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THE EUROPEAN HDR PROGRAMME :MAIN TARGETS AND RESULTS OF THE DEEPENING OF THE WELL GPK2 TO 5000 M

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ABSTRACT

In 1997 a circulation test was carried out at the European HDR Project in Soultz-sous-Forêts which showed that it was possible to circulate at around 25 l/s between two deep wells in the depth range of 3000-3500 m and a separation of about 450 m. The test lasted for about 4 months and produced excellent results but it was observed that although the heat produced was sufficient for space heating (140-150ºC, 10 MWth), the temperature was not sufficiently high for electricity generation at an economic rate.

Both the funding agencies and the industrial consortium felt that heat production by HDR at around 200ºC was more attractive for electricity generation and therefore it was decided to extend an existing deep well GPK2 to a depth of around 5000 m to access the required temperature. Scientific investigation was carried out to characterise the rock mass at great depth and assess if they would be as favourable as found for the successful circulation test at 3000-3500 m in 1997.

The targets and the preliminary scientific data obtained during and after the deepening of GPK2 are also described.

1. INTRODUCTION

The European HDR research site is situated at Soultz-sous-Forêts (France) on the western edge of the Rhine Graben, about 50 km north of Strasbourg. The site is in the former Pechelbronn oil field and was selected because of the high heat flow anomaly observed from a large number of oil wells. The surface expression of anomaly is tightly confined and suggests the existence of deep convective cells.

The European HDR project started in 1987 and is funded by France, Germany and the European Commission (EC). A number of organisations from other countries such as Italy, Sweden, United Kingdom and Switzerland are also involved.

The project is administered and co-ordinated by a Core Team of three senior staff (British, French and German) who are based permanently on site and provide a link between the funding agencies and the research organisations (Garnish et al., 1994). Recently, staff from the Industrial Consortium associated with the programme have been seconded to the site.

During the initial phase (1987 – 1989), a well (GPK1) was drilled to 2000 m depth in order to penetrate the crystalline basement at 1377 m depth and obtain basic data. The bottom hole temperature was 140.3°C. The temperature gradient and the heat flow values are high in the sedimentary cover (10.5°C/100 m ; 176 mW/m^2) and quasi-normal in the granite basement (2.8°C/100 m ; 82 mW/m^2). A number of geophysical measurements were carried out to assess the rock mass conditions at 2000 m depth (Bresee, 1992).

During 1989-1991, an attempt was made to drill a continuous cored well (EPS1) to 3500 m, re-opening an old oil well located about 400 m SSE of GPK1. The coring started at about 900 m but it proved to be difficult to control the deviation. The well was terminated at the depth of 2280 m, at which point the deviation had exceeded 25°. The continuous coring nevertheless gave very useful information on the joint network and mineralogy, and provided the basis for subsequent interpretation of cuttings and geophysical logs.

During 1992-1993 the existing well GPK1 was extended, essentially vertically, from 2000 m to 3590 m depth. Geophysical and other scientific measurements were carried out during and after drilling. Following the drilling of the well, large scale hydraulic tests were carried out to characterise the rock mass. Supporting activities during the injections included microseismic monitoring, production logging, fluid sampling, etc (Baria et al., 1993, Baria et al., 1995).

Following this stage, GPK1 was put on production (June / July 1994) to assess the productivity and the injection properties following the massive injections in 1993 (Baria et al., 1995). The existing information available (stress, joints, thermal modes and seismicity) was then used to target a second deep well GPK2 to a depth of around 3890 m approximately 450 m south of GPK1.

In 1995 and subsequently 1996, GPK2 was stimulated with a maximum flow of 78 l/s (Gérard et al., 1977) to improve the injectivity as a function of flowrate. During the 1996 injection a total of 28,000 m^3 of fluid was injected between 3200 m and 3600 m in three flow steps (24, 45 and 78 l/s) with a maximum wellhead pressure of 13 MPa for 78 l/s.

A 4 months circulation test was carried out in 1997 between the two deep wells GPK1 and GPK2 at around 25 l/s. The result of the test showed that brine can be circulated through the enhanced fracture rockmass at great depth with a separation in excess of around 450 m, with low power consumption for circulation, no geochemical problems and no water losses (Baumgärtner et al, 1998).

