Proceedings World Geothermal Congress 2000
Kyushu - Tohoku, Japan, May 28 - June 10, 2000

SOULTZ-SOUS-FORETS: MAIN TECHNICAL ASPECTS OF DEEPENING THE WELL GPK2

J. Baumgärtner [1], A. Gérard [1], R. Baria [1]
[1] Socomine, Route de Kutzenhausen, BP 39, 67250 Soultz-sous-Forêts, France

Key-words: deep drilling, crystalline rocks, well completion techniques, metal inflatable packers

ABSTRACT

The well GPK2 at the European HDR site was successfully re-entered and deepened from 3876 m to 5084 m depth and fully completed in 104 days (mid February to the end of May 1999). The programme of re-entry included pulling of the existing 3211 m long internal 9-5/8" by 7" casing string, fishing of a submersible pump and some 150 m of 2-3/8" tubing, sealing of a major loss zone and reaming open from 6-1/4" to 8-1/2" in granite (3211 – 3876 m). The well was extended to 5048 m in 8 1/2" hole size and again completed with a floating 9 5/8" by 7" casing string. The casing shoe is at 4431 m. A bottom hole core was taken at 5048 - 5051 m depth. The core recovery was app. 40%. A pilot hole in 6 1/4" was drilled from 5051 - 5084 m for in situ stress measurements.

The re-entry and deepening of the well GPK2 was accompanied by several technical developments. Metal casing packers were developed jointly by SOCOMINE and MeSy GmbH (patent pending). These packer elements were successfully integrated into the completion of the well. The full weight of the casing string is supported by these elements which are filled with and imbedded in cement. High temperature cementing strategies (up to 170 - 190^o C) for the complex saline fluids encountered in Soultz (High Magnesium Resistant Cements) were developed in a cooperation between Schlumberger Dowell (Vechta), SOCOMINE, SII of Houston, Ruhr-University Bochum, BGR Hannover and IFP Paris.

1. INTRODUCTION

The background to the European HDR programme and the basic in-situ properties are well documented (Baria et al., 1995 and Bresee et al., 1992). Further development of this technology required that the past successful experience at Soultz is replicated at higher temperatures and larger flow rates in order to further improve the efficiency and economy of the technology. Following the successful circulation experiment in 1997 at Soultz, it was decided to re-enter and deepen the well GPK2 from 3876 m to 5000 m. Temperatures of around 200°C were anticipated at this depth.

In 1995, the well GPK2 had been completed to a depth of 3876 m (Fig. 1). The temperature at 3800 m exceeded 168^o C (deepest observation point). During the drilling of GPK2, a large permeable fault was encountered at around 2110 m depth. Total fluid losses were encountered after the intersection of the fault. A hydraulic test showed that the injectivity of this fault was in the order of 50 Darcy m!

In early 1995 a submersible pump, 150 m of 2 3/8" tubing, some power cable and a tubing clamp had been lost in GPK2 during a scientific hydraulic experiment and were still lying at the bottom of the well. Wireline measurements showed the top of the fish at about 3623 m (probably crumbled power cable). Any deepening of the well would require the removal of this obstacle.

GPK2 had been stimulated twice, in 1995 and 1996, in order to create an underground heat exchanger (Fig. 2, Gérard et al., 1997). A total of 58,000 m^3 of water were injected below the casing shoe with a maximum flow rate of about 78 l/s. In 1997, during a 4 months "closed loop" circulation experiment, 244.000 tons of hot brine at rates of up to 90 tons per hour had been produced from the stimulated section in GPK2 (Baumgärtner et al., 1998, Jung et al. 1998).

From the past experience of drilling in the granites at Soultz, an extension of the well in 6 1/4" hole size (through the existing casing) appeared to be unsafe to operate over 4000 m in view of the 3-1/2" drill string and small drill bit which can be considered as too weak. Consequently, the existing 9 5/8" by 7" casing string had to be removed in order to allow an extension of the well in 8.5" hole size.

The internal casing in GPK2 was designed as a floating string, compensating the temperature changes in the well (Fig. 1). If the well was deepened in 8.5" hole size up to TD, no diameter change would be available at the bottom part of the well to support the weight of an extended floating casing string, it would have to be carried by the anchoring assembly (casing packers & casing shoe cementation).

The new completion would also have to take into consideration the previous experiences from GPK1 and GPK2 which had shown

- that considerable difficulties exist for cementing operations in the hot brines found in Soultz
- that rubber packers are not suitable for the temperatures encountered in Soultz.

2. STRATEGIES DEVELOPED FOR HIGH TEMPERATURE CEMENTING

At higher temperatures, cementing is a primary cause of wellbore problems, major time losses and casing problems throughout the geothermal industry as whole. Working in mixed brines at varying salt concentrations adds considerably to the problem. Having this in mind, the Soultz project has been making strong efforts to overcome these problems, new cementing strategies were developed. In the case of GPK2, cementing operations were anticipated:

- to seal the loss zone at 2110 m

- to isolate the bottom section of the new internal casing string and to inflate the casing packers.

Work on the development of new cementing strategies started as early as mid 1998. The following organizations participated to these research activities: Schlumberger Dowell, Vechta; Socomine, Soultz; Bundesanstalt für Geowissenschaften & Rohstoffe, Hannover; Ruhr-Universität, Bochum; Southern International Inc., Houston; Institut Français de Pétrole (IFP), Paris.. As a result of the joint investigations, a three-step program was proposed:

The first step was to replace cement wherever possible with a filler which should form a hydraulic seal but which should not bind with the casing string. Such materials should be used to seal longer sections of the annulus of the floating internal casing string. Numerous laboratory experiments with fly ash as base material were performed in 1998. These tests and analyses showed that some fly ashes have excellent settling and thus sealing capacities as long as they are kept in the slag below a critical concentration (this critical concentration depends on the type / origin of the fly ash). During the course of these investigations, clear differences in the settling capacity were observed between fly ashes of different origin !

