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HDR research programme and results of drill hole Urach 3 to depth of 4440 m – The key for realisation of a HDR programme in southern Germany and northern Switzerland

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ABSTRACT

The prerequisites for specific research into the use of Hot Dry Rock geothermal energy at great depths and temperatures of up to 147°C in Europe were created with the drilling and completion of the 3334 m deep research drill hole Urach 3 in its phase I (1977/78), and its subsequent extension to 3488 m in phase II (1982/83) within the metamorphic gneiss rock of Urach. Basic results concerning the temperature field, joint system, stress field and hydraulic behaviour of the rock were achieved.

Within the scope **of** a feasibility study (1990-1996) local boundary conditions, infrastructure, user potential and a preliminary utilisation concept (3 MWel, 17 MWth) were evaluated. Geological parameters were determined by the extension of the already existing drill hole Urach 3 from 3488 m to 4445 m depth. The bottom hole temperature at true vertical depth of 4394.72 m was determined with 170°C. It can be proved that the temperature gradient is constant with 2.9 °K/100 m depth. As main lithological units metamorphic rocks such as biotite-gneiss, anatexite and diatexite were drilled.

The crystalline is effected by brittle deformation. The resulting fracture system is sealed by hydrothermal products (clays, carbonates, sulphates). The aperture of fractures is in the range of some tenth to 10 millimetres. Televiewer and FMI logs show a general north-south orientated joint system and borehole breakouts around N 80-120° N. The orientation of maximum horizontal stress direction was determined with N 170" E. Wireline Hydrofrac Stress measurements at 3352 m depth yields values of S_{hmin} between 41-50 MPa. Estimated stress magnitudes of Anelastic Strain Recovery (ASR) measurements on cores from 4425 m depth yields values of S_h=63 MPa. It is proposed that the Urach site located in a widespread tectonic horizontal strike-slip system is suitable for a HDR demonstration project. The results can be applied in southern German and northern Swiss regions.

KEYWORDS

Borehole televiewer, FMI-logs, horizontal stress direction, Hot Dry Rock, hydrofrac, joint system.

Introduction

The prerequisites for specific research into the use of Hot Dry Rock geothermal energy at great depth and temperatures of up to **147°C** in Europe were created with the drilling an completion of the **3.334** m deep research drill hole Urach **3** in its phase I (1977/78), and its subsequent deepening to **3488** m in phase II (1982/83) within the metamorphic gneiss rock of Urach located **35km** south east of Stuttgart in Germany.

According to the European HDR guidelines, data from depths where a mean reservoir temperature of **175-180°C** prevails are necessary to carry out a HDR pilot project. Within the scope of a feasibility study the already existing drillhole Urach **3** was extended from **3488** m to **4444** m depth where the required rock temperature of > **170°C** was expected. The objective of the project was to determine rock parameters at depth of high temperatures.

Within the working programme of the project, the following operations were carried out: investigation of the lithology, HDR-relevant borehole logging with new developed tools, hydrofrac stress measurements with new developed Aluminium packers, break out analysis, stress field related Anelastic Strain Recovery Measurements, small scale hydraulic testing, structure analysis on cores and by the help of borehole imagery.

Well logging with borehole imagery logs enables continuous recording of natural and artificial planar discontinuities on the drill hole wall and data on the drill hole geometry to be measured. Efforts were made to resolve the orientation and characterisation of the natural joint system, the active fault pattern, the alteration zones, the direction of the maximum horizontal stress and the stress profile. With the help of specific well logs the orientation and frequency of planar discontinuities and their horizontal and vertical persistence can be determined, also their apparent apertures as well as the predominant orientation of the different apertures. Improvements in borehole logging and interpretation techniques for fracture analysis and new developments in stress field related investigation methods with respect to the creation of a heat exchange system in deep HDR reservoirs were achieved.