2. THE MAIN OBJECTIVE OF THE PROGRAMME FOR 1998-2001

During the latter part of the 1996-1998 European Programme, an Industrial Consortium (IC) was established and consisted of Electricité de Strasbourg, Pfalzwerke and ENEL. This consortium has expanded and formed a legal entity called GEIE "Exploitation Minière de la Chaleur". The members consist of Electricité de France (EDF), Electricité de France International (EDFI), Electricité de Strasbourg (France), Pfalzwerke, RWE (Germany), ENEL (Italy) and SHELL (The Netherlands).

The Industrial Consortium associated with the programme at that time considered (and this was supported by the funding agencies) that future industrial developments need a **confirmation that the favourable properties** seen during the circulation test at a depth range 3000 – 3500 m are also present at greater depth where the temperature is in the region of **200°C** (i.e. sufficiently high for electricity production). The depth at which this temperature could be accessed was estimated to be at around **5000 m**. The programme was based on these objectives. One of the main objective was to access the undergroung rockmass at around 5000 m depth (deepening of an existing well) and to carry out scientific investigations to evaluate the underground situation at this depth.

The primary measurements / evaluations include:

- Natural fracture system
- Temperature
- Stress field
- Hydraulic characteristics and results of stimulation
- Geochemical behaviour

3. STATUS OF GPK2 BEFORE DEEPENING

The well GPK2, the second deep borehole in Soultz, was completed in early 1995 to a depth of 3876 m (Fig. 1). A maximum temperature approaching 168°C was observed at around 3800 m (deepest observation point). GPK2 was positioned to the South of the well GPK1 at a distance of around 450 m, targeting the stimulated zone in GPK1 (between 2850 m and 3500 m). During the drilling of GPK2, a large permeable fault was encountered at around 2110 m depth which from there on caused total fluid losses during drilling. A small injection test performed immediately after drilling showed that the injectivity of this fault was in the order of 50 Darcy m.

Before any stimulation, after the completion of the well (with a sealed casing shoe at 3211 m), small scale hydraulic injection tests showed an injectivity of the 665 m long open section (3211 – 3876 m) in the order of 0.33 - 0.38 (l/s)/MPa.

The open hole section of GPK2 was twice stimulated in 1995 and 1996 in order to create an underground heat exchanger. A total of 58,000 m^3 of water were injected below the casing shoe at a maximum flow rate of about 78 l/s. During stimulation and subsequent hydraulic testing several permeable features were observed in the depth range from 3211 m (casing shoe) to 3600 m.

Finally, in 1997, during a 4 month circulation experiment, 244,000 tons of hot brine were produced from this zone from GPK2, cooled on surface and then re-injected in the well GPK1 (Fig. 1). For this experiment, a totally closed loop system had been installed on surface in order to prevent scaling or corrosion phenomena.

4. DRILLING PROGRAMME

A drilling programme was devised which took care of various options depending on the situations encountered (Fig. 2).

Other technological developments were also carried out in the field of high temperature cementing, high temperature metal packers and high temperature 6 arm calliper.

A MAS 6000 rig of ENEL was selected for various fishing and technical operations as well as the extension of GPK2 to 5000 m depth.
The plan for the re-entry and deepening of GPK2 is shown in Fig. 3.

The drilling operation started on 15th February 1999 and the overall operation was completed on 29th May 1999, a total of 104 days.

A combination of single shot and giro was run into the well to survey the trajectory of the well. Down to 3876 m (the depth of the well before the extension) GPK2 can be regarded as near vertical. The survey showed that there is a dog leg at a depth in the range between 3870 – 3910 m. At this depth a considerable enlargement of the hole was observed during 6 arm calliper runs. The final completion of the well is shown in Fig. 4.

5. SCIENTIFIC INVESTIGATION CARRIED OUT DURING OR JUST AFTER DRILLING

5.1 Geological investigation

The geological investigation consisted of coring, analysis of chip sample and geophysical logging.

Coring

The deepest core at the Soultz site before the deepening of GPK2 had been collected near the bottom of the GPK1 well (3523 – 3526 m). At that time, in early 1993, coring had been performed using a positive displacement motor and a diamond coring assembly. Two main problems had been observed during the coring operation in 1993:

- A motor failure
- A partial unscrewing of the core barrel (occurred twice!)

Both problems could be identified as temperature related technical difficulties.

As the conditions for coring after deepening of GPK2 had to be expected as even more hostile, after a careful analysis of all available techniques, it was decided to run a conventional roller cone coring bit without any motor in the well.

