Pore Pressure/Stress Coupling

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Pore Pressure/Stress Coupling

- introduction
- coupled changes: theory
- coupled changes: data
- implications
- conclusions
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Conclusions

- changes in $P_P$ are coupled to changes in $\sigma_h$ at both the 'oil field' and 'basin' scale
- predictions based on the assumption that $\sigma_h$ is independent of $P_P$ are unreliable
Effective Normal Stress ($\sigma_n - P_p$)

- overpressure (basin scale)
- depletion (field scale)

Shear Stress

failure envelope

initial state

0

Effective Normal Stress ($\sigma_n - P_p$)
$P_p/\sigma_h$ coupling has implications for:

- induced seismicity
- wellbore stability
- limits to overpressure
- mode of failure

\{
\begin{align*}
\text{field scale} \\
\text{basin scale}
\end{align*}
\}
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Poroelastic Theory

\[ \sigma_h = k (\sigma_v - P_p) + P_p \]

\[ k = \frac{\nu}{1 - \nu} ; \quad 0 < k < 1 \]

eg. \( \nu = 0.25; \ k \approx 0.33; \ \Delta\sigma_h/\Delta P_p \approx 0.67 \)
Frictional Limit Theory

\[
\frac{\sigma_1 - P_p}{\sigma_3 - P_p} = m
\]

\[
\sigma_h = \frac{1}{m} (\sigma_v - P_p) + P_p
\]

assuming normal fault regime

\[
m = \{(\mu^2 + 1)^{1/2} + \mu\}^2
\]

eg. \(\mu = 0.58; m \approx 3; \Delta\sigma_h/\Delta P_p \approx 0.67\)
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Ekofisk Field, North Sea: Field Scale

Pore Pressure (MPa) vs. Minimum Horizontal Stress (MPa)

- crest
- flank
- outer flank

(Ekofisk Field, North Sea) (Teufel et al. 1991)
Scotian Shelf, Canada: Basin Scale

Bell 1990
Scotian Shelf, Canada: Basin Scale

Pore Pressure Gradient (MPa/km)

Minimum Horizontal Stress Gradient (MPa/km)

(Bell 1990)
North West Shelf, Australia: Basin Scale
Gannet/Guillemot Fields, North Sea: Basin Scale
Vicksburg Formation, South Texas: Field Scale

Minimum Horizontal Stress Gradient (MPa/km) vs. Pore Pressure Gradient (MPa/km)

(Salz 1977)
Travis Peak Formation, East Texas: Field Scale

Minimum Horizontal Stress Gradient (MPa/km) vs. Pore Pressure Gradient (MPa/km)

(Whitehead et al. 1987)
Alberta Basin, Western Canada: Field Scale

(Pore Pressure Gradient (MPa/km)

Minimum Horizontal Stress Gradient (MPa/km)

Woodland & Bell, 1989)
<table>
<thead>
<tr>
<th>Area</th>
<th>Scale</th>
<th>$\Delta \sigma_h/\Delta P_p$</th>
<th>C.C.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scotian Shelf, Canada</td>
<td>B</td>
<td>0.76</td>
<td>0.77</td>
</tr>
<tr>
<td>North West Shelf, Australia</td>
<td>B</td>
<td>0.75</td>
<td>0.48</td>
</tr>
<tr>
<td>Gannet/Guillelmot Fields, North Sea</td>
<td>B</td>
<td>0.60</td>
<td>0.67</td>
</tr>
<tr>
<td>Vicksburg Formation, South Texas</td>
<td>F</td>
<td>0.48</td>
<td>0.88</td>
</tr>
<tr>
<td>Travis Peak Formation, East Texas</td>
<td>F</td>
<td>0.57</td>
<td>0.85</td>
</tr>
<tr>
<td>Alberta Basin, Western Canada</td>
<td>F</td>
<td>0.34</td>
<td>0.26</td>
</tr>
<tr>
<td>Ekofisk Field, North Sea</td>
<td>F</td>
<td>~0.8</td>
<td>-</td>
</tr>
<tr>
<td>US Gulf Coast</td>
<td>B &amp; F</td>
<td>0.46</td>
<td>-</td>
</tr>
<tr>
<td>Lake Maracaibo, Venezuela</td>
<td>F</td>
<td>0.56</td>
<td>-</td>
</tr>
<tr>
<td>Brunei</td>
<td>B &amp; F</td>
<td>0.49</td>
<td>-</td>
</tr>
<tr>
<td>Magnus Field, North Sea</td>
<td>F</td>
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</tr>
<tr>
<td>West Sole Field, North Sea</td>
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<td>1.18</td>
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</tr>
<tr>
<td>Wytch Farm Field, UK</td>
<td>F</td>
<td>0.65</td>
<td>-</td>
</tr>
<tr>
<td>Venture Field, Canada</td>
<td>B</td>
<td>0.56</td>
<td>-</td>
</tr>
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Implications

- changes in $P_p$ and $\sigma_h$ coupled
- changes in $P_p$ do not affect $\sigma_v$ (weight of overburden)
Implications

\[ \sigma'_h = \sigma_h - P_p \]

\[ \sigma'_v = \sigma_v - P_p \]
Stress Gradient (MPa/km)

Pore Pressure Gradient (MPa/km)

Field Scale (Depletion)

Basin Scale (Overpressure)

hydrostat
lithostat

diff. stress

\( \sigma_h \)

\( \sigma_v \)

\( \sigma_v' \)

\( \sigma_h' \)

diff. stress
overpressure (basin scale)

depletion (field scale)

failure envelope

initial state

Shear Stress

Effective Normal Stress ($\sigma_n - P_p$)

$\sigma_h'$

$\sigma_v'$
Shear Stress (MPa) vs. Effective Normal Stress \((\sigma_n - P_p)\)

- Depletion lines indicate the depletion of shear stress as the effective normal stress increases.
Shear Stress (MPa)

Effective Normal Stress ($\sigma_n - P_p$)

Overpressure

$\sigma_h'$

$\sigma_v'$
Implications: Field Scale

- $P_P/\sigma_h$ coupling can account for depletion-induced seismicity
- $P_P/\sigma_h$ coupling must be incorporated in models of the (changing) stability of open hole completions with the drawdown of reservoir pressure
Implications: Basin Scale

- $P_p/\sigma_h$ coupling implies that considerably more overpressure can be sustained than would be predicted by simple (uncoupled) models of rock failure.

- $P_p/\sigma_h$ coupling promotes tensile as opposed to shear failure with overpressure development.
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  \text{field scale}  
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\{  
  \text{basin scale}  
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