Drilling operation

It was decided to deepen Urach **3** from **3488** to about **4300 - 4500** m in order to investigate the crystalline rock at higher temperatures (>170 °C). Due to negotiations with funding agencies and drilling industry the drilling operation started with delay in September **1992.**

The existing drill hole includes a inner cemented **7**" casing to a depth of **3320** m. A casing packer at **2533** m depth limited the bit size to **5 7/8".** Generally the drilling plan based on the experiences from 1982/83 (extension drilling from **3334** to **3488** m). At that time **an** average penetration rate of less than 1 m/h had been achieved using a bentonite/polymer based mud. The extension drilling from 3488 m to the new final depth of 4444 m requested a 40 days operation. Within two days the work over operations and the redrilling of the previous open hole section (3320-3488 m) were carried out.

Drilling rig and extension work

The drilling rig selected was a modified Wilson M75 type from ITAG (Celle, Germany). The rig has a one lift telescope mast (36 m height) with a static hook load capacity of 1,500 kN and a exceptional load of 1,800 kN. The "swing up" type substructure has a capacity of 400,000 lbs. casing load.

Due to the spa clinics (potential users of geothermal energy) situated some 150 m from the drill site the operation requested special sound proof measures. A sound absorbing wall of 10 m up was erected. The draw works, engines, generator shelter, the hydraulic drive and centrifuge were fully sound proof. With the help of these measures the sound level of the rig was reduced below 39 dB(A) at a distance of 150 m. The sound level remained below the noise level of the spa area of 41-45 dB(A).

The drilling bit selected were mainly the improved roller bits of ATJ 55 D type from Hughes. Additionally improved roller bits of M89TFL and 1189TFL type from Security were used. Totally a number of 10 bits from Hughes and **2** bits from Security were used. The duration time of the bits was between 44 and 60 hrs with drilled sections between 58 and 130 m respectively

The penetration rate increased to ca. **4** m/h in some hole sections. The unexpected high penetration rate with these small bit size and normal weight on bit (6-8to) were achieved by using the combination of improved bits and the high temperature drilling mud (KTB-type, Therma Vis/Therma Check) with extraordinary good properties on viscosity and thixotropy as well as a distinct lubrication effect. Due to the use of a centrifuge a nearly solid free drilling mud (density of 1.02-1.06) was achieved. Using a junk basket above the bit the extraction of rock pieces up.to 10 cm of size were possible.

The trajectory of the extended drill hole show a direction to east and south east. The inclination from vertical starts with 14" at 3488 m of the previous hole and increased to 19.5" at 3650 m. From this depth the inclination was reduced to 10.5° at 4150 m. Below this depth the inclination increased to 17.5" at final depth of 4445 m. The landing point ***of*** the drill hole is around 335 m to ENE direction from the starting point on ground level (figure **2,** plan view).

However, at the end of the logging operation, during reaming and cleaning operation in the bottom section of the well a drill string rupture occurred. inn addition, during the following fishing operations a sudden breakage of the drilling line on the rig occurred. This then led to a series of highly complex fishing operations which were only partly successful. The fish is still inside the casing so that it can be easily accessed during likely future operations. The fish does not isolate the open hole section. The drill hole can be used hydraulically for full operations.

With the extension drilling a good drillability of the Urach crystalline was proved. The geological risk for further drillings was minimised. Using the technical and scientific findings of these drilling the extrapolation to greater depths can be done with a sufficient degree of certainty.

Coring programme

For the execution of the coring programme a special designed core bit of **5.718**" x **2.5/8" SC 279** N was used from Eastman Teleco (designed after experience during the KTB programme). This core bit was used for the core runs 57 **(3876-3884.7** m) and **58 (4340-4346.2** m).

The extraction of the core 59 **(4420-4424.2**m) and core 60 **(4424.2-4427.2)**were done with a standard core bit 5 **7/8"x 2 1/8" SC 279/D5RO.** Due to good experience and reasonable results by using a downhole motor the coring was carried out by a **4 314**" Mach 1 downhole motor. A core recovery of **8.2** in was achieved by using a standard **4 318**" x **2** *518"* core barrel series **250** of 9 m length. The total amount of core recovery is 15 m (17%-**97%).** This large core recovery and high core quality is a outstanding result in standard coring at such depth in crystalline basement. From the core sections more that 90% were re-orientated with the help of borehole imagery.