Coring in GPK2 was performed on May 9th 1999 in the depth range from 5048 – 5051 m. The 7-7/8" coring bit was operated at 55 rpm and 5 tons on bit. The penetration rate averaged 1.7 meters per hour. After 3 meters of coring, the penetration rate dropped significantly, indicating that the bit was worn. A total of ~ 1.2 m of core (40%) was recovered. The remainder of core had been lost at the bottom because it was not caught by the core catcher. The core retrieved was broken up into pieces of 5 – 10 cm length, probably caused by vibrations within the bottom hole assembly.

The analysis on the cores are continuing but the initial data suggests that the granite was mostly similar to that found in GPK1 and EPS1. A more fine grained granite was also sampled. This could be interpreted as an intrusion accross the main granitic facies. Some pieces of cores show well developed fractures (± 1 mm width) sealed with hydrothermal deposits which are now under analysis.

Cutting samples

Cuttings were sampled continuously through out the extension of GPK2. Samples were collected, washed and analysed. The data was used to produce a lithological log as shown in Fig. 5.

The log shows that GPK2 penetrated into granite down to the bottom (± 5100 m). Numerous alterations and fracture zones exist below 4000 m. Several sections show the presence of Xenolith. The hydrothermalisation appears to be more prominent at depth below 4500 m.

Geophysical logging

The information on the joint network has been well documented from the continuous cores and borehole imaging logs in existing wells (Genter and Traineau, 1992a and 1992b). The observations suggest that there are two principal joint sets striking N10E and N170E and dipping 65ºW and 70ºE respectively (Genter and Dezayes, 1993). The granite is pervasively fractured with a mean joint spacing of about 3.2 joints/m but with higher variations in joint density.

Following geophysical logs were run during the drilling operation: HNGS (2000–4500 m), 6-arm calliper (3200–4625 m), ARI (3500–4500 m) and UBI (3200–3875 m).

The data shows that the well is significantly enlarged in diameter at various depths, the joint network and pattern of alteration appears to be similar to that found higher up in the well (3500 m).

5.2 Temperature

The depth to which GPK2 had to be deepened was based on the temperature requirement by the Industrial Consortium which was in the range of 200°C. Various models / extrapolations indicated that GPK2 will have to be extended to 5000 m depth to obtain the required temperature (± 10°).

An initial temperature log was carried out during the drilling operation, 12 hours after the completion of the 8-1/2" diameter well to 5048 m. The tool was parked near the bottom and temperature was still rising (194°C) when the tool failed. The survey showed that the target temperature had been reached. Two months after the completion of the well, a temperature log was run which confirmed that the bottom hole temperature was very close to 200°C (Fig. 6).

5.3 Stress field

The stress regime at Soultz was obtained using hydrofracture stress measurement method (Klee and Rummel, 1993). The stress magnitude at Soultz as a function of depth (for 1458-3506 m depth) can be summarised as:

S_h = 15.8 + 0.0149 x (Z – 1458) least horizontal stress
S_H = 23.7 + 0.0336 x (Z – 1458) max. horizontal stress
S_v = 33.8 + 0.0255 x (Z – 1377) overburden

The direction of SH was assessed from borehole images such as FMS/FMI and BHTV. These measurements indicate that between 2000 m and 3315 m depth the direction of S_H is about N170ºE.

It is planned to carry out hydrofracture stress measurements in the pilot hole in later part of the year using high temperature metal packers. A 6-1/4" pilot hole has been drilled specially for this purpose (5048 – 5051 m).

5.4 Hydraulic characteristic for stimulation

An initial slug test was carried out in August 1999 showed that the injectivity of the open hole of GPK2 was around 0.3 l/MPa/s which is compatible to that measured for shallower depth (3200 – 3600 m) in GPK2 i.e. 0.33 - 0.38 (l/s)/MPa.

Further low flow rate tests are planned for October 1999 and a medium flowrate stimulation is anticipated for March / April 1999. The preliminary data indicate that the hydraulic characteristics for stimulation will be similar to those in the 3.5 km range, taking into consideration the depth, fluid density, temperature, etc…

5.5 Geochemical behaviour

The geochemical aspects are been investigated and the well is put on production using a downhole pump. The indication from the drilling fluid, etc... suggests that the characteristics are similar but this may change once larger quantities of brine from the deep formation at 200°C are sampled and analysed.

6. CONCLUSIONS

- The extension of GPK2 was successfully carried out taking into consideration the complexity of the operations, the risk associated with these operations and the limited budget.
- The target to obtain temperatures of around 200°C is achieved successfully.
- The geology (lithology) is very similar to that found at 3500 m depth with a well developed fracture network and alterations offering access the rock mass for stimulation.

- Although the hydraulic stress and geochemistry data have not been attained at present, the indications are that they will be similar to what was expected.

