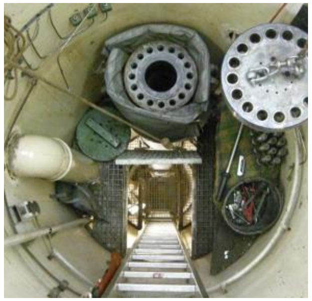
MeSy SOLEXPERTS

Rock testing and monitoring systems

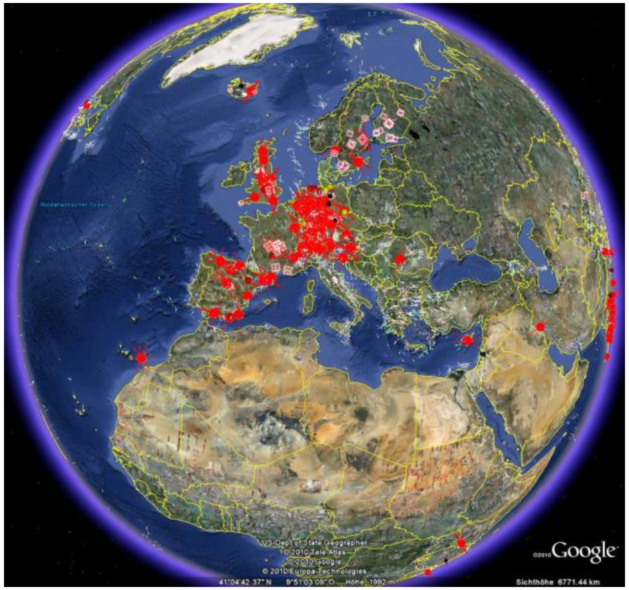


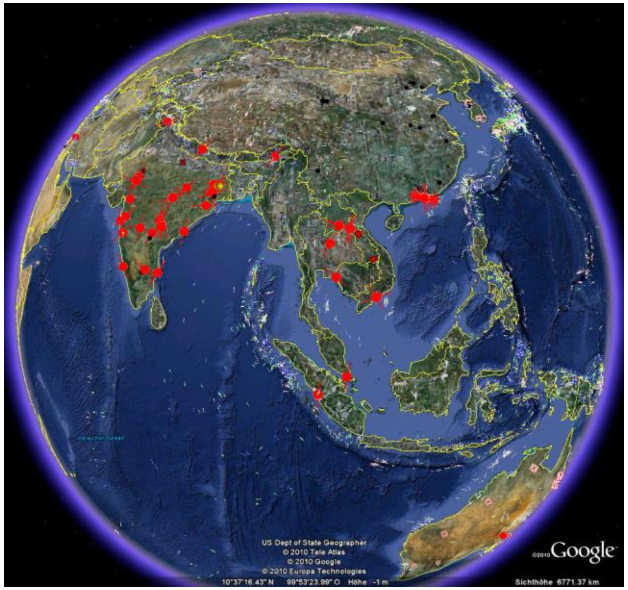
private photo F. Rummel

Hydrofrac-Test Demonstration

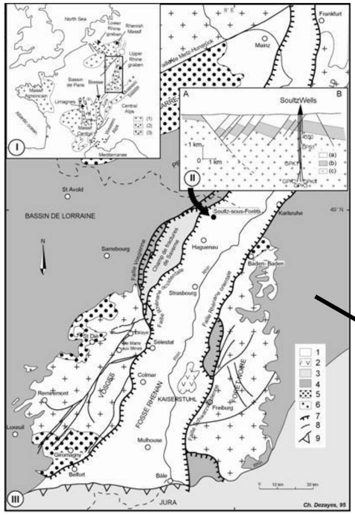
1969 granite quarry N-Minnesota

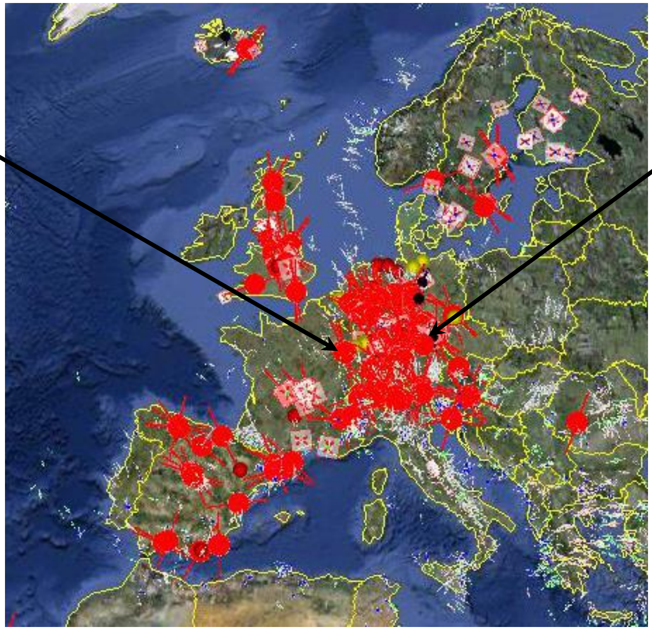
… more than 25 years of experience in hydrofrac testing all over the world !

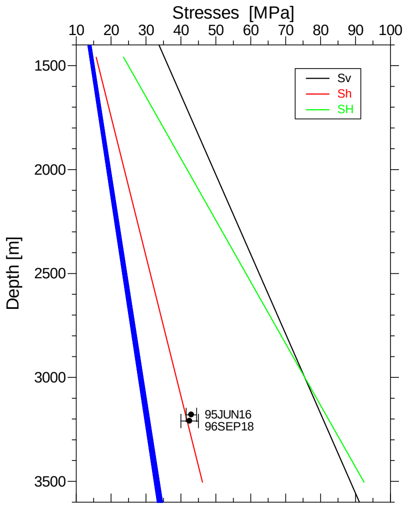


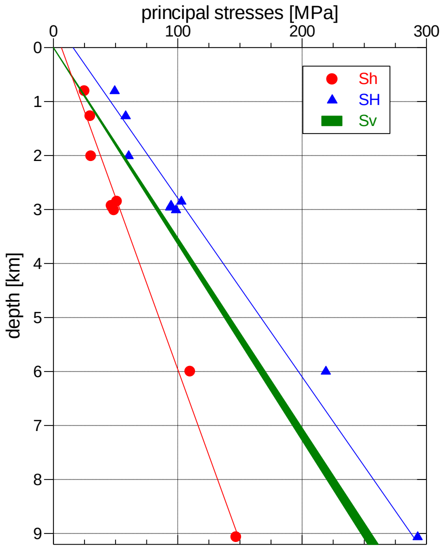


Highlights…






Stresses [MPa]
10 20 30 40 50 60 70 80 90 100
Depth [m]
1500
2000
2500
3000
3500
Sv
Sh
SH
95JUN16
96SEP18