The second step was to eliminate Portland cement, as far as possible, from the cement mixtures in order to reduce the time constraints. Portland cement (especially under high temperatures) has the characteristic to harden very rapidly ("flash") - once the retardation period has passed. Furthermore, especially Magnesium Chlorides as they are found in the brines at Soultz destabilize the cement reaction.

In co-operation with Schlumberger Dowell of Vechta and BGR of Hannover, numerous laboratory experiments, adapted to the conditions encountered in the Soultz granites, were performed with cement mixtures based on blast furnace based cements (BFC) and fly ash. These developments were triggered through experiences from oil wells in North Germany which had shown that cement mixtures based on BFC are less sensitive to mixed brines in the well than conventional API class G cements. Independent test series for the various mixtures were run also at IFP, Paris, to confirm the results. The resulting cements are called HMR cements (High Magnesium Resistant cement). Beside their insensitivity to various chlorides they are characterized by a high stability towards chloridic acids. The compressive strengths achieved with these cements in laboratory are comparable to those observed for API type class G cements. Furthermore, HMR cement mixtures set only gradually with time, no flashing is observed !! This behavior clearly improves the safety of the operations at high temperatures. However, hardening of the cement occurs also somewhat slower than for class G-cements.

Before being used in situ, every premixed charge was tested once more in the laboratory of Schlumberger Dowell. It was observed that considerable differences in thickening time (for the same amount of retarder) may occur for different delivery charges of HMR cement ! Testing of the pre-mixed cement charges to be actually used in the field again proved to be an absolute requirement !

The third step taken was to overcome the salinity problems by calibrating, testing and making up all cements slurries using a brine with an NACL concentration of 200 g/l, which is nearly twice the total natural salt concentration found in the Soultz area. This way a contamination of the cement with the much more complex natural brine could be eliminated.

3. DEVELOPMENT OF CASING-PACKER

Past experience at Soultz had shown that - at least for the hostile conditions found in Soultz (hot brines, gases) - for temperatures exceeding 120 to 140^o C conventional rubber based packer elements cannot be used. This experience was gained using conventional rubber based inflatable packer elements as well as compression type mechanical packers, both of various brands. Packer failures observed include brittle fractures of rubber sleeves as well packer leaks due to gas intrusion and expansion when changing packer depths. Further temperature related problems were observed with several kinds of valves and packer ports. On the other hand, the planned completion for the extension of GPK2 required casing-packers (ID 6.25") which

- would set properly in the hostile environment at Soultz (brine, gas) at temperatures between 170 - 190^o C
- would be able to support the full weight of the internal 9-5/8" by 7" casing string (> 4400 m, estimated weight in water: 160 tons).

Consequently, fully new casing-packers had to be developed. This development started early in 1998 and was performed in close cooperation between MeSy GmbH of Bochum and SOCOMINE. Decision was made to eliminate all rubber products from these packer elements (with the exception of static O-rings for sealing purpose). The packers were designed to be as simple and sturdy as possible, trying to avoid problems with complex mechanics at high temperatures. A solution was found by using inflatable soft metal packer shells. Selecting the right alloy, the behavior of such metals can be adapted to the prevailing chemical and temperature boundary conditions. For the extension of GPK2, for the 8.5" open hole section in granite, a packer design with a mandrill of 7" 26 lb./ft C 95 casing and a sleeve made of a salt water resistant Cu alloy was chosen. The packer sleeve is inflated through cement injection ("packer setting"). Numerous laboratory tests with such metal packer elements were run. Deformation of the sleeve (at room temperature) started at around 10 MPa. Setting pressures could be as high as 25 MPa. The packer elements designed for an 8.5" open hole could inflate up to 10" hole size. A special test set up was designed in order to measure the anchoring strength of a single packer element. The anchoring tests were performed inside test pipes with varying IDs from 8.5" to 10". The anchoring force of a single element increased from a minimum of 30 tons inside a totally smooth steel pipe to over 100 tons as soon as some minor irregularities (simulating a rough borehole wall) were machined into the test pipe. For the application in the GPK2 well, in order to facilitate the handling, the casing-packer elements were designed in such a way that 7 packer elements together with an upper and lower casing pop-joint (necessary to be able to set the slips on the rig floor and to run centralizers) could be pre-assembled to one long single packer unit at the length of a Range 3 casing joint (app. 12 m). The elements were connected via 7” BTC casing couplings. Each packer element had an overall length of app. 1.5 m (incl. one coupling). The sealing section for each element had a length of app. 0.8 m. Patents for the metal casing-packer technology are pending.

4. SELECTION OF A RIG

In order to safely re-enter and deepen the well GPK2 from 3976 m to 5000 m, a land rig of the 1500 hp class (1300 - 1700 hp) was necessary. After an extensive review, it was decided to select a rig of ENEL (Italy) based on the cost and the quality of the rig, the associated equipment (tubing, mud logging, coring, casing handling), the support to the rig, the size and the power of the rig. The main parameters of the rig selected are listed below.