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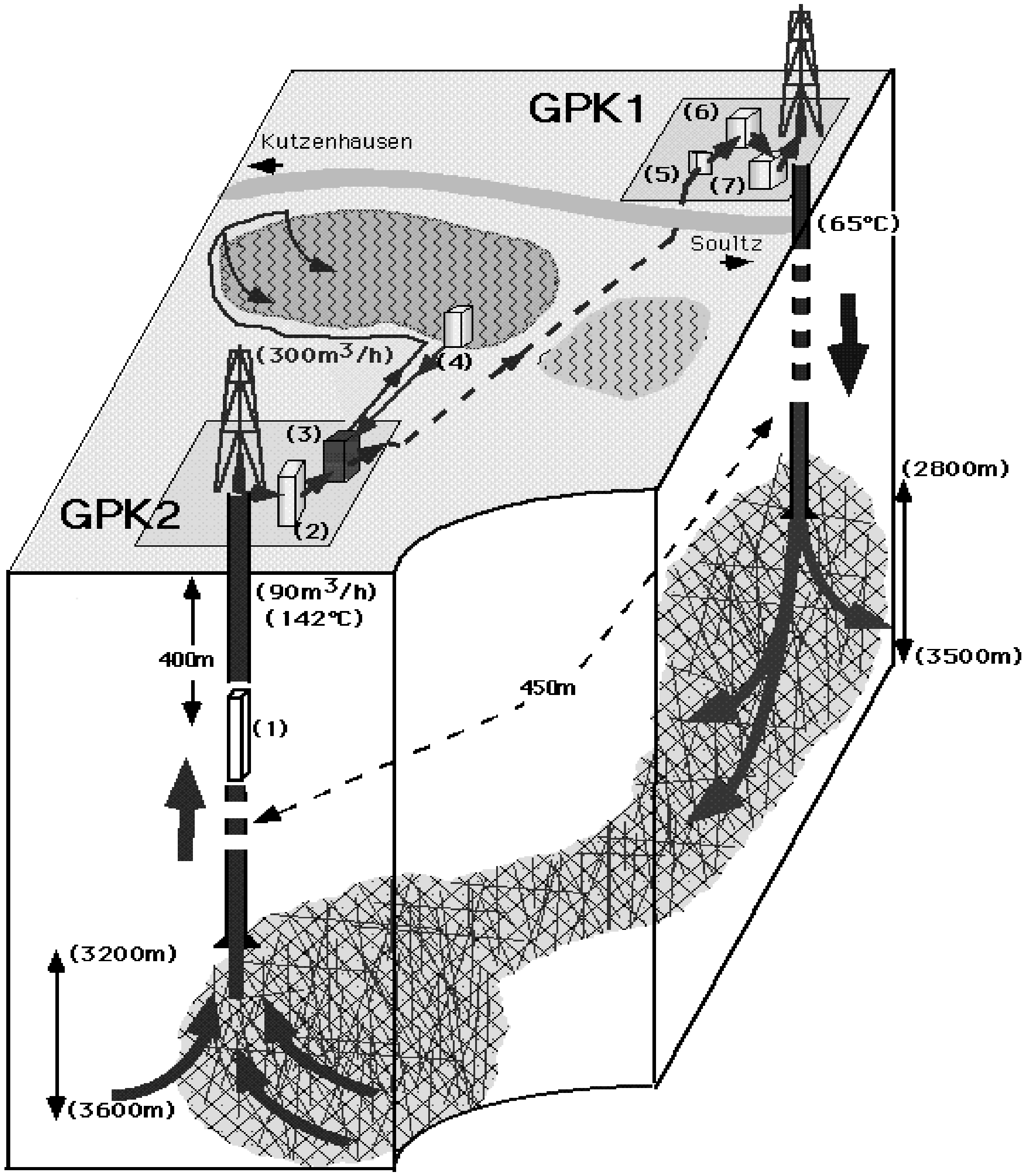

Fig. 1: Circulation experiment between the 2 deep wells GPK1 and GPK2 at the HDR test site in Soultz in 1997.
(1: submersible pump, 2: pre-filter, 3: heat exchanger, 4: pumps for cooling circuit, 5: corrosion test chambers, 6: filter battery, 7: re-injection pump)