Borehole measurements

Intense logging programmes and measurements were carried out in the HDR drill hole Urach **3** between **3488** and **4440** m depth. The various measurements are compiled in table 1. The logging programme was carried out successfully in three terms. Due to relaxation processes of the rock the drill hole had to be redrilled and conditioned several times in order to accomplish the measuring programme. A composite log of results of borehole logging between **3300** m - **4420** m is presented in figure 1.

Results

Lithology

As main lithological units metamorphic rocks as biotite-gneiss, anatexite and diatexite were determined in the extended drill hole. Sillimanite occurs in the metatectic gneiss, with a restitic habit; it means that the gneiss were derived from more or less siliceous shales. Anatexis produces segregation of quartzo-feldspathic leucosomes that may be mobilised as dykes crosscutting the metatexis. The different crystalline units are effected by brittle deformation. The resulting fracture system is sealed by hydrothermal products (clays, carbonates, sulphates) related to former deep hydrothermal circulation. At the boundaries of these fractures the rocks are affected by retrograde processes (Hottin, **1993).**

TEMP	Temperature
FMI	Formation Micro Imager (8 Pads)
FMS	Formation Micro Scanner (every measurement with 4-arm Caliper and high resolution Resistivity Log)
BHTV	Borehole Televiewer of DMT
AMS	Auxiliary (cable tension and Temperature)
DST	Digital Sonic Tool (acoustic wave velocity)
ARRAY SONIC	Acoustic Wave Velocity
LDL	Lithological Density Log
CML	Compensated Neutron Log (Porosity, Water saturation)
NGS	Natural Gamma Spectrometry (radio-active elements, determination of alteration zones)
GR	Gamma Ray (combined with every measurement)
ARI	Azimuthal Resistivity Imager
BGT	Borehole Geometry Log (Azimuth, Deviation, Caliper)
ATS	Borehole Televiewer Schlumberger (test measurement)
HFPT	Hydrofkac Packer Test

Temperature field

In the upper part of Urach 3 down to ca. 300 m depth a high geothermal gradient of 11°C/100 m was determined. From 300 to ca 1600 m the gradient is 3,9°C/100 m. In the crystalline basement down to 3488 m depth the average gradient is 2,9°C/100 m.

The temperature at 4394 m true vertical depth was determined under disturbed conditions at 169°C. It can be proved that the temperature gradient is constant with 2.9°K/100 m depth. Temperatures expected at 4500 m depth are in the range of 172-175°C.

Fracture system

Structural analysis of the joint system by borehole imagery obtains a maximum strike around N-S (maximum at N 160-170" E with submaxima at N 10-30° E). The main direction of dip is to the West with a submaxima to East (figure 2).

The hydraulically utilisable joint system strikes mainly N 160-190" E below 3750 m depth. These strike direction agree with the orientation of the major horizontal stress direction determined by various methods between N 157" E ±20° and N 192" E ±18°.