Rig type: MASSARENTI 6000 EE, DIESEL-ELECTRIC, 1700 hp
Max. drilling depth (5” DP): 5.200 m
Hook load: 453.000 kg
Rotary load: 453.000 kg
Setback load: 272.000 kg
Comb. substructure load: 725.000 kg
Motors: 4 x ISOTTA FRASCHINI / 16 cyl / 900 hp ea..
Generators: 4 x ANSALDO M2V 500 CH / 670 KW / 600 Volts
SCR unit: 1 x G.E. µDrill 3000 / 6 bays

5. MAJOR OPERATIONAL STEPS

During the re-entry and deepening of the well GPK2 several crucial technical operations had to be performed. These are described below in the sequence of operations (see Figures 1,2,3).

5.1 removal of the existing 9 5/8” by 7” internal casing string

The 9 5/8” by 7” casing string in GPK2 which had been installed in 1995 was isolated by a rubber casing packer and some 150 m of a sand and barite packing in the annulus (see Fig. 1). As the weight of the casing string in brine was in the order of 110 tons (128 tons in air) the maximum pulling force had to be restricted to 204 tons (i.e. 450.000 lb.), in order to not risk to tear apart the string. The plan was to engage the casing string with an ITCO casing spear and to work the casing loose by pulling and slacking off.
The pulling of the casing was performed between February 16th -18th. In order to be able to install the spear properly, two separate scraper runs were necessary inside the 9 5/8” (removing scaling, 8.5” and 8 5/8” blades). The casing was engaged and worked in the load range between 100 to 190 tons for about 5.5 hours before it came free. When the casing was laid down it appeared that one 7” centralizer, part of a 9 5/8” centralizer and some bands of the packer re-enforcement were missing. As the casing appeared to be still in good condition, it was decided to inspect and repair the best joints and to re-run them after the extension of the well in order to reduce the overall cost of the well.

5.2 recovery of a submersible pump and some 150 m of 2 3/8” tubing

The second critical operation was the recovery of a submersible pump and some 150 m of 2 3/8” tubing which had been lost in the well in spring 1995 (on top of this some 200 m of power cable and a tubing clamp had dropped in the well at that time). Again this operation was critical due to the fact that if the recovery was not successful the well would have had to be side-tracked (Fig.3).
The fishing operation was engaged immediately after the 9 5/8” by 7” casing was pulled (dates of fishing / milling operations: 19. - 25.2. and again 15. - 16.3.99). First the well was cleaned to the top of the fish with a 6 1/4” bit. The fish had been tagged by wrireline wireline at 3623 m. During the next step of the operation more than 1 m of the 2 3/8” tubing (first collar) was milled using a 5 7/8” flat bottom mill. Once the top collar was milled it was possible to grab the tubing with an overshot and retrieve the 150 m tubing in one run. At this point, the submersible pump, the tubing clamp, the power cable plus some centralizer pieces from the casing removal still remained at the bottom of the well. During a second mill run with a 5-1/2” flat bottom mill it was possible to destroy the vast majority of these pieces. As it turned out, after the cementation of the loss zone and the opening of the well to 8 1/2”, another mill run (5 7/8” flat bottom mill) was required to fully clean the well (15. - 16.3.99). During this last mill run high torque and drag values were observed. It became obvious, that this operation was performed in a difficult section of the well (remark: already in 1995, at the end of the drilling operations, very high values of torque and drag had been observed in this depth range, i.e. below 3870 m).

5.3 sealing-off of a major loss circulation zone at a depth of around 2110 m

During drilling of GPK2 in 1994 / 95 a major loss zone was encountered at 2110 - 2111 m. From this point on, GPK2 had to be drilled without returns (total losses). In order to improve the control of the drilling operations, it was decided that this zone has to be cemented. Past experience had shown that treatments with pills of slag slurry and LCM did not promise a large probability of success. Before the cementation, a 3 m^3 high viscosity was spotted below the loss zone at 2110 m. The loss zone was then successfully isolated during 3 subsequent cementing operations using HMR cements (March 6th - 9th, 1999). For this application BFC and fly ash were mixed in equal proportions. The cement was designed for a bottom hole curing temperature of 120^o C. The retarder used was D13. All three cement jobs were pumped through open ended drill pipe.

5.4 drilling hot & fractured granite at greater depth

At the beginning of the drilling operations 665 m of hole inside granite had to be opened from 6.25” to 8.5” (Fig. 1). Hole opening was performed with a standard 3 cone roller bit (SECURITY H100 FL, (IADC code 837Y). A standard bottom hole assembly consisted of:

8.5” bit,
8.5” 6pt roller reamer
6.5” short drill collar
8.5” 3 pt roller reamer

6.5” drill collar
8.5” 3 pt roller reamer
6.5” drill collar
8.5” 3 pt roller reamer
10 - 6.5” drill collars (ca. 91.5 m)
total length of BHA: app. 122 m

The 665 m (3211 - 3876 m) were reamed in 102.5 hours, consequently the average penetration rate was close from 6.5 m/h at an average weight on bit of 7 tons. 4 bits were used, the average length of hole opened per bit was 166 m.
Drilling in 8.5” was mainly performed with **drill bits** of the type H100 FL of SECURITY. With increasing depth the temperature impact on the roller bearings became apparent, more sealing failures could be observed. The penetration rates continuously dropped from about 2.8 to less than 2 m/h at weights on bit between 8 - 12 tons. The meters per bit dropped in parallel from 127 m (3900 - 4000 m depth range) to 50 to 70 m at depths below 4500 m. Some difficulties were encountered with **drilling breaks** i.e. zones of increased alteration or fracturing within the granite. The most important zone of this kind was intersected right at the bottom of the old well. In 1995, using a smaller rig, drilling of GPK2 had been stopped at 3876 m because a rapid increase of torque and drag was observed at this depth. The experience from the deepening of GPK2 proved that this had been the correct decision. The following major drilling breaks were observed during the extension of GPK2:

depth	caliper	remark
3876 - 3900 m	partly wide open (> 30”)	rapid increase of torque and drag, hole inclination increases , loose material in zone, falls out when circulating while passing this zone
4350 - 4370 m	up to 30”	increase of drag & torque
4560 - 4580 m	minor enlargement	drills at 4 m/h with zero weight on bit !