principal stresses [MPa]
0 100 200 300
depth [km]
0 1 2 3 4 5 6 7 8 9
Sh
SH
Sv

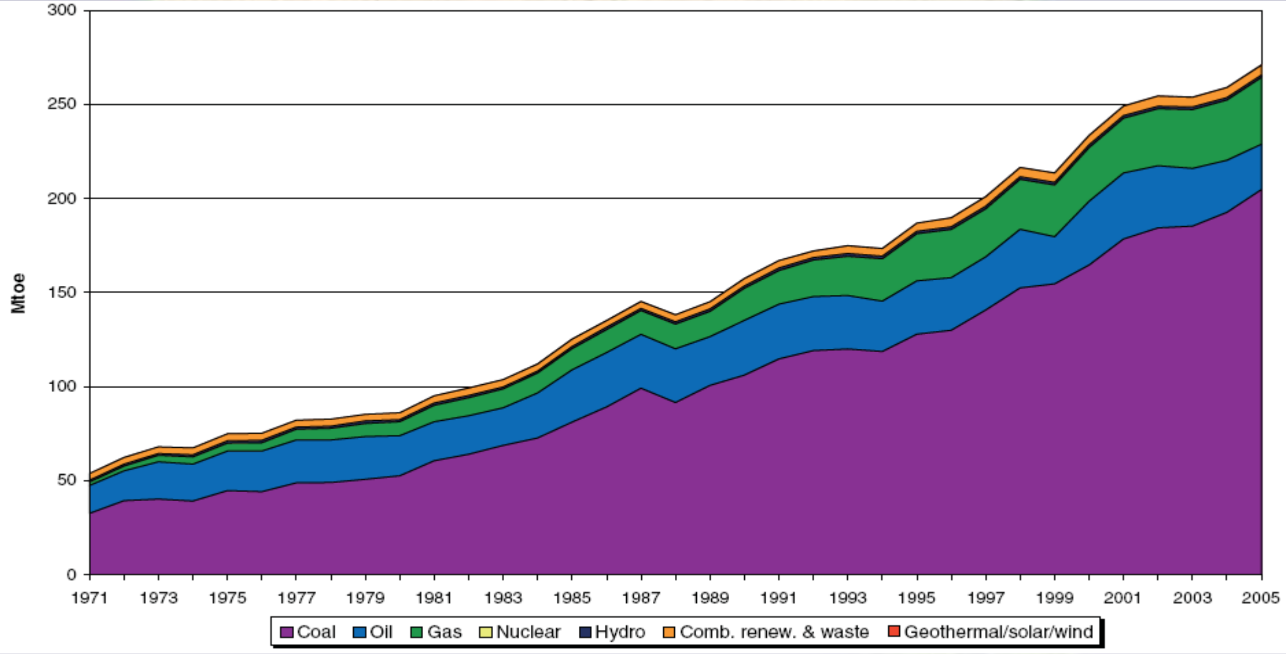
Deep Hydraulic Fracturing Stress Measurements

- Case Study from a Geothermal Energy Project in Australia -

A. Larking, G. Meyer	*GreenRock Energy, West Perth, Australia*
A.P. Bunger, B. Shen, R. Jeffrey	*CSIRO, Melbourne, Australia*
G. Klee, F. Rummel	*MeSy-Solexperts GmbH*

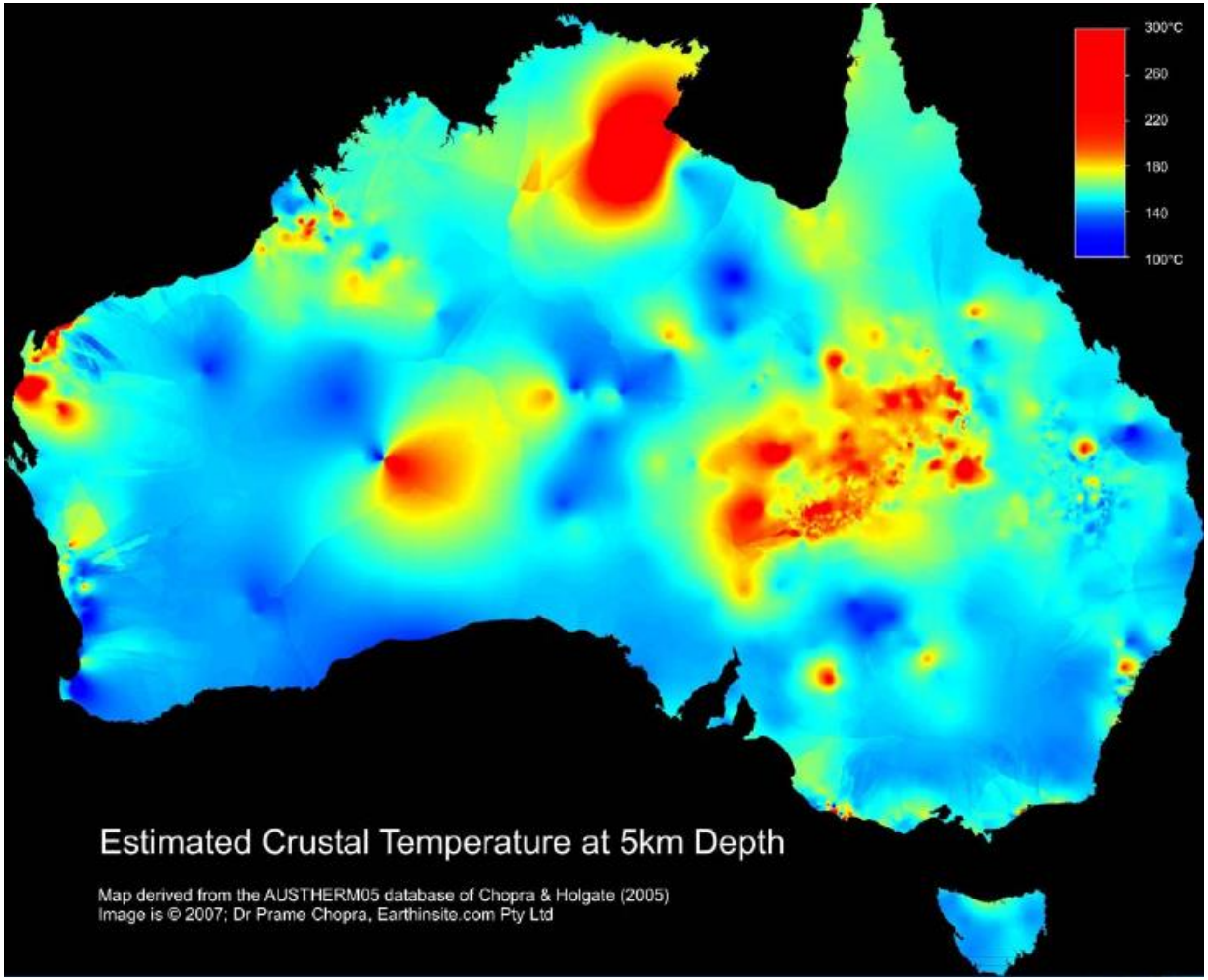
Klee G, Bunger AP, Meyer G, Rummel F and Shen B. 2011. In-situ stress in borehole Blanche-1/South Australia derived from breakouts, core discing and hydraulic-fracturing to 2 km depth. *Rock Mechanics and Rock Engineering, 44:531-540*

- Australia is the world sixth – largest country.
- Population of 21 million people.
- Large mineral resources, including coal, oil and natural gas.
- Electricity generation is dominated by coal-fired plants.



- GHG emission intensity is one of the highest in the world.
- In 1997, Australian government announced a series of measures designed to reduce the emissions of GHG.

