STATE OF STRESS AT THE EUROPEAN HDR CANDIDATE SITES URACH AND SOULTZ

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ABSTRACT

The operational costs of long-term HDR operations are determined by the energy demand for the underground fluid circulation as well as by fluid losses during circulation. both factors are controlled by in-situ stresses at depth. Therefore in-situ stress measurements are important parts of feasibility studies at the locations for a future European HDK prototype Bad Urach and Soultz-sous-Forets.

The results of numerous hydrofrac stress measurements yield at Bad Urach a compressive tectonic stress regime, at Soultz-sous-Forets a normal-faulting stress regime. At both sites a **N-S** to NNW-SSE orientation of the maximum horizontal compression was observed, which is in accordance with the tectonic situation in Central Europe.

1. INTRODUCTION

In-situ stresses are key parameters'in designing of a hot-dry-rock (HDR) operation for the extraction and economic use of geothermal energy. In-situ stresses control the operation pressure to induce or activate fracture-systems, determine the underground fluid flow paths between two or more boreholes, or influence the stability in un-cased borehole sections.

Conventional hydrofrac stress measurements and stimulation operations use sophisticated packer technology (high pressure, high temperature packers), which, however, shows insufficient performance at great depth due to the high temperature and gas content of the borehole fluids. Therefore a new packer technology development was required for deep fluid injection experiments at HDR test-sites.

This paper presents the results of numerous deep hydraulic-fracturing stress measurements carried out in the Urach-3 geothermal research borehole and in the drillholes of the European HDK project at Soultz-sous-Forets.

2. EUROPEAN HDR DEEP DRILLING PROJECTS

The geothermal research drilhole Urach-3 was drilled at Bad Urach (Swabian Alp, Germany) in the center of the Urach geothermal anomaly with a temperature of about 140 °C at about 3000 m depth. Project phase I took place during 1977 / 78 by drilling to a depth of 3334 m with a 14 m open-hole bottom section with 159 mm (6-½") diameter. The borehole was deepened **to** 3500 m depth in 1982 and to 4444 m with a diameter of 149 mm (5-7/8") in late 1992. The deep section of the borehole penetrates metamorphic rocks of the Moldanubian basement complex between the Pre-Variscan basement of the Black Forest in the west and the Bavarian Massif in the east. Due to borehole stability problems only a few hydrofrac stress tests could be conducted in the open-hole at a depth of about 3350 m.

The European HDR project at Soultz-sous-Forets in the Upper Rhine valley north of Strasbourg (Alsace. France) involves ***so*** far the deepening of two boreholes into the granitic basement at about 1400 m depth. In 1986, borehole GPK-1 was drilled to 2000 m (project phase **I)** and deepened to 3590 m depth with a diameter of 159 mm **(6-¼")** in late 1992 (project phase **II).** In addition, the existing neighbored oil exploration well EPS-1 was deepened into the granite to a depth of 2227 m **(96 mm /** 4" diameter). In both boreholes a number of hydrofrac tests was conducted, most of them via the wireline hydrofrac approach using the new developed aluminum packer technology with respect of the hostile downhole environment (Klee and Hegemann, submitted).

3. WIRELINE HYDROFRAC TECHNOLOGY

The technique of wireline hydraulic fracturing is well established. It allows a fast "stress logging" similar to conventional geophysical data logging in the absence of an on-site drill rig. In addition, a wireline hydraulic fracturing system enables a much better pressure and fracture growth control due to its high system stiffness and the possibility of downhole pressure recording. Originally a typical university development (e.g. Baumgartner *et al.*, 1987). the present commercially designed system is capable to carry out hydrofrac stress measurements to a depth of almost **5 km.** Major components of the system are (Figure 1):

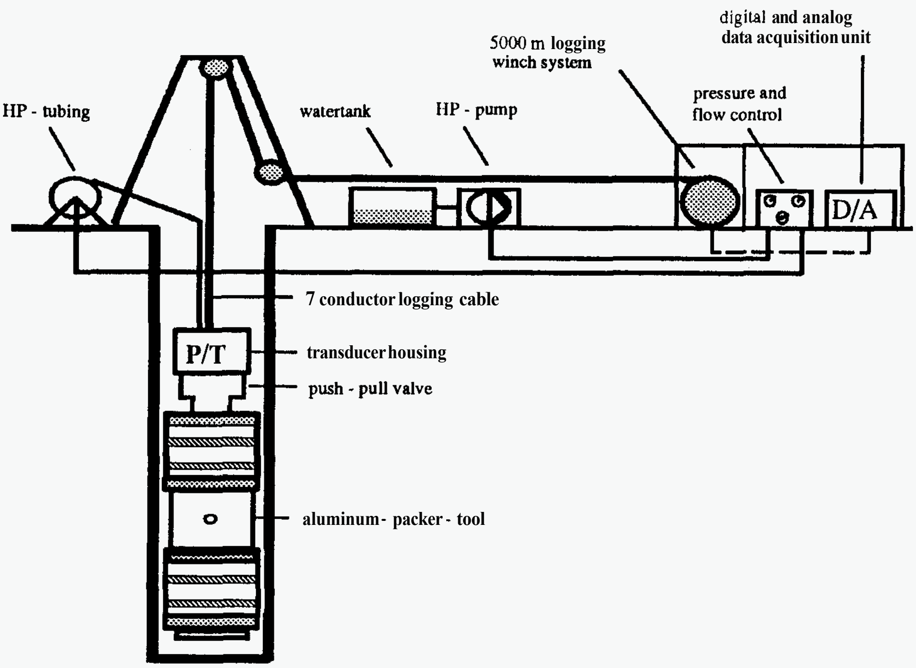

Figure 1: Schematic diagram of a wireline hydrofrac system.