The **increasing drag and torque** lead to modifications in the bottom hole assembly and the mud system. Between 3884 m and 4608 m the drag increased by more than 60 tons. This increase of drag was accompanied by an increase of hole inclination (see below). The drag was fought by reducing the number of drill collars in the bottom hole assembly and replacing them by heavy weight drill pipe.
However, at the same time further difficulties related to **wear and stress cracking** in the bottom hole assembly (BHA) were observed. In the depth range around 4200 m first stress cracks appeared in the roller reamer bodies. Several reamers had to be sent for repair. Consequently, depending on the availability of reamer bodies (several new bodies had to be ordered), varying reamer configurations were run. The problem disappeared once the RPM were dropped from 65 to 60. It can be speculated that these cracks were related to the fact that the vibrations of the drill string in the well had hit a resonance frequency.
The wear observed on the bottom hole assembly (and the drill string) was always related to certain geological features - often in combination with very fine cuttings in the mud system. Several attempts were made to overcome the wear and drag problems through modifications in **the mud system**. The base mud used was a salt water mud made up with brine produced from GPK1 and weighted up to balance the formation pressure (app. 1.06 - 1.07 g/cm^3). Corrosion protection was achieved through the addition of Caustic Soda (pH 10) and a filming agent. With this simple mud, good drilling results had been achieved in 1992 (GPK1) and 1995 (GPK2 first part). Furthermore, this mud had proved to be very cost efficient (Baumgärtner et al., 1995). In order to reduce the drag & torque in the well an **environmentally friendly lubricant** called ECOL LUBE from AVA, Italy was added to the mud system. ECOL LUBE is based on vegetable oils and synthetic polymers. This product was used very successfully in the depth range from about 4700 m to TD. In parallel to the use of ECOL LUBE as a lubricant, hole cleaning was improved through the addition of Attapulgit (salt water drilling clay) to the drilling mud in order to increase the viscosity.
The safety of the handling of the mud on surface could be considerably improved through the installation of a plate heat exchanger for **mud cooling**. This exchanger was linked to a 25,000 m^3 lagoon from which cold water was circulated through the exchanger at a rate of app. 150 m^3/hour. This way, the mud temperature at the surface (at the outlet of the heat exchanger) could be kept below 40^o C. It may be speculated, that the injection of rather cold mud into a hot well can help to support bit penetration. The mud circulation rates used were 1650 l/min while drilling 8.5” and app. 900 l/min while drilling the pilot hole in 6.25”.

Some of the technical difficulties described here - and which had to be solved one after the other - are clearly also directly related to the **well trajectory (Fig. 4).** Down to 3876 m, i.e within the existing well, GPK2 can be described as ”near vertical” (< 6^o inclination). Near the bottom of the well before extension, at 3850 m, less than 1^o was measured by Schlumberger. During the extension of the well borehole inclination was recorded at intermittent intervals using a TOTCO and a high temperature PEE WEE single shot tool (inclinometer) from Scientific Drilling. On 7.5.99 a wireline gyro survey was run by Scientific Drilling inside the drill string from 2764 m (last gyro survey before deepening) to 5014 m. During this log it was confirmed that a dog leg exists in GPK2 in the depth range between 3870 - 3910 m. In this depth range a considerable hole enlargement was observed during caliper logging. Within this zone, the bottom hole assembly obviously had no wall contact and lost its capacity to steer. It is interesting to observe also that this dog leg had probably

already been initiated in 1995 using a 3.5” drill string and a slimmer, more flexible bottom hole assembly ! Between 3870 - 3910 m hole inclination jumped from 1^o to 8^o and continued to build from there on until it approached 26^o at 4450 m. At this depth the inclination was dropped again slowly to about 16^o near the bottom of the well. Considering the above described difficulties with hole drag and torque, drilling engineering concentrated in maintaining the well trajectory, reducing the build tendency and finally dropping the well.
It has to be noted that as far as the gyro log was recorded (5014 m), the extension of GPK2 walks along a continues North-West trend. This North-West trend probably represents a formation tendency of the rock at this depth which will have to be taken into consideration for all future well planning.

5.5 coring near bottom
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. Both, the core bit (SMITH X3TC7 7 7/8”) and the core barrel (Christensen 6 1/4” x 3”) were furnished by the drilling contractor, ENEL.
Coring in GPK2 was performed on May 9th 1999 in the depth range from 5048 m - 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 app. 1.2 m of core (40 %) could be recovered. The remainder of core had been lost on bottom (and had to be broken up later) because it was not caught by the core catcher. The core retrieved was broken up to pieces of 5 - 10 cm length, probably caused by vibrations within the bottom hole assembly. Nevertheless, this short core appeared to be a very good example of the varying types of granite encountered at this depth !

