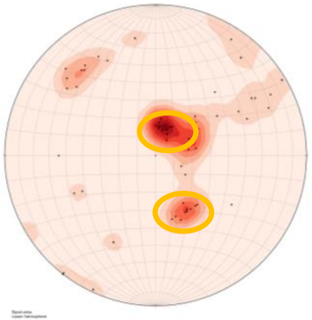
- Predominantly dipping 15° towards the SW.
- Secondary population dipping 30° to the N.

Joints



- Variable distribution of sub-vertical joints with a subset striking NNW-SSE and dipping 60° to the NE.

Shears



- Orientation of sheared surfaces are consistent with bedding populations. Predominantly dipping 15° towards the SW.
- Secondary population dipping 30° to the N.

Structural Permeability Analysis

One of the primary objectives for this study was to evaluate the relative geomechanical permeability of local structural elements within the changing horizons of interest and consider the risk of conduits propagating to the surface from the ISG chamber. Given the uncertainties in the geomechanical model and rock strength estimates we consider this a qualitative approach. Additionally it is a static assessment of initial conditions of the demonstration area and further numerical modelling of the dynamic nature of the system should be undertaken to better predict activity over time.

Here we consider the changes in stress regime with respect to depth as defined by the three geomechanical models: the Expected Case, the Overcoring Case, and the Strike-slip (regional) Case.

Depth (m)	Expected Case	Overcore Case	Strike-Slip Case
50	Reverse	Reverse	Reverse
150	Reverse	Strike-slip	Reverse
500	Normal	Normal	Strike-slip

Stress regime with respect to depth for three stress models within the ISG demonstration site

Structural Permeability Analysis

Structural permeability plots were generated for representative stress and depth scenarios and compared with mean orientations of structural elements documented previously. The scenarios under consideration were:

- Normal stress regime within the mudstone above the Main Series Coal.
- Strike-slip stress regime within the overburden mudstone, and;
- Reverse stress regime within the mudstone above the Main Series Coal and within the overburden.

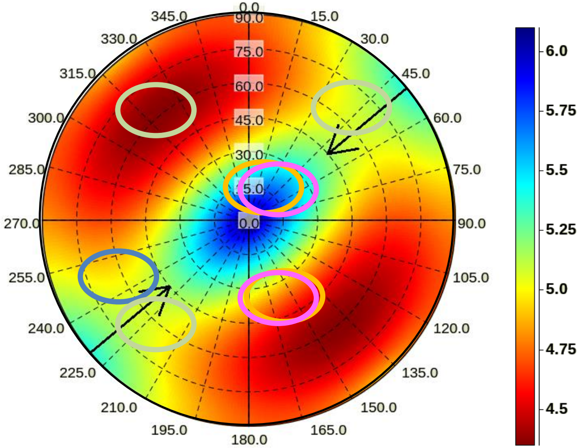
Sensitivity to stress orientation was also considered using the breakout derived azimuth (50^{o}N) and regional orientation (91^{o}N). The Expected stress case was applied in all scenarios with the exception of the strike-slip case.

For each scenario, structural permeability stereonets were generated assuming the strength of the host rock and a conservative assumption of fault/fracture strength (no cohesion). Structural permeability stereonets are presented with fracture planes plotted as poles to planes (southern hemisphere projection).

Structural Permeability Analysis – Expected Case

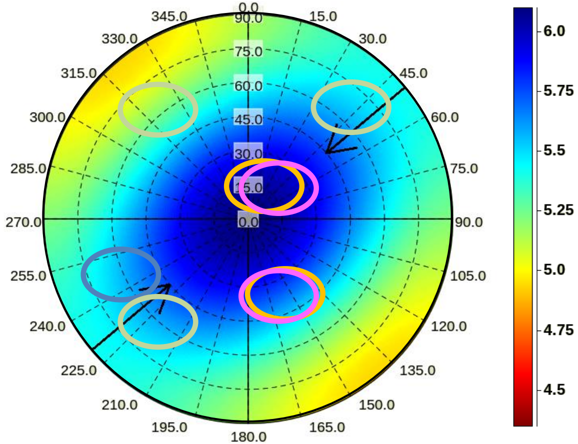
TVDGL = 500.0 m, PP = 4.99 MPa, Shmin = 9.92 MPa, SHmax = 10.40 MPa, Sv = 11.08 MPa, SHmax Ori. = 50°N, Lithology = Mudstone

