Tracer testing using naphthalene disulfonate compounds during the stimulation operations carried out in the wells GPK-2, GPK-3 and GPK-4 between 2003 and 2004 at Soultz-sous-Forêts (France).

Bernard Sanjuan, Peter Rose, André Gerard, Michel Brach, Gilles Braibant, Jean-Claude Foucher, Anne Gautier, Stéphane Touzelet

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TRACER TESTING USING NAPHTHALENE DISULFONATE COMPOUNDS DURING THE STIMULATION OPERATIONS CARRIED OUT IN THE WELLS GPK-2, GPK-3 AND GPK-4 BETWEEN 2003 AND 2004 AT SOULTZ-SOUS-FORÊTS (FRANCE)

SANJUAN Bernard(1), ROSE Peter(2), GERARD André(3), BRACH Michel(1), BRAIBANT Gilles(1), FOUCHER Jean-Claude(1), GAUTIER Anne(1), TOUZELET Stéphane(1)

(1)BRGM - 3, Av. Claude Guillemin - 45065 ORLEANS Cédex 02, France
(2)EGI (Energy & Geoscience Institute), University of Utah - 423, Wakara Way suite 300, Salt Lake City - Utah 84108, USA
(3)G.E.I.E. - BP38, Route de Soultz - 67250 KUTZENHAUSEN, France

e-mail: b.sanjuan@brgm.fr

ABSTRACT

Between 2003 and 2004, several hydraulic stimulation operations were carried out in the wells GPK-2, GPK-3 and GPK-4 at Soultz-sous-Forêts, France. The aim of this presentation is to show the main results and conclusions obtained during the tracer tests using naphthalene disulfonate compounds (1,5-, 2,7-, 1,6- and 2,6-nds), associated with the stimulation operations. Estimations of the proportions in the discharged fluids of geothermal reservoir brine and water injected into the wells are given. The percentage of injected fluid recovered during production and the fluid circulation rate between wells are also estimated. Additional 2,6-nds will be injected into GPK-4 in 2005 and other tracer tests will also be carried out during this year.

INTRODUCTION

The main objective of the European Hot Dry Rock Energy (HDR) Program is to develop a deep heat exchanger for power production. The site of this exchanger is Soultz-sous-Forêts, France, within the Rhine Graben (Fig. 1), which forms part of the West European Rift. Presently, the first phase of construction of a Scientific Pilot Plant is in progress.

The last three wells, with depths of about 5,100 m, will make up the thermal exchanger in a granitic environment. GPK-3 will be the injection well and GPK-2 and GPK-4 will be the production wells (Fig. 2a). Temperature at depth is close to 200°C and a geothermal NaCl fluid (TDS ≈ 100 g/l) was intersected by each well. In order to ameliorate the quality of the connections between wells (Fig. 2b), hydraulic stimulation tests were carried out in GPK-2 in 2000 and 2003, in GPK-3 in 2003 and 2004, and in GPK-4 in 2004 and 2005. Tracer tests accompanied each stimulation operation.

This study, performed in the framework of the accompanying scientific work of the European HDR Program, presents the main results obtained during the tracer testing associated with the different hydraulic stimulation operations, in particular the stimulation operation carried in GPK-3 in 2003 and 2004.

PREVIOUS RESULTS

Results obtained after the hydraulic stimulation operation carried out in well GPK-2 in 1996 and during a long-term circulation test between the wells GPK-1 and GPK-2 from July to November 1997

A four-month circulation test between GPK-1 and GPK-2 (depth of 3.6 and 3.8 km, respectively) was carried out in 1997. A circulation loop was created between these two wells.

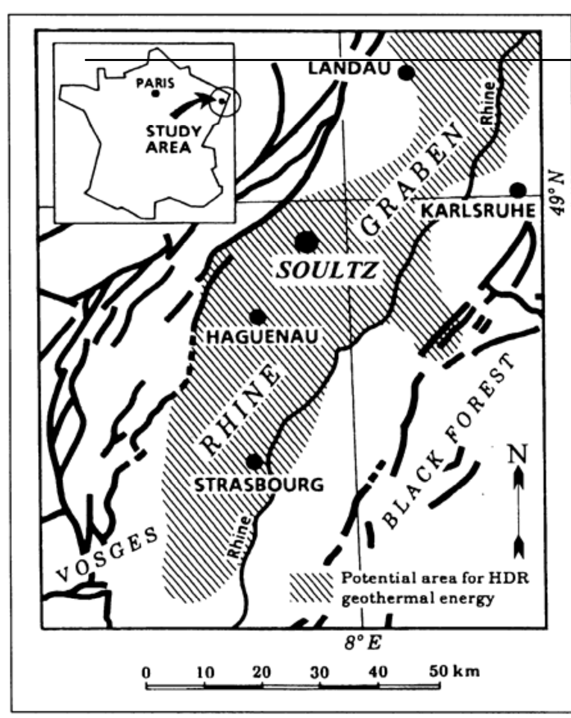


Figure 1 - Location map of the Rhine Graben and Soultz-sous-Forêts.

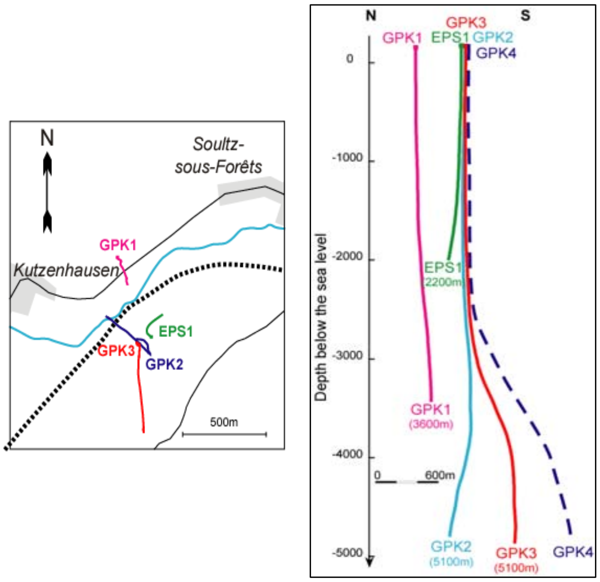


Figure 2a - Location map and profiles of the geothermal wells (from Gentier et al., 2003a and b).

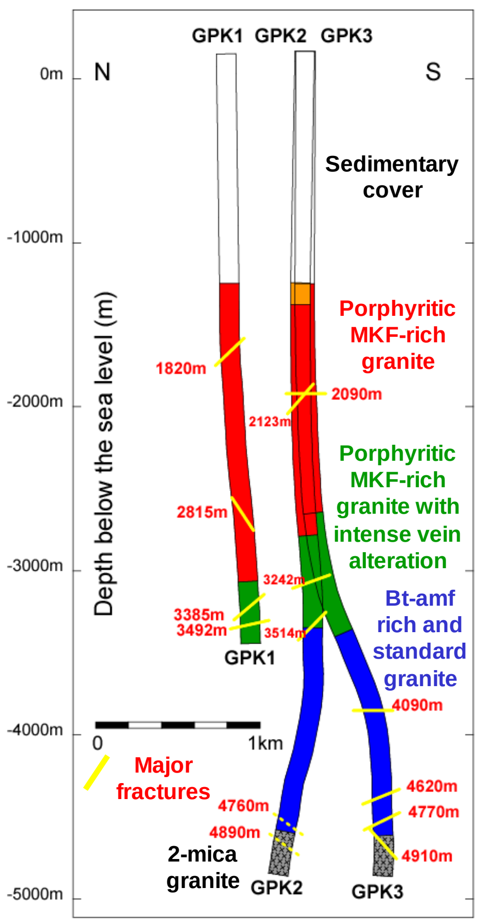


Figure 2b - Geological cross-section between the geothermal wells (from Gentier et al., 2003b).

The hot fluid produced from GPK-2 (3,500 m of depth at that time) was cooled in a surface heat exchanger before being re-injected into GPK-1, at around the same depth. The bottom hole temperature was close to 150°C. Tracing of the circulating fluid during this experiment was performed using Na-benzoate (292 kg) among other tracers. It demonstrated a direct hydraulic connection between both wells. At the beginning of the experiment, the tracers injected into GPK-1 were detected 3 to 6 days after their injection in the fluid produced from GPK-2 (Vaute, 1998). Tracer maxima were observed between 6 and 10 days after this injection. It was also shown that only 25 to 30% of the total amount of injected Na-benzoate was recovered at the end of the four month circulation test.

Results obtained after the hydraulic stimulation operation carried out in the well GPK-2 in July 2000 and during the four production tests performed in this well between December 2000 and April 2002

A hydraulic stimulation was conducted in well GPK-2, in July 2000, one year after its deepening from a depth of 3,500 m to 5,100 m. As described by Gentier *et al.* (2003a and b) and Sanjuan *et al.* (2004), two organic tracers (Na-benzoate and 1,5-nds) were continuously injected, during this operation, at a controlled concentration of about 2 mg/l into GPK-2 with about 26,800 m^3 of fresh water and 1,000 m^3 of heavy brine. Na-benzoate had been already used by BRGM at Soultz (Vaute, 1998) and in another geothermal site (Bouillante, in Guadeloupe, French West Indies; Sanjuan *et al.*, 1999; 2000).). The 1,5-nds had also been used in several tracer tests carried out in geothermal areas (Rose *et al.*, 1999; 2000; 2001).