5.6 installation and isolation of a floating casing string at a depth of 4431 m
GPK2 was completed in the period between 13.5. to 28.5 1999. Again, a floating 9 5/8” by 7” mixed casing string was installed as the production / injection string (Fig. 5). To a large degree it was possible to re-run those casing joints which had been pulled at the beginning of the operations. Before being re-used each of these joints was carefully inspected and repaired if necessary. The casing to be installed was a mixed string assembled of:

0 - 501 m 9 5/8” 47 lb./ft N80 BTC (pump chamber)
cross-over 9 5/8” 47 lb./ft - 7” 23lbs/ft (L80)
501 m - 2167 m 7” 23 lb./ft L80 BTC
2167 m - 4419 m 7” 26 lb./ft C95 BTC
4419 m - 4431 m packer assembly (7 metal packers), float shoe & float collar

The whole casing string was designed and inspected for a special drift of 6.25” ! In order to isolate and anchor the casing string near the shoe and to support the weight of the casing string it was planned

- to first pump some 1000 m of a filler (fly ash)
- followed by app. 250 m of cement in the annulus of the casing
- and to install 7 metal casing-packers which are inflated with cement.

Critical points for the design of the completion were:

- the weight of the string hanging on the top joints of the 7” 23 lb./ft casing during installation of the casing
- the burst pressure of the 7” 23 lb./ft casing during the inflation of the packer elements
- to avoid a break-down respectively fluid losses in the open hole section due to the increased weight of the fluid column in the well
- identification of a suitable zone (caliper < 10”) for the setting of the inflatable packer elements.

The weight of the casing string during installation was controlled running a float shoe and float collar in combination (double safety). In order to reduce the differential pressure across the 7” 23lbs/ft casing it was decided to tail the cement in the casing string with a heavy brine of 1.20 density. To avoid fluid respectively cement losses in the open hole section it was decided to sand-up the well from the bottom to some 10 m below the casing shoe. Although this was a somewhat lengthy operation it offered the maximum guarantee to circulate the filler and cement behind the casing string. The open hole section for the setting of the packer elements was carefully selected on the basis of the results of wireline logging (caliper, UBI). Difficulties occurred trying to achieve a depth match between drilling and wireline depths because of the very different thermal stretch observed in the wireline and the 5” drill string.
The installation of the casing could be performed without any difficulties. A total of 34 m^3 of fly ash, 8 m^3 of HMR high temperature cement and - after a plug - 2 m^3 of HMR cement for packer inflation and 97.3 m^3 of displacement were pumped. For this application the HMR cement contained BFC and fly ash at a ratio of 78 : 22. The salt content in the cement was again 200 g/l. The cement density was 1.90 g/cm^3. The retarder used was D28. This way a pumping time (thickening time) in the order of 10 hours at 170^o C could be achieved. The fly ash filler was mixed at a density of 1.37 g/cm^3. During various laboratory tests it had shown good settling capacities, solid settled sediment was observed after 24 hours. During the cementing and filler injection minor difficulties occurred due to:

- a short period failure of the data acquisition system
- the fact that the 1.20 g/cm^3 tail brine got mixed and diluted in the mud tanks with return fluid. The leak in the

tanks could not be identified. Consequently, the tail fluid density dropped to 1.16.

- a leak which occurred during packer inflation. Rapidly increasing the injection rate it was possible to raise the packer setting pressure to about 17 MPa for a short period of time. About 1 m^3 of additional cement volume was pumped through this leak into the annulus.

After cementation, the well was shut-in for 2 days with the casing still being held in the elevators. After these 2 days, first the casing pressure was checked (casing integrity test). The casing was holding 7.5 MPa. At this point decision was made to fully slack-off the casing weight. The packers and the cement were fully supporting the string weight. The casing and the sand from the open hole section were cleaned using a 6.25" tooth bit. Once the plug and float shoe were drilled only 4 meters of cement was found below the casing shoe indicating that the cement and filler had fully risen into the annulus.

Summarizing, it has to be stated that out of the 104 days of operations only 54 days were consumed for actual drilling operations, i.e. 52% of the total rig time (9 days for opening hole from 6.25" to 8.5", 42.5 days drilling 8.5", 1 day coring, 1.5 days drilling 6.25" pilot hole).

ACKNOWLEDGMENTS

The authors would like to thank all the teams who contributed to the success of the 1999 drilling operations at Soultz.
The authors are especially grateful to T. Gandy of SII whose enthusiasm carried this drilling operation through various difficult phases. The authors would also like to acknowledge their gratitude to the dedication shown over the drilling period by P.L. Moore, J. Treadway, Ph. Harney (all SII), J.P. Strobel (Seamat) and L. Riff and R. Corrège (both Socomine).
Special thanks go to all organizations who were actively involved in the drilling operations, their preparation and the scientific follow-up (SII, ENEL, Seamat, BRGM, Stadtwerke Bad Urach, GTC, Ruhr-Universität Bochum, MeSy, Schlumberger Dowell, IFP, NLfB-GGA, Tohoku University, Guthertz et Fils, Leipziger Logistik).
The European HDR Program is part of the "Community Research Program" of the European Commission. Funding for the European HDR program was provided by DGXII of the European Commission (Brussels), ADEME, BRGM and CNRS (France), BMBF and KFA (Germany) and other national and private sources. Additional technical on site support was provided by the geothermal division of ENEL (Italy).