CF = 30°, Cohesion = 0 MPa



ΔP (MPa)

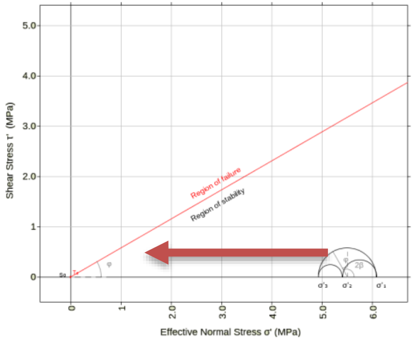
CF = 30°, Cohesion = 0.58 MPa



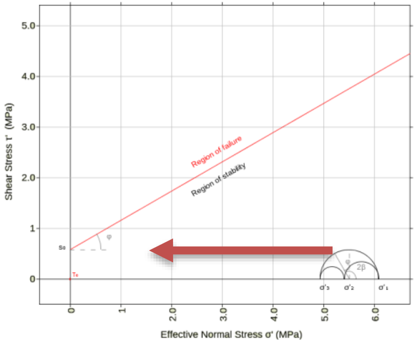
ΔP (MPa)

Normal Stress Regime

Fracture planes plotted as poles to planes



Faults
Joints
Bedding
Shears



CF = Coefficient of internal friction

Structural Permeability Analysis

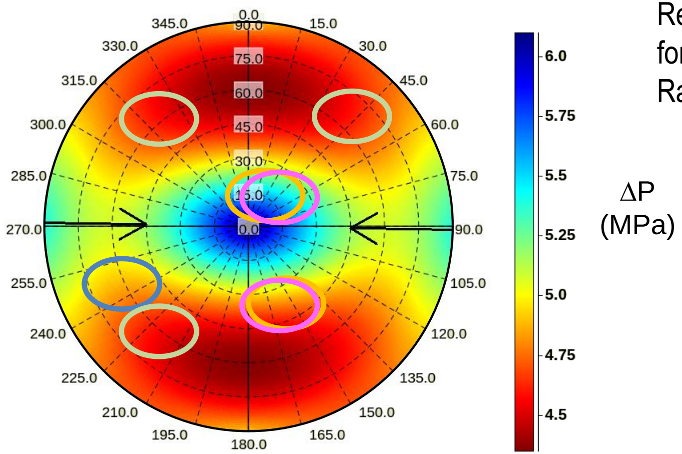
Expected Case, 500 m (TVDGL), SHmax = 50°N

- Above the Main Series Coal under Expected Case stress conditions the dominant NW-SE striking fault population and the dominant joint population remain an intermediate risk.
- The smaller NE-SW fault population is critically oriented and has the highest relative risk for reactivation.
- The ENE-WSW bedding population also has a high risk and its possible that the sheared surfaces corresponding with this orientation are reactivated bedding.
- The NW-SE beds have the lowest relative risk of reactivation.
- Absolute risk is relatively low as the effective differential stress is smaller than the critical ΔP by a factor of 5.

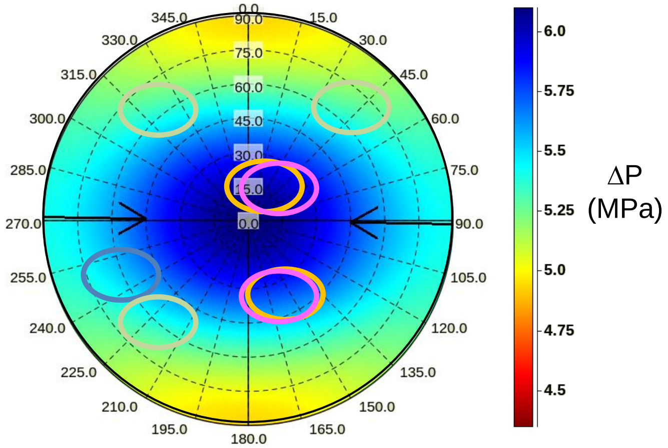
Structural Permeability Analysis – SHmax Orientation