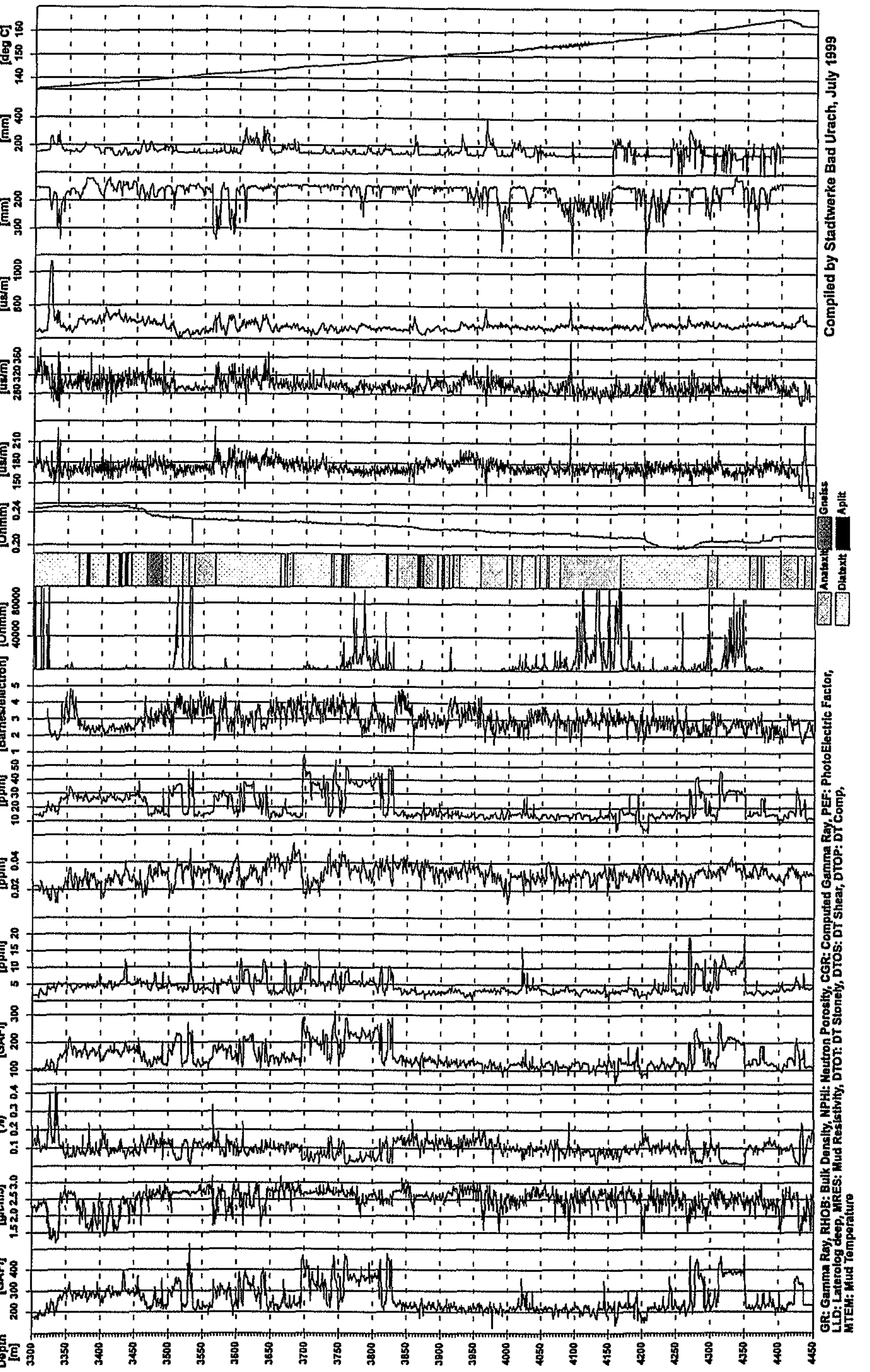

Figure 1: Extension of drill hole Urach 3 from 3488 to 4445 m. Composite log section: 3300 – 4445 m