- 5000 m winch system with a 7-conductor standard logging cable.
- Downhole pressure and temperature monitoring system placed in a dewar with a wood metal heat sink.
- Precision push-pull valve to allow to switch between packer and interval pressurization, activated by controlling the tension of the logging cable.
- 50 MPa / 5 liter per minute surface pumping system.
- 8 mm or 6 mm ID stainless steel coil tubing attached to the logging cable at 50 m intervals via special aluminum cable clamps.
- 4-channel digital data acquisition system together with a paper strip chart recorder to monitor downhole packer and interval pressure, dewar temperature and surface flow rate.
- Finally, the new developed aluminum straddle packer tool adequate to the hot-(up to 170 °C), gassy and geochemically aggressive downhole conditions. The tool consists mainly of two soft aluminum shells with an intelligent inner steel mandrel as hydraulic connection to both, packer elements and test interval (Klee and Hegemann, submitted).

A typical pressure record for the stress measurement at 3315 m depth in borehole Soultz GPK-1 is shown in Figure 2.

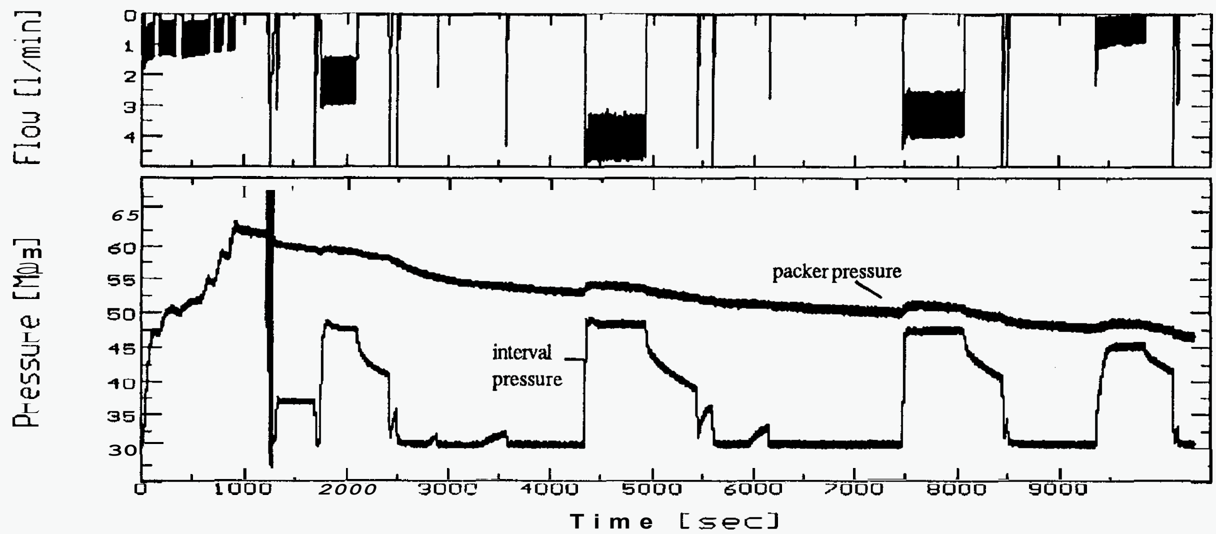

Figure 2: Downhole packer- and interval-pressure and surface flow rate record of the hydrofrac test in borehole Soultz GPK-1 at 3315 m depth.

4. RESULTS OF HYDROFRAC STRESS MEASUREMENTS

For easier comparison, the hydrofrac stress data available are summarized in the following format:

$$\frac{S_{h,H}}{S_v} = \frac{\alpha}{z\,[m]} + \beta$$

where $S_{h,H}$ are the minor and major horizontal principle stresses, S_v is the vertical stress due to the weight of the overburden with given rock density. The stress data are given in Table 1 together with the derived orientation of the maximum horizontal compression θ (S_H). The stress profiles for both locations are shown in Figure 3.

5. CONCLUSIONS

The aluminum straddle packer technology operated by a wireline system is a first approach for fluid injection tests at great depth with hostile downhole environment. The new technology was successfully used down to 3.5 km depth and provided excellent results.

Considering Central Europe as a plate tectonic unit, the result of the hydrofrac stress measurements yield

- at Bad Urach a more or less strike -slip faulting stress regime (S_h < S, < S_H) with compressive tectonics,
- at Soultz-sous-Forets a normal faulting stress regime (S_h < S_H ≤ S,) , typical for the Graben tectonics in the Upper Rhine valley.