After this tracer injection, four short-term production tests were carried out between December 2000 and April 2002. During each test, the fluid discharged from GPK-2 was geochemically monitored by BRGM (December 11-21 2000; January 30-February 23 2001; June 21-28 2001; April 23-24 2002). The volume of fluid discharged during each test was 1,170, 2,720, 450 and 253 m^3 respectively, which represents a total discharged volume of 4,593 m^3.

Comparison with natural tracers such as chloride indicated that the organic tracers were remarkably stable and had a conservative behavior during a period of almost 2 years under bottom-hole GPK-2 conditions, at a temperature value close to 200°C (Sanjuan *et al.*, 2004). The results obtained for the 1,5-nds tracer, analyzed by the BRGM and EGI laboratories using High Pressure Liquid Chromatography (HPLC) and fluorescence detection, were compared and showed very close values (Sanjuan *et al.*, 2004). Their difference was usually smaller than their relative uncertainty (from 15 to 20%).

At each production test, the mass proportions of injected fresh water and geothermal brine could be estimated. At the end of the fourth and last production, the mass proportion of fresh water injected during the hydraulic stimulation decreased to about 19% in the fluid produced from GPK-2 whereas less than 7% of this water was recovered. It was observed that the injected fresh water was internally replaced by the geothermal brine in the reservoir. All these results coupled with the temperature of the deep geothermal brine estimated using the chemical geothermometers (about 240°C) suggested the existence of an internal convection in the reservoir with a relatively significant circulation rate. A value close to 1-1.2 m^3/h was determined for this circulation rate (Sanjuan *et al.*, 2004).

Results obtained after the hydraulic stimulation operation carried out in the well GPK-2 between January and March 2003 and during the production test performed in the well GPK-3 in March 2003

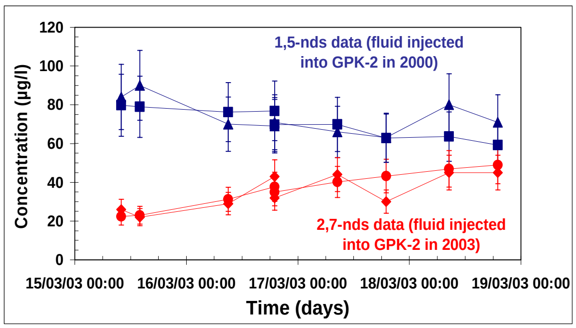
Three injection tests were carried out in GPK-2 between January and March 2003 during this hydraulic stimulation operation. The volume of fresh water injected during the first test (January 23-30) was 9,214 m^3 using a flow rate of 15 l/s. During the second and third tests (February 12-16; March 11-16), these volumes were 5,814 and 8,950 m^3, respectively, using flow rates of 15 and 30 l/s. The complete volume of fresh water injected into GPK-2 was 23,978 m^3.

During each injection test, 2,7-nds was continuously injected at a controlled concentration of about 3 mg/l into GPK-2 (Gentier *et al.*, 2003a and b; Sanjuan *et al.*, 2004).

After this tracer injection, a volume of fluid of about 1,890 m^3 was discharged from GPK-3 in March 2003, using a flow rate of 4 l/s. A geochemical monitoring of this fluid was carried out by BRGM between March 12 and 18. All the results and main conclusions are given in Gentier et *al.* (2003a and b) and Sanjuan *et al.* (2004). The results obtained for the 1,5- and 2,7-nds tracers, analyzed by the BRGM and EGI laboratories using HPLC and fluorescence detection, again showed very close values (Sanjuan *et al.*, 2004), with differences usually smaller than their relative uncertainty (from 15 to 20%).

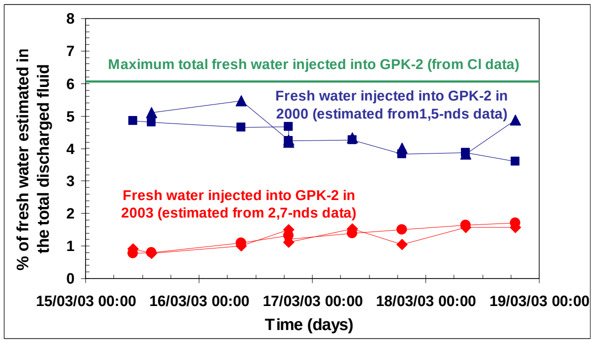
The detection of 1,5-nds, almost 3 years after its injection into GPK-2, and that of 2,7-nds in the fluid discharged from GPK-3, indicated that the recently drilled GPK-3 well (depth of 5,100 m) was directly connected to GPK-2 (Gentier *et al.*, 2003b ; Sanjuan *et al.*, 2004). It was demonstrated that about 94-95% of geothermal brine and 5-6% of fresh water injected into GPK-2 were present in the fluid discharged from GPK-3 at the end of the production test carried out in March 2003. Among this 5-6% of fresh water, the concentrations of 1,5-nds and 2,7-nds indicated that the fluid discharged from GPK-3 consisted of 4-5% of fresh water injected into GPK-2 in 2000 and about 1-2% of fresh water injected into GPK-2 in 2003. Taking into account the analytical uncertainties, the organic tracer data were in very good agreement with those of dissolved Na, K, Ca, Mg, Cl, Br and Li.

The figures 3 and 4 illustrate how the fresh water injected in 2000 into GPK-2 (represented by 1,5-nds) is progressively replaced by the fresh water injected in 2003 into this same well (represented by 2,7-nds), between March 14 and 18, 2003.



Blue triangles and red diamonds: BRGM data
Blue squares and red circles: EGI data

Figure 3 - Results of the 1,5-nds and 2,7-nds tracers analyzed in the fluid discharged from the well GPK-3.



Blue triangles and red diamonds: BRGM data
Blue squares and red circles: EGI data

Figure 4 - Estimation of the proportions of fresh water injected into GPK-2 in 2000 and 2003, relative to the total mass of fluid discharged from the well GPK-3 (March 2003), using the concentrations of Cl and organic tracers (1,5-nds and 2,7-nds).

During this period, the contribution of fresh water injected in 2000 decreases approximately from 5.0 to 4.0% whereas that of fresh water injected in 2003 increases from 0.9 to 1.6%. Overall, fresh water slightly decreases from 5.9 to 5.6%. At the beginning of this production test, the fresh water consisted of about 87% of fresh water injected in 2000 and 13% of fresh water injected in 2003. At the end of this test, the respective proportions are around 70 and 30%. The amount of fresh water injected between January and March 2003 into GPK-2, which was recovered in the well GPK-3, after a production of 1,890 m^3 of fluid, can be estimated as 32 m^3, which represents 0.13% of the total volume of fresh water injected into GPK-2 (23,978 m^3).

All these data suggested the existence of a hydraulic connection between GPK-2 and GPK-3 before any stimulation of GPK-3. They confirmed the internal convection evidenced from the monitoring of the previous production tests carried out in GPK-2 and the value estimated for the natural flow rate of the deep fluid (1.0-1.2 m^3/h). They also showed that the 1,5-nds tracer had a conservative behavior at least during a period of almost 3 years at a temperature close to 200°C.

TRACER TEST ASSOCIATED TO THE STIMULATION OPERATIONS CARRIED OUT IN THE WELL GPK-3 IN 2003

Two injection tests were carried out into GPK-3 between May and July 2003. The fluid volume injected during the first test (May 27-June 6) was about 34,000 m^3 using flow rates of 20-90 l/s. During the second test (June 24-July 11), this volume was 25,305 m^3 using flow rates of 15-23 l/s. The complete fluid volume injected into GPK-3 was 59,305 m^3. In the first injection test, only fresh water ("Etang" water) was injected into GPK-3. In the second test, a mixture consisting of a high proportion of fluid produced by GPK-2 and a low amount of fresh water was injected. A short injection of 3,300 m^3 of fluid with a solution of 2,7-nds tracer was also made into GPK-2 on June 3-5.

Injection of 1,6-nds into the well GPK-3 in 2003

During each injection test, 1,6-nds was continuously injected at a constant concentration into GPK-3. This concentration was fixed at 3 mg/l. For this tracer injection, 100 kg of pure 1,6-nds was dissolved in 1,000 l of fresh water by BRGM using a tank of 1 m^3 in order to prepare a tracer solution of about 100 g/l. As this volume of tracer solution was not sufficient, 75 kg of pure 1,6-nds were additionally dissolved in 750 l of fresh water in the same tank.

This solution was mixed with the fluid injected into GPK-3 with a pump whose flow rate was permanently adapted to that of the injected fluid in order to have a fixed tracer concentration of about 3 mg/l. During each injection test, some samples were collected at the well head to monitor the concentration of 1,6-nds in the fluid injected into GPK-3 and also, those of other tracers (Na-benzoate, 1,5-nds and 2,7-nds). The results of these analyses performed by BRGM and EGI using HPLC and fluorescence detection are reported in Table 1. Analytical uncertainty is close to 15-20%.

Some chemical analyses (dissolved Ca, K, Cl, Br and B) were also performed (Table 1) in the BRGM laboratories, using classical analytical techniques such as titration, atomic absorption spectrometry, ion chromatography or ICP-MS. For the analyses of dissolved major species (Ca, K and Cl), relative uncertainty varies from 2 to 5%. For those of the dissolved trace species (Br and B), relative precision is 10-15%.

