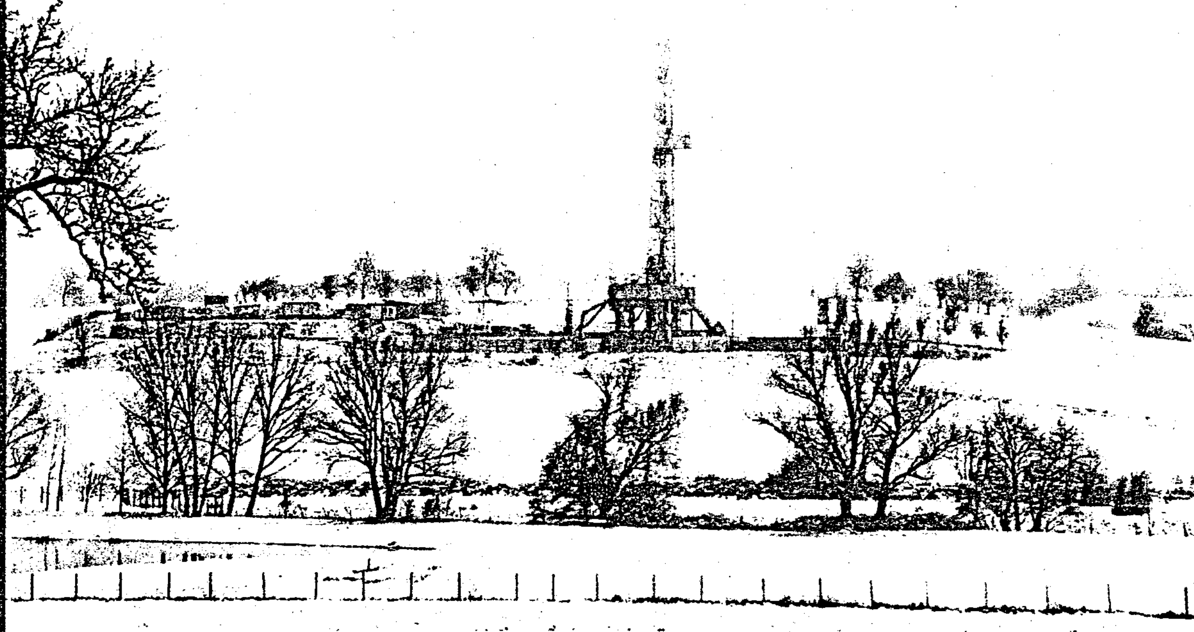
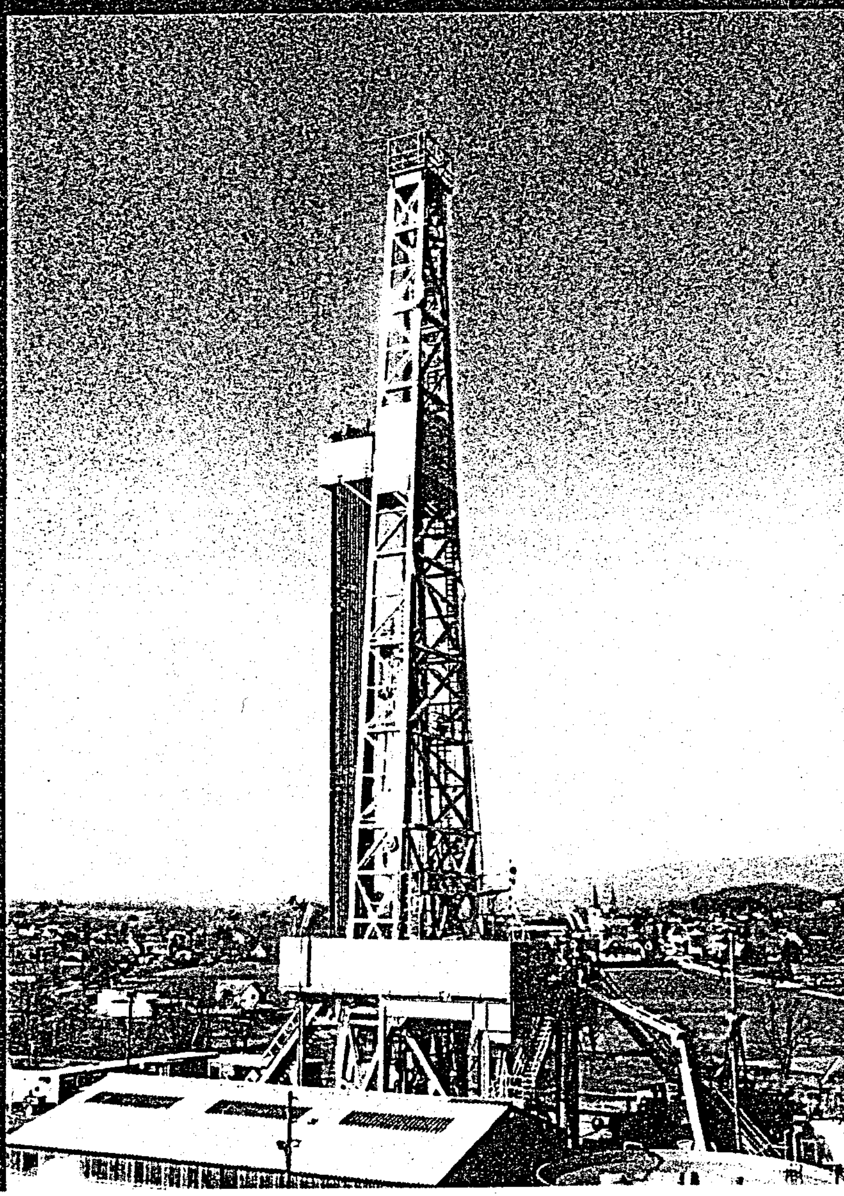
GPK-2

RE-ENTRY & DEEPENING - A TECHNICAL REPORT



Soultz 1999



J. BAUMGÄRTNER
A. GÉRARD
R. BARIA

SOCOMINE S.A.

DISCLAIMER

CONTENT

Jög

PAGE

GPK2
RE-ENTRY AND DEEPENING
A TECHNICAL NOTE

SUMMARY

Between mid February to end of May 1999 (in 104 days) the well GPK2 at the Soultz HDR site was successfully re-entered and deepened from 3876 m to a final depth of 5084 m and fully completed.

Re-entry included the 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 opening of a 6 1/4" well section in granite (3211 - 3876 m) to 8 1/2" hole size.

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 in the depth range 5048 - 5051 m. The core recovery was app. 40%. A pilot hole in 6 1/4" was drilled from 5051 - 5084 m for in situ stress measurements using the hydraulic fracturing technique.

The re-entry and deepening of the well GPK2 was accompanied by several technical developments. New casing packer elements based on inflatable metal shells were developed in a close cooperation between 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° 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. The development of several high temperature logging tools (200° C range, 6- arm caliper, PTF probe) was initiated with CSMA (Cornwall) during the preparation of the deepening of GPK2.

Initial scientific investigations included borehole logging (NGS, CLIPER, ARI, UBI, TEMPERATURE), geological investigations (cuttings, core) and seismic monitoring while drilling. During the first temperature log performed, 12 hours after circulation, a temperature of 194° C was recorded at 5048 m (bottom hole at that time) when the temperature tool failed. At this time the temperature was still climbing. Geological investigations and borehole logging indicate a strong degree of fracturation in the open hole section between 4431 - 5084 m. Several zones of hydrothermal alteration were identified.

I: INTRODUCTION

1.1 objectives

The future industrial deployment of the HDR technology developed at Soultz requires that the past experiments be replicated at higher temperatures and larger flow rates in order to further improve the efficiency and economy of the technology.

To evaluate the feasibility and the design of a pre-industrial prototype, it will be necessary initially to build and operate a Scientific Pilot Plant.

Consequently, following the success of the 1997 circulation experiment, it was proposed to re-enter and deepen the GPK2 well from 3,876 m to 5,000 m. At this depth temperatures of around 200°C were anticipated (Ref.: 1,2,3,4,5,6,7).

The primary objective for this operation was to obtain knowledge of the medium at this depth with regard to the further creation, development and maintenance of a deep Hot Dry Rock exchanger. In order to achieve this objective, a list of first degree of priority measurements was established for the scientific program:

- temperature
- natural fracture system
- stress field
- hydraulic investigations (natural conditions, capacity to stimulate)
- geochemistry

Operations had to take into consideration the integration of these priority measurements as well as the fact that drilling had to be performed within a tight budget.

1.2 background: the well GPK2

The well GPK2, the second deep borehole in Soultz, was completed in early 1995 to a depth of 3876 m (Fig. 1). The temperature exceeded 168° C at 3800 m (deepest observation point). GPK2 was positioned to the South of the well GPK1 at a distance of around 450 m, targeting the deeper stimulated zone in GPK1 (at around 3500 m). During the drilling of GPK2, a large permeable fault was encountered at around 2110 m depth. From there onwards this fault 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 (4,5,6).

Before any stimulation, after the completion of the well (with a sealed casing shoe at 3211 m), small scale hydraulic injection tests showed an apparent permeability of the 665 m long open section (3211 - 3876 m) which was in the order of 150 mDarcy (Ref.: 7).

GPK2 BEFORE EXTENSION

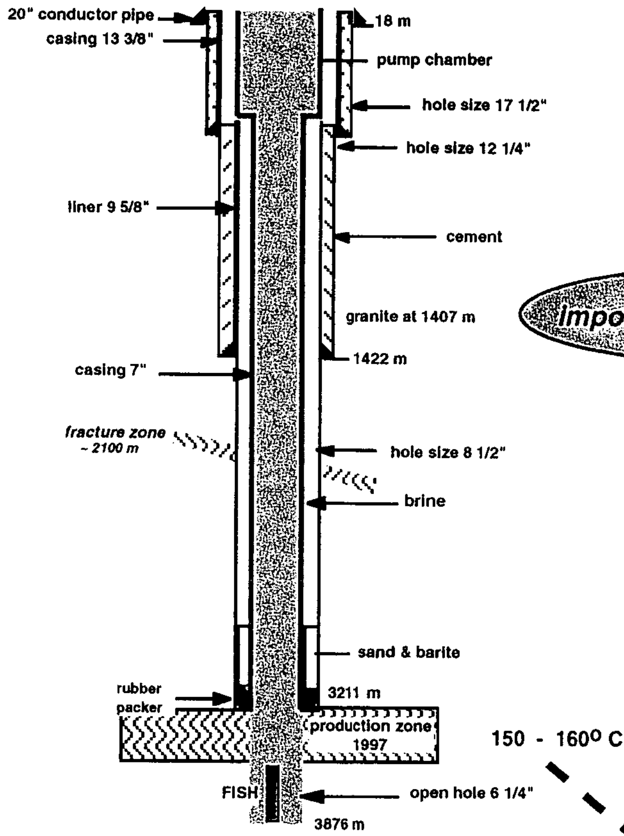


Fig.: 1 GPK2 before extension

important items marked in red

PLANNED COMPLETION FOR GPK2 AFTER EXTENSION

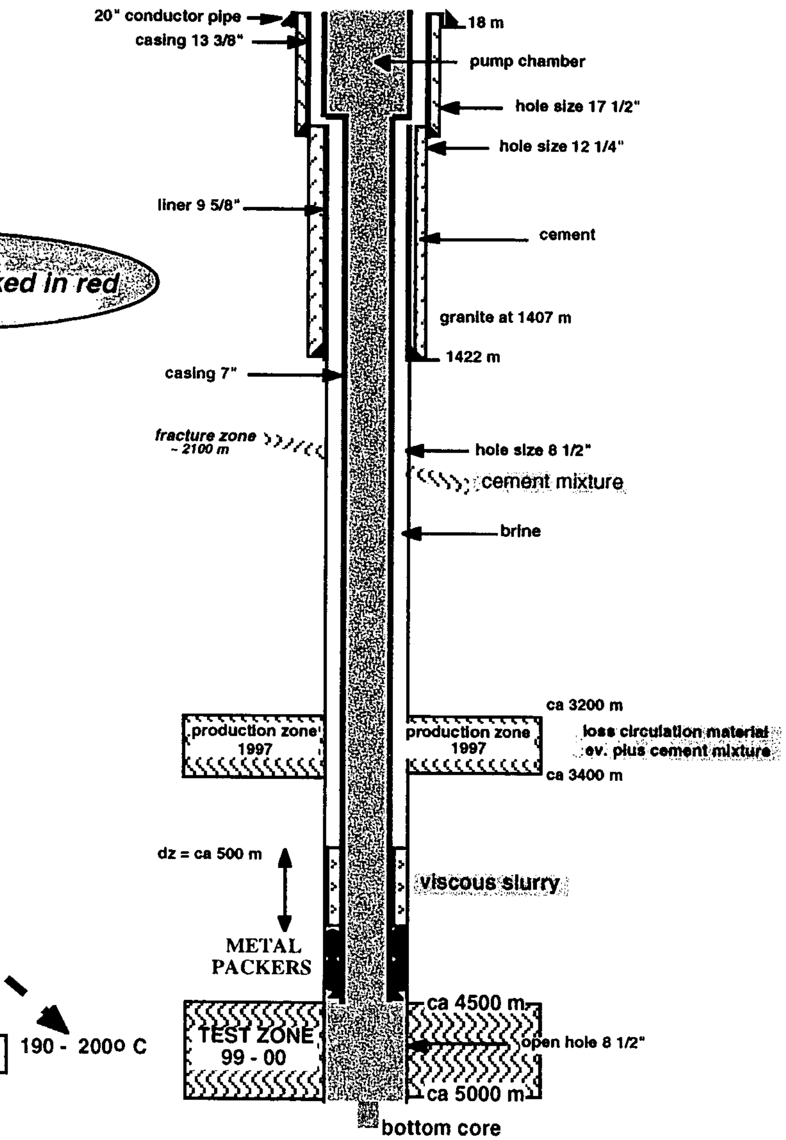


Fig.: 2 GPK2 after extension

The open hole section of GPK2 was stimulated twice in 1995 and 1996 (Ref.: 8) in order to create an underground heat exchanger. A total of 58,000 m³ of water were injected below the casing shoe at a maximum flow rate of about 78 l/s. During these stimulations 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 months "closed loop" circulation experiment, 244.000 tons of hot brine at rates of up to 90 tons per hour were produced from the stimulated section in GPK2, cooled on surface and re-injected into the underground heat exchanger at a distance of 450 m in the well GPK1 (see Fig. 3).