Australia - Geothermal Energy Potential

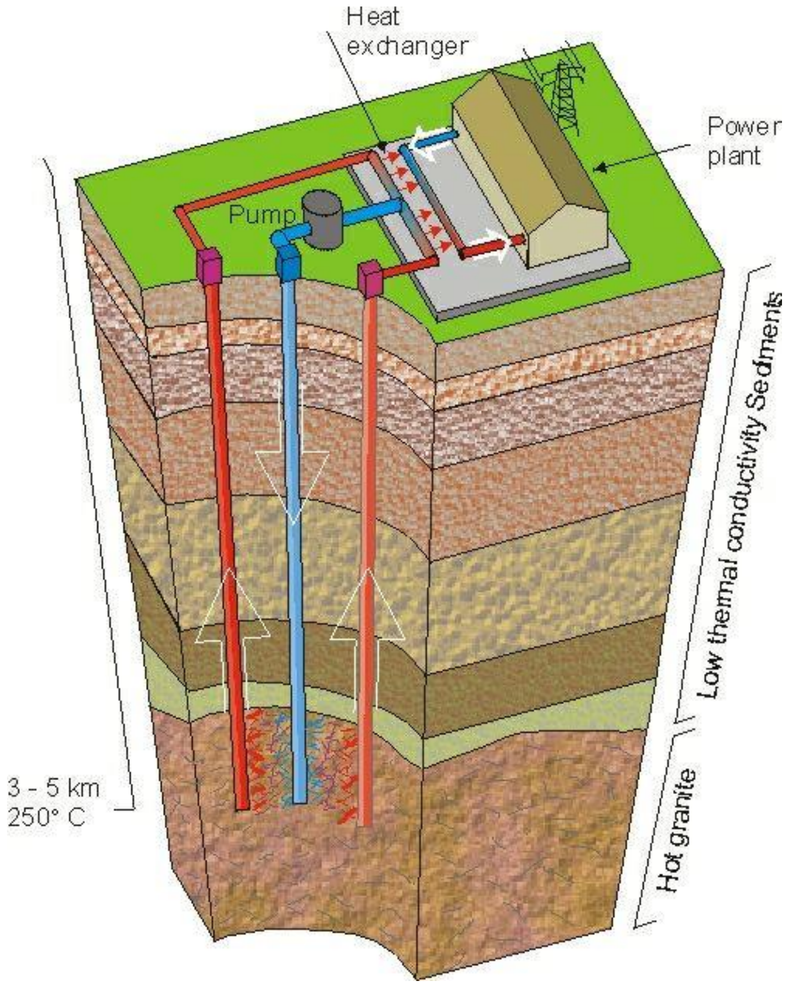


S-Australia

heat flow density

of ≈ 90 $\mu W/m^2$

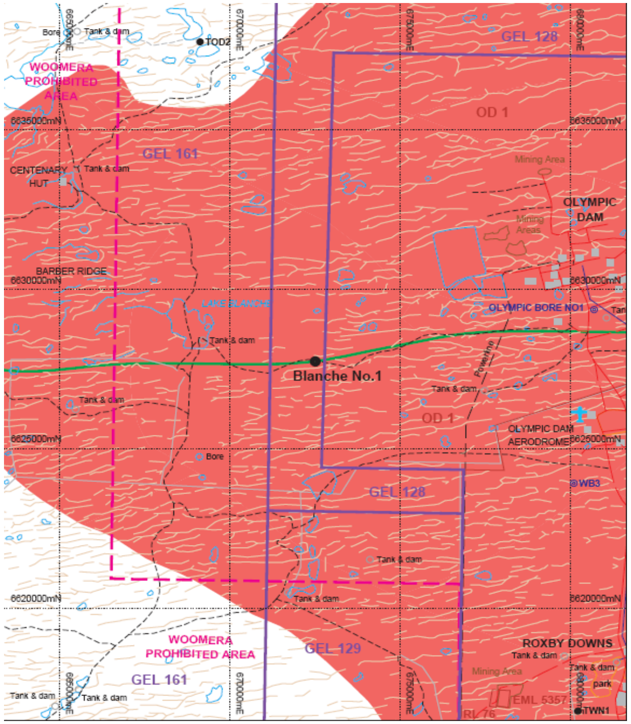
Principle of Hot-Dry-Rock (HDR, HFR, EGS)



In – Situ Stress Regime controls…

- pressure to induce fractures or to stimulate pre-existing joint systems
- flow resistance
- direction of the underground fluid flow path
- micro-seismicity
- borehole stability

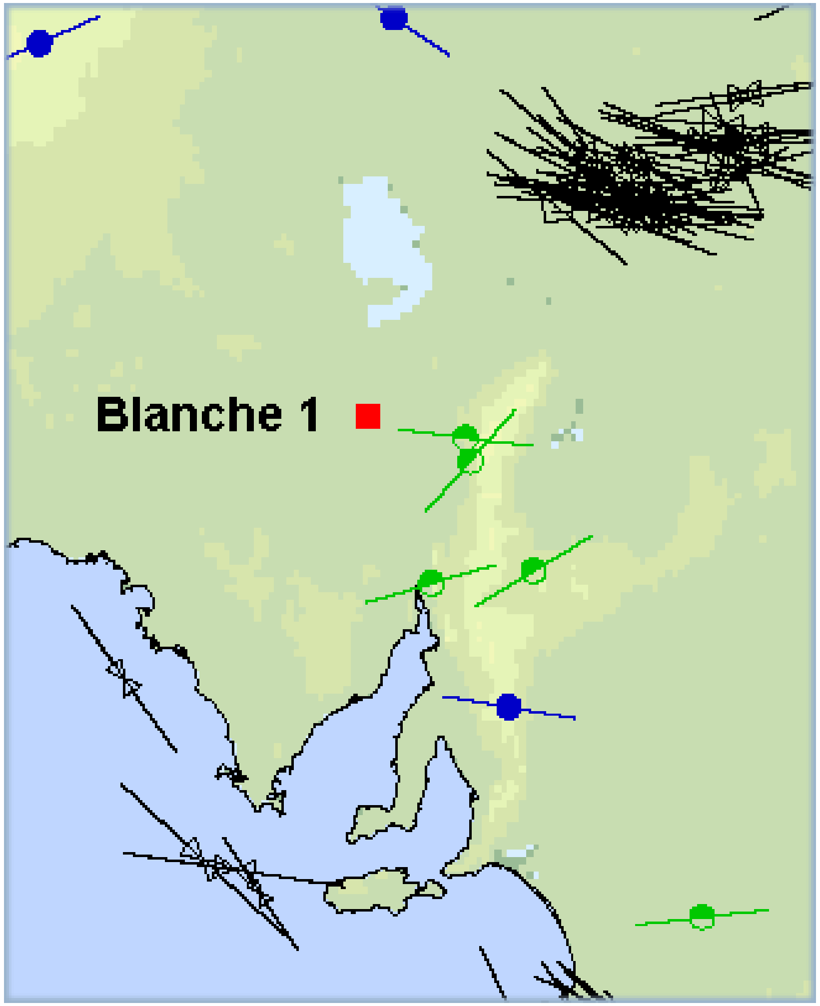
Olympic Dam Geothermal Project



Borehole Blanche-1

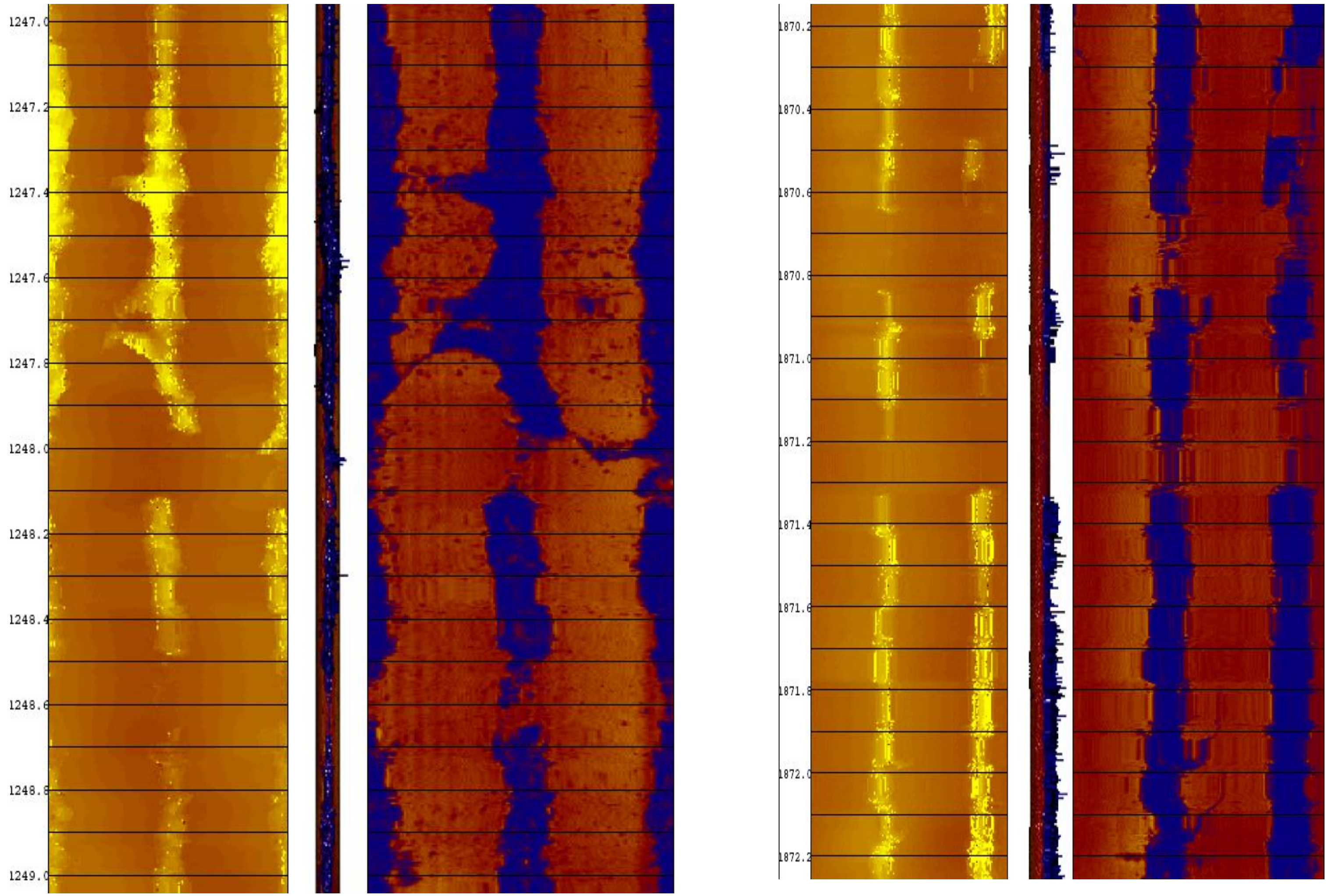
- drilled near the western edge of the Roxby Down Granite (part of the Burgoyne Batholithe)
- depth: 1934.6 m, open-hole diameter: 76 mm below 830.1 m
- bottom-hole temperature: ≈86 ° C