The concentrations of Na-benzoate and 1,5-nds, at the well head, are always very low and can be neglected when compared to those of 1,6-nds (Table 1). The concentrations of 2,7-nds are also very low when only fresh water is injected into GPK-3. They become significant in the second injection test, after using the fluid produced from GPK-2 (Table 1).

During the first injection test, the scattered values of 1,6-nds between 1 and 3 mg/l, observed for the fluid collected at the head of GPK-3 (Table 1), are probably caused by the same phenomena as those described for the injection of 2,7-nds (inaccurate adjustment of the flow rate of the pump used to inject the tracer, relative to the variations of flow rate for the injected fresh water; bad homogeneity of the fluid at the sampling point). For mass balance calculations, it was decided to use a mean value of about 2.79 mg/l for the fixed concentration. This concentration was calculated considering that, during the first injection test, about 0.95 m^3 of solution of 1,6-nds at 100 g/l were injected with 34,000 m^3 of fresh water into GPK-3.

During the second injection test, most of the values of 1,6-nds in the fluid samples collected at the head of GPK-3 are higher than 3 mg/l at the beginning, then lower between July 6 and 8 (Table 1). The high values can be explained by the two same processes as those previously described but also by the use of the fluid produced from GPK-2 for injection into GPK-3 (Table 2). Indeed, this fluid already contained some 1,6-nds tracer, which was then added to the fixed concentration of about 3 mg/l. The low values were intentional due to the fact that only fresh water was traced with a concentration of 1,6-nds close to 3 mg/l and that the proportion of this fresh water was small in the fluid injected into GPK-3.

A mean estimation of the fixed concentration can be calculated as 3.16 mg/l, considering that, during the second injection test, about 0.80 m^3 of solution of 1,6-nds at 100 g/l was injected with 25,305 m^3 of fluid into GPK-3. The concentration of 1,6-nds, daily analysed in the fluid produced from GPK-2 and used for injection into GPK-3, must be also added to this value. Consequently, the concentrations of 1,6-nds in the fluid initially injected into GPK-3 vary from 3.16 + 0.42 = 3.58 mg/l to 3.16 + 0.87 = 4.03 mg/l during the second injection test, between June 24 and July 9, 2003. Between July 6 and 8, the analyzed low values reported in Table 1 (< 1 mg/l) can be considered to be close to the concentrations of 1,6-nds of the fluid injected into GPK-3.

Injection of $NaNO_3$ into the well GPK-3 in 2003

This tracer was injected into GPK-3 to the request of GEIE while GPK-2 was producing. A solution of about 245 g/l was prepared on June 25 by dissolving 250 kg of 98% pure $NaNO_3$ in 1 m^3 of fresh water. A volume of 0.95 m^3 of this solution mixed to 33.41 m^3 of fluid was injected into GPK-3 on June 26, between 14h04 and 14h28. For this mixing, a pump whose flow rate was adapted to that of the injected fluid (23.2 l/s) was used in order to have a constant $NaNO_3$ concentration of 6.8 g/l (0.95 x 245 / 34.36).

Geochemical monitoring of the fluid produced from GPK-2 (June-July 2003)

Two production tests were carried out from GPK-2 between June 11 and 16, and June 24 and July 9, 2003. During the first test, a volume of fluid of about 4,030 m^3 was discharged from GPK-2 using flow rates of about 10-15 l/s. A volume of 22,456 m^3 was produced in the second test with flow rates of 12-20 l/s.

A geochemical monitoring of this fluid was performed by BRGM during these two tests. The values of the parameters measured on site such as temperature, density, conductivity, pH, alkalinity and concentrations of dissolved chloride, calcium and silica, are reported in Table 2. For these measurements and analyses, relative uncertainty is lower than 5%.

<u>NaNO3 results</u>

Nitrate analyses were performed:

- on site using a colorimetric method (Merck kit);
- in the BRGM laboratory using ion chromatography.

Precision for both methods is about 5%. All the results are reported in Gentier *et al.* (2003b). The data obtained using the IC technique indicate that the nitrate tracer was not detected in the fluid discharged from GPK-2. However, these results are very different from those analyzed by colorimetry, which show relatively high nitrate concentrations between July 3 and 8, at the end of the production test (Fig. 5).

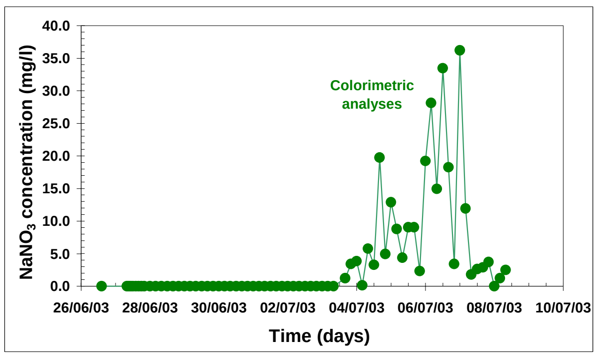


Figure 5 - Geochemical monitoring of the fluid discharged from the well GPK-2 (from 26/06 to 9/07/2003): Analytical results of the $NaNO_3$ tracer obtained using the colorimetric technique on site.

Normally, the colorimetric method cannot be quantitatively applied on saline fluids such as those produced from GPK-2 because of ion interference. This technique was only used in this study to be able to qualitatively detect nitrate ions on site. Tests carried out in the BRGM laboratory have shown that the NO_3 signal is hardly reduced in a high chloride solution (Gentier *et al.*, 2003b).

Ion chromatography is the recommended technique and had to confirm and quantify the presence of nitrate ions detected on site. However, in this particular case, it is extremely probable that the high concentrations of nitrate analyzed on site by colorimetry between July 3 and 8 are really related to the injection of $NaNO_3$ into GPK-3. In reduced medium such as that of the fluid produced from GPK-2, the nitrate ions may have been transformed in nitrite ions, which would have been then the ions detected by colorimetry. Indeed, tests performed in the BRGM laboratory have shown these ions can strongly interfere with nitrate ions using this technique (Gentier *et al.*, 2003b). The fact that the nitrite ions are lowly stable as a function of time and that their chromatographic peak is very close to that of the chloride ions could explain why they have not been detected by IC in the high Cl fluid produced from GPK-2.

Assuming that the signal observed by colorimetry in the fluid produced from GPK-2 between July 3 and 8 is related to the injection of $NaNO_3$ into GPK-3 done on June 26 (Fig. 5), it can be then deduced that only 7.25 days were required for this tracer to go from GPK-3 to GPK-2. Maximum of signal was detected between 8 and 11 days after the $NaNO_3$ injection (Fig. 5). These results are similar to those obtained in 1997 for the tracer tests carried out during the circulation test between GPK-1 and GPK-2. In these tests, the tracers injected into GPK-1 were detected in the fluid discharged from GPK-2 3 to 6 days after their injection and the maximum concentrations were observed between 6 and 10 days after this injection (Vaute *et al.*, 1998 ; Aquilina *et al.*, 2004).

The time of circulation, slightly higher from GPK-3 to GPK-2 than from GPK-1 to GPK-2, can be explained by the inter-well distance and the well depth:

- the distance between the wells GPK-2 and GPK-3 is about 650 m whereas that between GPK-1 and GPK-2 is only 450 m;
- the depth of the wells GPK-2 and GPK-3 is presently greater (5.1 km) than previously for GPK-1 and GPK-2 (3.6 and 3.8 km, respectively).

The time of tracer circulation between GPK-3 and GPK-2, corrected from the time used by the tracer to go down in GPK-3 and go up in GPK-2 (depth of 5.1 km for each well), is estimated to 6.65 days, under the conditions of the circulation test. Dividing the travel distance by this time of circulation, a value of circulation fluid rate between GPK-3 and GPK-2 is evaluated to about 4 m/h. This value is close to that given by Aquilina *et al.* (2004) between the wells GPK-1 and GPK-2 using benzoic acid and deuterium data (4.9 - 6.6 m/h).

If the circulation fluid rate between GPK-3 and GPK-2 is estimated using the time necessary to detect the maximum nitrate concentration, we then obtain values close to 2.6-3.7 m/h. These values are slightly higher than those estimated by Aquilina *et al.* (2004) using benzoic acid, fluorescein and deuterium data (1.35-2.2 m/h).

Given the qualitative nature of the colorimetric $NaNO_3$ analyses, the amount of tracer recovered in the fluid discharged from GPK-2 cannot be calculated.

<u>Na-benzoate and naphthalene disulfonate results</u>

The results for the organic tracers (1,5-nds, Na-benzoate, 2,7-nds and 1,6-nds) analyzed by HPLC in the BRGM laboratories are given and compared to the analytical results reported by EGI in Table 2 and in figures 6, 7 and 8. These values are very close and their difference is usually smaller than their relative uncertainty (from 15 to 20%).

The results concerning the 1,6-nds tracer seem to be rather in agreement with those found for nitrate (Fig. 8). Indeed, the concentrations of 1,6-nds are already relatively high in the fluid discharged from GPK-2, only 15 days after the injection of this tracer into GPK-3. A contribution of fresh water injected into GPK-3 of about 10-11% of the total mass of fluid produced from GPK-2 can be already estimated at the beginning of the first production test (Table 2).