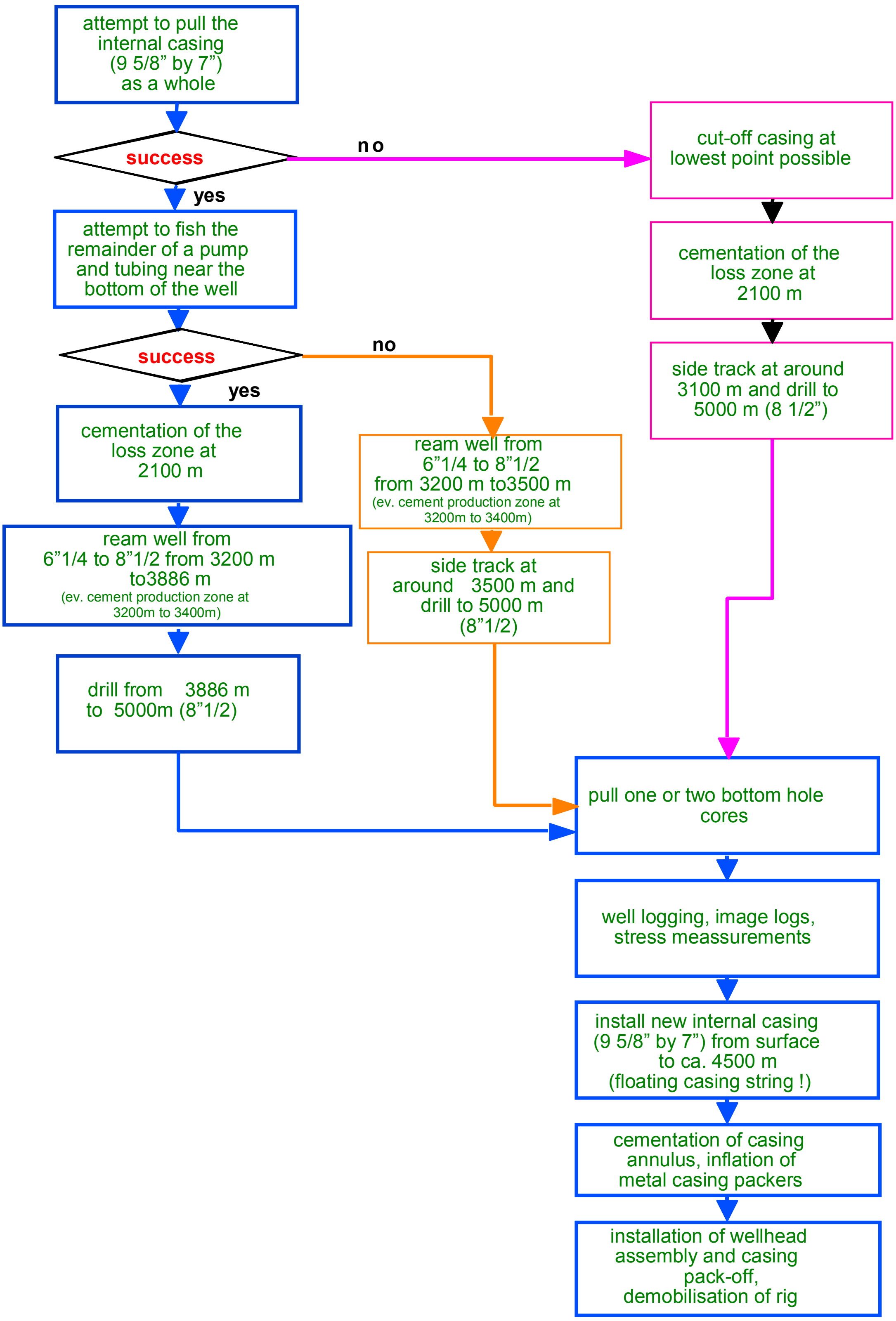

Fig. 2: Planned sequence of operations during the re-entry and deepening of GPK2