Regional Stress Data



www.world-stress-map.org, 2008

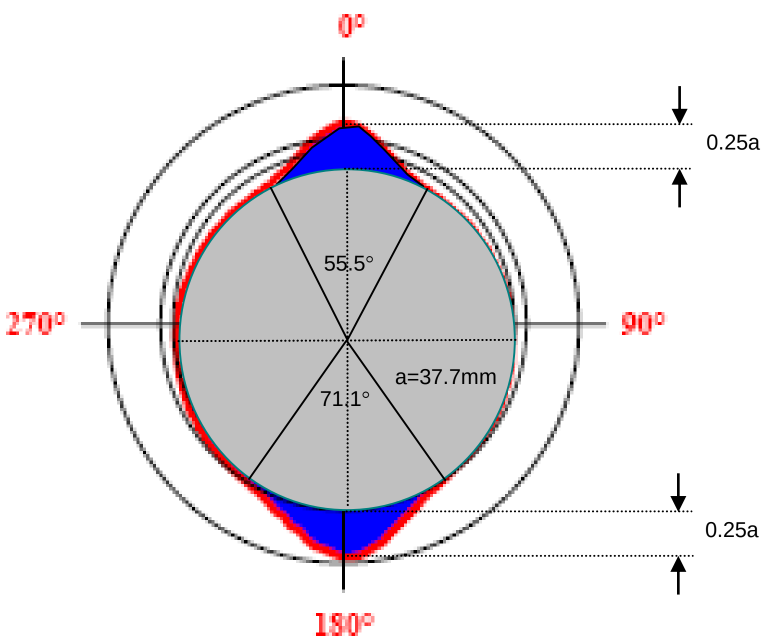
Analysis of Borehole Breakouts



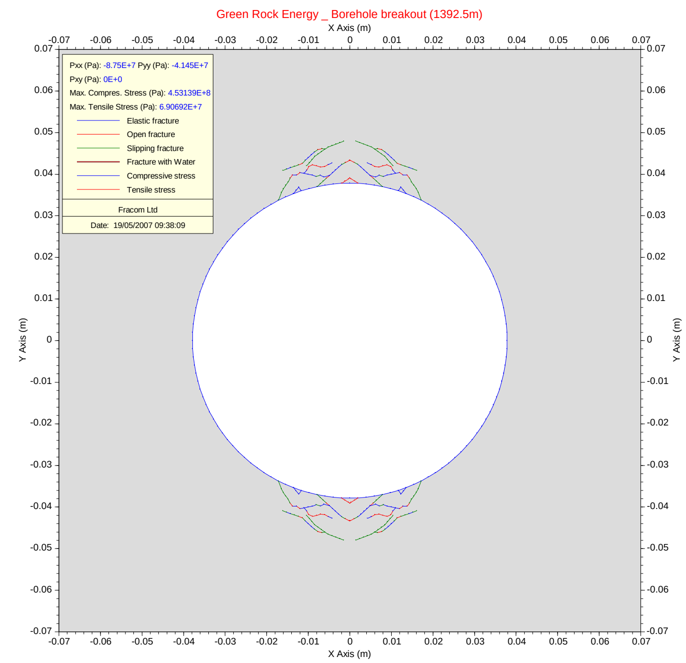
Analysis of Borehole Breakouts with FRACOD^{2D} (Fracon Ltd., Finnland)

➢ for 3 cross-sections at 1146.5 m, 1247.5 m and 1392.5 m the breakout dimensions were modeled