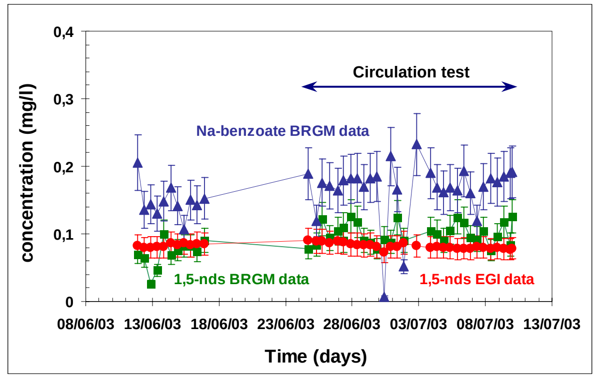


Figure 6 - Geochemical monitoring of the fluid discharged from the well GPK-2 (from 11/06 to 9/07/2003): Analytical results of the organic tracers injected into GPK-2 in 2000 (Na-benzoate and 1,5-nds).

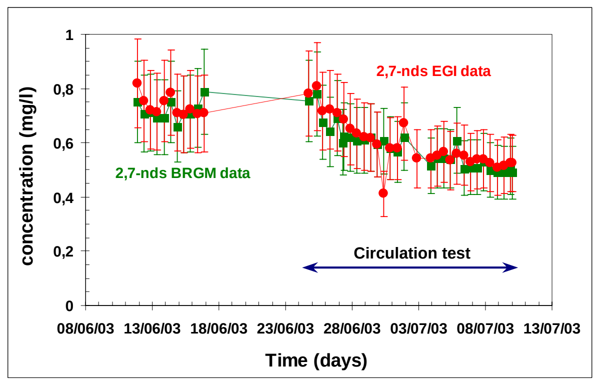


Figure 7 - Geochemical monitoring of the fluid discharged from the well GPK-2 (from 11/06 to 9/07/2003): Analytical results of the 2,7-nds tracer injected into GPK-2 in 2003.

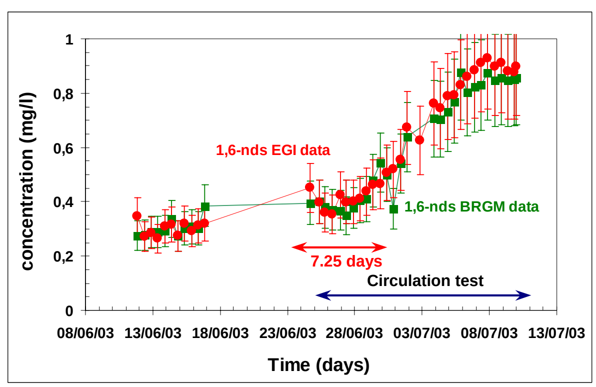


Figure 8 - Geochemical monitoring of the fluid discharged from the well GPK-2 (from 11/06 to 9/07/2003): Analytical results of the 1,6-nds tracer injected into GPK-3 in 2003.

During this first test, the chloride concentrations indicate an increasing contribution of geothermal brine from about 37 to 50% (Table 2). This increase is mainly due to the partial discharge of the 3,300 m^3 of 2,7-nds-traced fresh water injected into GPK-2 on June 3-5. As the concentration of 2,7-nds is badly known during the injection of this fresh water into GPK-2, it is difficult to do a mass balance using this tracer, at the beginning of this production test.

At the end of the first production test, the concentrations of the four tracers analyzed in the fluid discharged from GPK-2 (Table 2; Figs. 6, 9 and 10) indicate a contribution of about:

- 4-5% of fresh water injected into GPK-2 in 2000 (estimated using 1,5-nds). The concentrations of Na-benzoate show a slightly higher proportion (6-7%). These differences can be attributed to analytical uncertainties but also to a low background of this tracer, which was injected in 1997 into GPK-1;
- 24-26% of fresh water injected into GPK-2 between January and March, and June 2003 (estimated using 2,7-nds; Fig. 9);
- 12-14% of fresh water injected into GPK-3 during the first injection test carried out in 2003 (estimated using 1,6-nds; Fig 10).

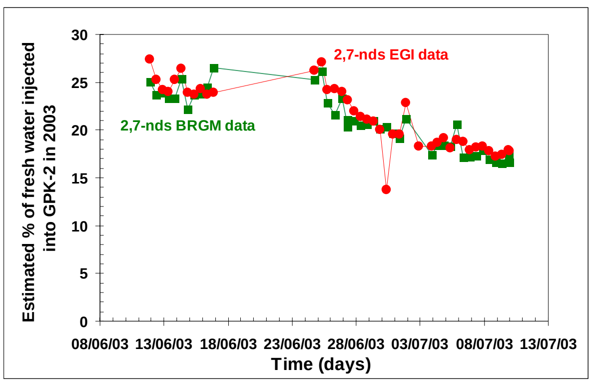


Figure 9 - Estimation of the proportions of the fresh water injected into GPK-2 in 2003, relative to the total mass of fluid discharged from this well (from 11/06 to 9/07/2003), using the concentrations of 2,7-nds.

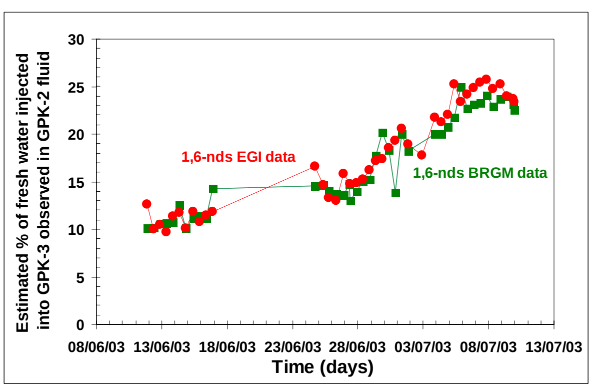


Figure 10 - Estimation of the proportions of the fluid injected into GPK-3 in 2003, relative to the total mass of fluid discharged from the well GPK-2 (from 11/06 to 9/07/2003), using the concentrations of 1,6-nds.

At the end of this test, the proportion of fresh water is close to 43% of the total mass of fluid produced from GPK-2 and the contribution of geothermal brine is approximately 50% (Table 2), which represents a total mass of fluid of 93%. The missing 5 to 10% of fluid mass are probably caused by the inaccuracy on the tracer concentrations of the fluids during their injection and the analytical results.

In the second production test, the chloride concentrations indicate an increasing contribution of geothermal brine from about 50 to 58% of the total mass of fluid produced from GPK-2 (Table 2). This increase is lower than that observed during the first test whereas the volume of discharged fluid is much larger in this second test.

It is obvious that the influence of fresh water injected on June 4-5, 2003, on the fluid produced from GPK-2, is less significant in this second production test.

In this production test, the concentrations of 1,5-nds (Fig. 6) suggest a relatively stable proportion of fresh water injected into GPK-2 well in 2000 close to 4-5% (Table 2). As in the first production test, those of Na-benzoate indicate a slightly higher proportion (7-9%; Table 2).

The concentrations of 2,7-nds show a decreasing contribution of the fluid injected into GPK-2 between January and March, and June 2003, from about 26 to 17-18% of the total mass of fluid produced by GPK-2 (Table 2, Figs. 7 and 9).

The re-injection of the fluid produced from GPK-2 into GPK-3, during the second injection test, influences these data (chloride, 1,5-nds, Na-benzoate and 2,7-nds tracers) and don't easily allow for their use in drawing conclusions about the natural fluid circulation.

The concentrations of 1,6-nds indicate increasing values in the fluid produced from GPK-2 (Fig. 8). In order to estimate the proportion of fluid injected between May and July 2003 into GPK-3, relative to the total mass of fluid discharged from GPK-2, it must be considered that:

- the initial concentration of 1,6-nds of the fluid injected into GPK-3 was also increasing from about 2.79 to 4.03 g/l;
- the time of fluid circulation is about 7.25 days.

So, at the beginning of this production test, the mass proportion of fluid injected into GPK-3 present in the fluid discharged from GPK-2 can be estimated as follows: analyzed tracer concentration (mg/l) x fluid density / initial tracer concentration (mg/l) x 100. We then obtain a value close to: 0.42 x 1.025 / 2.79 x 100 = 15% of the total mass of the fluid produced from GPK-2 (Table 2, Fig. 10).

After 7.25 days where a more significant concentration of 1,6-nds is observed in the GPK2-P27 fluid sample (Table 2, Fig. 8), relative to the previous data, the initial concentration of 1,6-nds in the fluid injected into GPK-3 can be estimated by using the fixed value of 3.16 g/l and adding the concentration analyzed 7.25 days before, in the fluid discharged from the well GPK-2. The proportion of fluid injected into GPK-3 present in the GPK2-P27 sample is then evaluated to be about: 0.66 x 1.0415 / ((3.16 + 0.43) x 1.025) x 100 = 19% (Table 2, Fig. 10). The values of 1.0415 and 1.025 are those of the fluid densities.

At the end of this test, this proportion is close to: 0.87 x 1.0395 / ((3.16 + 0.63) x 1.0345) x 100 = 23% of the total mass of the fluid discharged from GPK-2 (Fig. 10). The values of 1.0395 and 1.0345 are those of the fluid densities. These data imply that about 6,092 m^3 of the fluid injected into GPK-3 have been recovered in GPK-2, at the end of the second test, after a total production of 26,488 m^3 of fluid. This volume of fluid recovered during a very limited production time represents approximately 10% of the total volume of fluid injected into GPK-3 (59,305 m^3).