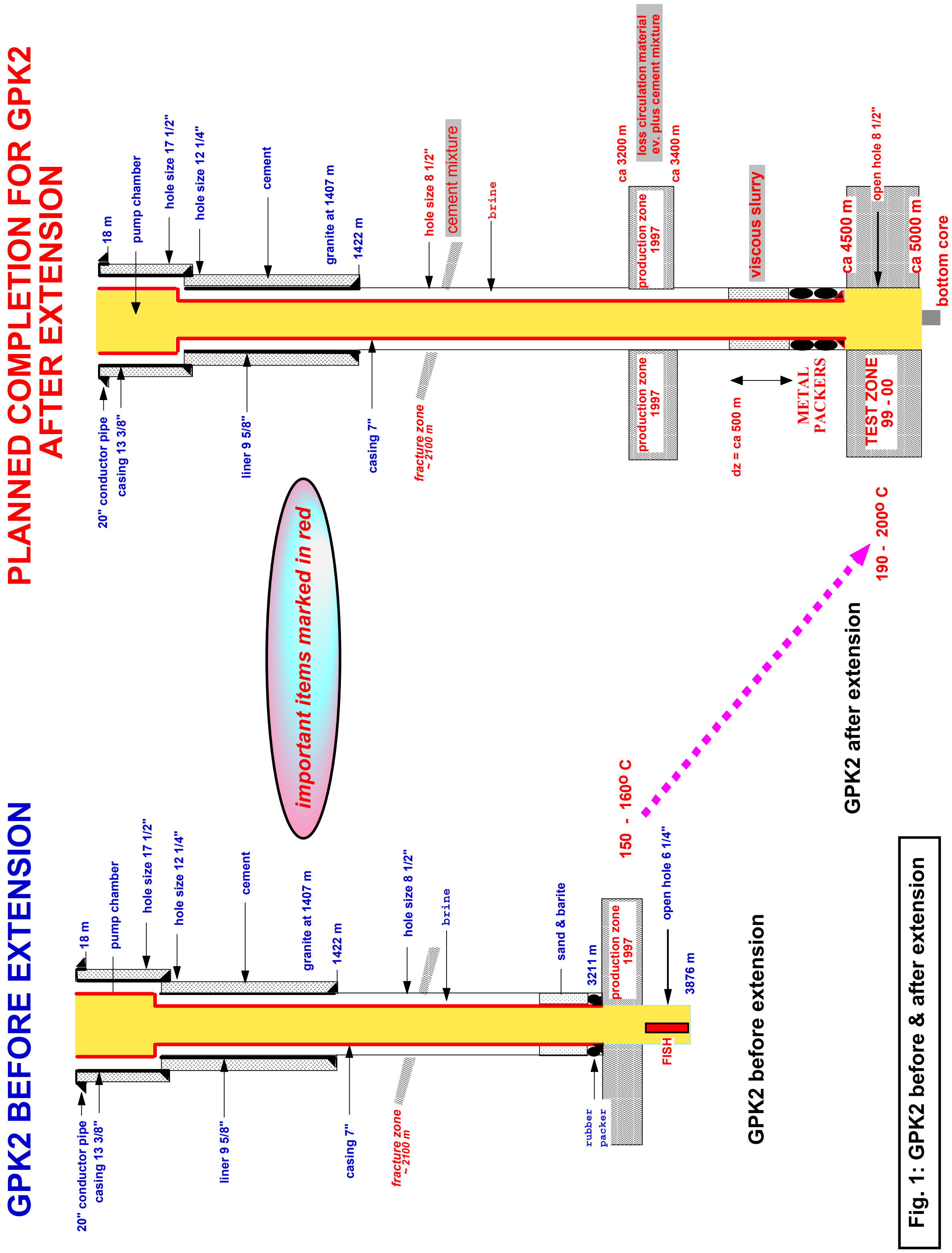

Fig. 1: GPK2 before & after extension

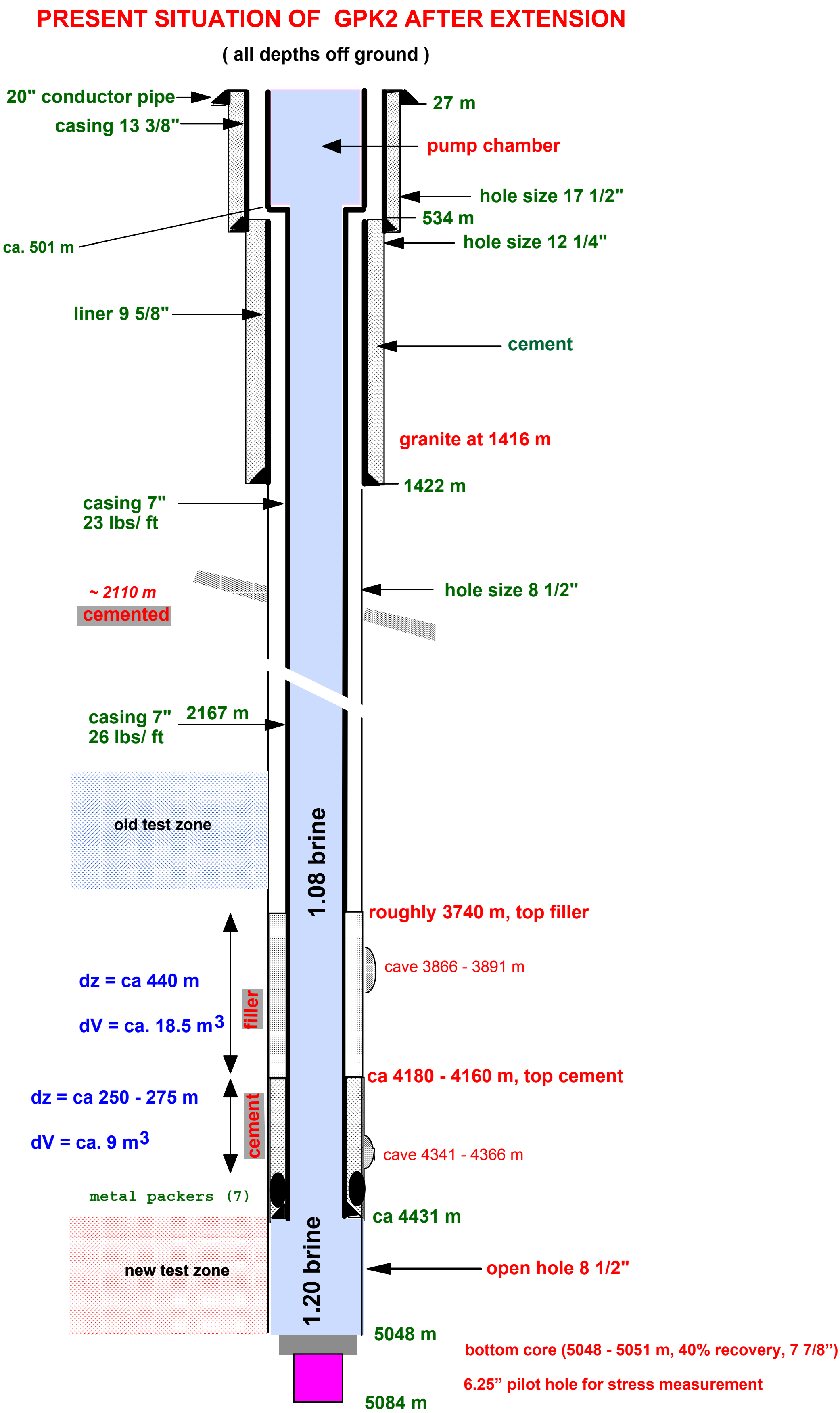

Fig. 4: Present situation of the well GPK2 after re-entry and deepening to 5084 m (app. 5024 m **Tr**ue **V**ertical **D**epth)