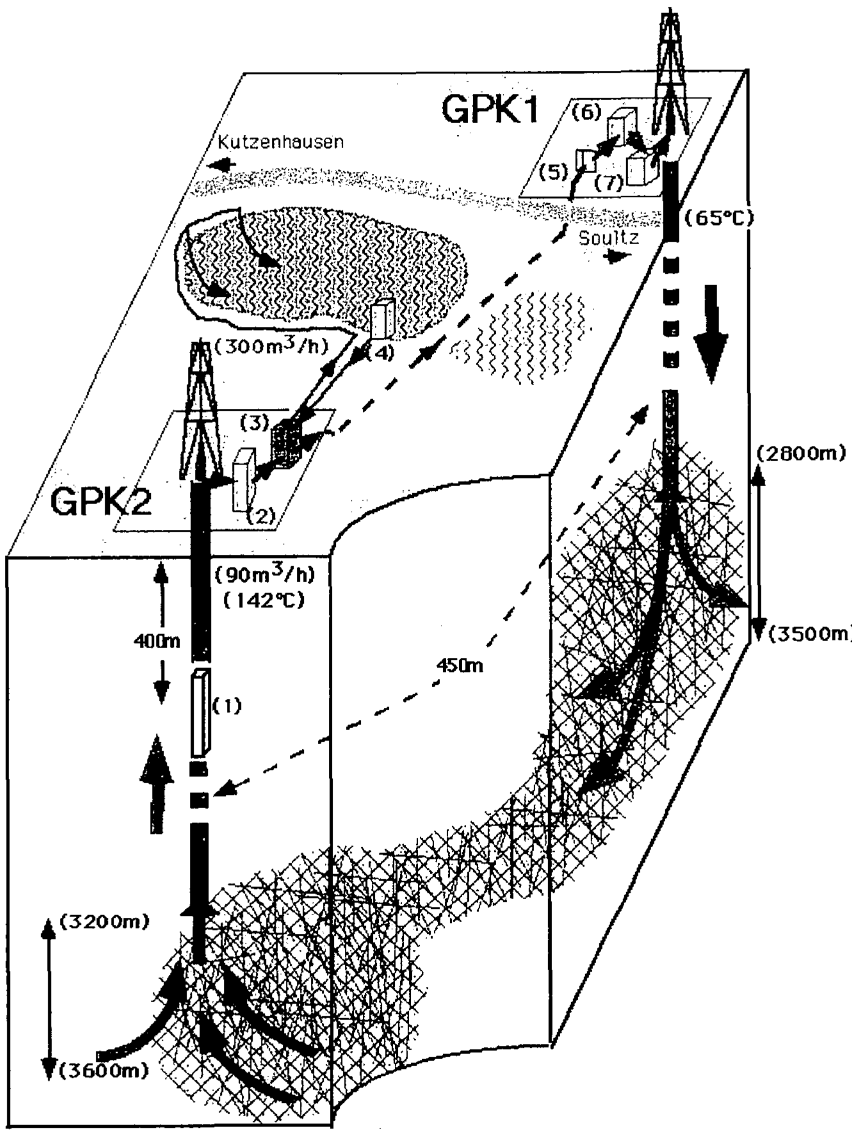


Fig. 3: Circulation experiment between the 2 deep wells GPK1 and GPK2 at the HDR test site in SOULTZ in 1997.
(1: submersible pump, 2: pre-filter, 3: heat exchanger, 4: pumps for cooling circuit, 5: corrosion test chambers, 6: filter battery, 7: re-injection pump)

II: THE DRILLING PLAN

Any plan for an extension of the well GPK2 from 3887 m to 5000 m had to deal with three major technical problems (see also Fig 1 and Fig 2):

1. Based on past experience in drilling the granites at Soultz, an extension of the well in 6 1/4" hole size through the existing casing appeared to be not safe to operate at a depth of more than 4000 m because the tools (bits, drill collars, 3 1/2" drill string) can be considered as too weak, thus increasing the risk for an accident in the well. Furthermore, for the completion of the well this approach would have left only the option to install a small liner in the range of 4.5" to 5" in order to isolate the bottom section of the extended well. These tubing sizes were considered as too small for future hydraulic experiments - and especially for any use of the well within the frame of a future pilot plant. 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.

2. In spring 1995 a submersible pump, 150 m of 2 3/8" tubing, some power cable and a tubing clamp had been lost in GPK2 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. Consequently, both the details of a fishing operation and in case this fishing operation fails, the possibility for a side track had to be carefully investigated.

3. Up to now the internal casing in GPK2 was designed as a floating string (thus fully compensating the rapid temperature changes in the well during the various hydraulic experiments, (Fig. 1)), isolated at the bottom by a rubber packer and some 150 m of a barite / sand filling and resting with its weight on the hole diameter change from 8.5" to 6.25" at 3211m. If the well was deepened in 8.5" hole size up to TD, no diameter change would be available in the bottom part of the well to support the weight of an extended floating casing string.

4. 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
   - and which also clearly indicated that rubber packers are not suitable for the temperatures encountered in Soultz.

   Consequently, in preparation of the re-entry and deepening of GPK2, maintaining the concept of a floating casing string, considerable effort was made to improve the cementing strategies / techniques and to develop a packer technology which - in a hostile environment - not only would allow to isolate the casing string but would also be able to fully support the weight of the extended internal casing string.

Based on these considerations the drilling plan shown in Fig. 4 was developed.

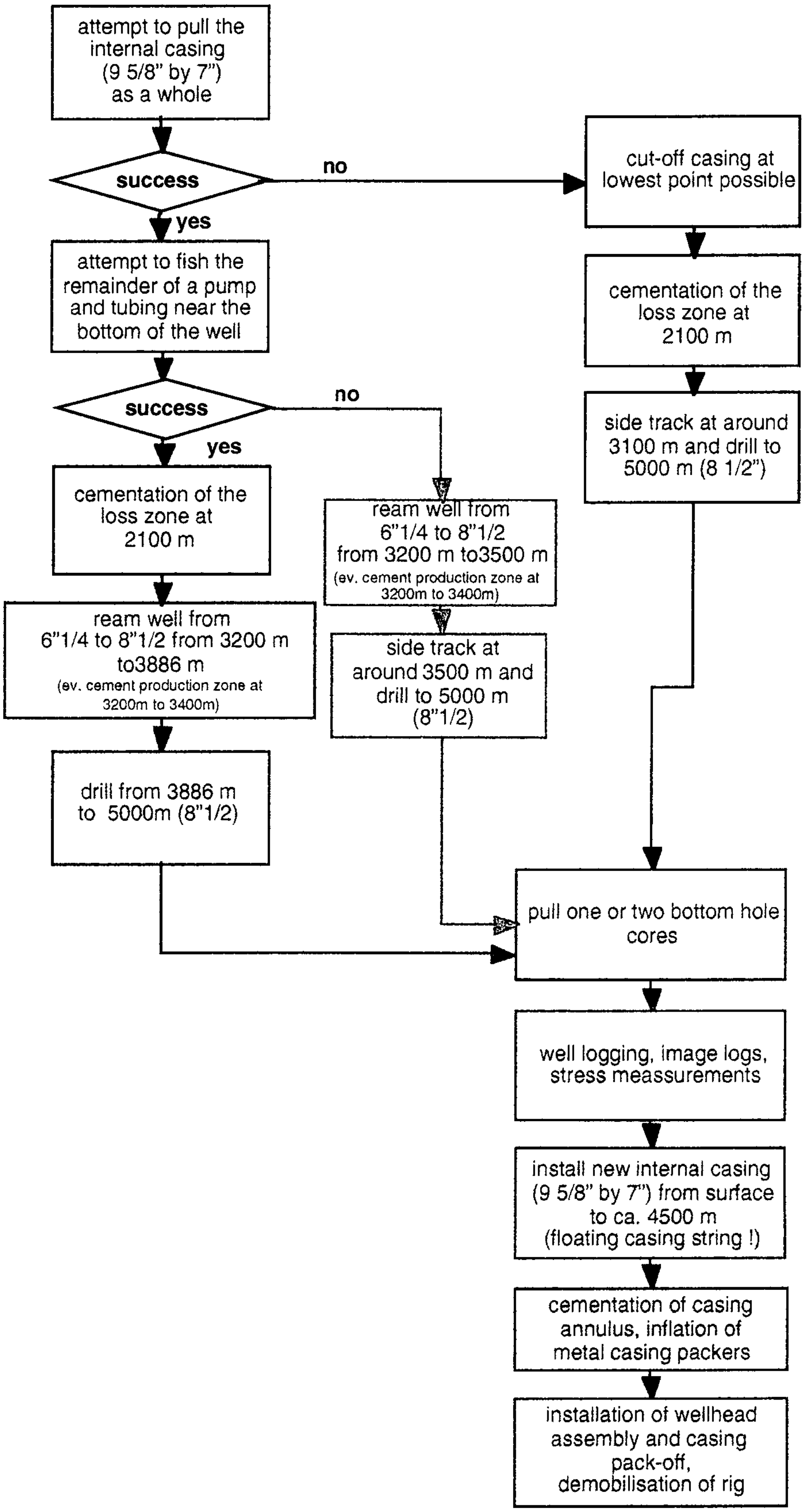


Fig. 4: Planned sequence of operations during the re-entry and deepening of GPK2

III: CEMENTING STRATEGIES

Cementing at higher temperatures 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, Germany
- SOCOMINE, Soultz, France
- Bundesanstalt für Geowissenschaften und Rohstoffe, Hannover, Germany
- Ruhr-University, Bochum, Germany
- Southern International Inc., Houston, USA
- Institut Français de Pétrole (IFP), Paris, France.

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 (see below, point 9). Numerous laboratory experiments with fly ash as base material were performed in 1998 by Dimitra Tezas of the Ruhr-University in Bochum. Further in depth investigations were performed by Trach Tran-Viet of BGR in Hannover. 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 general, past experience in Soultz working in hot brines with changing salt concentrations and containing a combination of Calcium, Potassium and Magnesium Ions has shown that for API type cements it is very difficult to transfer the retardation periods observed in laboratory to in situ conditions.

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 (Ref.: 9) 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, a property which may be important for future experiments in case acids can be used as a mean to improve the stimulation results in the Soultz granites (laboratory experiments are undergoing at ENEL). The compressive strengths achieved with these cements in laboratory are comparable to those observed for API type class G cements.

HMR cements are composed as follows:

PORTLAND CEMENT + BLAST FURNACE -> BLAST FURNACE CEMENT
(APPROX.: 30 + 70)

BLAST FURNACE CEMENT + FLY ASH FILLER -> **HMR CEMENT**
(Varying mixing ratios) (+ RETARDER)

Once a retarded HMR cement mixture starts to set, it thickens 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. In a rather extreme case like in Soultz, for a strongly retarded high temperature mixture (laboratory thickening time 10 hours at 190° C) compressive strengths in the order of 500 psi (ca. 30 bar) were achieved after 2 days, while after 6 days 2200 psi (ca. 150 bar) could be measured (compressive strength continued to still increase). The request from SOCOMINE was to obtain pumping times (thickening times) in the order of at least 5 - 6 hours for temperatures of 120 - 150° C (isolation of the loss zone at 2110 m), respectively 170 - 190° C and 8 - 9 hours (isolation & support of internal casing).

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 is an absolute requirement !**

Fig. 6 shows the mixing of a high temperature HMR cement slug at the GPK2 drill site.

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.**

Fig. 7 shows the mixing of HMR cement at the GPK2 drill site.

IV: CASING-PACKER TECHNOLOGY

Past experience at Soultz the last 10 years had shown that - at least for the hostile conditions found in Soultz (hot brines, gases) - for temperatures exceeding 120 to 140° 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 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° 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 is 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 (avoiding problems with complex mechanics at high temperatures).

The 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 lbs/ft C 95 casing and a sleeve made of a salt water resistant Cu alloy adapted to the conditions as found in Soultz was chosen. The packer sleeve is inflated through cement injection ("packer setting"). Numerous laboratory tests with such metal packer elements were run by P. Hegemann of MeSy. 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 (see below Fig. 5).

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.

Fig. 6 shows the assembly of the casing-packer unit (7 elements) at the Soultz test site using a bucking machine of Weatherford. Patents for the metal casing-packer technology are pending.