TVDGL = 500.0 m, PP = 4.99 MPa, Shmin = 9.92 MPa, SHmax = 10.40 MPa, Sv = 11.08 MPa, **SHmax Ori. = 91°N**, Lithology = Mudstone

CF = 30°, Cohesion = 0 MPa

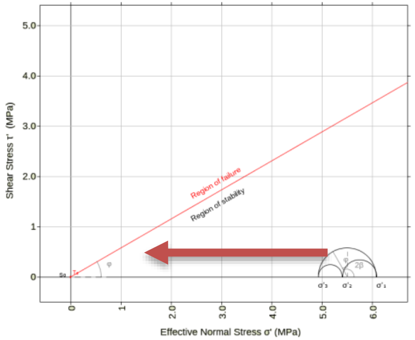


CF = 30°, Cohesion = 0.58 MPa

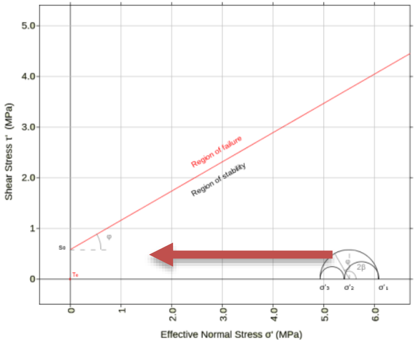


Regional SHmax orientation for the Flinders and Mt Lofty Ranges

Fracture planes plotted as poles to planes



Faults
Joints
Bedding
Shears



CF = Coefficient of internal friction

Structural Permeability Analysis

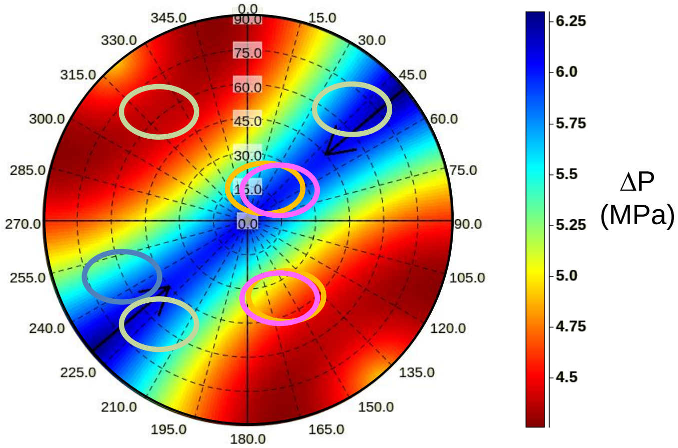
Expected Case, 500 m (TVDGL), SHmax = 91°N

- The risk distribution for reactivating structural elements where the Stress Orientation is assumed to be SHmax = 91ºN.
- Above the Main Series Coal under Expected Case stress conditions the NE-SW fault population reduces in risk from critical to high and the NW-SE striking faults increase in risk from intermediate to high.
- The dominant joint population remains an intermediate risk.
- The risk associated with each bedding population and corresponding shear surfaces remains the same.
- Absolute risk remains relatively low.

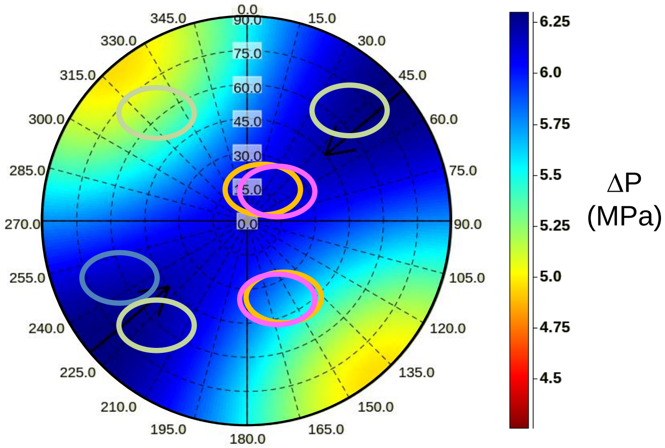
Structural Permeability Analysis – Strike-Slip Case

