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Chapter 3.2

Main Results and further research work at HDR-Testsite of Urach Spa Development of a HDR Demonstration Pilot-Plant

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ABSTRACT

The first phase of the Hot Dry Rock (HDR) Project in Urach Spa begann in 1977/78 with the Urach 3 drilling hole. A depth of 3334 m within a metamorphic gneiss rock was achieved. An extension of the drill hole to 3488 m depth followed in a second phase in the year 1982/83, where a temperature of 147° C was attained. A single hole circulation system was tested. Basic results concerning the temperature field, joint system, stress field and hydraulic behaviour of the rock were achieved. Due to high flow impedance the concept was turned back to a doublette system.

To reach higher temperatures for realizing a HDR pilot plant, futher investigations had to be obtained. The Urach 3 drill- hole had to be extended from 3488 m to higher depths, where the required rock temperature of > 170°C was expected. The final depth was reached in a third phase, at 4444 m. 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. Temperatures expected at 4500 m depth are in the range of 175°C. As main lithological units, metamorphic rocks such as biotite-gneiss, anatexite and diatexite were determined in the extended drill hole.

The different crystalline units are effectted 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 tenn millimeters. Subvertical sinistral strike-slip shears and faults which correspond to the most intense cataclastic structures, strike N 170° E. Televiewer and FMI logs show a general North-South orien-tated joint system and borehole break-outs around N 80-120° E. The orien-tation of maximum horizontal stress di-rection 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 around 4425 m depth yields values of S_h = 63 MPa.

Within a carried out study (1990-1996), local boundary conditions, infrastructure, user potential and a preliminary utilisation concept (3 MWel, 17 MWth) were evaluated. Due to the results of the investigations, 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 and in other areas of Europe. Many potential consumers of geothermal energy produced by the HDR concept are situated close around the Urach 3 drill site.

1. 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 and completition of the 3334 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 methamorphic gneiss rock of Urach, located 35km Southeast 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. The creation of a circulation system by a second drillhole in 1984 was not rendered possible due to amendments in research politics.

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 relateted Anelastic Strain Recovery (ASR)-measurements, small scale hydraulic testing, structure analysis on cores and 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 borhole 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.

2. DRILLING OPERATION

It was decided to deepen Urach 3 from 3488 m to about 4300-4500 m in order to investigate the cristalline rock at higher temperatures (>170 °C). Due to negotiations with funding agencies and drilling industry the drilling opera-tion 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 is based on the experiences from 1982/83 (extensi-on drilling from 3334 m to 3488 m). At that time an average penetration rate of less than 1 m/h had been achived 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.

2.1 The Drilling Rig and Extension of Drill Hole

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 exeptional 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 measurements. A sound absorbing wall of 10 m hight was erected. The draworks, engines, generator shelter, the hydraulic drive and centrifuge were fully sound proof. With the help of these measurements 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 roler bits of type ATJ 55 D from Hughes. Additionally improved roler bits of type M89TFL and 1189TFL from Security too were used. Totally, a number of 10 bits from Hughes and 2 bits from Security werde used during drilling operation.

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 (6-8 tons) were achieved by using a combination of improved bits and 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 was possible.

The trajectory of the extended drill hole shows a direction towards East and Southeast. 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 on, the inclination reduced to 10.5° at 4150 m. Below this depth the inclination increased to 17.5° at a final depth of 4445 m. The final target point of the drill hole is arround 335 m to the ENE direction from the starting point on ground level (Fig. 1).

However, at the end of the logging operation, during reaming and cleaning operation in the bottom section of the well, a drill string rupture occured. Inn addition, during the following fishing operations an abrupt breakage of the drilling line on the rig took place. 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 accesed during future operations. The fish does not isolate the open hole section, so that the drill hole can be used for hydraulically full operations.

With the extension drilling, a good drill ability of the Urach cristalline was proved. The geological risk for further drillings was minimised. Using the technical and scientific results of the drilling, the extrapolation to greater depths can be done with a sufficient degree of certainity.

2.2 Coring Programme

For the execution of the coring programme a special designed core bit of 5.7/8" 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 core 59 (4420-4424.2 m) and core 60 (4424.2-4427.2 m) was 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 3/4" Mach 1 downhole motor. A core recovery of 8.2 m was achieved by using a standard 4 3/8" x 2 5/8" core barrel series 250 of 9 m length.

The total amount of core recovery was 15 m (17%-97%). This large core recovery and high core quality is an outstanding result in standard coring at such depth in cristalline basement.

From the core sections more that 90% werde re-orientated with the help of borehole imagery.

3. 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 the results of borhole logging between 3300 to 4420 m is presented in Fig. 2

4. RESULTS

4.1 Lithology

As main lithological units, metamorphic rocks such as biotite-gneiss, anatexite and diatexite were determined in the extended drill hole.

Sillimanite occurs in the metatectic gneiss, with a restitic habit; this means that the gneiss derived from more or less silicous shales. Anatexis produces segre--gation of quarzo-feldspathic leucosomes that may be mobilised as dykes cross-cutting the metatectic gneiss. The different cristalline units are effected by brittle deformation. The resulting fracture system is sealed by hydrothermal products (clays, carbonates, sulfates) related to former deep hydrothermal circulation. At the bounderies of these fractures the rocks are affected by retrograde processes (Hottin, 1993).

4.2 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 m to ca. 1600 m the gradiend 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.

4.3 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 (Fig. 1).
The hydraulically utilizable joint system strikes mainly N 160-190° E below 3750 m depth. These strike directions agree with the orientation of the major horizontal stress direction determined by various methods between N 157° E ±20° and N 192° E ±18°. The prefered 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. 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 frature 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 catalastic structures occurring in these cores, strike N 170° E. Features of core disking strike 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 strikes N 10-20° E with a secondary fracture set striking N 120° E (Genter, 1994).

4.4 Stress Field

Hydrofrac packer tests at 3352 m depth yields stress values of Sh=41-50 MPa and of SH=76-102 Mpa (Rummel, 1993). Estimated stress magnitudess 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 arround 65 MPa at 4420 m depth (Röckel et al., 1996). The major horizontal stress direction was determined by different methods: as borehole breakouts, hydrofracs, core disking and ASR-measuremts. The directions are 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 a NNW-SSE direction.

5. CONCLUSIONS

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

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Table 1	**Well logging in the extension drill hole Urach 3**
TEMP	Temperature
FMI	Formation Micro Imager (8 Pads, high resolution electric measurements of joint network)
FMS	Formation Micro Scanner (4-arm Caliper, high resulution Resistivity Log,)
BHTV	Borehole Televiewer of DMT (acustic measurements of joint network)
AMS	Auxiliary (cable tension and temperature)
DST	Digital Sonic Tool (acoustic wave velocity)
ARRAY SONIC	Acoustic wave velocity
LDL	Litho Density Log
CNL	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	Hydrofrac Packer Test