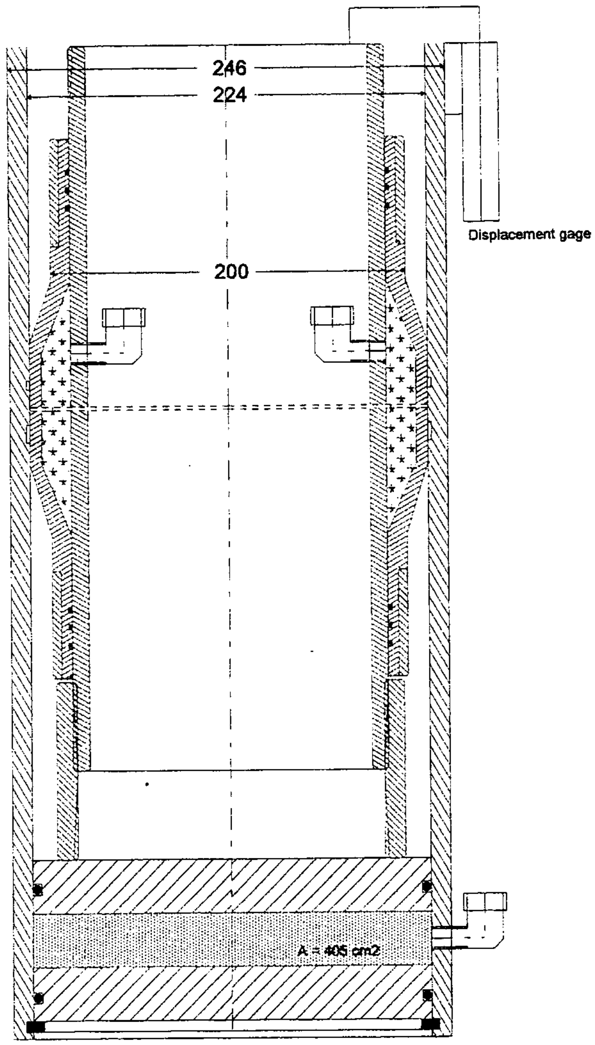
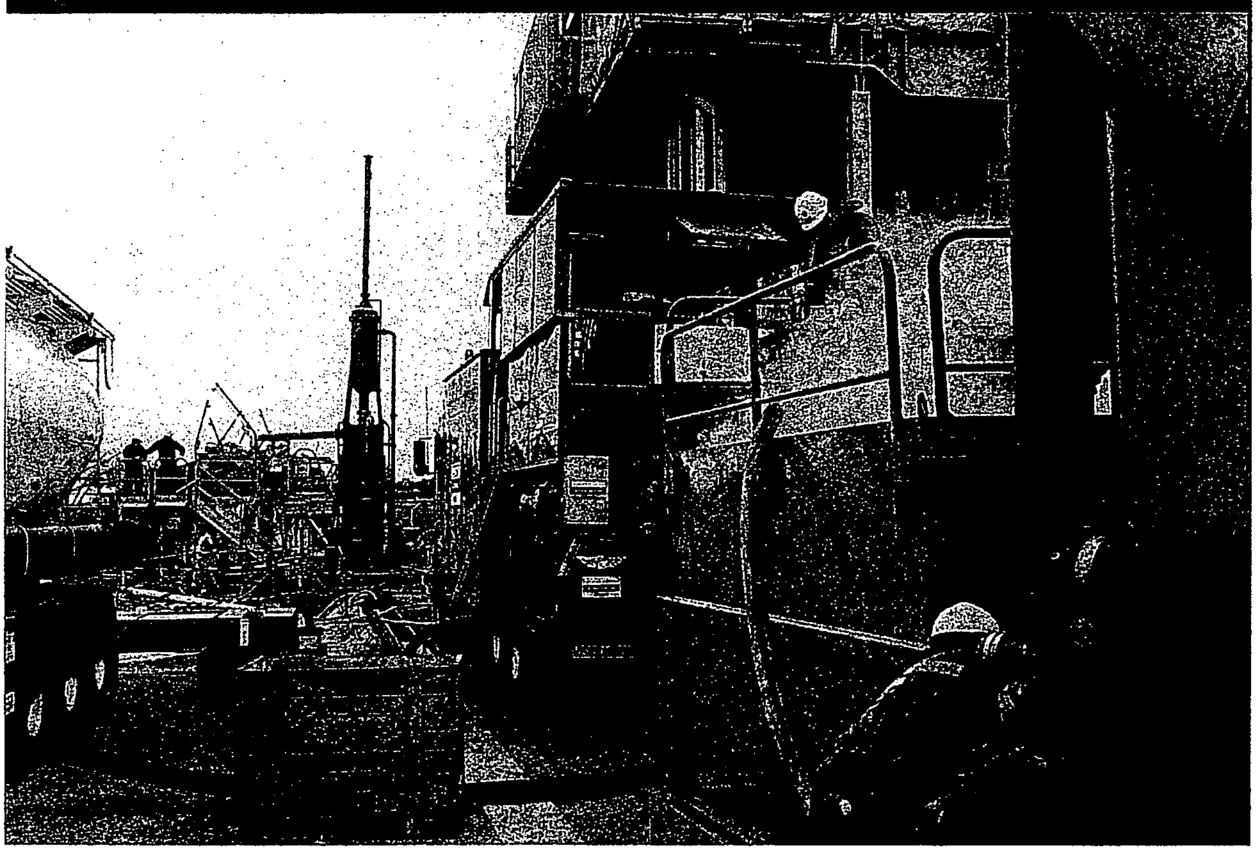


Fig. 5: Test set up (piston assembly) used to determine the anchoring capacity of a single, inflatable metal casing-packer element **(patent pending for packer technology)**.



V: THE RIG SELECTED

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.

Once the rig had been selected, the existing platform at GPK2 had to be modified to accommodate the rig and the associated equipment (Fig. 8).

The main parameters of the rig selected are listed below:

Rig type:	MASSARENTI 6000 E
	DIESEL-ELECTRIC, SCR, 1700 hp
construction year:	1985
Capabilities:	
Max. drilling depth (5" DP):	5.200 m
Hook load:	453.000 kg
Setback load:	272.000 kg
Rotary load:	453.000 kg
Comb. substructure load:	725.000 kg
Storage:	
Fuel:	75.000 l
Liquid mud:	145.000 l
Power generation:	
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
Mast:	
Type:	MASSARENTI / cantilever beam leg
API gross nominal capacity:	604.000 kg
Height:	43 m (142 ft)
Substructure:	
Floor height:	8.8 m (28.8 ft)
Pipe set back capacity:	272.000 kg
Draw-work:	
Type:	MASSARENTI 6000E
Rated capacity:	360.000 kg
E-motors:	2 x GE 752 R, 2 x 850 h.p.

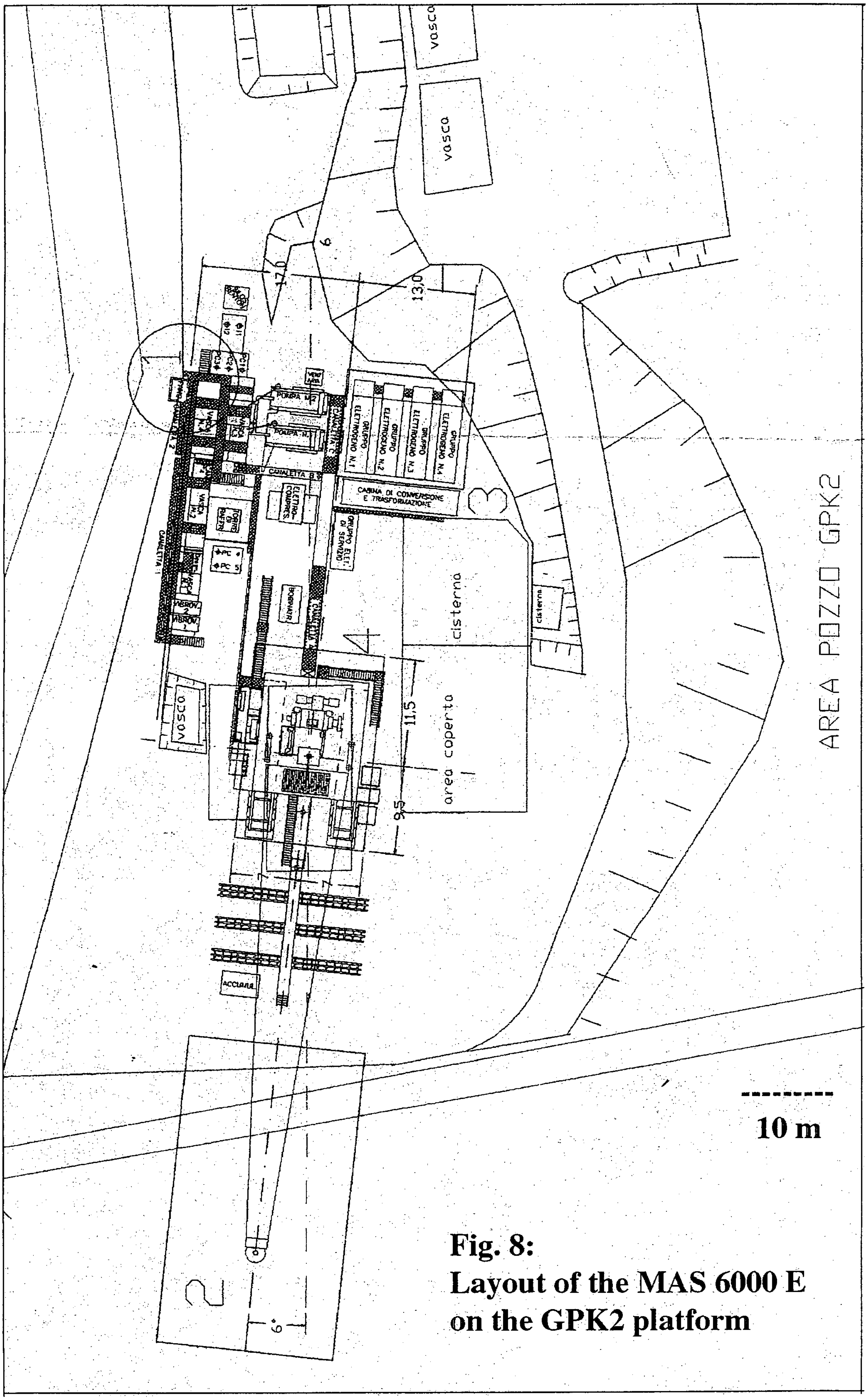


Fig. 8:
Layout of the MAS 6000 E on the GPK2 platform

Crown block:

Type:	MASARENTI
Rated Capacity:	604.000 kg
Crown block safety device:	VICTOR pneumatic

Travelling Block:

Type:	National 500 H 500
Sheaves:	6 x 50"
Rated capacity:	454.000 kg
Groove size:	1 3/8"

Hook:

Type:	B.J. dynaplex 5500
Rated capacity:	454.000 kg

Rotary Table:

Type:	Oilwell type A
Size:	37 1/2"
RPM (high / low gear):	210 / 120
Rated load capacity:	453.000 kg

Kelly Spinner:

Type:	VARCO 27 HDP

Pipe Handling:

Pipe spinner:	VARCO SSW 30 for 5" & 3 1/2" D.P.
Torque wrench:	VARCO TW-60 (4" - 8")

Mud Pumps:

Engines:	2 x G.E. 752, 2 x 800 h.p.
Pumps:	2 x EMSCO PD 55 - 5000 psi

Well Control Equipment:

Ram BOP:	SHAFFER SL/DBL, 5000 psi, 13 5/8" FL
Annular preventer:	SHAFFER, 5000 psi, 13 5/8"
Power unit:	KOOMEY, Type 80, 3000 psi work pressure, 12 bottles, 180 galls.
Choke manifold:	5000 psi / 3000 psi

Mud Treatment Equipment:

Tanks:	4 x (9 m x 2.5 m x 2.5 m)
Theoret. volume:	160.000 l
Usable volume:	145.000 l
Mud agitators	6, type SAMIC PF 60, 7.5 h.p. e.a.
Pill, Slug Tank:	1 x 15.000 l
Trip Tank:	1 x 4.000 l
Shale shakers:	2 x SWACO Superscreen (single)

Desilter:	SWACO HC48 Double, hydrocyclones 4"/16, screen size (mesh) 120 - 150 - 200, discharges in 2nd pit
Vacuum degasser:	BURGESS MAGNAVAC - 1000 GPM

Additional equipment:

- mud logging data unit incl. all necessary sensors
- mud gas analysis (CO2, CH4, H2S)
- casing spider BJ 350 ton for casing 9 5/8" & 7"
- Eckel power tongs for 7" casing
- Eckel power tongs for 9 5/8" casing
- Power unit for Eckel tongs
- Core barrel Christensen 6 1/4" x 3"
- Core bit SMITH X3TC7 7 7/8"
- Fishing equipment
- 5000 m - 5" drill Pipe S135 19.5 lbs/ft
- 4700 m - 3 1/2" drill pipe G105 15.5.lbs/ft
- 30 - drill collars 6 1/2"
- 18 - drill collars 4 3/4"

The layout of the MAS 6000 rig on the GPK2 platform is shown in Fig. 8.

VI: THE MANAGEMENT STRUCTURE

SOCOMINE was the designated project manager and was represented on site during drilling operations by Jörg Baumgärtner, André Gérard and Roy Baria. All problems associated with site operations, drilling logistics and scientific work were directed by this group.

Southern International of Houston was selected by SOCOMINE to plan and supervise the re-entry and drilling operations. Terry Gandy and Perry L. Moore served as on-site drilling managers / supervisors. They were supported by Phil Harney and Jimmy Treadway for the hour by hour supervision.

Seamet International served as operations advisor to both SOCOMINE and Southern International. Seamet was represented on site by J.P. Strobel.

A morning meeting was held daily by at least one member from each of the three groups. The purpose of this meeting was to ensure that all groups had a clear understanding of the schedule and the work to be performed for the following day. Costs were reviewed on a daily basis as were any operational and supply problems. This daily review of the operation from three different view points allowed constructive discussions to make the operation more efficient.