STIMULATION OPERATIONS CARRIED OUT IN THE WELLS GPK-3 AND GPK-4 IN 2004

Fluid injection and production test carried out in the well GPK-3 in August 2004

A hydraulic stimulation operation was carried out in the well GPK-3 between August 17 and 23, 2004. A total volume of fluid of 6,860 m^3 was injected into GPK-3 at flow rates of 11.8-23.8 l/s. No organic tracer was injected during this operation.

Just after this operation, a production test was performed in GPK-3 between August 28 and 31. A total volume of 2,556 m^3 was discharged from this well, using a flow rate of 16 l/s.

A geochemical monitoring of the fluid injected into GPK-3 and discharged from this same well was performed by BRGM. The values of the parameters measured on site such as temperature, density, conductivity, pH, Eh, O_2, alkalinity and the concentrations of dissolved chloride, calcium and silica and organic tracers are reported in Tables 3a and 3b.

The results reported in Table 3a confirm that the fluid injected into GPK-3 between August 17 and 19 is a mixture of geothermal brine collected from GPK-2 and fresh water. If we take into account the concentrations of dissolved chloride and 1,5-, 2,7- and 1,6-nds analyzed in the last fluid samples collected from GPK-2 in Table 2, we can estimate that the fluid injected into GPK-3 is constituted of about 60-70% of geothermal brine collected from GPK-2 and 30-40% of fresh water. The concentrations of dissolved chloride and organic tracers tend to slightly increase in the fluid injected into the well GPK-3. This is probably due to the fact that this trend is also observed in the fluid collected from GPK-2, used for injection (Table 2). Between August 20 and 23, the fluid injected into GPK-3 was only fresh water.

The results presented in Table 3b indicate that the two first fluid samples consist essentially of fresh water injected into GPK-3. These fluid samples are representative of the fresh water injected at the end of the stimulation test and which remained trapped inside this well, whose volume is estimated to be about 365 m^3.

After 8 hours of production, which corresponds to a volume of discharged fluid close to 460 m^3 (this volume is higher than that of the well GPK-3), the fresh water is replaced by a mixture of geothermal brine and fresh water (Table 3b). Results show that except for the fresh water which was trapped inside GPK-4, the fresh water injected into GPK-3 was quickly mixed with the fluids previously injected into GPK-3 (March 2003 - May and July 2003 - August 17 and 19, 2004) and the geothermal reservoir brine. The pH values of the mixture discharged from GPK-3 (Table 3b) are much lower than those of the injected mixture (Table 3a). The concentrations of dissolved calcium, silica and organic tracers are higher (Tables 3a and 3b). The increasing values of conductivity, concentrations of dissolved chloride, calcium and organic tracers and the decreasing pH values in the fluid discharged from GPK-3 (Table 3b) indicate that the proportion of fresh water injected into GPK-3 decreases in the fluid discharged from this well, from the beginning to the end of the production test. This decrease is estimated to be close to 10-12%.

Fluids injected into GPK-4 during a stimulation operation of this well and production test carried out in GPK-3 in September 2004

Stimulation operations carried out in the well GPK-4 in September 2004

Before presenting the tracer test associated with the stimulation operations carried out in GPK-4 in 2004, it is interesting to remember the results of the geochemical monitoring performed during the drilling of this well.

Geochemical monitoring (gases and drilling fluids) performed during the drilling of GPK-4 (September 2003 - April 2004).

A geochemical monitoring (gases and drilling fluids) was carried out during the drilling of GPK-4 (September 2003 - April 2004).

Continuous gas profiles (C1, C2 and He) were performed by GEOSERVICES (Fig. 11). A He profile using a mass spectrometer ALCATEL ASM 100, continuously connected to GPK-4, was also done by BRGM from a depth of 2,600 m (Fig. 11). Analytical uncertainty is 0.02 ppm.

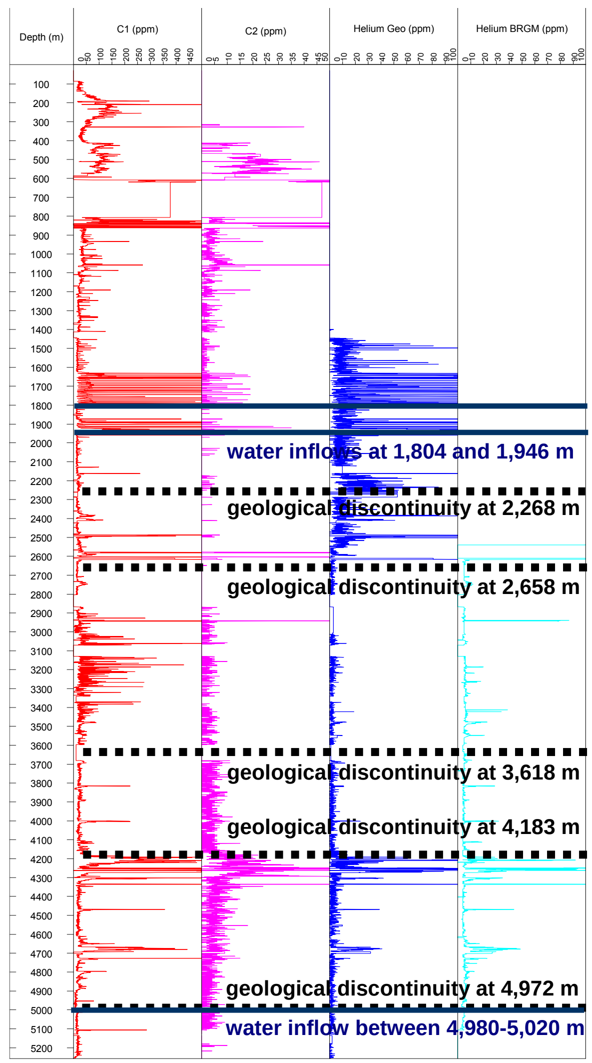


Figure 11 - Gas profiles obtained during the drilling of the well GPK-4 (September 2003 - April 2004).

Results indicate that several deep gas inflows were intersected by the well GPK-4, especially in the areas located between depths of 1,450-1,550 m, 1,570-1,800 m, 1,880-1,960 m, 2,150-2,300 m, 2,380-2,400 m, 2,490-2,500 m, 2,612-2,618 m, 2,940-2,943 m, 3,815-3,821 m, 4,192-4,337 m, 4,468-4,472 m and 4,667-4,733 m. In some of these areas (the most superficial and between 4,192-4,337 m), the He anomalies are higher than 100 ppm and can be, sometimes, close to 200 ppm. As a comparison, the atmospheric He concentration is 5.24 ppm.

Except for the areas situated at depths of 1,804 m, 1,946 m (Table 4) and between 4,980 and 5,020 m, the restricted geochemical monitoring of the drilling fluids carried out by BRGM during the drilling of GPK-4 shows no inflow of geothermal brine (Table 5). The fluids collected at the depths of 1,804 and 1,946 m (Table 4) contain significant amounts of 1,6-nds (244 and 266 µg/l, respectively). As this organic tracer was injected into GPK-3, this suggests a possible hydraulic connection between the deep areas of this well and some superficial areas of the well GPK-4. However, these significant amounts of 1,6-nds could be also the result of a contamination due to the use of fluid discharged from the wells GPK-2 or GPK-3 as drilling fluids. The chemistry of two fluid samples collected between 4,980 and 5,020 m (low pH values close to 6, salinity and chemical compositions similar to those previously analyzed for the geothermal brines of GPK-1, GPK-2 and GPK-3) suggests an inflow of geothermal reservoir brine (Table 5). The presence of 1,6-nds in these two fluid samples which is, however, lower than in the fluid samples previously collected, probably results from a contamination by the drilling fluid.

The main areas of gas anomalies and the water inflow observed between 4,980 and 5,020 m coincide with most of the geological discontinuities which separate each depth section in terms of lithofacies and fracturation. These geological discontinuities, described by Dezayes *et al.* (2005) and reported in Figure 11, are more permeable areas.

Tracer testing using 2,6-nds associated to the stimulation operations carried out in GPK-4 in September 2004

Two tests of fluid injection were carried out in GPK-4 between September 8 and 13 and between September 13 and 16, 2004. During the first test, about 250 m^3 of brine were injected into GPK-4 at a very low flow rate of 0.77 l/s. During the second test, a total volume of 9,073 m^3 of fresh water was injected into GPK-4 at a flow rate of 30 and 45 l/s.

Because of the low flow rate used for the brine injection, the tracer test using 2,6-nds was essentially associated to the second operation of fluid injection. This tracer test will be continued during the additional stimulation operations conducted in 2005.

In July 2004, 50 kg of 2,6-nds were dissolved in a tank containing 1 m^3 of fresh water in order to prepare a concentrated solution of 50 g/l. Some difficulties to dissolve this organic tracer occurred and a pump was used to stir the solution. The concentration of 2,6-nds in the tank solution was checked several times (Table 6) and the last values, before injection, were close to 50 g/l.

As for the previous tests, the tank solution was mixed to the fluid injected into GPK-4 with a pump whose flow rate was permanently adapted to that of the injected fluid in order to have a fixed concentration of about 2 mg/l. During each injection test, some samples were collected at the well head to monitor the concentration of 2,6-nds in the fluid injected into GPK-4 and also, those of other tracers (1,5-, 2,7- and 1,6-nds). The fluids injected into GPK-4 were geochemically monitored. The 2,6-nds was analyzed by the BRGM laboratories using HPLC and fluorescence detection. Relative analytical uncertainties are lower than 20%. All the results are reported in Table 7.