REFERENCES

BAUMGÄRTNER, J., GÉRARD, A., BARIA, R., JUNG, R., TRAN-VIET, T., GANDY, T., AQUILINA, L. and GARNISH, J., 1998: Circulating the HDR Reservoir at Soultz: Maintaining Production and Injection Flow in Complete Balance, Initial Results of 1997 Experiment, *Proceedings 23rd Workshop on Geothermal Reservoir Engineering, Stanford University*, Stanford, CA

JUNG, R., BAUMGÄRTNER, J., RUMMEL, F., TENZER, H. und TRAN-VIET, T., 1998: *Erfolgreicher Langzeit-Zirkulationstest im Europäischen HDR Versuchsfeld Soultz-sous-Forêts, Geothermische Energie*, Nr. 22/23, 6. Jahrg., Heft 2/3, S. 1 - 8, Dezember

GÉRARD, A., BAUMGÄRTNER, J. and BARIA R., 1997: An Attempt towards a Conceptual Model Derived from 1993 - 1996 Hydraulic Operations at Soultz, *Proceedings of NEDO International Geothermal Symposium*, **vol. 2**, 329 - 341

BAUMGÄRTNER, J., MOORE, P.L. and GÉRARD, A.: Drilling of Hot and Fractured Granite at Soultz-sous-Forêts (France), *Proceedings of the World Geothermal Congress*, Florence, Italy, International Geothermal Association, vol. 4, p. 2657 -2663, **1995**, ISBN 0-473-03123-X

BARIA, R., GARNISH, J., BAUMGÄRTNER, J., GERARD, A., JUNG, R., 1995: Recent development in the European HDR research programme at Soultz-sous-Forêts (France). In: *Proceedings of the World Geothermal Congress,* Florence, Italy, 4 pp. 2631-2637

BRESEE, J.C., 1992: *Geothermal Energy in Europe. The Soultz Hot Dry Rock Project*. Gordon and Breach Science Publication; edited by J.C. Bresee