VII: WORK OUTLINE

note:

- **all depths off ground**
- **due to differences in pipe stretch, 3m of depth difference were observed between the measurements of pipe length performed with the MAS 3000 in 1995 using 3 1/2" D.P. and the measurements performed with 5" D.P. on the MAS 6000 this year.**

	TASK DESCRIPTION	*DAYS*	*DATE*
•	Mobilization of ENEL's MAS 6000 rig & associated equipment from Larderello (Italy) to Soultz (France, Alsace), 77 truck loads, out of which 24 loads were special transports because of size or weight of the load		5.1.-9.2.99
•	Rig-up of MAS 6000 rig (gradually increasing number of personnel)		12.1.-14.2.99
•	Move in rotary tools and rig up same, remove wellhead and install BOPS		14.2.99
1.	Align BOP & wellhead, drill rathole, latch into 9 5/8" casing with spear and free casing working casing from 100 -190 tons **(date of re-entry)**	1 day	**15.2.99**
2.	Remove 9 5/8" by 7" casing from wellbore	3 days	16.-18.2.99
3.	Pick up 6 1/4" bit & BHA and 3 1/2" by 5" mixed drill string, clean well to 3600 meters, ream to top of fish (3680 m, pump and 150 m of 2 3/8" tubing)	3 days	19.-21.2.99
4.	Pick-up 5 7/8" flat bottom mill, mill top of fish (tubing collar)	1 day	22.2.99
5.	Pick up overshot & bumper sub, engage overshot, trip out with 150 m of 2 3/8" tubing (fish), lay down tubing (remainder of pump is still in the well !)	1 days	23.2.99
6.	Pick-up 5 1/2" mill, trip in hole, mill from 3829 to 3834 m	2 days	24.-25.2.99

7. Lay down 3 1/2" drill pipe & 4 3/4" drill collars, pick up 8 1/2" BHA	1 day	26.2.99
8. Ream 6 1/4" hole to 8 1/2" from 3209 to 3794 meters	7 days	27.2-5.3.99
9. Cement job on lost circulation zone @ 2111 m (3 jobs), drill cement	8 days	6.-13.3.99
10. Ream & clean old 6 1/4" hole to 3833 m, debris in well	1 day	14.3.99
11. Pick-up 5 7/8" mill, mill 3834 m - 3835 m, wash & ream to 3869 m, mill 3870 m to 3873 m, trip out of hole, lay down 6 1/4" BHA	2 days	15.-16.3.99
12. Pick up 8 1/2" bit, BHA, ream 6 1/4" hole to 8 1/2" from 3794 m to 3884 m, high torque & drag	2 days	17.-18.3.99
13. Drill 8 1/2" hole from 3884 m to 4607 m	22.5 days	19.3-10.4.99
14. Electric logging (6-arm cal, GR, TEMP) 3200 m - 4347 m, unable to log below 4354 m (cave), decision to ream enlarged sections	1 day	10.-11.4.99
15. Trip in hole, ream well from 4331 - 43 67 m, 4509 - 4607 m Drill 8 1/2" to 4659 m, cool well	1.5 days	11.-12.4.99
16. Electric logging (6-arm cal, GR, TEMP) 4246 - 4616 m, UBI 3479 - 3866 m, **lost bottom sub of UBI at 3900 m**, pick-up 8 1/2" bit and heavy weight DP	1 day	13.4.99
17. Trip in hole, unsuccessful attempt to drill 8 1/2" at 4659 m	1 day	14.4.99
18. Pick-up 8.25" flat bottom mill, run in hole, mill junk at 4659 m, work stuck pipe, repeat run with 8 3/8" flat bottom mill, stuck mill at 2900 m, trip out, run 8 1/4" flat mill bottom, mill junk at 4659 m	4 days	15.-18.4.99
19. Drill 8 1/2" to 5048 m, partly strong wear on reamers & drill pipe observed	18.5 days	19.4.-7.5.99
20. Run wireline gyro deviation survey inside the drill string to 5014 m	0.5 days	7.5.99

21. Trip out of hole, SOCOMINE temperature log 1403 - 5048 m, temp. tool fails on bottom at 194° C, temp. still rising, pick-up core barrel and 7 7/8" roller cone core bit	1 day	8.5.99
22. Core from 5048 - 5051 m, retrieve core, 40 % core recovery, trip out of hole, lay down 8 1/2" BHA, pick up 4 3/4" drill collars & 6 1/4" bit	1 day	9.5.99
23. Drill 6 1/4" pilot hole from 5051 to **5084 m (TD)**	1.5 days	10.-**11.5.99**
Electrical logging, UBI 3200 - 3500 m, HNGS 3200 - 4500 m, UBI near 4500m & 4235 - 4348 m (tool not working properly), change to ARI, run ARI & HNGS 3500 - 4500 m, **4500 m max. logging depth because of temperature restriction on logging tools**	1.5 days	11.-12.5.99
24. Trip in hole with open ended drill pipe, sand up well from 5084 m to 4466 m	1 day	13.5.99
25. Lay down 5" drill pipe	1 day	14.5.99
26. Run 7 metal-packer-assembly and 7" 26#, 7" 23#, 9 5/8" 47# mixed casing string to 4431 m	3 days	15.-17.5.99
27. Rip up cementing unit, pump 34m^3 of fly ash, 8 m^3 of cement, plug, 2m^3 of cement and 97 m^3 of dsplmt., set packers to 121 bar, leak developed, increase pressure to 170 bar, pump an additional 1m^3 of cement through packer leak	1 day	18.5.99
28. Wait on cement, slack-off casing, packers support full casing weight, nipple down BOPs, cut casing	2 days	19.-20.5.99
29. Install wellhead B-section and casing pack-off, nipple-up riser & BOPs.	1 day	21.5.99
30. Pick-up 3 1/2" drill pipe, trip in hole with 6 1/4" bit, drill cement & plug, remove sand to 5078 m (top of sand), unable to remove the last 6 m of sand, spot 1.20 density pill in open hole section, circulate & increase brine density in casing to 1.08, ph 10	5 days	22.-26.5.99

31. Lay-down 3 1/2" drill pipe, nipple-down BOPS, install SOCOMINE wellhead | 2 days | 27.-28.5.99

32. Clean rig equipment and release drilling rig | 1 day | **29.5.99**

(end of day rate operations)

Total: 104 days

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).

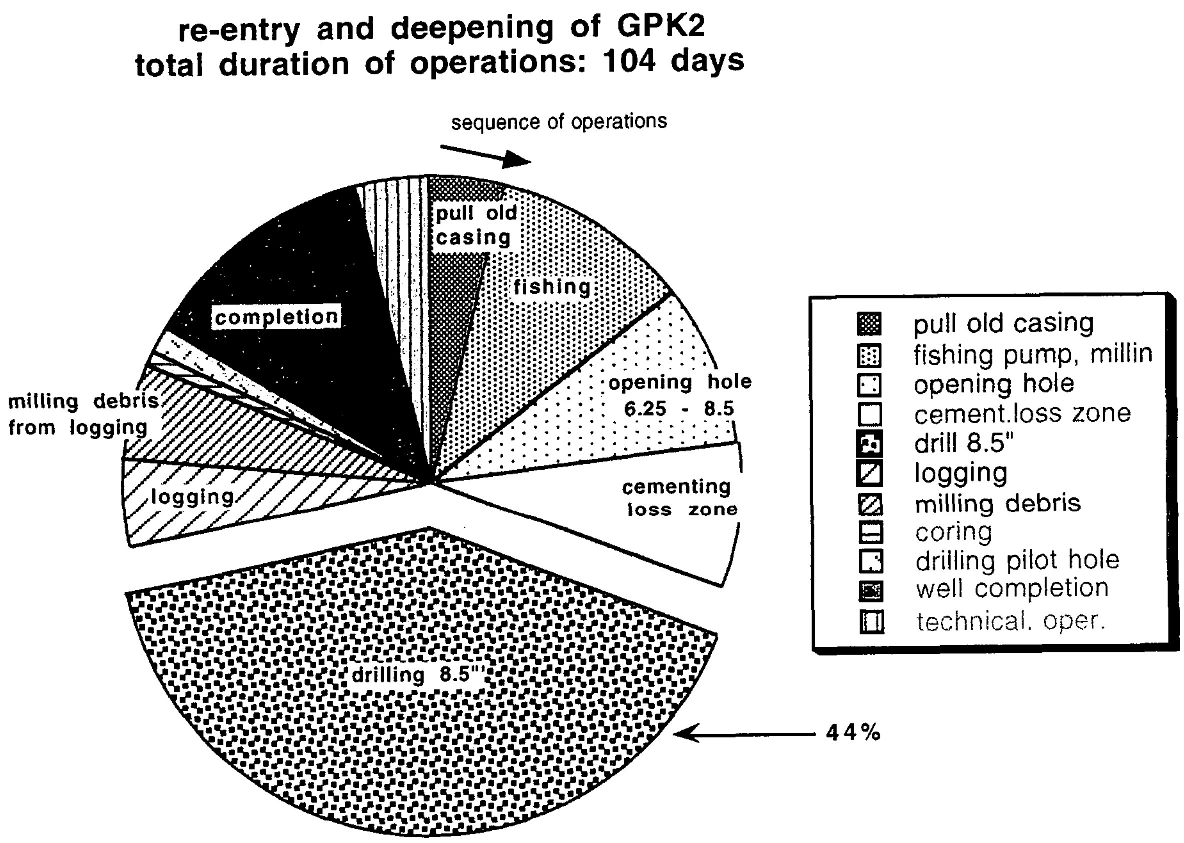


Fig. 9: Distribution of time spent for the various tasks during the re-entry and deepening of GPK2

VIII: CRUCIAL OPERATIONS

During the re-entry and deepening of the well GPK2 several curtail technical operations had to be performed. These are listed and described in more detail below (compare also Fig. 4, drilling plan).

1. mobilization of a 1500 hp drilling rig from Italy under the supervision of SOCOMINE
2. pulling of the existing 9 5/8" by 7" internal casing string
3. recovery of a submersible pump and some 150 m of 2 3/8" tubing from the bottom of the well
4. isolation of a major loss circulation zone at a depth of around 2110 m
5. sealing-off of the 1997 production zone at 3200 - 3600 m depth
6. planning & preparation of a side-track in granite in case either the pulling of the entire casing string or the fishing operation were not successful
7. drilling of hot, fractured granite at greater depth
8. coring near the bottom
9. installation and isolation of a floating casing string at a depth of around 4400 - 4500 m.

1: mobilization of a 1700 hp drilling rig from Italy

After a careful market analysis, Leipziger Logistik of Karlsruhe (Germany) was selected as contractor for the rig move. The transport of the rig from Larderello (Italy) to Soultz (France, Alsace) was coordinated by SOCOMINE in co-operation with ENEL. The transports occurred during the period 5.1. - 9.2.99. A total of 77 truck loads was necessary to move the rig and its associated equipment. Out of these, 24 loads were special transports because of the weight or size of their loads. Some difficulties were encountered because of the extreme weather conditions (snow) in the Alpine and Apennine mountains during January 99.

2: pulling of the existing 9 5/8" by 7" internal casing string

This operation was considered as very critical with a high degree of uncertainty. If we would have not been successful in pulling the casing, the casing had to be cut off at the lowest point possible and the wellbore side-tracked !

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). Otherwise the casing was free to float, compensating the temperature changes in the well. 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.

3. 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.

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 was tagged at 3680 m (last wireline depth 3623 m, probably due to some power cable from the pump plugging the well at this depth). 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. When the mill was retrieved, it showed clear marks of the tubing. 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).

4. 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, to stabilize the hydraulic activity of the well, and - in view of the fact that GPK2 is also an exploration well - to obtain again cuttings for geological analyses, it was decided that this zone has to be sealed. Past experience with this zone at 2110 m had shown that treatments with pills of slag slurry and LCM did not promise a large probability of success. Consequently, it was decided to cement this zone before to start to opening of the hole from 6 1/4“ to 8 1/2“.

Before the first cementation, a 3 m^3 high viscosity pill 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° C. The retarder used was D13. All three cement jobs were pumped through open ended drill pipe.

While the first job was pumped with the drill pipe above the fracture zone, for the second and third job the drill pipe was placed just below this fracture zone (cement rises in the well). During each cement job several samples of the HMR cement were taken and kept in an oven at a temperature comparable to the temperature anticipated at depth. Subsequent operations only continued once these samples had hardened.

During the first job (March 6th) a 12 m^3 high viscous loss circulation pill and 9 m^3 of HMR cement were pumped. This operation clearly reduced the permeability of the fracture zone at 2110 m. The impact of the cementation could also be observed in the water level of the observation well EPS1 which is linked to this fracture zone. However, part of the cement was lost in the open hole and created a cement plug below the loss zone.

The second and third cement plug pumped (March 7th, 8.5 m^3 cement and 10 m^3 high viscosity pill & March 9th, 5 m^3) then fully penetrated the fractures of the loss zone and sealed them off. During the 3rd cement job, the water level in observation well EPS1 showed nor more reaction, GPK2 was de-coupled from the loss zone. From there on, during the whole sequence of operations following, no further mud losses were observed at this depth.

After the third cement job, the slips in the rotary table were stuck (corrosion !!) when the drill pipe was picked up in order to pull it out of cement. Each time the drill pipe was moved the whole rotary table would be picked up. The rotary table had to be worked for about 15 minutes before the slips came loose. Once the slips came loose, the first 1.5 joints had to be pulled at more than 30 tons over string weight. In this situation, the characteristic property of the HMR cement of thickening gradually rather than to flash prevented a major accident !

5. sealing-off of the 1997 production zone at 3200 - 3600

Contrary to what was anticipated, no special measures had to be undertaken to seal-off the production zone between 3200 - 3600 m. A first plugging of this well section could be observed already during the drilling of the cement left in the well after the sealing of the loss zone at 2110 m (caused by the fly ash in the cement ??). This plugging process continued during the reaming and drilling operations. The fact, that during the drilling of the granite unusually fine particles were produced (in the order of 1 micron), may have contributed to the plugging. As long as the mud density was not raised above 1.07 g/cm^3 only minor losses (1 - 1.5 m^3/h) and - after warming up of the well - no production was observed from this zone.

6. planning & preparation of a side-track in granite

There were two situations in the drilling plan for the extension of GPK2 (Fig. 4) which could have required that the wellbore be side-tracked. The first situation was if the casing had not been successfully removed. The second situation was if the fish (pump and tubing) had not been successfully removed from the wellbore. In both cases the wellbore would have had to be side-tracked to allow forward progress.

In order to be prepared for these scenarios technical preparations for a side-track started earlier during the initial planning phase of the deepening of GPK2. The following organizations participated to these investigations:

- MeSy GmbH, Bochum Germany
- SOCOMINE, Soultz, France
- Southern International Inc., Houston, USA

Decision was made to use (in any case) a permanent whipstock for the side-track. After a careful market analysis, a whipstock assembly for 8 1/2" hole size including a finned anchor was bought from DOSCO / Black Max (Holland / Canada). This whipstock was of a special design, as it had been foreseen to not only secure the whipstock through cementing the finned anchor but to run also two of the above described metal casing-packers as additional anchors. The worry was, that a side track in a hard formation such as the Soultz granite would be a long and rough operation increasing the risk for the whipstock to rotate / move. The new developed packers thus appeared as the most promising solution for a permanent anchor.