All these data will be available for the next production tests planned in GPK-4 or in the other wells.

<u>Geochemical monitoring of the fluid discharged from GPK-3 during a production test carried out between September 19 and 20, 2004</u>

After the two injection tests carried out in GPK-4 in September 2004, a production test was performed in the well GPK-3 between September 19 and 20. A total volume of fluid of 612 m^3 was discharged from this well using a flow rate of 10 l/s.

A restricted geochemical monitoring of this fluid was performed by BRGM. Only some parameters (pH, conductivity, alkalinity) and dissolved species (chloride, organic tracers such as 1,5-, 2,7-, 1,6- and 2,6-nds) were analyzed by the BRGM laboratories in three fluid samples. All the results are reported in Table 3b.

Given the short fluid production, no traces of 2,6-nds injected into GPK-4 was detected in the fluid discharged from GPK-3 (Table 3b). The analytical results indicate similar values. However, a trend of increasing concentrations is observed for dissolved Cl and organic tracers, especially 1,6-nds (Table 3b). Moreover, these values are higher than those observed during the previous production test carried out in GPK-3 between August 28 and 31, 2004 (Table 3b).

All these data confirm that the fresh water injected into the well GPK-3 in August 2003, with no organic tracers, has been mixed with the fluids previously injected into the well GPK-3 and the geothermal reservoir brine (Tables 1, 2 and 3a), and is progressively replaced by these fluids. Relative to the end of the previous production test, the proportion of fresh water injected into GPK-3 in August 2004 has still decreased in the fluid discharged from this well. This decrease is estimated to be close to 18-20%. Relative to the beginning of the previous production test, the total decrease of this fresh water can then be evaluated to 28-32%. Because of the variety of the fluids injected into GPK-3 and GPK-2 and the existent connections between these wells, it is very difficult to establish mass balances.

CONCLUSION

Tracer testing is an efficient method to detect possible connections between wells, to understand the migration of the injected and natural fluids, and to estimate their circulation rates.

This study has shown that the Na-benzoate and 1,5-nds organic tracers have a conservative behavior during a long period under bottom-hole conditions, at a temperature close to 200°C: at least 3 years for Na-benzoate and 4 years for 1,5-nds.

A tracer test using Na-benzoate and 1,5-nds, associated to the stimulation operation performed in July 2000, indicated that after two years, the fluid discharged from GPK-2 was constituted of 19% of fresh water injected in 2000 and 81% of geothermal brine. Less than 7% of the injected fresh water was recovered from this well. The natural flow rate of the geothermal brine was estimated to be close to 1-1.2 m^3/h. The geochemical monitoring of the fluid discharged from GPK-3 in March 2003, especially the results obtained for the dissolved chloride and the 1,5 and 2,7-nds tracers injected into GPK-2, gave evidence of a hydraulic connection between these two wells. This monitoring confirmed the value estimated for the natural flow rate of the deep fluid.

The chemical monitoring of two tracers injected into GPK-3 (1,6-nds and nitrates) and recovered in the fluid discharged from GPK-2 in 2003 gave additional information. Results showed that only 7.25 days were necessary to these two tracers to go from GPK-3 to GPK-2. For nitrates, maximum signal was detected between 8 and 11 days after their injection. If we take into account the inter-well distance and the well depth, these results are similar to those obtained in 1997 during the circulation test carried out between GPK-1 and GPK-2, where the tracers injected into GPK-1 were detected in the fluid discharged from GPK-2 3 to 6 days after their injection and the maximum signal was observed between 6 and 10 days after their injection. The rates of fluid circulation between wells can then be estimated to be between 2 and 6 m/h.

At several stages of the production tests, estimations of the proportions of injected fresh water and geothermal brine can be performed using the concentrations of the organic tracers and dissolved chloride. These estimations are very useful to better understand the fluid migration and to evaluate the percentage of fluid injected into a well, which is recovered during a production test in this same well or in another well. As an example, the use of 1,6-nds allowed for the estimation that the fluid discharged from GPK-2, at the beginning of the first test of production carried out in June 2003, consisted of about 10% of fluid injected into GPK-3. This proportion is higher than that observed in the fluid discharged from GPK-3 in March 2003; before the hydraulic stimulation of this well, only 1-2% of fresh water injected into GPK-2 had been found in this fluid. At the end of the second production test (circulation test) carried out in June and July 2003, the proportion of fresh water injected into GPK-3 increased to 23% of the fluid discharged from GPK-2. This last estimation can be, then, used to show that only about 10% of fluid injected into GPK-3 has been recovered in the well GPK-2, at the end of this production test, where the total volume of discharged fluid was 26,488 m^3.

The possible hydraulic connections between GPK-3 and GPK-4 are, for the moment, badly known. The injection of a new tracer (2,6-nds) into GPK-4 during the stimulation operations carried out in this well in 2004 and 2005, the use of fluorescein in 2005 and of the other organic tracers already injected into GPK-2 and GPK-3, as well as the next production tests, must give new data and ameliorate this knowledge.

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Fluid sample Injection of 2,7-nds into GPK-2	Date	Cl mg/l	Br mg/l	B mg/l	Ca mg/l	K mg/l	1,5-nds (BRGM) mg/l	1,5-nds (EGI) mg/l	2,7-nds (BRGM) mg/l	2,7-nds (EGI) mg/l	1,6-nds (BRGM) mg/l	1,6-nds (EGI) mg/l
GPK2-INJ1	03/06/03 09:00	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	< 0.5	*n.a.*	0.32	*n.a.*	< 0.5	*n.a.*

Fluid sample Injection of 1,6-nds into GPK-3	Date	Cl mg/l	Br mg/l	B mg/l	Ca mg/l	K mg/l	Na-benzoate mg/l	1,5-nds (BRGM) mg/l	1,5-nds (EGI) mg/l	2,7-nds (BRGM) mg/l	2,7-nds (EGI) mg/l	1,6-nds (BRGM) mg/l	1,6-nds (EGI) mg/l
Etang		*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	< 0.01	0.06	*n.a.*	0.46	*n.a.*	0.33	*n.a.*
GPK3-INJ-BP1	27/05/03 17:32	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	< 0.5	*n.a.*	< 0.5	*n.a.*	1.21	*n.a.*
GPK3-INJ1	27/05/03 09:00	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	0	*n.a.*	0.015	*n.a.*	1.388
GPK3-INJ2	28/05/03 09:00	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	< 0.5	0	< 0.5	0	2.06	2.205
GPK3-INJ3	29/05/03 09:00	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	< 0.5	0	< 0.5	0	2.02	1.875
GPK3-INJ4	30/05/03 09:00	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	< 0.02	< 0.25	0	< 0.25	0	2.35	2.174
GPK3-INJ5	31/05/03 09:00	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	< 0.25	0	< 0.25	0	2.43	2.544
GPK3-INJ6	01/06/03 09:00	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	< 0.25	0	< 0.25	0	2.55	2.565
GPK3-INJ7	02/06/03 09:00	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	< 0.25	0	< 0.25	0	2.54	2.611
GPK3-INJ8	03/06/03 09:00	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	< 0.25	0	< 0.25	0	2.01	1.947
GPK3-INJ9	04/06/03 09:00	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	< 0.25	0	< 0.25	0	3.91	1.952
GPK3-INJ10	05/06/03 09:00	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	< 0.25	0	< 0.25	0	0.92	1.276
GPK3-INJ11	**06/06/03 09:00**	**397**	**1.4**	**0.117**	**88.3**	**6.6**	***n.a.***	**< 0.5**	**0**	**< 0.5**	**0**	**1.84**	**1.886**
GPK3-INJ13	24/06/03 22:00	18100	56.8	10.50	1800	742	*n.a.*	< 0.5	0	0.41	0.479	4.50	4.688
GPK3-INJ14	25/06/03 09:00	21200	67.3	12.40	2020	903	*n.a.*	< 0.5	0	0.43	0.537	4.50	5.105
GPK3-INJ15	25/06/03 21:00	20800	72.1	12.30	2300	822	*n.a.*	< 0.5	0.089	0.59	0.618	4.29	4.270
GPK3-INJ16	26/06/03 09:00	20300	70.3	12.60	2440	837	*n.a.*	< 0.5	0.038	0.46	0.564	4.21	4.237
GPK3-INJ17	26/06/03 21:00	23400	85.9	15.20	2930	1050	*n.a.*	< 0.5	0.085	0.53	0.645	4.19	6.757
GPK3-INJ18	27/06/03 09:00	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	< 0.5	0.059	0.77	0.656	5.48	5.513
GPK3-INJ19	27/06/03 21:00	25100	88.2	15.10	3120	1100	*n.a.*	< 0.5	0.082	0.69	0.624	6.18	5.530
GPK3-INJ20	28/06/03 09:00	23800	82.4	14.50	2900	1030	*n.a.*	< 0.25	0.083	0.63	0.567	4.33	6.003
GPK3-INJ21	28/06/03 21:00	22500	78.9	13.10	2680	956	*n.a.*	< 0.25	0.038	0.61	0.518	4.95	5.954
GPK3-INJ22	29/06/03 09:00	21300	75.2	15.80	2610	921	*n.a.*	< 0.25	0.023	0.48	0.477	6.20	4.851
GPK3-INJ23	29/06/03 21:00	20500	71.5	11.85	2430	894	*n.a.*	< 0.25	0.010	0.43	0.433	4.92	5.256
GPK3-INJ24	**30/06/03 21:00**	**13200**	**47.6**	**9.21**	**1630**	**572**	***n.a.***	**< 0.25**	**0**	**0.19**	**0.297**	**5.45**	**4.977**
GPK3-INJ26	01/07/03 09:00	14500	53.0	10.60	1770	610	*n.a.*	< 0.5	0.016	0.27	0.428	0.13	0.258
GPK3-INJ27	01/07/03 21:00	15600	55.6	10.50	1870	636	*n.a.*	< 0.25	0.063	0.39	0.345	< 0.25	0.411
GPK3-INJ28	02/07/03 09:00	16300	58.7	10.75	1970	683	*n.a.*	< 0.25	0	0.52	0.254	4.72	4.180
GPK3-INJ29	02/07/03 21:00	17000	61.5	11.90	2050	722	*n.a.*	< 0.25	0	0.38	0.309	3.06	4.202
GPK3-INJ30	03/07/03 09:00	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	< 0.25	0	0.25	0.310	3.82	3.837
GPK3-INJ31	**03/07/03 21:00**	**23800**	**85.6**	**17.50**	**2910**	**1060**	***n.a.***	**< 0.25**	**0**	**0.54**	**0.479**	**3.49**	**3.690**
GPK3-INJ32	04/07/03 09:00	28600	101	18.70	3390	1300	*n.a.*	< 0.25	0	0.50	0.612	3.44	4.148
GPK3-INJ33	04/07/03 21:00	26900	98.6	20.40	3240	1200	*n.a.*	< 0.25	0	0.40	0.529	3.98	3.856
GPK3-INJ34	05/07/03 09:00	28700	104	19.30	3360	1250	*n.a.*	< 0.25	0.088	0.53	0.596	3.73	3.052
GPK3-INJ35	05/07/03 21:00	28900	106	20.20	2200	1440	*n.a.*	*n.a.*	0.035	*n.a.*	0.537	*n.a.*	2.444
GPK3-INJ36	06/07/03 09:00	31300	109	19.70	2320	1430	*n.a.*	< 0.25	0.024	0.61	0.586	0.48	0.557
GPK3-INJ37	06/07/03 21:00	25600	92.6	18.40	2340	1260	*n.a.*	< 0.25	0.020	0.54	0.478	0.45	0.510
GPK3-INJ38	07/07/03 09:00	24700	90.2	15.20	2220	1090	*n.a.*	< 0.25	0.024	0.36	0.460	0.52	0.460
GPK3-INJ39	07/07/03 21:00	28200	99.1	20.50	2590	1370	*n.a.*	< 0.25	0.059	0.49	0.486	0.55	0.544
GPK3-INJ40	08/07/03 09:00	29700	104	19.10	2540	1335	*n.a.*	< 0.25	0.054	0.58	0.519	0.69	0.638
GPK3-INJ41	08/07/03 21:00	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	0.102	*n.a.*	0.703	*n.a.*	4.141
GPK3-INJ42	**09/07/03 21:00**	**34600**	**126**	**23.10**	**3100**	**1650**	**< 0.01**	**< 0.25**	**0.042**	**0.61**	**0.594**	**2.85**	**4.024**