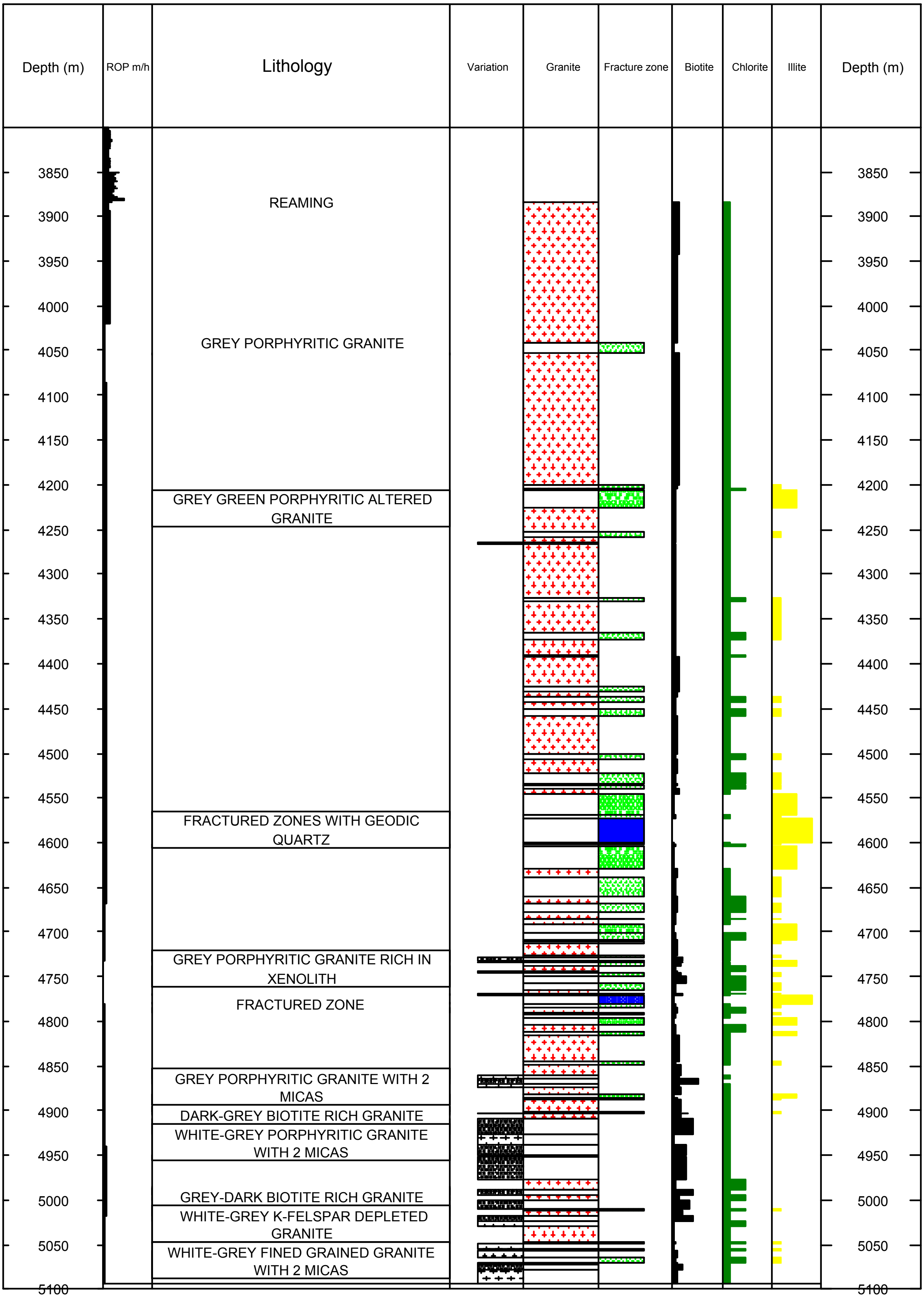

Fig. 5 Preliminary geological cross section of GPK2 after extension
(courtesy of A. Genter, BRGM)

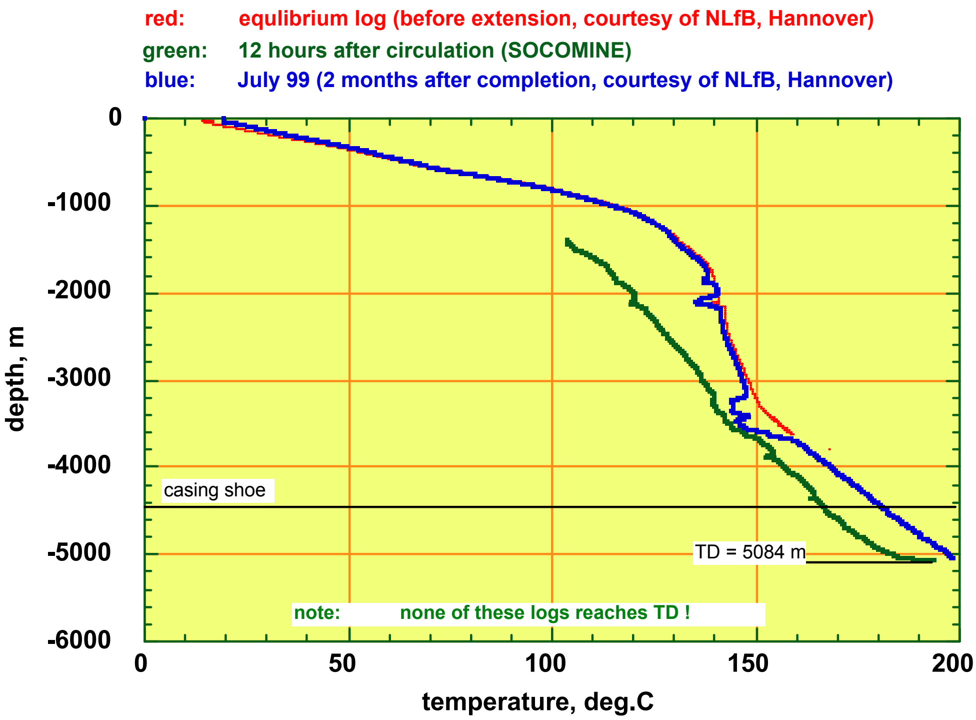

Fig. 6: Temperature logs in GPK2 before & after deepening