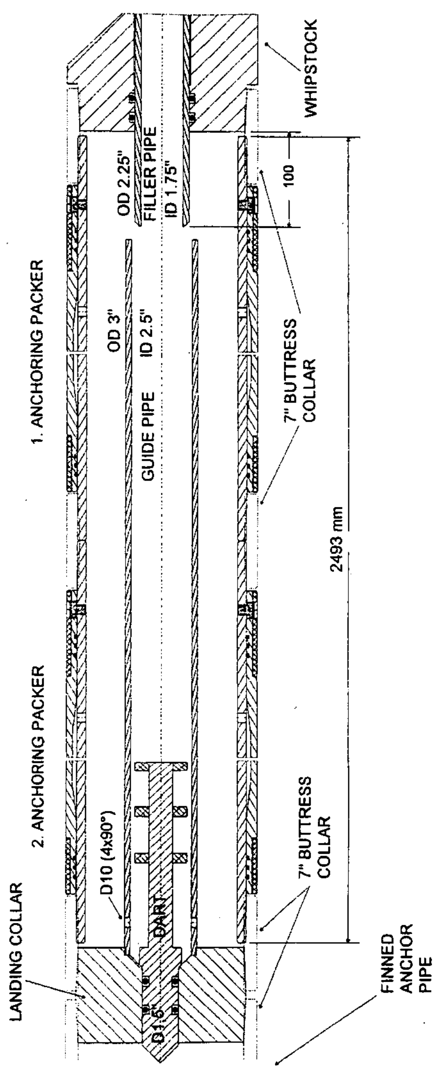


Fig. 10: Whipstock - packer assembly for a possible side-track in GPK2.

The whipstock assembly was adapted in such a way so that it could be run on a shear stinger which allowed to first cement the finned anchor, land a wiper plug in a float shoe and set the packers hydraulically with cement before to withdraw the stinger (see Fig. 10 below). The wiper plug was designed to wipe as well the 5" drill pipe (4.276" ID) as a 1 3/4" ID filler tube inside the whipstock assembly. The plug and the float shoe were designed for temperatures of 160° C (using rubber products which at least had to be resistant against these temperatures for short periods of time) and pressures exceeding 50 MPa (packer inflation).

Several options for a side-track bit were investigated. The bit finally considered was a TB 26 (8 1/2") of SECURITY DBS, a side track bit with natural diamonds and an aggressive lateral gage.

As side-tracking in granite was considered a high risk operation, every effort was made from the beginning on to avoid it. Nevertheless, all equipment required for a side-track was on site when the drilling operations started in order to avoid any (expensive) stand-by of the rig.

7. drilling hot & fractured granite at greater depth

7.1. opening 6.25" to 8.5" (3211 - 3876 m)

At the beginning of the drilling operations 665 m of hole inside granite had to be opened from 6.25" to 8.5". Hole opening was performed with a standard 3 cone roller bit (SECURITY H100 FL). 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.

7.2 drilling in 8.5"

Drilling in 8.5" was mainly performed with **drill bits** of the type H100 FL of SECURITY (IADC code 837Y). 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. The hours per bit were determined through careful monitoring of the characteristic mud logging parameters like torque and pressure (in relation to weight on bit and geological observations made in parallel). Experience proved that decisions made to pull a bit on this basis gave very reliable results, never a roller cone was lost during the sequence of operations ! The exact bit records are shown below in Table. 1.

Considerable 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, drilling of GPK2 had been stopped at 3876 m because a rapid increase of torque and drag was observed at this depth and the drilling MAS 3000 rig and the 3.5" drill string used at that time were considered as to weak to overcome this problem. **The experience from the deepening of GPK2 proved that this decision had been the correct decision !**

SOCOMINE BIT RECORD							**Well:** GPK2					**Country:** France				
Run	**Size**	**Make**	**Type**	**Serial**	**TFA**	**M IN**	**M OUT**	**M Drid**	**Hours**	**m/H**	**WOB**	**RPM**	**Flow LPM**	**SPP BAR**	**MW S.G.**	**Form**	**Misc**
1	6.25	Sec	M89TF	703551	Open	3628	3689	61	8.75	7	2	50	800	40	1	fish	Clean out
2	8.5	Sec	H100FL	699681	12.12.2012	3217	3439	222	30	7.4	7	60	800	45	1	granite	Open 6.25"
3	8.5	Sec	H100FL	699645	12.12.2012	3439	3630	191	29.5	6.5	7	60	800	50	1	granite	Open 6.25"
4	8.5	Sec	H100FL	699595	13/13/13	3630	3803	173	30.25	5.7	7	60	990	50	1	granite	Open 6.25"
5	8.5	Sec	M89TF	729526	13/13/13	2650	3140	490	32	15	5	60	990	60	1.06	cement	Drill cement
6	6.25	Sec	HZM89FP	710232	Open	3803	3843	40	5.5	7.3	4	60	990	60	1.06	fish	Clean out
7	8.5	Sec	H100FL	699546	13/13/13	3803	3893	90	15.25	5.9	12	65	1500	125	1.07	granite	Open 6.25" & drill
8	8.5	Sec	M89TF	729464	14/14/14	3893	4020	127	28.5	4.5	12	65	1650	140	1.06	granite	
9	8.5	Sec	M89TF	729452	14/14/14	4020	4085	65	28.75	2.3	8	65	1650	140	1.06	granite	
10	8.5	Sec	M89TF	729493	14/14/14	4085	4165	80	28.25	2.8	10	65	1650	145	1.07	granite	
11	8.5	Sec	H100FL	699636	14/14/14	4165	4258	93	34.75	2.7	10	65	1650	145	1.07	granite	
12	8.5	Sec	H100FL	699597	14/14/14	4258	4351	93	30.5	3	10	60	1650	145	1.06	granite	
13	8.5	Sec	H100FL	699544	14/14/14	4351	4443	92	33.25	2.8	8	60	1650	145	1.06	granite	
14	8.5	Sec	H100FL	699572	14/14/14	4443	4541	98	33.75	2.9	8	60	1650	145	1.06	granite	
15	8.5	Sec	H100FL	706764	14/14/14	4541	4616	75	29.5	2.5	8	60	1650	145	1.07	granite	
16	8.5	Sec	H100FL	711421	14/14/14	4616	4668	52	19.75	2.6	8	60	1650	145	1.07	granite	
17	8.5	Sec	H100FL	706748	14/14/14	4668	4680	12	7.5	1.6	5	60	1650	145	1.07	granite	Junk in hole
18	8.5	Sec	H100FL	703462	14/14/14	4680	4731	51	27.5	1.9	10	60	1650	145	1.07	granite	
19	8.5	Sec	H100FL	703427	14/14/14	4731	4781	50	34.5	1.4	10	60	1650	145	1.07	granite	
20	8.5	Sec	H100FL	706752	14/14/14	4781	4841	60	34.75	1.7	12	60	1650	145	1.06	granite	
21	8.5	Sec	H100FL	706749	14/14/14	4841	4869	28	14	2	10	60	1650	145	1.06	granite	Junk in hole
22	8.5	Sec	H100FL	706751	14/14/14	4869	4939	70	30	2.3	12	60	1650	145	1.06	granite	
23	8.5	Sec	H100FL	706750	14/14/14	4939	5018	79	29	2.7	12	60	1650	145	1.05	granite	
24	8.5	Sec	H100FL	696833	14/14/14	5018	5057	39	24	1.6	10	60	1650	145	1.05	granite	
25	7.875	Smith	X3TC7	ENEL	Core	5057	5060	3	1.75	1.7	5	55	1000	45	1.05	granite	Core
26	6.25	Sec	M89TF	648708	Open	5060	5092	32	18	1.8	7	55	1200	80	1.05	granite	Total depth

Tab. 1: Drill bit record of the re-entry and deepening of GPK2.

NOTE: this is a drilling engineering document, all depths are RKB depths (off rig floor, ground depth = rig floor RKB depth - 9.2 m). !

The following major drilling breaks were observed (see also Fig. 11):

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	only minor hole enlargement	drills at 4 m/h with 0 weight on bit !

Tab. 2: Drilling breaks encountered during the extension of GPK2

The average hole size in the new section of GPK2 (below 3900 m) is around 10" - 11" and therefore considerably larger than in the upper part of GPK2 (average hole size around 9" for 8.5" bit) !

The **increasing drag and torque** lead to modifications in the bottom hole assembly and the mud system. Between 3884 m (3893 m RKB depth) and 4608 m (4616 m RKB) 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. Near 4600 m depth a typical BHA was composed of:

8.5" bit
8.5" 3pt 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
4 - 6.5" drill collars (ca. 36.4 m)
1 - cross over
12 heavy weight drill pipes (112.1 m)
----
total length of BHA: 177.2 m

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

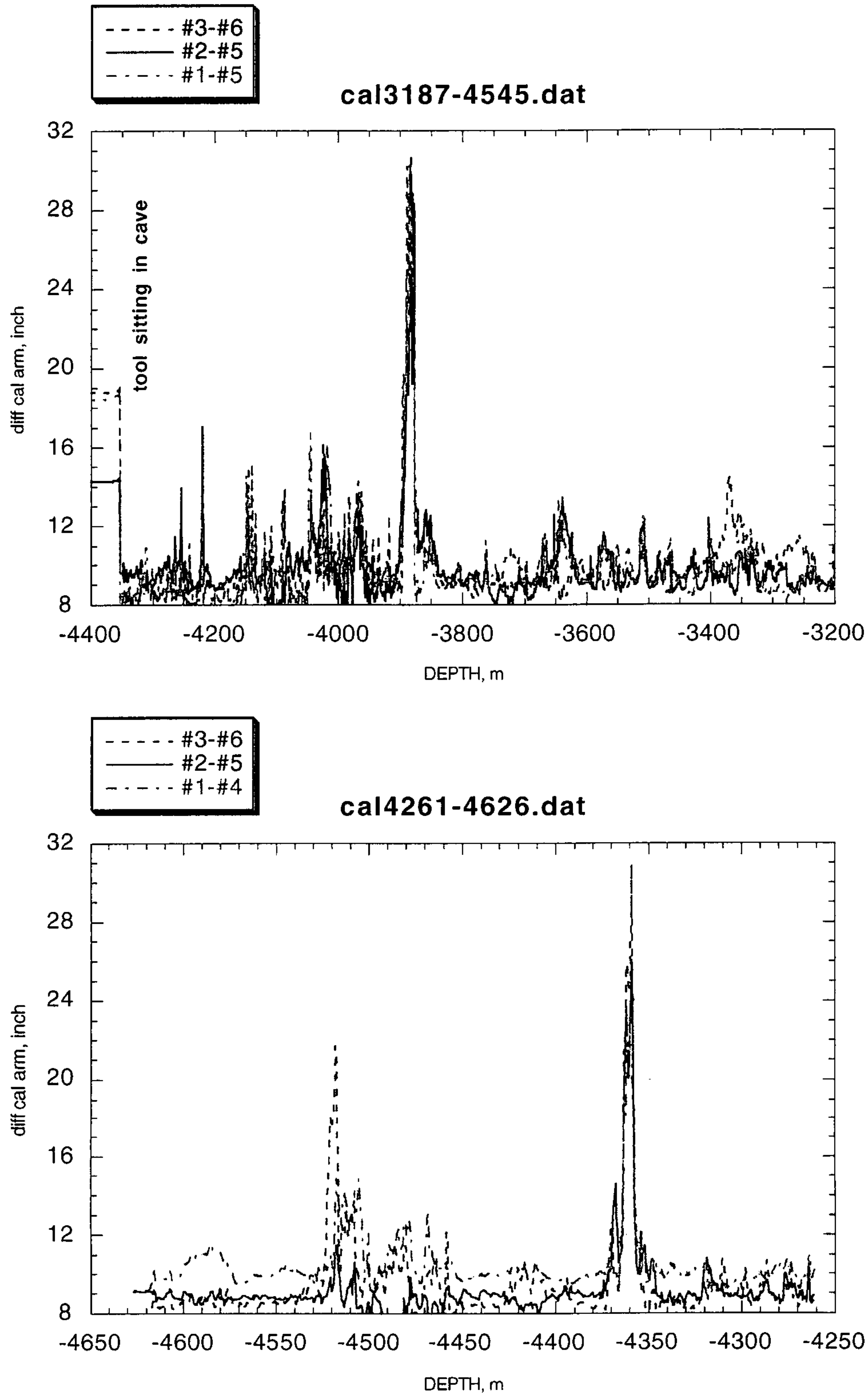


Fig. 11: 6-arm caliper data from the extension of GPK2. Due to temperature restrictions for the logging tools (app. 170° C), logs were only performed above a depth of 4650 m.

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 MEXEL (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.

First attempts to reduce the drag & torque in the well using BARACARB 5 (from BAROID, 5 μ carbide balls) as a friction reducer were not successful. Beside the fact that the drag did not drop, BARACARB caused the mud density to increase above the limit at which severe fluid losses in the well were initiated. Much more success was obtained with an environmentally friendly **lubricant** called ECOL LUBE from AVA, Italy. ECOL LUBE is based on vegetable oils and synthetic polymers. This product was used successfully in the depth range from about 4700 m to TD. When this product was introduced at around 4700 m depth, both, torque and drag dropped instantaneously by about 70 % of the increase which had occurred since the beginning of the deepening of the well !
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. However, it appears that for future operations - at the encountered temperatures and depths in Soultz - options for an improved mud system will have to be investigated.

The safety of the handling of the mud on surface was 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° 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".

All 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. 12 & 13)**.