breakout geometry at 1392.5 m

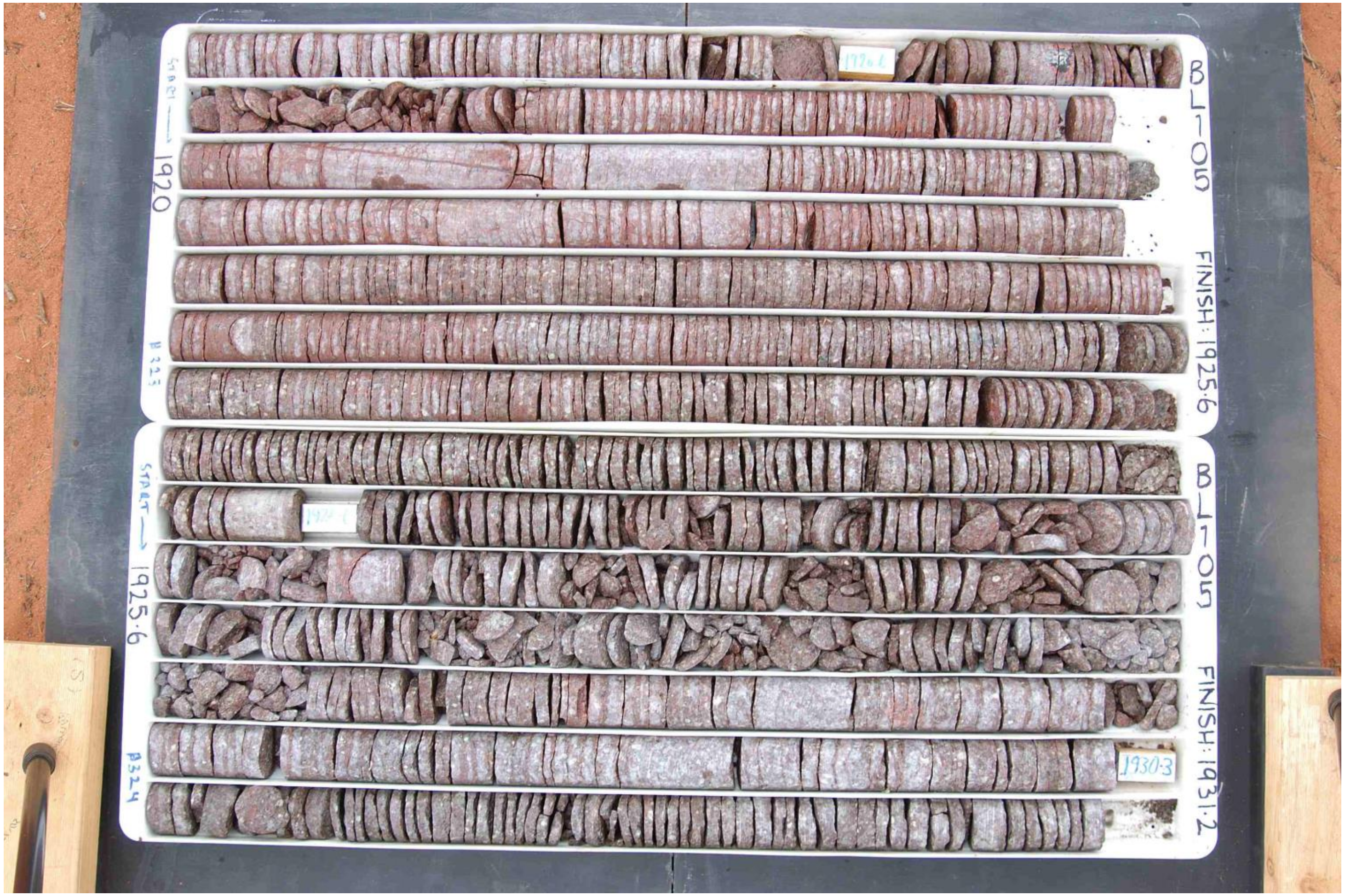


numerical modeling result



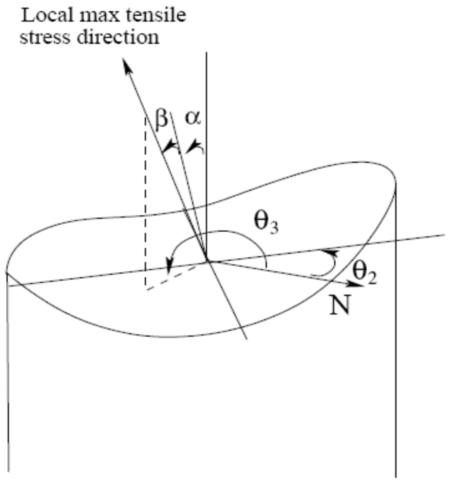
S_H / S_h / S_v ≈ (2.5-2.75) / (1.25-1.5) / 1

Analysis of Core Discing



- discs are flat, slightly upwardly cup-shaped or saddle-shaped

Core Disc Characteristics – Saddle Shapes



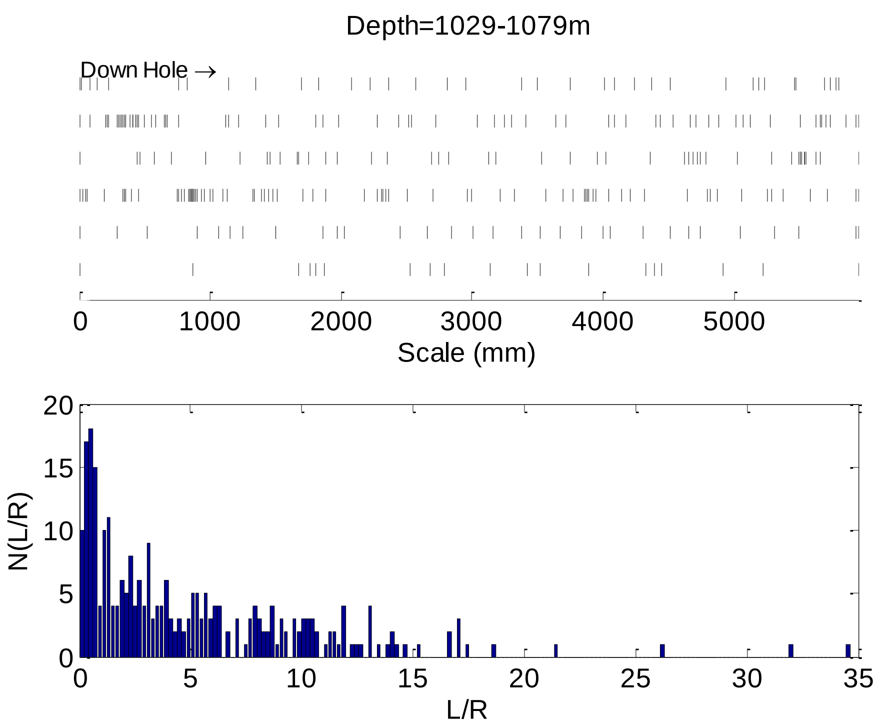
after Matsuki et al. (2004), IJRMMS

- sections of core oriented using natural fractures that appear in the BHTV-log
- maximum curvature of saddle shapes oriented at N (185-187), the minimum horizontal stress direction implied by breakouts

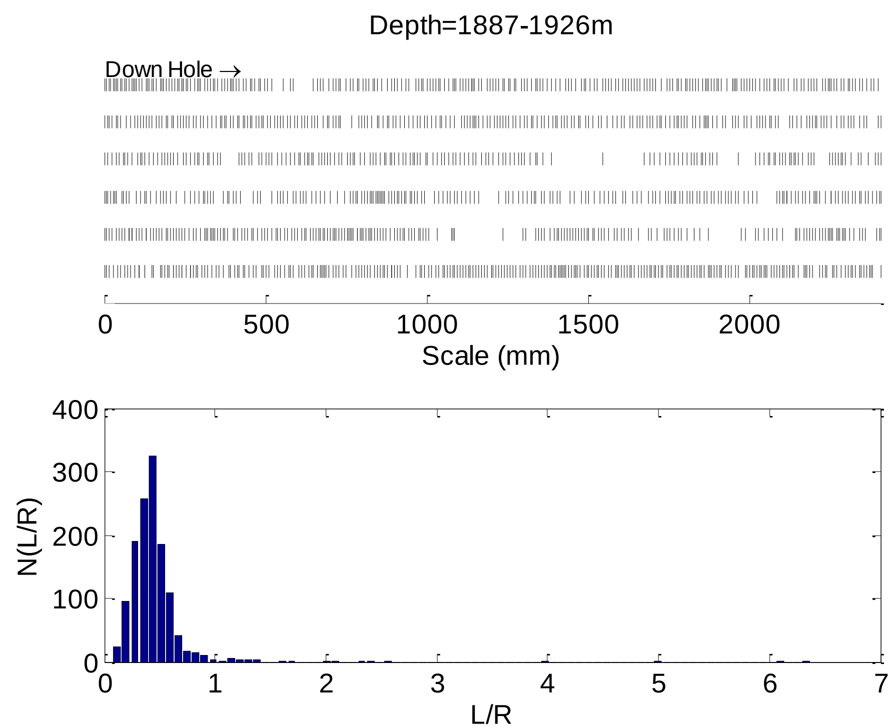
Disc Length Distributions

- 8 zones of 40-70 m length
- tending to cluster with similar length discs
- right tail dominated disc length distributions in shallow sections
- bell-shaped distributions in the deepest sections

Shallow – Right-Tail Dominant



Deep – Bell Shaped



Stochastic Discing Analysis (for details see Bunger AP, 2010, *RMRE*, 43(3):275-286)

- Assumes randomly varying in situ stresses and rock strength follow normal distributions.

$$\sigma_x \sim \mathrm{N}\left(\langle\sigma_x\rangle, \mathrm{std}(\sigma)^2\right) \qquad \sigma_z \sim \mathrm{N}\left(\langle\sigma_z\rangle, \mathrm{std}(\sigma)^2\right)$$

$$\sigma_y \sim \mathrm{N}\left(\langle\sigma_y\rangle, \mathrm{std}(\sigma)^2\right) \qquad \sigma_t \sim \mathrm{N}\left(\langle\sigma_t\rangle, \mathrm{std}(\sigma_t)^2\right)$$

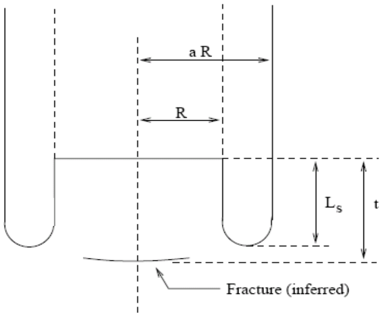
- Discing occurs when the local stresses and rock strength conditions satisfy a failure criteria (Matsuki et al. (2004), IJRMMS)

Numerically determined, length dependent functions

$$\sigma_x k_x\left(\frac{L_s}{R}\right) + \sigma_y k_y\left(\frac{L_s}{R}\right) + \sigma_z k_z\left(\frac{L_s}{R}\right) - \sigma_t \geq 0$$