The observed orientation of the acting major horizontal stress of N-S to NNW-SSE is in accordance with geological stress indicators at both sites (Tenzer et *al.*, 1992) and with existing stress data for Central Europe (Muller et *al.*, 1992).

The stress data presently are used as direct input data for feasibility studies at both locations. However, the uncertainities in extrapolating the stress data to the HDR reservoir depth at temperatures of 180 °C to 200 °C asked for further and deeper stress measurements in the hot underground. This also requires a further development of the metal packer technology.

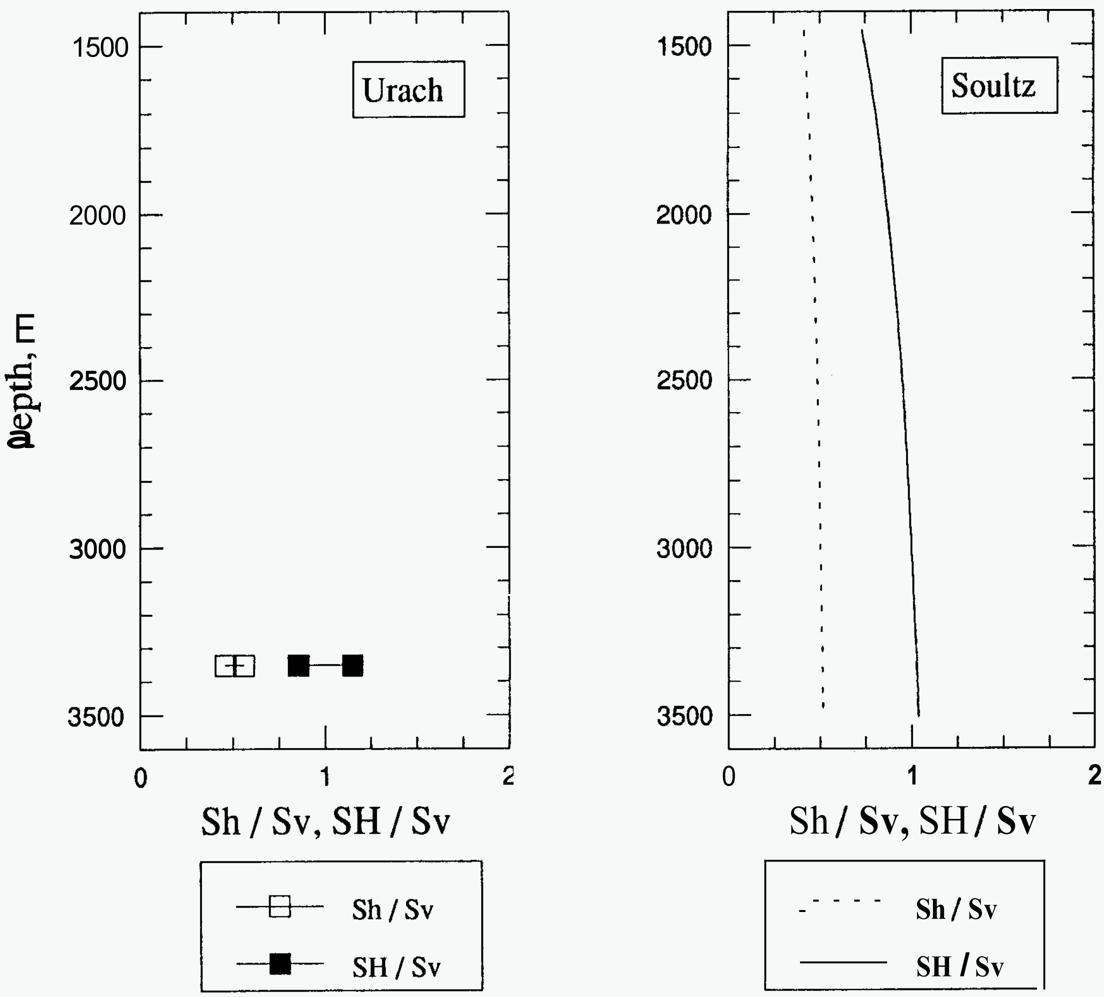

Figure 3: Stress-Depth-Profiles at the HDR-research test-sites Bad Urach and Soultz-sous-Forets.

Table 1: Stress profiles derived from hydrofrac testing at the HDR research project sites Bad Urach and Soultz-sous-Forets.

project site	depth range km	dS_v / dz MPa/m	S_h S_H	α m	β	θ (S_H) degrees	reference
Bad Urach	at 3.35	0.0265	S_h		0.46-0.56		Rummel *et al.*,
			S_H		0.86-1.15	NNW-SSE	1991
Soultz-s.-Forets	1.46 - 3.50	0.0255	S_h	-235	0.584	155 ± 3 for 1.4 - 2 km	Klee and
			S_H	-1004	1.322	170± 10 for 2.8 - 3.3 km	Rummel, 1993

6. ACKNOWLEDGMENT

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