Stress and Strain:
Implications for fault reactivation and seal integrity within the Exeter and Mutineer Fields, Australian North West Shelf

Adrian White 1, Warwick Crowe 2, Mat Harrowfield 2, Richard Hillis 1 and Myra Keep 2

1 Australian School of Petroleum, Univ. of Adelaide, Adelaide, SA 5005, AUSTRALIA
2 Tectonics Special Research Centre, Univ. of Western Australia, Crawley, WA 6009, AUSTRALIA
Presentation Outline

• Location of the study region
• Orientation of the principal stresses
• Magnitudes of the principal stresses
• Fault orientations
• Geomechanical modelling
  • Fault reactivation risk
  • Creation of new faults and fractures
• Strain manifestation
• Implications and conclusions
Location of the Exeter and Mutineer Fields
Orientation of the principal stresses

- The principal stresses are assumed to be:
  - $S_h$
  - $S_H$
  - $S_V$
Orientation of the horizontal stresses

- Orientation of the horizontal stresses can be determined from FMI logs:
  - The presence of **borehole breakouts** and/or
  - **drilling-induced tensile fractures** (DITFs)
Orientation of the horizontal stresses

• Analysis of FMI logs from Mutineer 1b reveals poorly-developed borehole breakouts.

• Mutineer 1b also shows poorly-developed DITFs.
Orientation of the maximum horizontal stress ($S_H$)

- Breakouts reveal a $S_H$ orientation of 107°N
- Consistent with:
  - Breakouts from Wanaea-Cossack (Hillis & Williams, 1993)
  - $S_H$ orientations from data shown on *Australian Stress Map* (Hillis & Reynolds, 2000)
Magnitudes of the principal stresses

- $S_V$ calculated from density logs and the Nafe-Drake transform
- $S_h$ determined from leak-off test records – best of fit line applied to the data
- Upper bound for $S_H$ calculated using frictional limits to stress relation...

$$\frac{S_1 - P_p}{S_3 - P_p} = \left[\sqrt{\mu^2 + 1 + \mu}\right]^2$$

...and a best of fit line applied to the data
Magnitudes of the principal stresses

- \( S_H \) modelled using SWIFT software and information on:
  - Presence of incipient borehole breakouts
  - Presence of incipient DITFs
  - Rock mechanical properties
  - Pore pressures
  - Magnitudes of other principal stresses

\[ \frac{S_H}{S_V} = 0.766 \]
Quantification of the Exeter-Mutineer stress tensor

- $S_h$ gradient approximately 17.1 MPa/km
- $S_H$ upper bound gradient (frictional limits) approximately 32.3 MPa/km
- $S_H$ (rock mechanical determination) gradient approximately 28.6 MPa/km
- $S_V$ gradient approximately 23.6 MPa/km
Fault orientations within Exeter-Mutineer

- Faults loaded into TrapTester software
- Faults are predominantly orientated NE-SW
- Faults range in depth from 3000 to 6000 metres

(Depth scale in metres TVDSS)
Geomechanical modelling: fault reactivation risk

- Reactivation risk relates to the increase in pore pressure required to cause slip on pre-existing structures.
- Modelling requires:
  - Pore pressure profile – HYDROSTATIC
  - Contemporary stress tensor – $S_h < S_v < S_H$
Geomechanical modelling: fault reactivation risk

- Reactivation risk assessment based on a reduction in effective stress
- Mohr circle driven towards failure envelope with a $P_p$ increase
- Faults most likely to fail require a smaller $\Delta P_p$
Fault reactivation risk

- Reactivation risk measures the likelihood of movement on pre-existing faults
- Modelling assumes cohesionless fault surfaces and uses a failure envelope with a $\mu = 0.6$
- Results show faults most susceptible to slip strike NW-SE
Fault reactivation risk

- Reactivation risk assessed for all possible fault orientations
- Dark arcs represent Exeter-Mutineer faults
- Deep red colours show faults most likely to be reactivated as poles to planes
- Most risky Exeter-Mutineer faults have 45°N dips and strikes of ~ 080°N
Geomechanical modelling: formation of new faults & fractures

• Formation of new faults and fractures relates to the increase in pore pressure required to fail intact rock
• Modelling requires knowledge of:
  • Pore pressures
  • Contemporary stress tensor
  • Rock mechanical data
Formation of new faults & fractures

- Fracture tendency assessed for all possible orientations
- Deep red colours show new faults and fractures most likely to be formed
- New features most likely to be sub-vertical and have orientations of 085°N and 130°N
Stress tensor implications for fault movement

- The structural regime is shown to be $S_h < S_v < S_H$
- Production will lead to $P_p$ reduction
- $P_p$ – stress coupling not an issue:
  - $S_1$ and $S_3$ both horizontal
  - Respond to negative $\Delta P_p$ in same way
  - Reactivation of faults and/or formation of new structures unlikely
Strain manifestation

- Seismic images show minimal offsets across Jurassic-Cretaceous faults
- No faults mapped in the Tertiary
- Long wavelength, low amplitude bulge across the region
  - Suggested to represent ductile strain from very low strain rates
Conclusions (1)

- $S_h$ magnitude is $\sim 75\% S_V$
- Modelling estimates $S_H$ to be 5 MPa/km above $S_V$
- The differential stress is estimated to be $\sim 12$ MPa/km
- Breakouts show the mean $S_H$ orientation is 107°N
- Fault reactivation risking shows Exeter-Mutineer faults are unfavourably oriented for reactivation
  - Faults most susceptible to reactivation strike NW-SE
- Failure of intact rock requires greater increases in pore pressure than fault reactivation
Conclusions (2)

• Production leads to drawdown
  • Mohr circle moves away from the failure envelope therefore reactivation more unlikely

• Strain analyses show no significant faulting in Tertiary

• Strain manifests as a low amplitude bulge across Exeter-Mutineer
  • Further evidence for a low risk of brittle fault reactivation