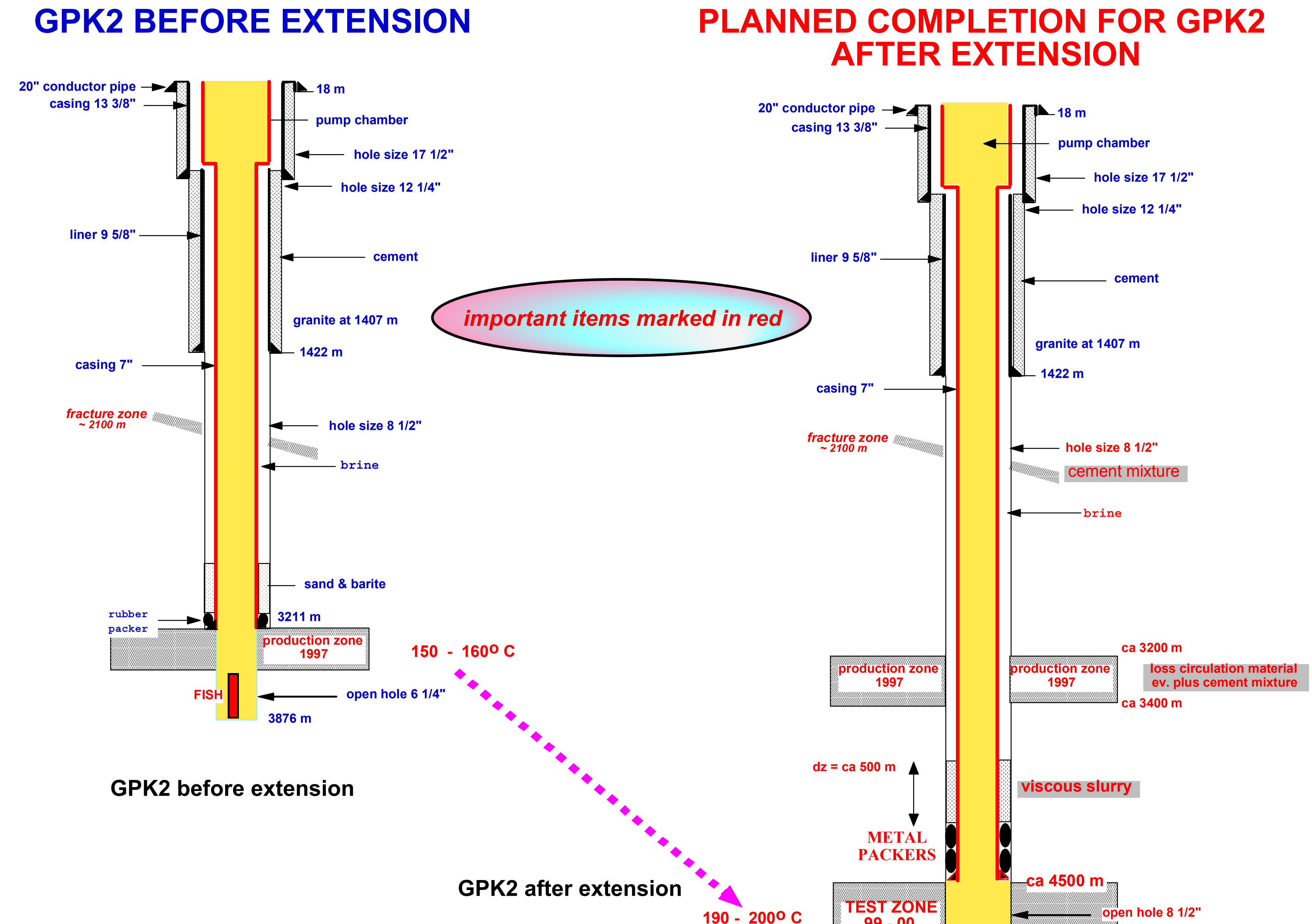

Fig. 1: GPK2 before & after extension

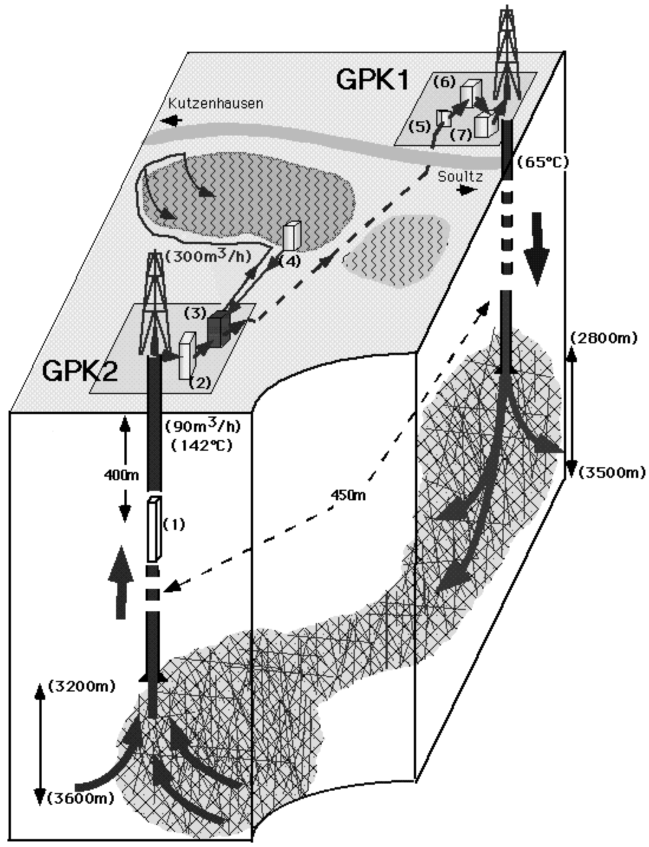

Fig. 2: Circulation experiment between the 2 deep wells GPK1 and GPK2 at the HDR test site in SOULTZ in 1997. (1: submersible pump, 2: pre-filter, 3: heat exchanger, 4: pumps for cooling circuit, 5: corrosion test chambers, 6: filter battery, 7: re-injection pump)