TVDGL = 501.0 m, PP = 5.0 MPa, Shmin = 9.94 MPa, **SHmax = 11.30 MPa**, Sv = 11.10 MPa, SHmax Ori. = 50ºN, Lithology = Mudstone

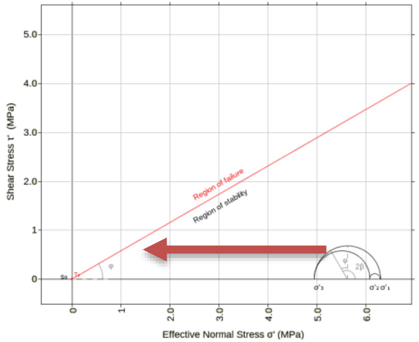
CF = 30º, Cohesion = 0 MPa



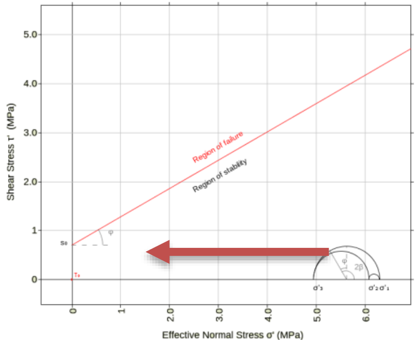
CF = 30º, Cohesion = 1.38 MPa



Fracture planes plotted as poles to planes



Faults
Joints
Bedding
Shears



CF = Coefficient of internal friction

Structural Permeability Analysis

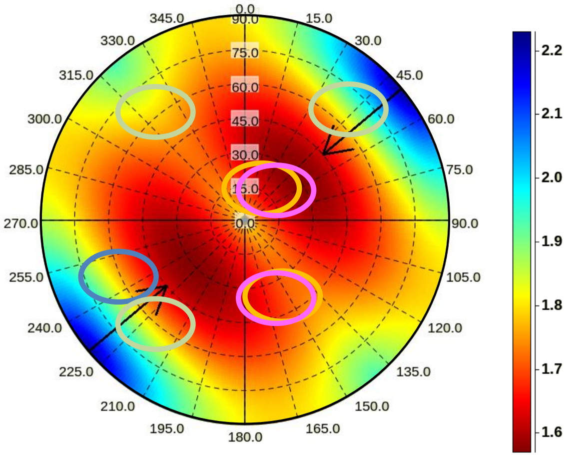
Strike-Slip Case, 500 m (TVDGL), SHmax = 50°N

- The risk distribution for reactivating structural elements assuming the strike-slip stress case and the observed SHmax = 50ºN.
- Above the Main Series Coal under strike-slip case stress conditions, the relative risk of the NE-SW fault population remains high.
- NW-SE striking faults reduce to low relative risk.
- The dominant joint population remains an intermediate relative risk.
- The relative risk associated with both bedding populations and corresponding shear surfaces remains the same.
- Absolute risk remains relatively low.

Structural Permeability Analysis – Expected Case

TVDGL = 150.0 m, PP = 1.56 MPa, Shmin = 3.50 MPa, SHmax = 3.79 MPa, Sv = 3.35 MPa, SHmax Ori. = 50°N, Lithology = Mudstone

CF = 30°, Cohesion = 0 MPa

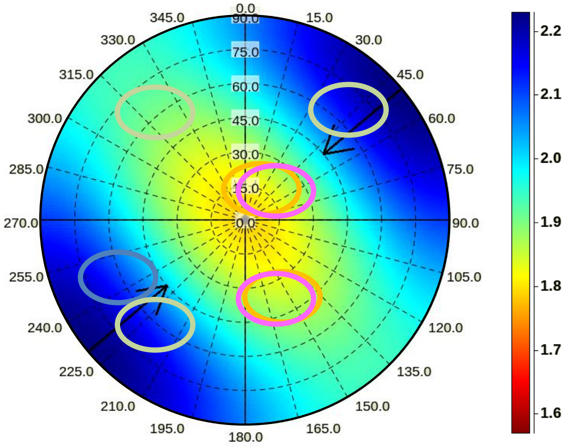


ΔP (MPa)

