Re-evaluation of the in situ stress field at Forsmark, Sweden

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Why stress is important

> stress defines the mechanical performance of rock
> stress influences the behaviour of fractures and faults
> stress determines the hydraulic behaviour of the geosphere system

Stress field understanding is a prerequisite for any geomechanical analysis!
Content

> consolidation of the stress field information available on the Forsmark area

> discussion of consistency of data interpretation

> derivation of an alternative stress model
Existing basic stress models (500m level)

<table>
<thead>
<tr>
<th>SH</th>
<th>Sh</th>
<th>SV</th>
<th>$P_p$</th>
<th>stress regime</th>
<th>reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>[MPa]</td>
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<tr>
<td>41.0 ± 6.2</td>
<td>23.2 ± 4.6</td>
<td>13.3 ± 0.3</td>
<td>5</td>
<td>reverse</td>
<td>Martin, 2007: SKB's “most likely”</td>
</tr>
<tr>
<td>22.7 ± 1.1</td>
<td>10.2 ± 1.6</td>
<td>13</td>
<td>5</td>
<td>strike-slip</td>
<td>SKB, 2009: SKB’s “unlikely minimum”</td>
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<tr>
<td>56 ± 6</td>
<td>35 ± 15</td>
<td>13.3 ± 0.3</td>
<td>5</td>
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Comments on stress field models

> SKB: hydraulic data omitted, as results contradict general regime in Fennoscandia

  but: Stephansson et al. (1991) suggest a transition regime (RF to SS) for that depth

> SKB: individual measurements omitted

> Ask: relies heavily on hydraulic data
SSM stress model

wells DBT 1 and 3 outside lens

Ask et al.

Alternative stress model based on HF & HTPF

$\sigma_{\text{vert}}$ = Calculated vertical stress

Maximum horizontal stress (MPa)

Minimum horizontal stress (MPa)
Applied methodology

Stress polygon analysis (aka concept of limited stress ratios)

> assumption: unfavourably oriented fractures limit the strength of the rock mass

> hence, the frictional strength of the fractures limits the possible stress states

references: Peska and Zoback 1995, Jaeger et al. 2007
stability limit

calculation of limiting stresses for a certain depth, here 500m

stability model

stress regime

reverse faulting

SH = \sqrt{\sqrt{\mu^2 + 1} + \mu} \cdot SV

Sh = SV / \sqrt{\sqrt{\mu^2 + 1} + \mu}
SSM most likely
> outside stability limit as reported by SSM
> but still within rock strength
> critical fracture orientations would be gently dipping like ZFMF1 or ZFMF2
> but healed fractures would allow for larger stresses

Ask et al.
> within and close to the stability limit

software: geomecon in-house

stability limit for rock mass, assumed 40°, i.e. 2/3 of rock strength

stability limit for fractures in FFM01, Glamheden et al 2007, 35°

SV = 0.0265 z
new stress model
> structural geology indicates transitional regime
> below 300m there is only limited data, except the hydraulic measurements
local stress variations (simulation with roxol, www.roxol.de)
Conclusions

> indications for transitional regime (RF to SS) consistently in literature for repository level

> with considerations about rock mass strength, we propose an estimate with

\[ SH \approx 35\text{MPa}, \quad Sh \approx SV \approx 13\text{MPa} \]

> data density very limited, additional parameter determination and stress measurements are needed

> stress field inversion modelling suggested