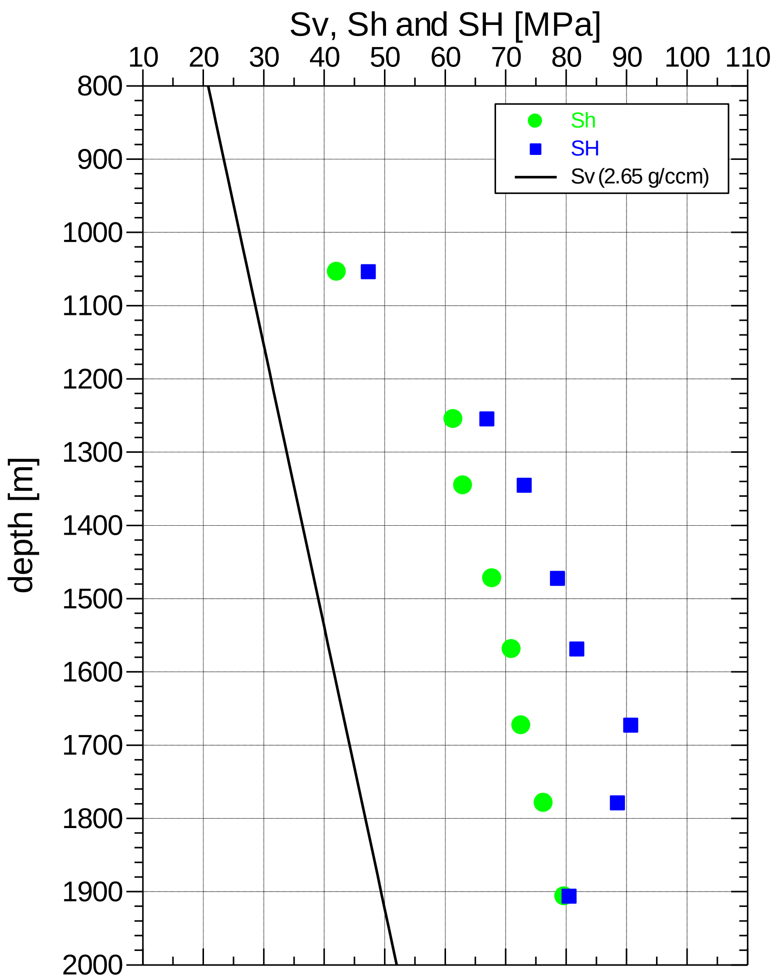
In situ stresses

Rock Tensile Strength

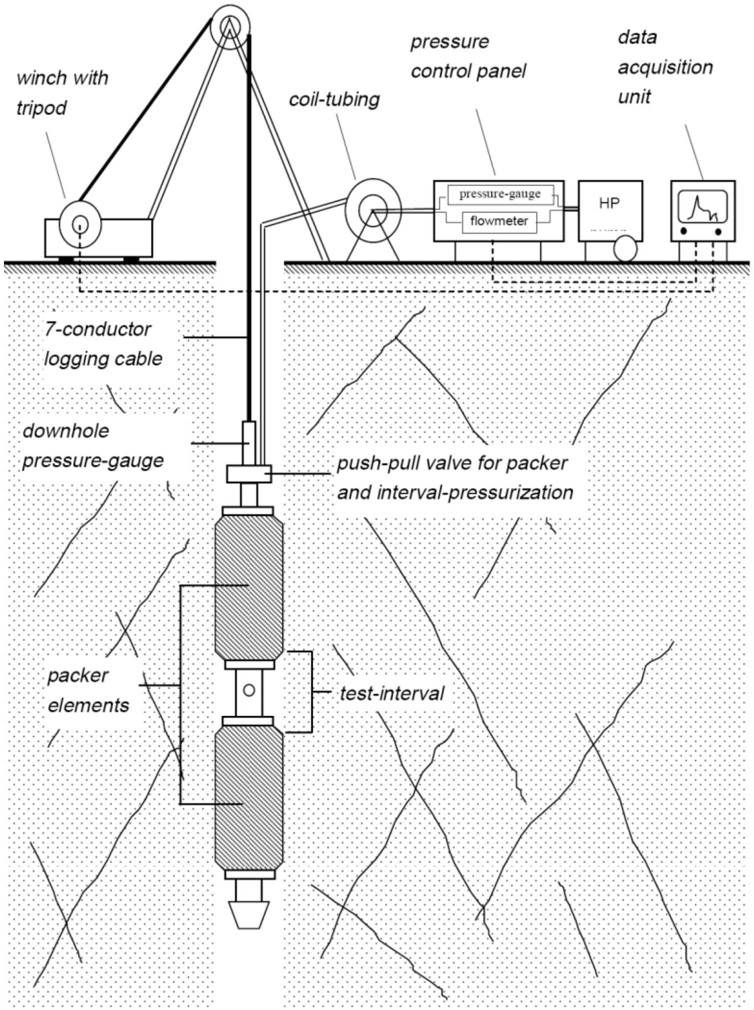


- Monte Carlo technique used to predict disc length distributions for given in situ conditions
- Choose parameters of stress and strength distributions so that predicted disc length distributions matches measurements