n.a. : not analyzed

Table 1 - Concentrations of some chemical species and organic tracers in the fluids injected into the wells GPK-2 and GPK-3 (from 27/05 to 9/07/2003).

Sample	Date	Density	Cond. (25°C) mS/cm	pH	Cl mg/kg	Ca mg/kg	Alk. meq/l	SiO_2 mg/l	1,5-nds (BRGM) mg/l	1,5-nds (EGI) mg/l	Na-benz. (BRGM) mg/l	2,7-nds (BRGM) mg/l	2,7-nds (EGI) mg/l	1,6-nds (BRGM) mg/l	1,6-nds (EGI) mg/l
GPK2-P1	11/06/03 21:00	1.0220	52.9	6.41	19940	2192	*n.a.*	*n.a.*	0.07	0.082	0.21	0.75	0.819	0.28	0.346
GPK2-P2	12/06/03 09:00	1.0250	59.1	5.80	22804	2481	*n.a.*	*n.a.*	0.06	0.079	0.14	0.71	0.755	0.28	0.272
GPK2-P3	12/06/03 21:00	1.0270	63.1	5.80	23780	2628	*n.a.*	*n.a.*	0.03	0.080	0.14	0.71	0.721	0.29	0.285
GPK2-P4	13/06/03 09:00	1.0270	64.7	5.82	24655	2697	*n.a.*	*n.a.*	0.05	0.080	0.13	0.69	0.715	0.29	0.264
GPK2-P5	13/06/03 21:00	1.0280	65.6	5.57	24838	2761	*n.a.*	*n.a.*	0.10	0.081	0.15	0.69	0.753	0.29	0.309
GPK2-P6	14/06/03 09:00	1.0305	71.6	5.83	28015	3089	*n.a.*	*n.a.*	0.07	0.086	0.17	0.75	0.785	0.34	0.317
GPK2-P7	14/06/03 21:00	1.0290	68.1	5.63	26151	2898	*n.a.*	*n.a.*	0.08	0.083	0.14	0.66	0.711	0.27	0.274
GPK2-P8	15/06/03 09:00	1.0290	67.4	5.63	26428	2904	*n.a.*	*n.a.*	0.08	0.087	0.11	0.71	0.705	0.30	0.321
GPK2-P9	15/06/03 21:00	1.0290	67.7	5.74	26460	2851	*n.a.*	*n.a.*	0.08	0.083	0.15	0.71	0.724	0.31	0.292
GPK2-P10	16/06/03 09:00	1.0295	68.4	5.64	27558	2898	*n.a.*	*n.a.*	0.07	0.085	0.14	0.73	0.706	0.30	0.312
GPK2-P11	16/06/03 21:00	1.0295	68.8	5.65	26605	2902	*n.a.*	*n.a.*	0.09	0.085	0.15	0.79	0.709	0.39	0.321
GPK2-P12	24/06/03 17:00	1.0250	63.6	5.79	26684	*n.a.*	3.19	150	0.08	0.090	0.19	0.75	0.783	0.40	0.451
GPK2-P13	25/06/03 08:00	1.0250	65.0	6.81	30693	*n.a.*	2.38	*n.a.*	0.08	0.089	0.12	0.78	0.808	0.40	0.399
GPK2-P14	25/06/03 18:00	1.0320	69.0	6.16	28547	*n.a.*	*n.a.*	210	0.12	0.089	0.18	0.68	0.716	0.38	0.360
GPK2-P15	26/06/03 08:00	1.0300	70.2	6.78	29642	*n.a.*	1.61	203	0.09	0.087	0.17	0.64	0.722	0.37	0.353
GPK2-P16	26/06/03 22:00	1.0340	72.0	5.96	29474	*n.a.*	1.37	248	0.10	0.089	0.16	0.69	0.711	0.37	0.426
GPK2-P17	27/06/03 08:00	1.0320	70.5	5.96	29782	*n.a.*	1.69	240	0.09	*n.a.*	*n.a.*	0.60	*n.a.*	0.40	*n.a.*
GPK2-P18	27/06/03 09:00	1.0345	72.2	6.15	29582	3255	1.35	*n.a.*	0.11	0.087	0.18	0.62	0.685	0.35	0.399
GPK2-P19	27/06/03 21:00	1.0345	73.0	5.56	29663	3262	1.01	*n.a.*	0.13	0.085	0.18	0.62	0.650	0.38	0.401
GPK2-P20	28/06/03 09:00	1.0345	74.0	5.66	29414	3242	1.30	*n.a.*	0.12	0.084	0.18	0.61	0.633	0.41	0.411
GPK2-P21	28/06/03 21:00	1.0345	74.0	5.43	30360	3207	1.24	*n.a.*	0.09	0.083	0.17	0.61	0.623	0.41	0.437
GPK2-P22	29/06/03 09:00	1.0345	72.8	5.78	30361	3241	1.20	*n.a.*	0.09	0.084	0.18	0.62	0.619	0.48	0.463
GPK2-P23	29/06/03 21:00	1.0345	73.3	5.36	29333	3201	0.96	*n.a.*	0.08	0.081	0.19	0.59	0.594	0.54	0.468
GPK2-P24	30/06/03 09:00	1.0230	52.5	7.23	19938	2269	2.89	231	0.09	0.072	0.01	0.61	0.411	0.50	0.507
GPK2-P25	30/06/03 21:00	1.0350	74.6	5.27	29871	3289	1.21	*n.a.*	0.09	0.081	0.21	0.58	0.579	0.37	0.520
GPK2-P26	01/07/03 09:00	1.0350	75.0	5.39	29977	3308	1.48	225	0.12	0.081	0.17	0.57	0.579	0.54	0.554
GPK2-P27	01/07/03 21:00	1.0415	75.2	6.45	33649	3802	1.19	231	0.09	0.087	0.05	0.62	0.671	0.64	0.673
GPK2-P28	02/07/03 21:00	1.0345	75.1	5.62	29617	3277	1.38	250	*n.a.*	0.082	0.23	*n.a.*	0.541	*n.a.*	0.627
GPK2-P29	03/07/03 21:00	1.0355	75.7	5.78	30345	3254	2.28	*n.a.*	0.10	0.080	0.19	0.52	0.541	0.71	0.763
GPK2-P30	04/07/03 09:00	1.0355	74.3	5.70	30196	3274	2.27	*n.a.*	0.10	0.081	0.17	0.54	0.552	0.70	0.744
GPK2-P31	04/07/03 21:00	1.0355	74.8	5.51	30762	3225	2.48	*n.a.*	0.09	0.080	0.16	0.54	0.565	0.73	0.788
GPK2-P32	05/07/03 09:00	1.0360	74.8	5.67	30563	3243	2.33	*n.a.*	0.11	0.080	0.17	0.54	0.535	0.77	0.794
GPK2-P33	05/07/03 21:00	1.0360	74.8	5.63	31212	3234	2.13	*n.a.*	0.13	0.078	0.16	0.61	0.559	0.88	0.831
GPK2-P34	06/07/03 09:00	1.0360	75.3	5.71	30903	3263	2.09	*n.a.*	0.12	0.079	0.19	0.51	0.553	0.80	0.861
GPK2-P35	06/07/03 21:00	1.0360	76.1	5.54	31409	3243	1.80	*n.a.*	0.09	0.078	0.16	0.51	0.530	0.82	0.885
GPK2-P36	07/07/03 09:00	1.0365	77.5	5.73	31349	3338	1.94	240	0.09	0.081	0.12	0.51	0.538	0.83	0.913
GPK2-P37	07/07/03 21:00	1.0370	75.9	5.52	31159	3298	1.71	*n.a.*	0.10	0.080	0.17	0.53	0.540	0.87	0.929
GPK2-P38	08/07/03 09:00	1.0355	75.5	5.70	31259	3341	1.75	225	0.08	0.078	0.18	0.50	0.525	0.85	0.897
GPK2-P39	08/07/03 21:00	1.0380	75.3	5.68	31314	3295	1.62	212	0.10	0.079	0.18	0.49	0.509	0.86	0.911
GPK2-P40	09/07/03 09:00	1.0350	75.0	5.68	31489	3304	1.65	*n.a.*	0.12	0.078	0.18	0.49	0.516	0.85	0.881
GPK2-P41	09/07/03 21:00	1.0390	77.9	5.61	31477	3263	1.56	*n.a.*	0.08	0.077	0.19	0.51	0.527	0.85	0.878
GPK2-P42	09/07/03 23:45	1.0395	78.0	5.67	31400	3329	2.05	*n.a.*	0.13	0.079	0.19	0.49	0.525	0.86	0.897