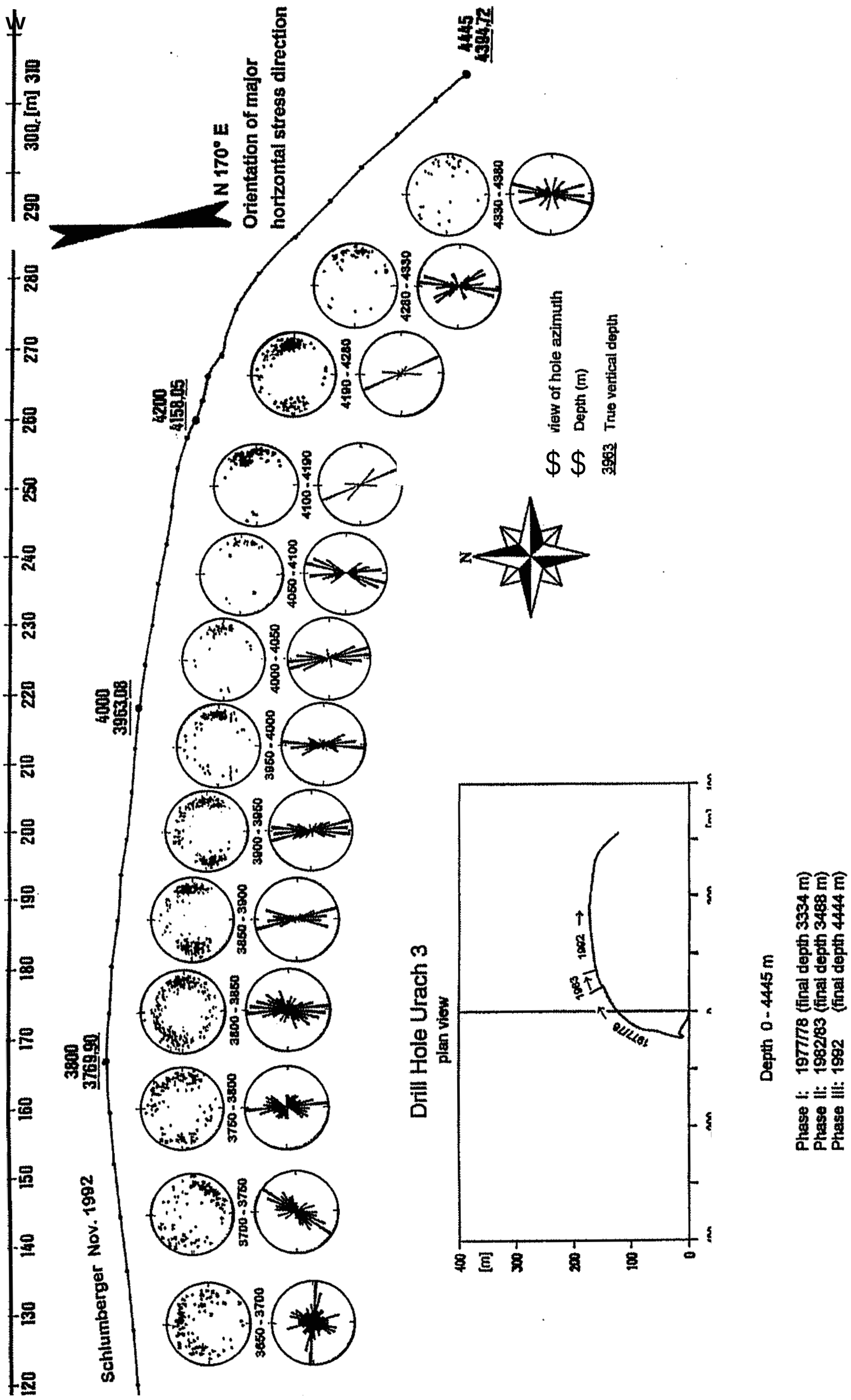

Figure 2: Extension of drill hole Urach 3. Orientation of planar discontinuities and trajectory of drill hole

The preferred N-S orientation of the joint system at possible upper reservoir depth **(3750–4445** m) were determined over a vertical distance of **690** m and a horizontal distance over **160** m from West to East (figure **2)** The homogeneous **N-S** orientation of the joint system is effected by the stress field conditions and is very favourable for the creation of a further downhole heat exchanger between two drill holes.