Down to 3876 m, i.e within the existing well, GPK2 can be described as "near vertical". The maximum inclination seen before was approaching 6°. Near the bottom of the well before extension, at 3850 m, less than 1° 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 (the observation had already been made while drilling through TOTCO and single shot surveys as well as through recording of drilling parameters) 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 (see Fig. 11). 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 was probably already initiated in 1995 using a 3.5" drill string and a slimmer, more flexible bottom hole assembly ! Between 3870 - 3910 m hole inclination jumps 1° to 8° and continues to build from there on until it approaches 26° at 4450 m. At this depth the inclination was dropped again slowly to about 16 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 trying to drop the well again gently.

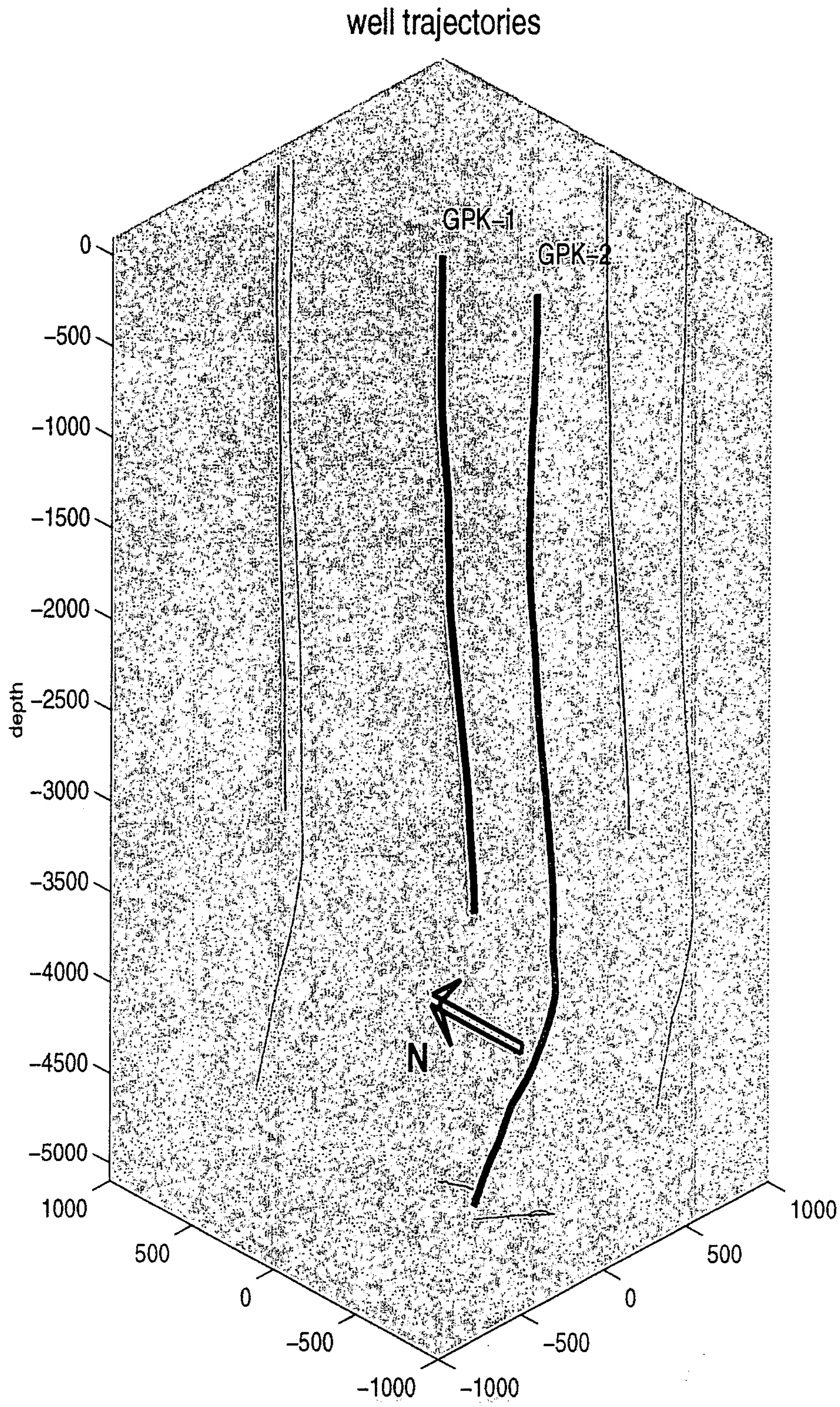


Fig. 12: 3D projection of the well trajectories of GPK1 & GPK2 (courtesy of R. Weidler, BGR)

Depths & distances in meter !

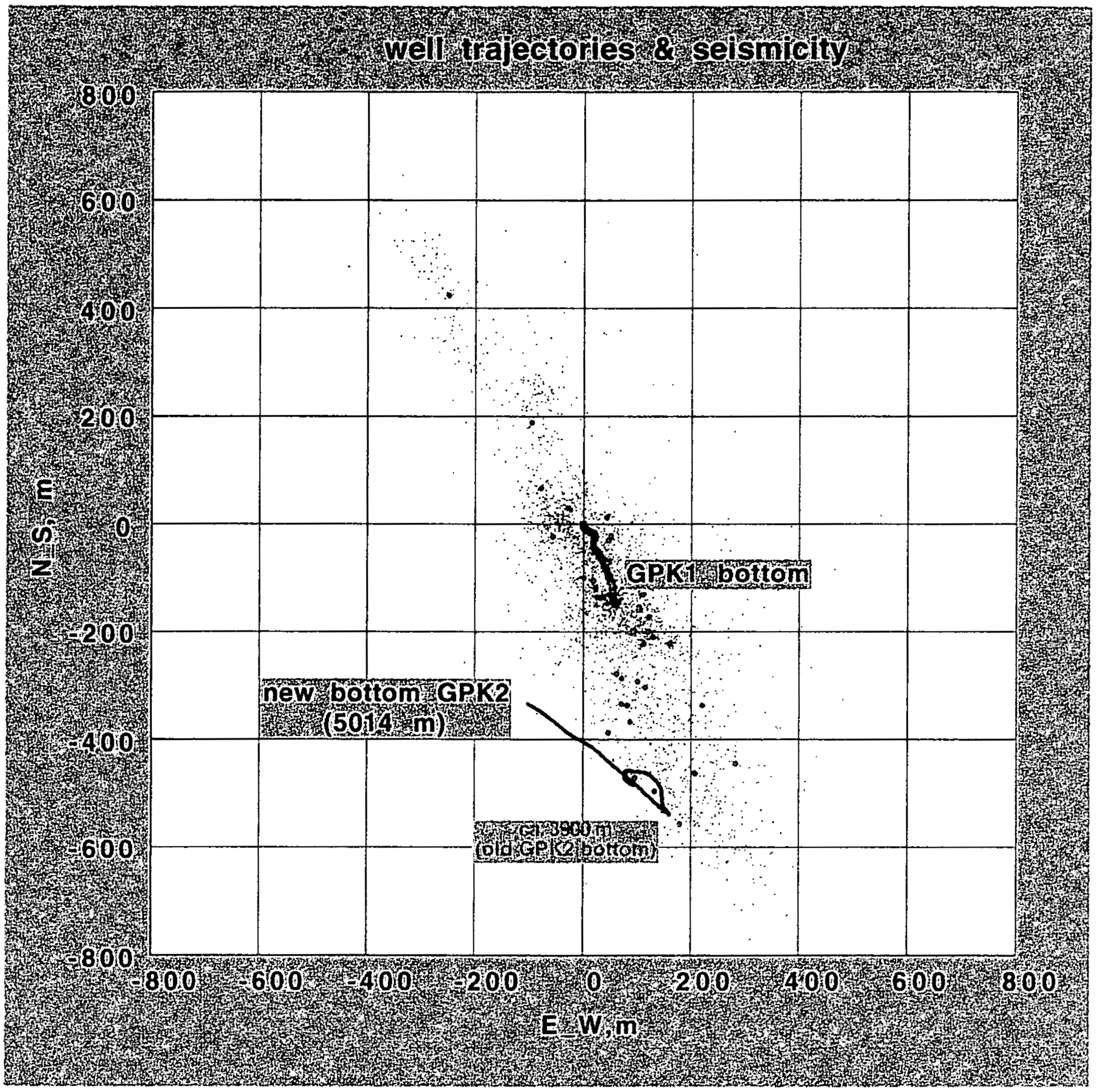


Fig. 13: Projection of the well trajectories of GPK2 & GPK1 and locations of seismic events recorded in the depth range 3200 - 4000 m during the creation of the heat exchanger. **Note the straight path of GPK2 below 3900 m !**

The dog leg can be clearly identified in Fig. 12 (3D well trajectories of GPK2 & GPK1). 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 (Fig. 13). **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.**

8. coring near the 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 good example for the varying types of granite encountered at this depth !

9. installation and isolation of a floating casing string at a depth of 4431 m

The plan for the completion for GPK2 is shown below in Fig. 14. Please note, as this is again a drilling engineering document, all depths are measured off RKB (rig floor).

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. 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 casing string with:

0 - 501 m	**9 5/8" 47lbs/ft N80 BTC (pump chamber)**
1 cross-over	**9 5/8" 47lbs/ft - 7" 23lbs/ft (L80)**
501 m - 2167 m	**7" 23 lbs/ft L80 BTC**
2167 m - 4419 m	**7" 26 lbs/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 (see discussion above) which are inflated with cement.

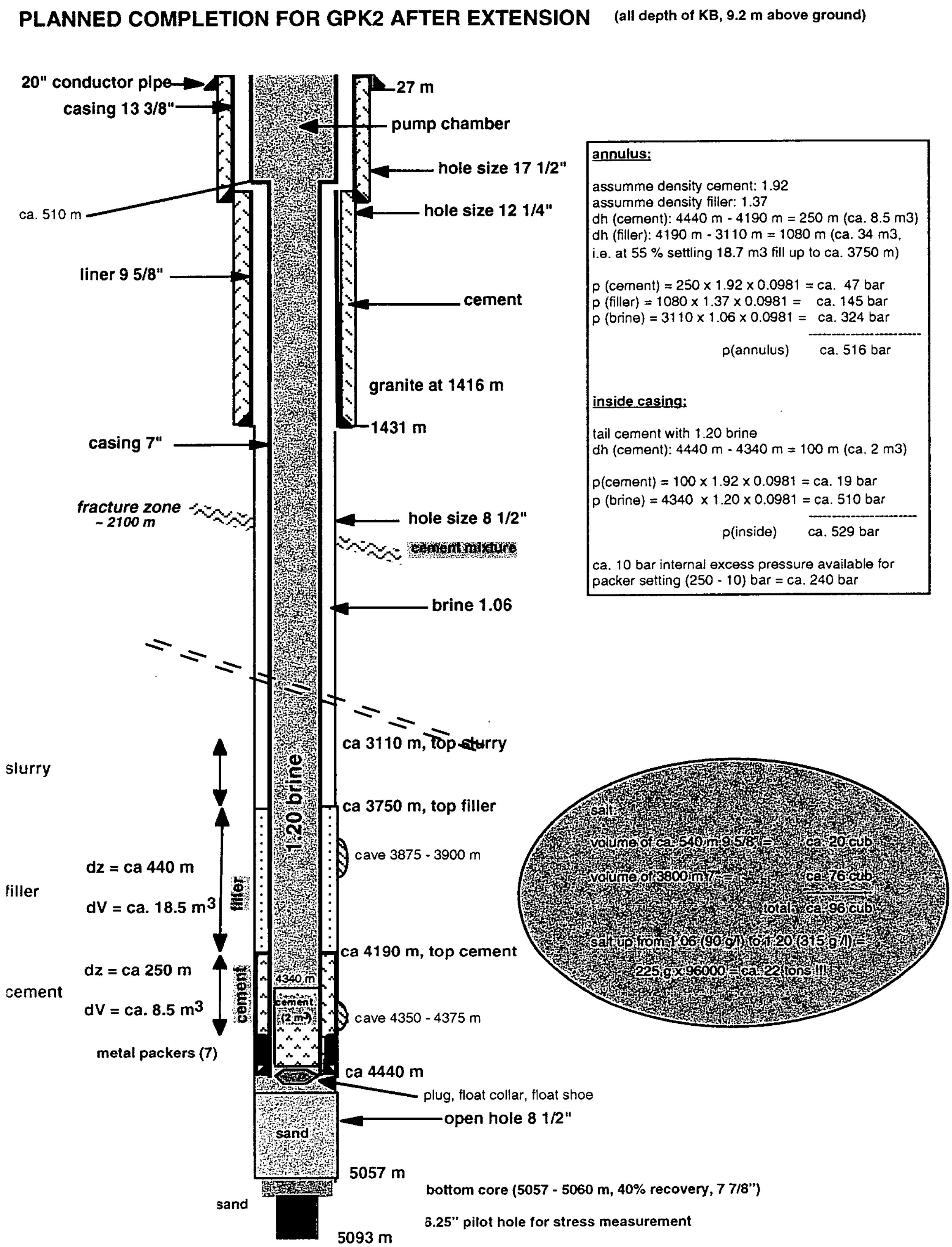


Fig.: 14 Plan for completion of the well GPK2 after extension **(all depths off RKB !)**

The filler and cement volumes were calculated trying to make an attempt to fill up the hole enlargements at 4350 m (cement) and 3900 m (fly ash) in order to support the casing string inside the well.

Critical points for the design of the completion were:

- the weight of the string hanging on the top joints of the 7" 23 lbs/ft casing during installation of the casing
- the burst pressure of the 7" 23 lbs/ft casing during the inflation of the packer elements. During the inflation of the packers also the weight of the column in the annulus (brine + filler + cement) had to be overcome
- 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 offers 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 match used for the completion was based on observations made during the various drilling breaks.

The installation of the casing could be performed without any difficulties. Circulation around the casing was broken every time a new layer of joints had to be measured on the racks. A total of 8 centralizers were run, 4 on the 7" casing (above and below the packer assembly) and another 4 on the 9 5/8" casing. The casing passed the hole enlargements without problems.