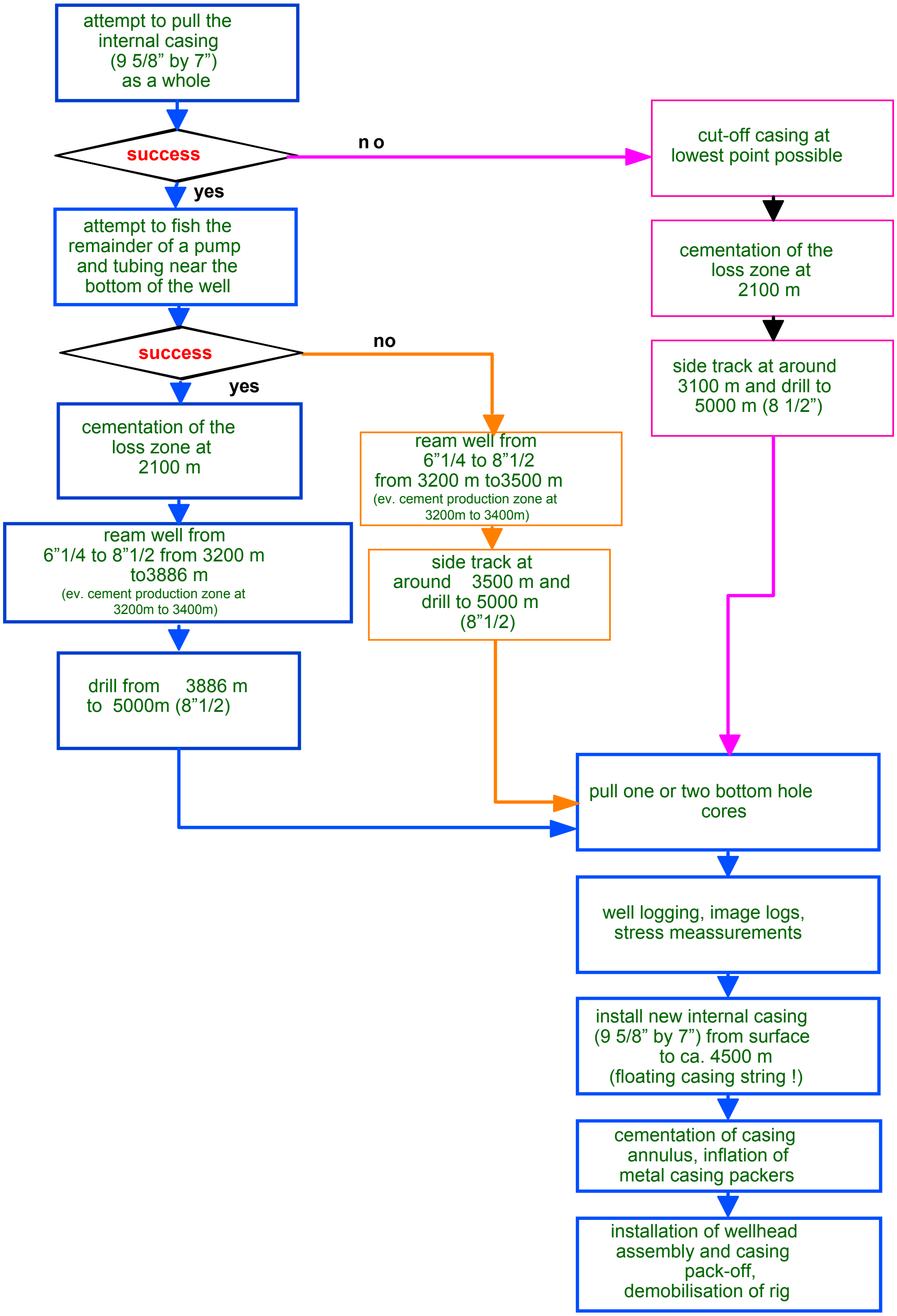

Fig. 3: Planned sequence of operations during the re-entry and deepening of GPK2

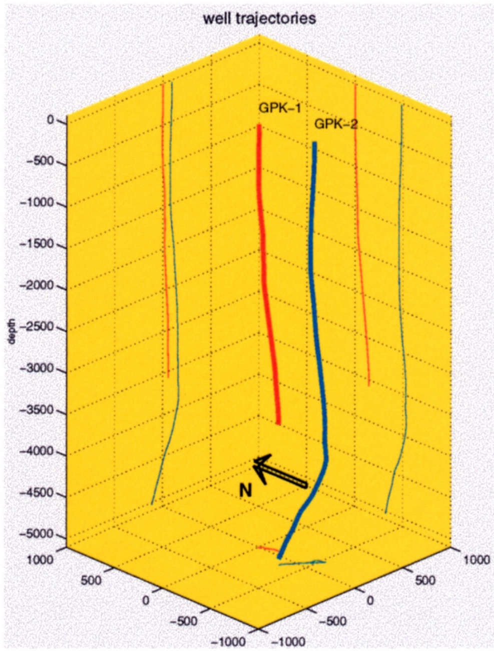

Fig. 4: 3D projection of the well trajectories of GPK1 & GPK2 (courtesy of R. Weidler, BGR, depth, distances in meter)

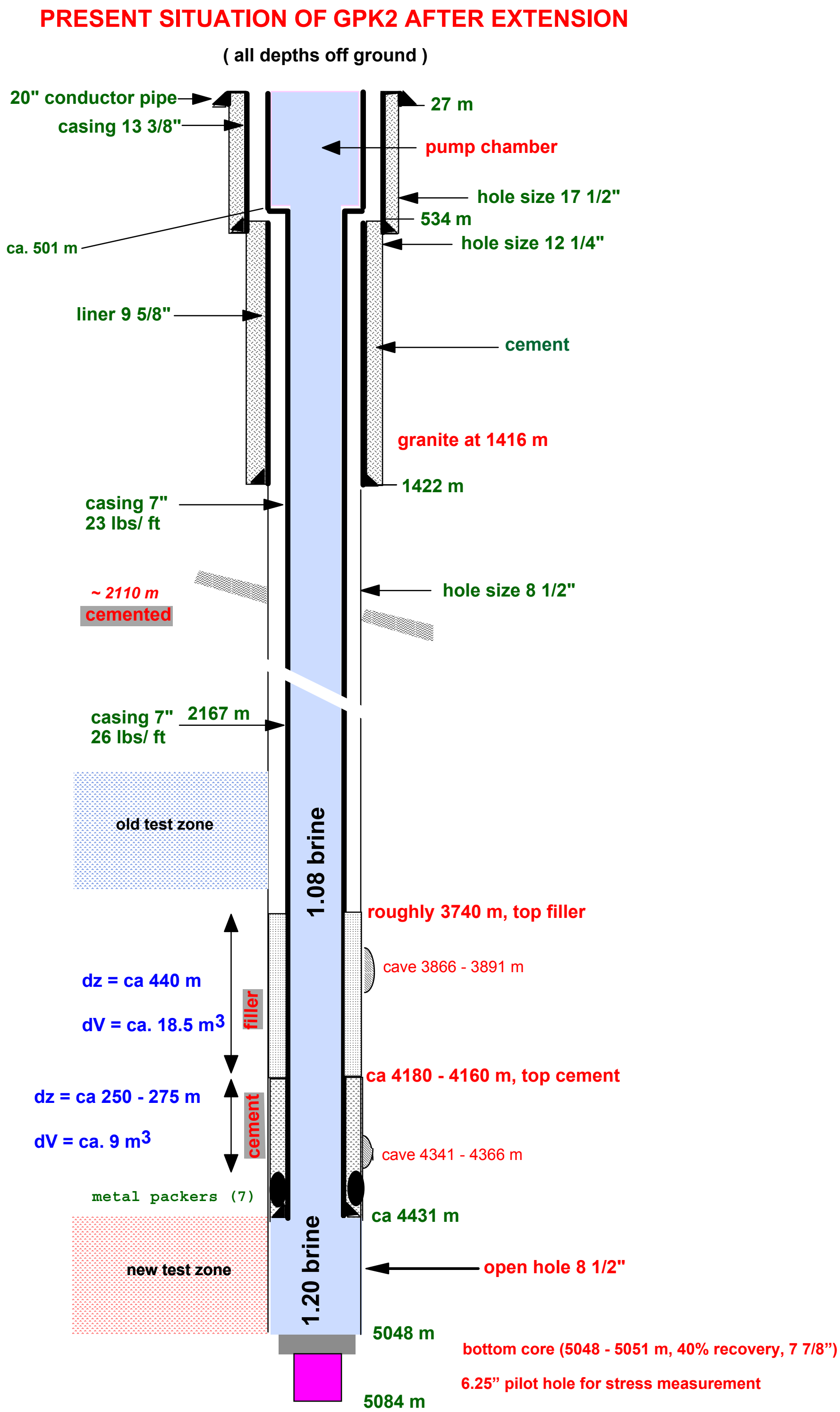

Fig. 5: Present situation of the well GPK2 after re-entry and deepening to 5084 m (app. 5024 m **Tr**ue **V**ertical **D**epth)