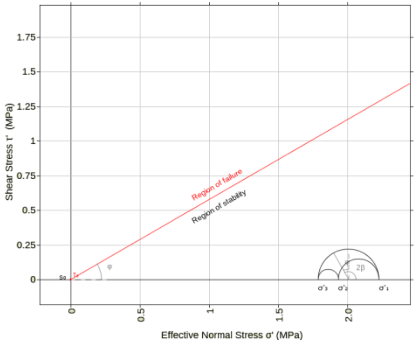
Reverse Stress Regime

Fracture planes plotted as poles to planes

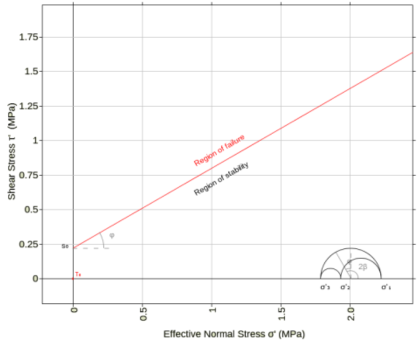
CF = 30°, Cohesion = 0.22 MPa



ΔP (MPa)



Faults
Joints
Bedding
Shears



CF = Coefficient of internal friction

Structural Permeability Analysis

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Expected Case, 150 m (TVDGL), SHmax = 50°N

- The risk distribution for reactivating structural elements assuming the Expected stress case and the observed SHmax = 50ºN.
- In the shallow overburden under reverse stress conditions, the relative risk of all fault populations and the dominant joint population is low to intermediate.
- The relative risk associated with both bedding populations and corresponding shear surfaces is high to critical.
- Absolute risk remains relatively low.

Structural Permeability - Summary

Results suggest that although the strike of the structural elements associated with high relative structural permeability may vary between stress models directly above Main Coal Series, in all cases it is the steeper dipping faults/joints/beds that have a higher likelihood of reactivation.

Where a reverse stress regime is in effect within the overburden the critical orientations for reactivation are surfaces dipping approximately 30º and striking perpendicular to SHmax i.e. NW-SE. These orientations correspond with observed bedding surfaces and sheared planes implying bed reactivation.

Each stress case is characterized by a stress transition from extension at depth in the reservoir through strike-slip within the overburden to reverse at the surface, however, the depths at which these transitions occur varies between each case. The transition from a strike-slip to a reverse regime corresponds with a rotation of the critical surface reactivation orientation from sub-vertical to sub-horizontal. In the context of the Leigh Creek Energy Demonstration Project, this implies that any surface that is reactivated due to changed pressure and stress conditions adjacent to the gasification chamber is likely to be the steeper dipping faults and or joints. Any vertically propagating structural element is likely to be retarded or rotated by the reverse stress environment where sub-horizontal features (bedding) would be preferentially reactivated.