Analysis of Core Discing – In-situ Stress Estimates



Hydraulic-Fracturing Tests using the Wireline Approach



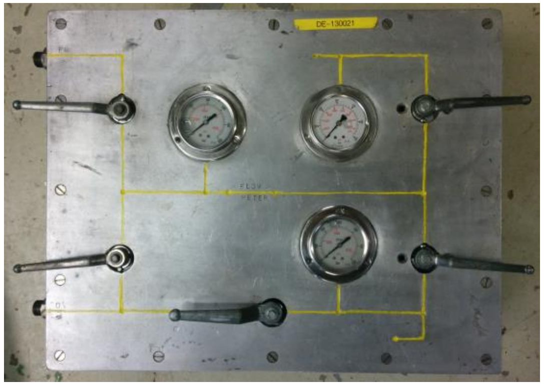
<u>disadvantage</u>

- limited pull-out force

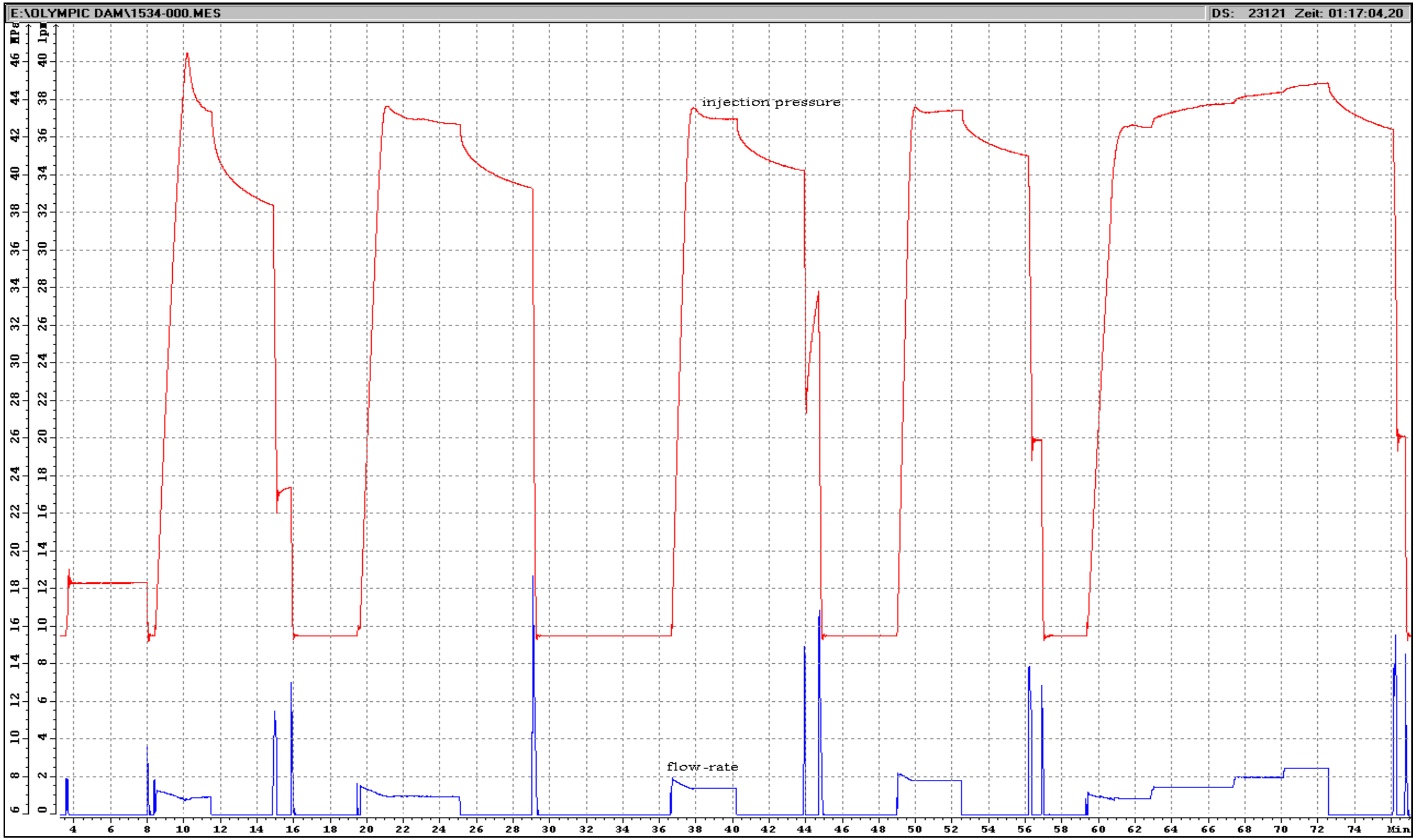
<u>advantages</u>

- no drill-rig/crew necessary
- downhole pressure monitoring
- high system stiffness dP/dV
- fast (impression packer testing)

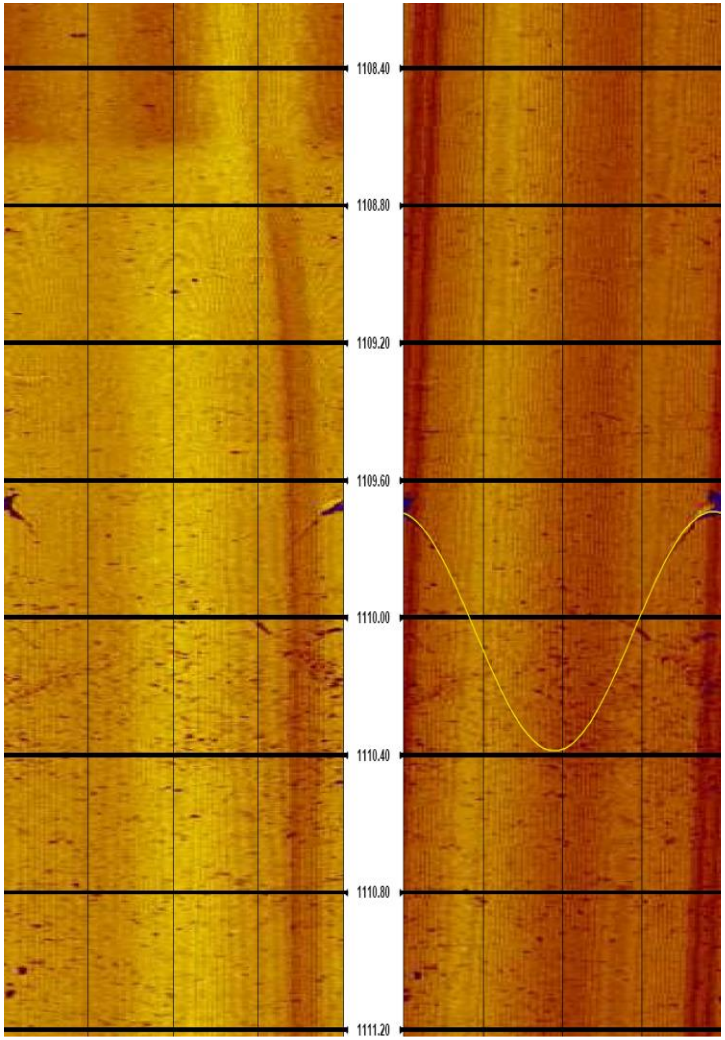
Hydraulic-Fracturing Tests using the Wireline Approach



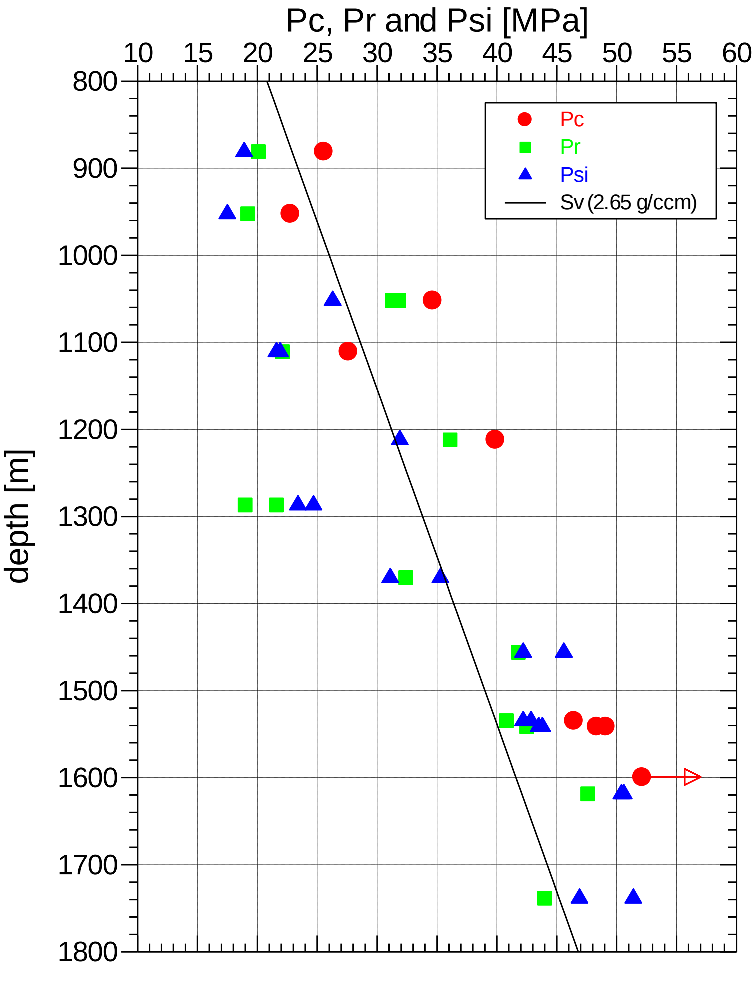
Hydrofrac Test Record



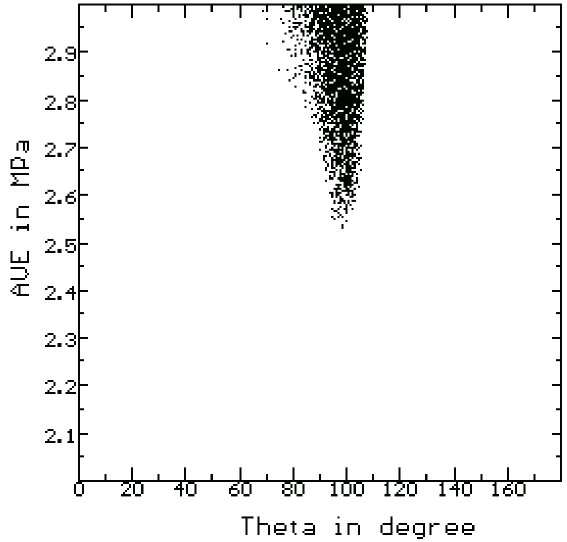
Pre- and Post-Frac BHTV-logs



Characteristic Pressure Values



Hydrofrac Stress Calculation



SH MPa	dSH/dz MPa/m	Sh MPa	dSh/dz MPa/m	Theta degree	AVE MPa
38.72	0.0559	12.09	0.0380	99	2.53
37.30	0.0568	12.52	0.0376	99	2.54
38.31	0.0626	11.28	0.0402	100	2.54
37.84	0.0519	13.59	0.0351	96	2.55
37.11	0.0608	12.40	0.0377	97	2.55
37.29	0.0524	13.41	0.0357	95	2.55
38.24	0.0507	12.62	0.0370	98	2.56
38.43	0.0554	13.07	0.0356	97	2.56
35.22	0.0608	13.60	0.0352	97	2.56
32.97	0.0698	12.09	0.0384	100	2.56