Orientated drill core were investigated. Three main type of structures observed on core section **(14.8** m) are chronologically organised as magmatic foliation, post magmatic vein sealed by early granitic dike, natural fracture and core -instabilities. Brittle fracture frequency per meter in core sections **57 (3876-3885** m) and **59 (4420-4424** m) is about **2** and 8 respectively. On core 57 subvertical sinistral strike-slip shears and faults which correspond

to the most intense cataclastic structures occurring these cores, are striking N **170"** E. Features of core disking are striking N **160-170** E and N **10-20°** E. On core **59** two main orientations were determined N **100°** E and N **30"** E with submaxima at N **70"** E and N **120"** E. Core instabilities show a preferential fracture set which is striking N **10-20°** E with a secondary fracture set striking N **120"** E (Genter, **1994).**

Stress field

Hydrofrac packer tests at **3352** m depth yield stress values of **Sh=41-50** MPa and of **SH=76-102** MPa (Rummel, **1993).** Estimated stress magnitudes of Anelastic Strain Recovery (ASR) measurements on cores from **4424** and **4426** m depth yields values of SH between **99±2** and 137±8 MPa (Wolter, **1993).** Extrapolation of hydraulic leak-off tests leads to an estimated Sh around **65** MPa at **4420** in depth (Röckel et al., **1996).** The major horizontal stress direction was determined by different methods (figure **3)** as borehole breakouts, Hydrofracs, core disking and ASR measurements to be between N **157"** E **±20** and N **194"** E **±18** (Heinemann et **al.,1992)**. The stress regime in the Urach gneiss is characterised by a nearly left lateral strike-slip faulting regime with the maximum principle stress having NNW-SSE direction (figure **3).**

Conclusions

Due to the results of the investigations is proposed that the Urach site is suitable for a industrial HDR demonstration project. The classical HDR technology can here be followed in the wide spread tectonic horizontal strike-slip system. Many potential consumers of geothermal energy produced by the HDR concept are situated close around the Urach **3** drill site.

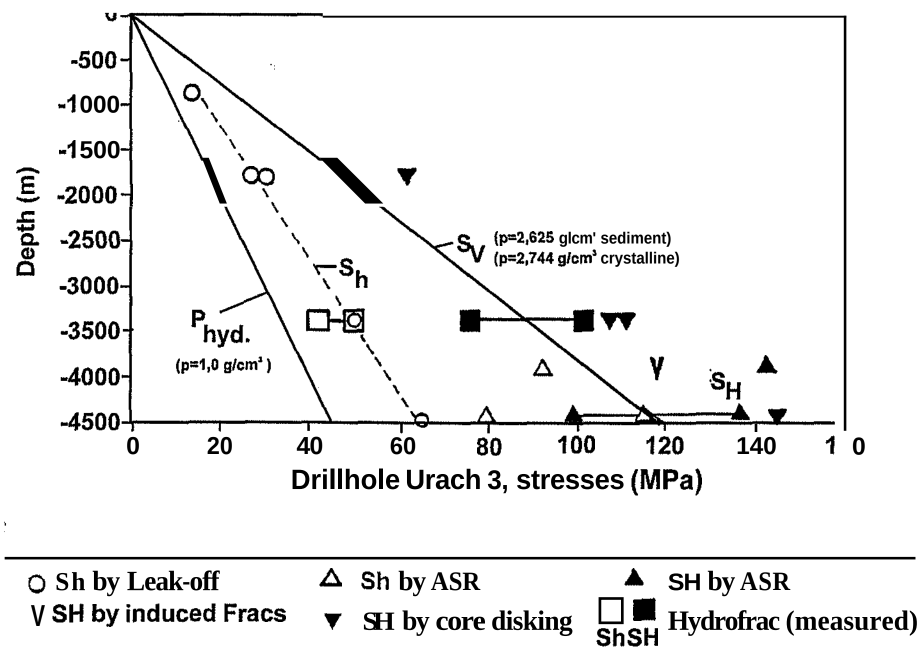

Figure 3: Compilation of stress data

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