The cementing and filler injection operations are shown below in Fig. 15 a,b. 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° 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 Schlumberger Dowell 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 (open valve) 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. Another 1 m^3 remained for safety reasons inside the casing string ensuring a proper cement filling of the packer elements.

During injection high returns were observed at the beginning. Returns remained good until app. 17 m^3 of flay ash had been pumped into the annulus. At this point returns dropped to app. 500 l/min. Returns fully stopped once 5 m^3 of displacement had been pumped. If this effect indicates real losses into the formation or was just caused by the rapidly dropping cement column cannot be separated at this point - especially because it was impossible to accurately record the returns with the set up of ENEL.

After cementation, the well was shut-in for 2 days with the casing still being held in the elevators. As the cement hardened and the well warmed up the weight held by the elevators dropped slowly from 179 tons to 159 tons (casing was growing, part of the weight was supported by the packers and the cement). 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 then was cleaned inside with 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.**

Circulating the sand out proved to a rather long and difficult operation. At the end some 6 m of sand filling had to be left in the well. Several attempts to circulate them out failed because they probably were pumped into enlarged sections of the hole from where they dropped back as soon as the mud circulation was stopped.

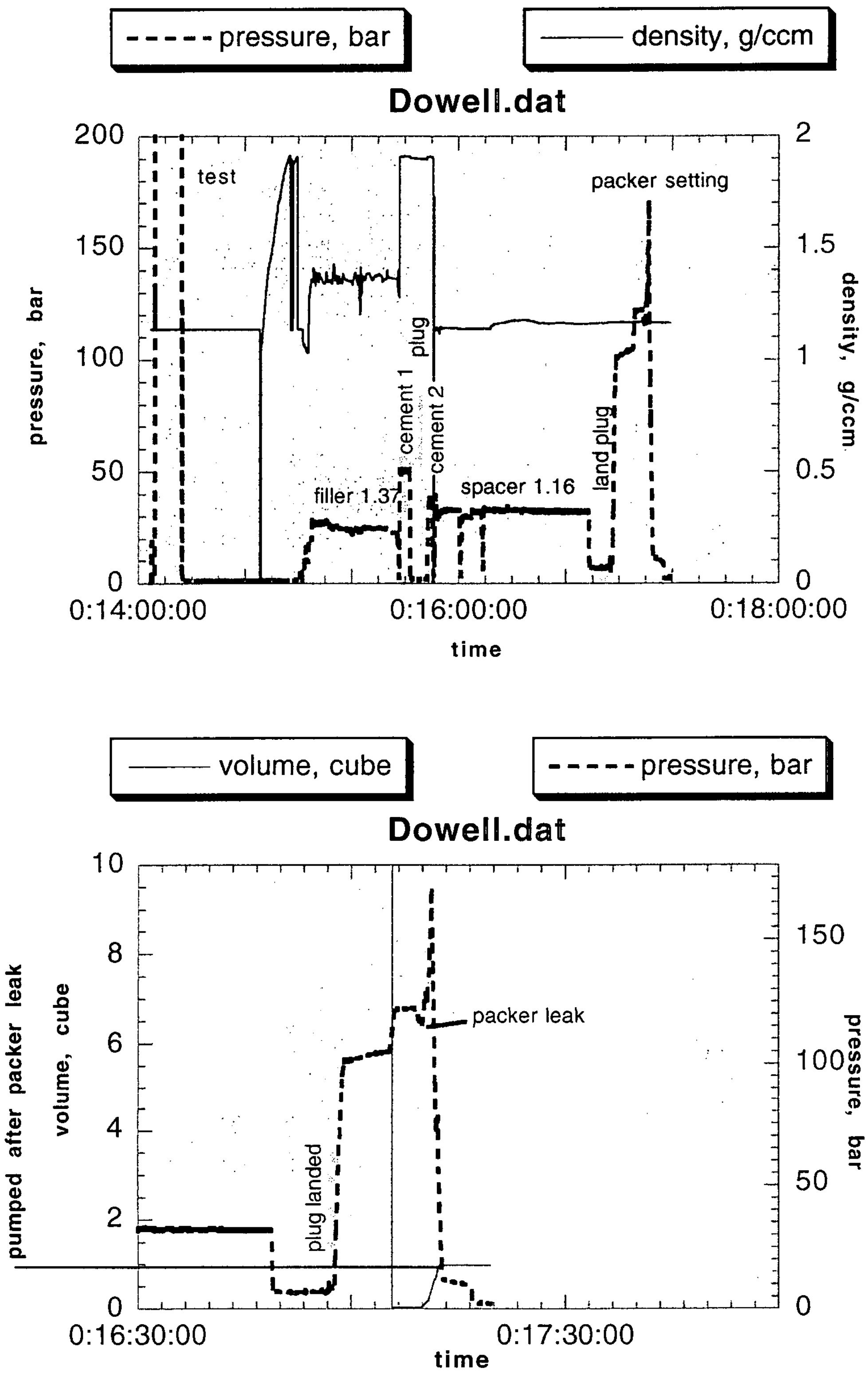


Fig. 15 a,b: Injection of filler, cement and displacement during the completion of GPK2. Data courtesy of Schlumberger Dowell.

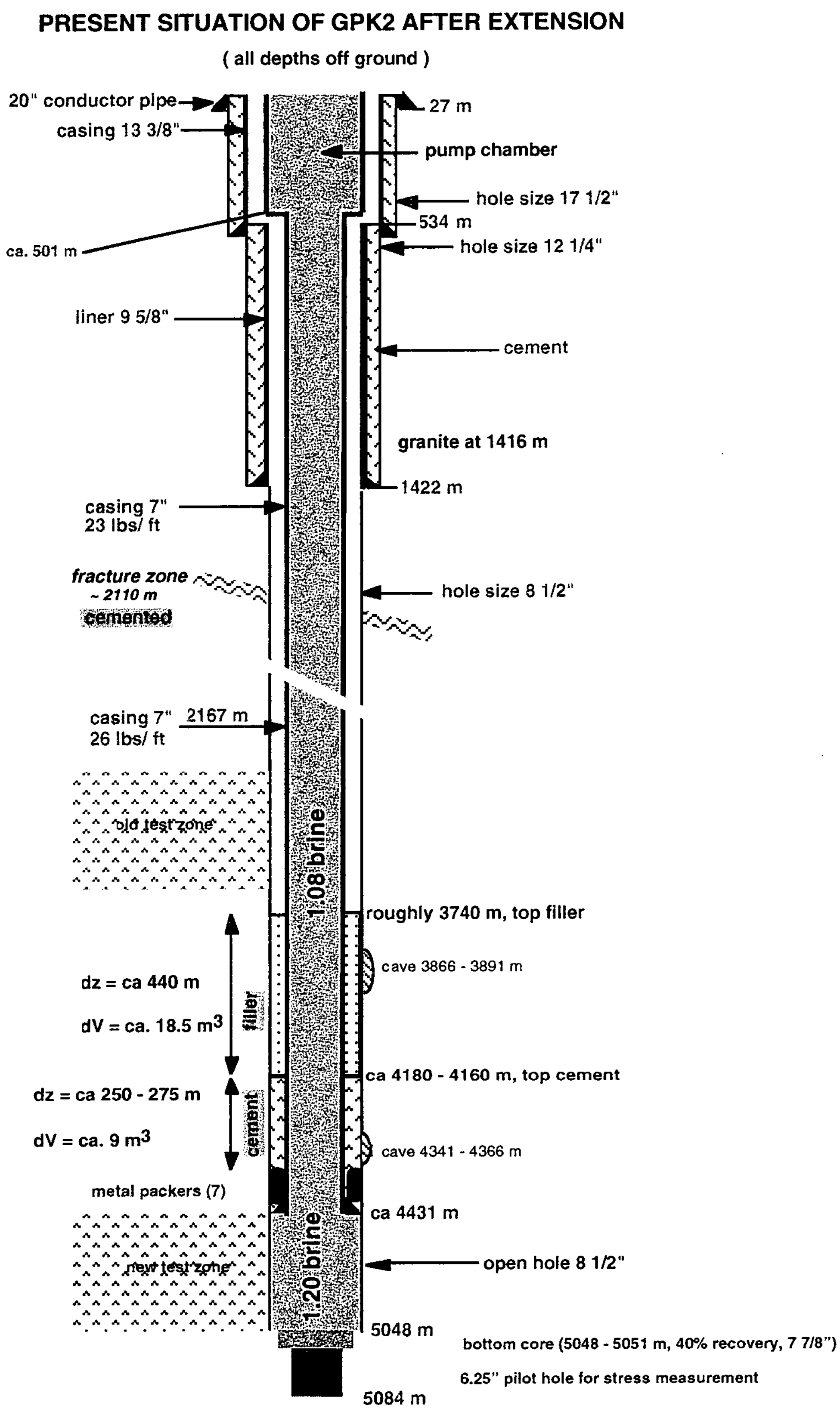


Fig. 16: Present situation of the well GPK2 after re-entry and deepening to 5084 m (app. 5024 m **T**rue **V**ertical **D**epth)

IX: SCIENTIFIC PROGRAM & FIRST RESULTS

The scientific program associated with the re-entry and deepening of GPK2 included the following activities:

description	partners involved
continuous recording of all drilling parameters, mud composition and gas content in mud (CO2, CH4, H2S, HE)	ENEL, Pisa & BRGM, Orléans
analysis of cuttings, geological follow-up	BRGM, Orléans & Stadtwerke Bad Urach
coring near bottom	SII, ENEL, SOCOMINE
continuous water level observations in seismic observation wells	Geothermik Consult, Karlsruhe
continuous recording of the drilling noise to profile ahead of drilling (3 sensors in the seismic observation wells 4550, 4616, 4601)	Tohoku University, Sendai
material analyses of casing joints retrieved from GPK2	EDF, Paris & Ruhr-University, Bochum
analysis of scaling / deposits in the retrieved casing	Université Paris VI
borehole logging:	
HNGS, UBI, CAL, ARI	Schlumberger, Pau
TEMP	SOCOMINE & NLfB-GGA, Hannover
Trajectory	Scientific Drilling, Alkmaar

- **for engineering research activities see chapters on cementing strategies and packer technology !**

Tab. 3: summary of scientific tasks performed during the re-entry and deepening of GPK2

The geological follow-up on the drilling site, **the near bottom core**, **the image logs** as well as the **recording of the drilling parameters** (mud logging) reveal **that**:

- GPK2 is penetrating into granite down to TD
- numerous alteration and fracture zones exist below 4000 m, also within the future test zone (below the casing shoe at 4431 m)
- several sections with granites rich in Xenolith can be observed
- below a depth of about 4500 m the (granite) lithology is changing more frequently

A summary geological profile is shown below in Fig. 17. This plot is based on (and includes) the drilling parameters collected through ENEL's computerized mud logging and gas analysis unit. Further on line gas analyses (He) were performed by BRGM. A detailed analysis of the geological and mud logging data as well as the mud gas recordings is undergoing at BRGM and Stadtwerke Bad Urach.

The fact that the natural fracture network extends below a depth of 4431 m (casing shoe) is also demonstrated by the image from the ARI log between (Fig. 18).

The temperatures logs which were performed up to depths of around 5040 m fully confirmed the temperature predictions. The last log, conducted in July 1999 by NLfB-GGA, roughly 2 months after the end of the drilling operations, recorded a temperature of slightly more than **198° C at a depth of around 5037 m** (some depth uncertainty exists due to the stretch observed in the new logging cable of NLfB-GGA). Fig. 19 shows a comparison of temperature logs in GPK2 before and after deepening.

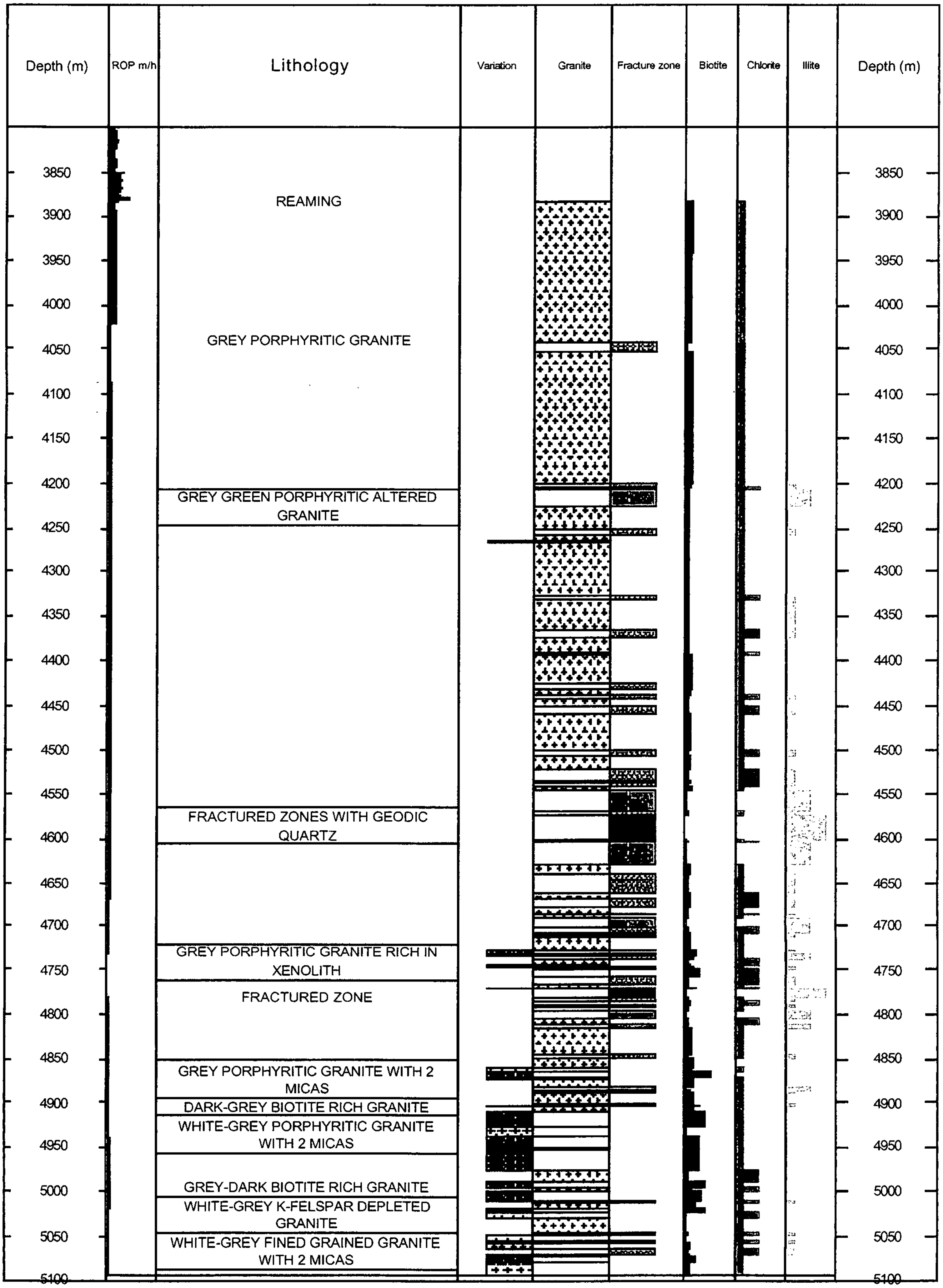
Type	Tool	Parameters	Depth (m)
HNGS	Hostile Natural Gamma Ray Spectrometry	Natural radioactivity, U content, K content, Th content	2000 - 4500
Caliper	Diplog - 6 arms	C1, C2, C3 (3 diameters) R1, R2, R3, R4, R5, R6 (6 independent radii) 6 pads - resistivity	3200 - 4625
ARI	Azimuthal Resistivity Imager	Oriented Borehole Imager with coarse resolution (12 electrodes)	3500 - 4500
UBI	Ultrasonic Borehole Imager	Oriented Borehole Imager with fine resolution	3200 - 3875
TEMP	First Temperature log (12 hours after circ.)	Temperature	1400 - 5048
	2nd Temperature log (July 99)	Temperature	0 - app. 5037 m