8. Summary and Recommendations

Summary

- A geomechanical model was created based on data from the Playford-5 well. Rock mechanics tests and DFIT data indicates that the overburden section is strong and a normal stress regime (Shmin < SHmax < Sv) is dominant (Expected Case). An additional stress model was examined due to regional information suggesting that other stress regimes are prevalent in the Flinders Ranges. The alternative stress model has a strike-slip stress regime (Shmin < Sv < SHmax) in the overburden section. A normal stress regime is predicted in the Main Series Coal no matter which of the two stress regime cases occur in the overburden section.
- Wellbore failure (borehole breakouts) were only observed in the coal lithology on the image log from Playford-5. A maximum horizontal stress orientation of 50°N was used in this study based on the breakouts. However, a regional SHmax orientation of ~90°N cannot be ruled out. A good match is achieved between the observed wellbore failure, or lack of failure, and the modelled wellbore failure when using a Mohr-Coulomb failure criterion.
- Wellbore stability should not be an issue in the overburden section for both the normal stress regime scenario (Expected Case) and the alternative strike-slip stress regime scenario. In both scenarios, the MW required to prevent breakout initiation is below 1.0 SG for all wellbore trajectories. The coal lithology displays the highest risk for wellbore stability related issues. Horizontal wells in a normal stress regime require higher MWs to prevent breakout initiation than required for vertical wells. Thus, the risk of wellbore failure is predicted to be higher in horizontal wells drilled through the coal lithology. Direct strength measurements are not available for the coal lithology, which increases the uncertainty in the predicted MWs required to prevent breakout initiation and wellbore collapse in the coal lithology. Additional calibration data and modelling is required to provide a more accurate prediction of coal failure response.
- The fault reactivation/structural permeability assessment of the overburden directly above the Main Series Coal (normal stress regime) indicates that faults/fractures striking towards 15°-80° and 195°-260° with a dip angle of 45°-75° have the highest likelihood of being reactivated/open and provide conduits to fluid flow based on a SHmax orientation of 50°N. The faults/fractures would most likely open in shear failure.

Implications

The Leigh Creek ISG Demonstration will be a dynamic system with high temperatures and variable pressures. These changing conditions cannot be fully assessed using a static geomechanical model with uncertainties. The following implications derived from this analysis are based on the initial conditions of the site. Therefore, a fully coupled thermal poro-elastic numerical model, or equivalent, is recommended to understand the dynamic changes in stability, flow and containment across the life of the system.

- Wellbore stability analysis indicates that the Main Series Coals are susceptible to breakout and this risk is elevated with increasing wellbore deviation. The required MW to prevent breakout for horizontal wells deviated in the Shmin direction (NW-SE) is slightly less than the SHmax direction. Given that the operating pressure is expected to be <1.0 S.G., compressive failure of the coal is expected. Failure is expected to initiate on the side of the wellbore and is predicted to extend around the majority of the wellbore at the proposed low operating pressures. Additional calibration data and modelling is required to provide a more accurate prediction of coal failure response.
- Each stress case is characterized by a stress transition from extension at depth in the reservoir through strike-slip within the overburden to reverse at the surface, however, the depths at which these transitions occur varies between each case. The transition from a strike-slip to a reverse regime corresponds with a rotation of the critical surface reactivation orientation from sub-vertical to sub-horizontal. In the context of the Leigh Creek Energy Demonstration Project, this implies that any surface that is reactivated due to changed pressure and stress conditions adjacent to the gasification chamber is likely to be the steeper dipping faults and or joints. Any vertically propagating structural element is likely to be retarded or rotated by the reverse stress environment where sub-horizontal features (bedding) would be preferentially reactivated unless activating pressure is significant enough to continue propagate to surface.
- The Expected Stress Case implies a 250 m reverse stress regime to surface and the Overcoring Stress Case implies 70 m reverse stress regime to surface implying both models indicate conditions conducive to sub-vertical surface reactivation and fault/fracture creation.

Recommendations

- Acquiring shear velocity (Vs) data is advised in order to reduce the uncertainty in the rock elastic properties. This will in turn assist to reduce the uncertainty in the horizontal stress magnitudes.
- Acquiring additional DFIT tests in the overburden, underburden and Main Series Coal would reduce the uncertainty in Shmin magnitude.
- Image logs should be recorded as they can provide a direct indication of geomechanical failure in wellbores and can be used to better calibrate geomechanical models and to determine horizontal stress orientation.
- Rock mechanics tests (UCS and Triaxial tests) would assist in further calibrating the log-derived rock strength estimates. In particular the coal lithology requires rock mechanics tests in order to reduce the uncertainty in the wellbore stability results for the Main Series Coal.
- Triaxial tests are important in order to establish the correct dynamic to static relationship for the elastic properties. Improving the constraint on the elastic properties will reduce the uncertainty in both the rock strength and stress models. Triaxial tests will also provide vital calibration for the friction angle. Additional calibration of the rock strength model, particularly the UCS strength, would assist in reducing the uncertainty in other geomechanical model input parameters, such as the minimum horizontal and maximum horizontal stresses.