Input:

Depth m	Psi MPa	Theta degree	Alpha degree
881.10	18.90	68.0	85.0
952.50	17.50	89.0	84.0
1052.10	26.30	98.0	40.0
1110.90	21.60	88.0	82.0
1212.00	31.90	112.0	31.0
1286.90	23.40	98.0	89.0
1370.50	31.10	60.0	4.0
1456.20	42.20	125.0	65.0
1534.80	42.20	122.0	81.0
1541.50	43.50	111.0	11.0
1738.50	46.90	101.0	79.0

Result.....: 880.00 m

SH, MPa = 35.84 + 0.0603 * (z,m - 880.00)

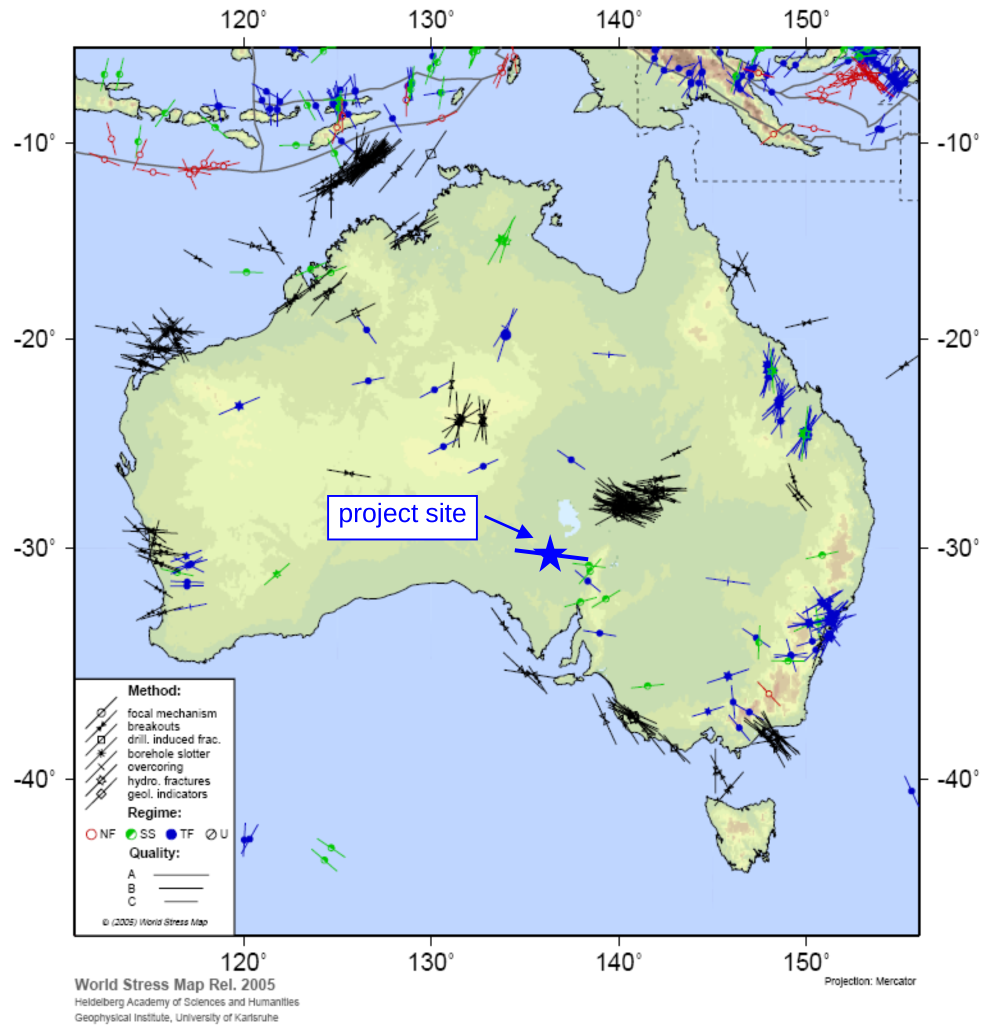
Sh, MPa = 12.44 + 0.0377 * (z,m - 880.00)

Theta,° = 95 - 100

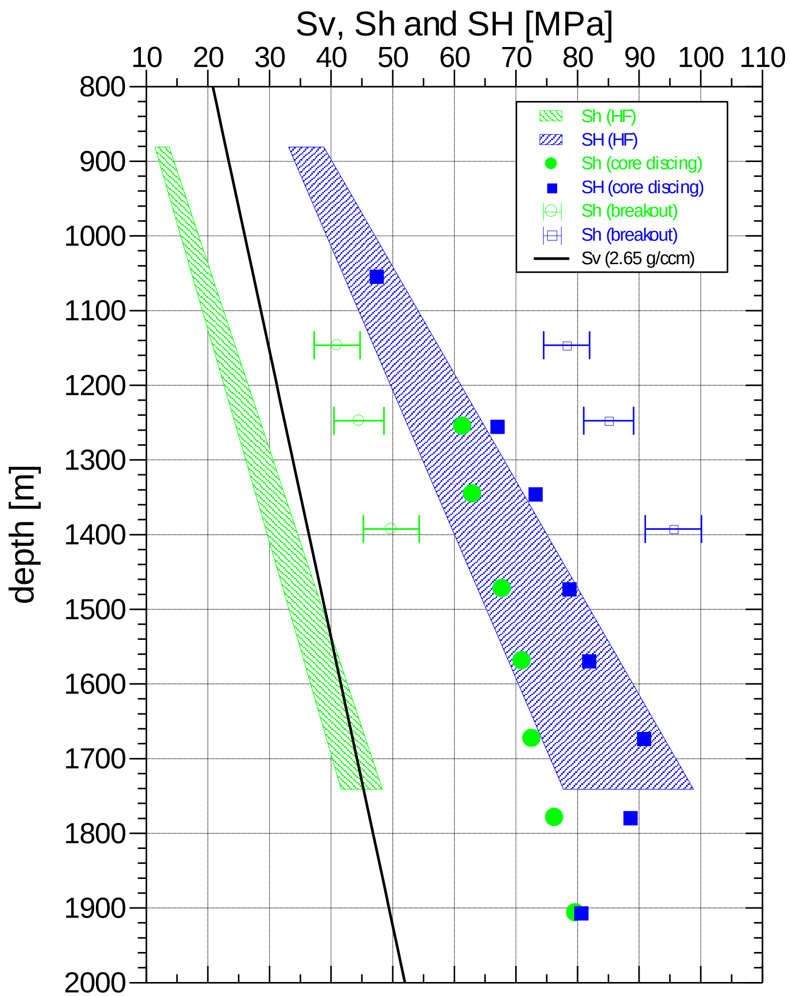
Number of tested models........:500000

Number of fitting models.......:3197

Blanche-1: Orientation of Maximum Horizontal Stress



Blanche-1: Comparison of Stress Magnitudes



Result of Hydrofrac Tests

$S_h = (12.4 \pm 1.2) + (0.038 \pm 0.003) \cdot (z - 880)$

$S_H = (35.8 \pm 2.8) + (0.060 \pm 0.010) \cdot (z - 880)$

$S_v = 0.026 \cdot z$

$\theta_{SH} = N\ 97^\circ \pm 3^\circ$

(z in m, S_v, $S_{H,}$ S_h in MPa)

Conclusions

- Analysis of breakouts, core-discing and hydraulic-fracturing tests yield consistently an E-W orientation of the maximum horizontal stress S_H.
- The results of the different methods indicate that the vertical stress S_v is the minimum principle stress, at least at the bottom of the investigated borehole section.
- High horizontal stresses will favor the creation of horizontal fractures during stimulation of the geothermal reservoir and will require operation pressure in the order of the vertical stress.
- High horizontal stresses were reported for the coal mines throughout the Eastern Coal Basin of New South Wales as well as for the Cooper Basin.

Concluding Remark

- Combination HF with HTPF
- Stress profiles rather than singular measurements
- Cost efficiency by using a wireline system