Tab. 4: Summary of geophysical logs and borehole image logs in GPK2 (during & after extension)

next page:

Tab.: 5 / Fig. 17 ***Key for description of vein alteration in GPK2 and geological summary log (courtesy of BRGM, A. Genter)***

Altered porphyritic granite (low grade)
Biotite in process of illitisation
Plagioclase non modified
Altered granite (moderate grade)
Biotite transformed into illite
Plagioclase non modified
Altered granite (high grade)
Biotite transformed into illite
Plagioclase in process of illitisation
Altered granite (very high grade)
Biotite transformed into illite
Plagioclase transformed into illite
Occurrence of geodic quartz vein + (mud losses, high ROP)


Depth (m)
ROP m/h
Lithology
Variation
Granite
Fracture zone
Biotite
Chlorite
Illite
Depth (m)
3850
3900
3950
4000
4050
4100
4150
4200
4250
4300
4350
4400
4450
4500
4550
4600
4650
4700
4750
4800
4850
4900
4950
5000
5050
5100
REAMING
GREY PORPHYRITIC GRANITE
GREY GREEN PORPHYRITIC ALTERED GRANITE
FRACTURED ZONES WITH GEODIC QUARTZ
GREY PORPHYRITIC GRANITE RICH IN XENOLITH
FRACTURED ZONE
GREY PORPHYRITIC GRANITE WITH 2 MICAS
DARK-GREY BIOTITE RICH GRANITE
WHITE-GREY PORPHYRITIC GRANITE WITH 2 MICAS
GREY-DARK BIOTITE RICH GRANITE
WHITE-GREY K-FELSPAR DEPLETED GRANITE
WHITE-GREY FINED GRAINED GRANITE WITH 2 MICAS

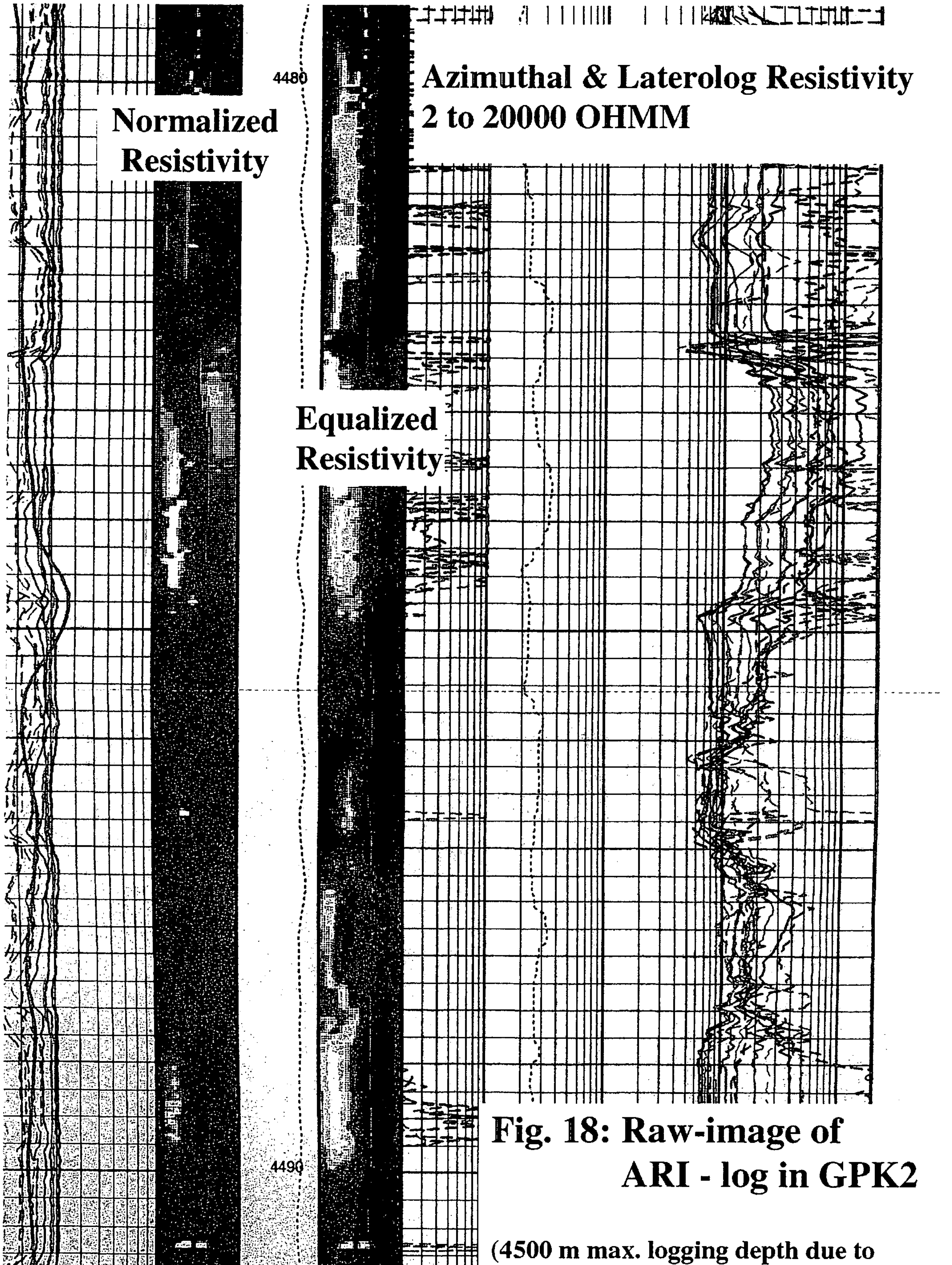


Fig. 18: Raw-image of ARI - log in GPK2

(4500 m max. logging depth due to temperature restriction of logging tool)

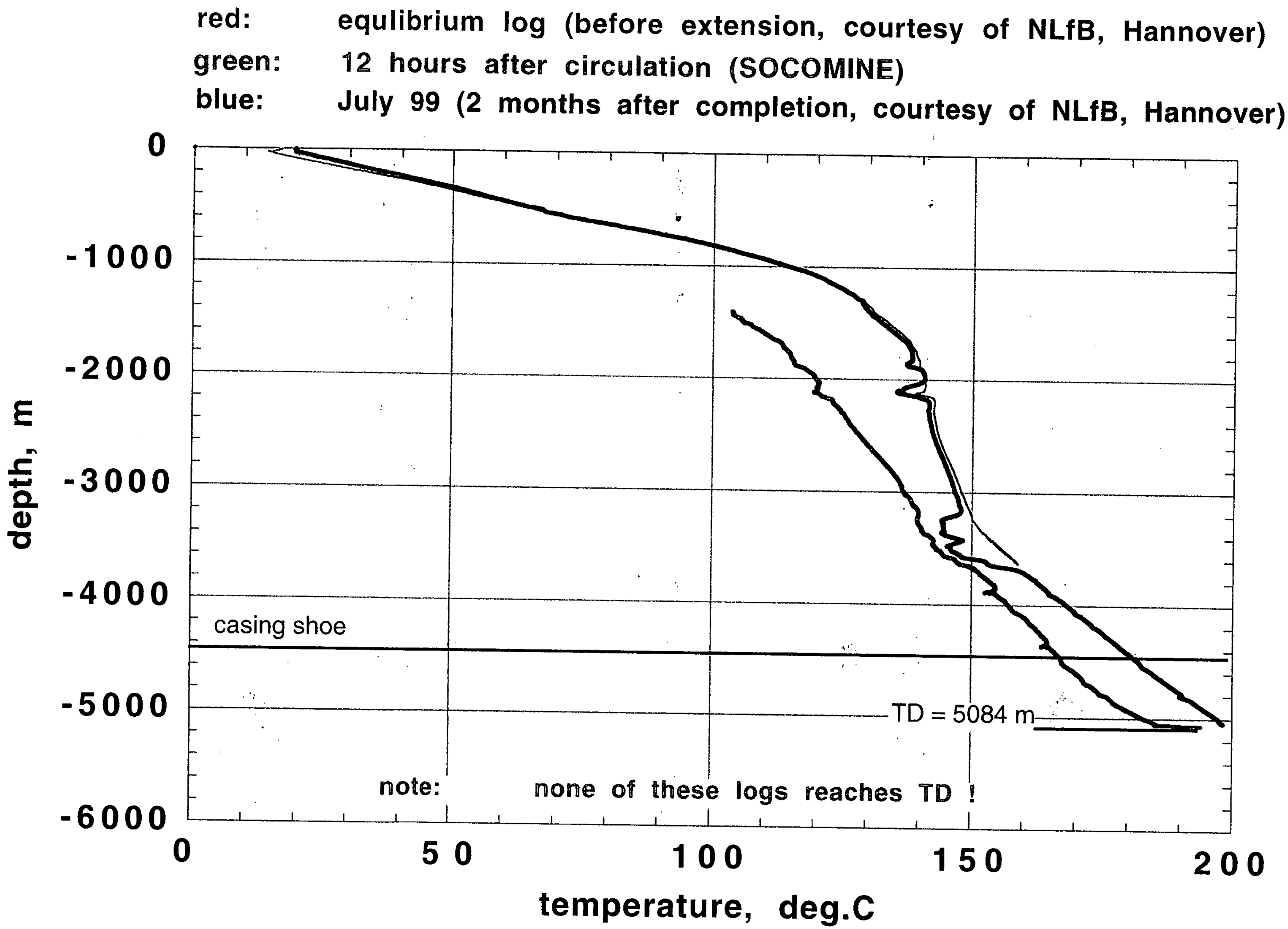


Fig. 19: Comparison of temperature logs in GPK2 before and after deepening

REFERENCES:

1. Baumgärtner, J., Gérard, A., Baria, R., Jung, R., Tran-Viet, T., Gandy, T., Aquilina, L. and Garnish, J.: 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, **1998**

2. Jung, R., Baumgärtner, J., Rummel, F., Tenzer, H. und Tran-Viet, T.: Erfolgreicher Langzeit-Zirkulationstest im Europäischen HDR Versuchsfeld Soultz-sous-Forêts, Geothermische Energie, Nr. 22/23, 6. Jahrg., Heft 2/3, S. 1 - 8, Dezember **1998**

3. Aquilina, L., Rose, P., Vaute, L., Brach, M., Gentier, S., Jeannot, R., Jacquot, E., Audigane, P., Tran-Viet, T., Jung, R., Baumgärtner, J., Baria, R., Gérard, A.: A Tracer Test at the Soultz-sous-Forêts Hot Dry Rock Geothermal Site, Proceedings 23rd Workshop on Geothermal Reservoir Engineering, Stanford University, Stanford, CA, **1998**

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

5. Baria, R., Garnish, J., Baumgärtner, J., Gérard, A. and Jung, R.: Recent Developments in the European HDR Research Programme at Soultz-sous- Forêts (France), Proceedings of the World Geothermal Congress, Florence, Italy, International Geothermal Association, vol. 4, p. 2631-2637, **1995**, ISBN 0-473-03123-X

6. 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

7. Genter, H. Traineau, Ch. Dezayes, Ph. Elsass, B. Ledésert, A. Meunier, Th. Villemin: Fracture analysis and reservoir characterisations of the granitic basement in the HDR Soultz project (France), Geothermal Science Tech., Volume 4 (3), pp. 189-214, **1995**

8. Jung, R., Willis-Richard, J., Nicholls, J., Bertozzi, A. and Heinemann, B.: Evaluation of Hydraulic Tests at Soultz-sous-Forêts, European HDR Site, Proceedings of the World Geothermal Congress, Florence, Italy, International Geothermal Association, vol. 4, p. 2671-2676, **1995**, ISBN 0-473-03123-X

9. Maikranz (BEB Laboratorien): Hochofenzement anstatt Portlandzement, DGMK Vortrag, **1984**

ACKNOWLEDGMENT

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, Guthertz et Fils, Stadtwerke Bad Urach, GTC, NLfB-GGA, Ruhr-Universität Bochum, MeSy, Leipziger Logistik, Tohoku University).

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).