Sample	Date	Geothermal brine (Cl) %	Geothermal brine (Ca) %	Fresh water injected in 2000 (1,5-nds BRGM) %	Fresh water injected in 2000 (1,5-nds EGI) %	Fresh water injected in 2000 (Na-benzoate) %	Fresh water injected in 2003 (2,7-nds BRGM) %	Fresh water injected in 2003 (2,7-nds EGI) %	Fluid injected into GPK-3 (1,6-nds BRGM) %	Fluid injected into GPK-3 (1,6-nds EGI) %
GPK2-P1	11/06/03 21:00	36.59	35.35	4.09	4.81	9.33	25.05	27.34	10.11	12.67
GPK2-P2	12/06/03 09:00	41.84	40.02	3.75	4.63	6.17	23.72	25.29	10.21	9.99
GPK2-P3	12/06/03 21:00	43.63	42.39	1.53	4.68	6.55	23.90	24.20	10.60	10.50
GPK2-P4	13/06/03 09:00	45.24	43.50	2.70	4.72	5.94	23.29	23.98	10.67	9.73
GPK2-P5	13/06/03 21:00	45.57	44.53	5.87	4.77	6.78	23.31	25.30	10.76	11.39
GPK2-P6	14/06/03 09:00	51.40	49.82	4.00	5.06	7.70	25.32	26.43	12.48	11.70
GPK2-P7	14/06/03 21:00	47.98	46.74	4.47	4.88	6.48	22.19	23.92	10.11	10.10
GPK2-P8	15/06/03 09:00	48.49	46.84	4.82	5.10	4.86	23.74	23.69	11.14	11.82
GPK2-P9	15/06/03 21:00	48.55	45.99	4.82	4.88	6.86	23.81	24.34	11.36	10.78
GPK2-P10	16/06/03 09:00	50.57	46.75	4.35	5.03	6.54	24.49	23.74	11.14	11.49
GPK2-P11	16/06/03 21:00	48.82	46.81	5.29	5.00	6.98	26.51	23.86	14.24	11.83
GPK2-P12	24/06/03 17:00	48.96		4.57	5.28	8.62	25.26	26.22	14.55	16.57
GPK2-P13	25/06/03 08:00	56.32		4.92	5.20	5.42	26.13	27.06	14.70	14.67
GPK2-P14	25/06/03 18:00	52.38		7.19	5.22	8.05	22.80	24.15	14.06	13.30
GPK2-P15	26/06/03 08:00	54.39		5.53	5.10	7.82	21.54	24.31	13.73	13.04
GPK2-P16	26/06/03 22:00	54.08		6.14	5.24	7.56	23.32	24.04	13.64	15.80
GPK2-P17	27/06/03 08:00	54.65		5.31			20.30	*n.d.*	14.80	
GPK2-P18	27/06/03 09:00	54.28	52.50	6.50	5.16	8.23	21.10	23.15	12.98	14.78
GPK2-P19	27/06/03 21:00	54.43	52.62	7.45	5.01	8.36	20.96	21.98	14.02	14.86
GPK2-P20	28/06/03 09:00	53.97	52.29	6.98	4.96	8.39	20.55	21.40	15.05	15.24
GPK2-P21	28/06/03 21:00	55.71	51.73	5.32	4.91	7.79	20.62	21.05	15.20	16.21
GPK2-P22	29/06/03 09:00	55.71	52.28	5.20	4.98	8.41	20.96	20.93	17.72	17.15
GPK2-P23	29/06/03 21:00	53.82	51.62	4.61	4.78	8.52	20.08	20.08	20.17	17.33
GPK2-P24	30/06/03 09:00	36.58	36.59	5.38	4.24	0.32	20.29	13.75	18.33	18.58
GPK2-P25	30/06/03 21:00	54.81	53.05	5.22	4.79	9.86	19.61	19.57	13.89	19.28
GPK2-P26	01/07/03 09:00	55.00	53.36	7.33	4.78	7.64	19.14	19.59	20.03	20.57
GPK2-P27	01/07/03 21:00	61.74	61.33	5.36	5.15	2.40	21.17	22.84	18.23	18.93
GPK2-P28	02/07/03 21:00	54.34	52.85		4.83	10.68		18.30		17.78
GPK2-P29	03/07/03 21:00	55.68	52.49	6.15	4.74	8.75	17.46	18.31	20.01	21.74
GPK2-P30	04/07/03 09:00	55.41	52.80	5.92	4.79	7.77	18.34	18.69	20.04	21.28
GPK2-P31	04/07/03 21:00	56.44	52.02	5.33	4.71	7.41	18.34	19.13	20.78	22.01
GPK2-P32	05/07/03 09:00	56.08	52.31	6.28	4.71	7.76	18.28	18.12	21.71	22.38
GPK2-P33	05/07/03 21:00	57.27	52.15	7.41	4.60	7.55	20.58	18.93	24.99	23.40
GPK2-P34	06/07/03 09:00	56.70	52.62	6.87	4.66	8.88	17.13	18.74	22.70	24.21
GPK2-P35	06/07/03 21:00	57.63	52.31	5.56	4.60	7.37	17.27	17.93	23.08	24.81
GPK2-P36	07/07/03 09:00	57.52	53.84	5.45	4.80	5.48	17.28	18.22	23.29	25.42
GPK2-P37	07/07/03 21:00	57.17	53.19	6.16	4.74	7.85	17.89	18.31	24.08	25.69
GPK2-P38	08/07/03 09:00	57.36	53.89	4.50	4.59	8.39	16.92	17.77	22.92	24.74
GPK2-P39	08/07/03 21:00	57.46	53.14	5.69	4.69	8.17	16.69	17.27	23.73	25.20
GPK2-P40	09/07/03 09:00	57.78	53.30	6.98	4.61	8.50	16.57	17.47	23.99	23.93
GPK2-P41	09/07/03 21:00	57.76	52.63	4.99	4.58	8.77	17.45	17.88	23.12	23.74
GPK2-P42	09/07/03 23:45	57.61	53.69	7.48	4.67	8.85	16.65	17.82	22.49	23.36

Table 2 - Results obtained during the geochemical monitoring of the fluid discharged from GPK-2 (from 11/06 to 9/07/2003) and estimations of the proportions of injected fresh water and geothermal brine in this fluid.

Fluid sample	Date	Type of fluid	Injection flow rate (l/s)	T °C	Density	Cond. (25°C) mS/cm	pH	Eh mv	O_2 %	Alk. meq/l	Cl mg/kg	Ca mg/kg	SiO_2 mg/l	1,5-nds (BRGM) µg/l	1,5-nds (EGI) µg/l	2,7-nds (BRGM) µg/l	2,7-nds (EGI) µg/l	1,6-nds (BRGM) µg/l	1,6-nds (EGI) µg/l
GPK3-04-I1	17/08/04 11:45	mixing	11.8	17	1.020	51.0	7.35	197	61	2.66	19390	1146	25	24.5	*n.a.*	124	*n.a.*	232	*n.a.*
GPK3-04-I2	17/08/04 19:05	mixing	11.8	20	1.025	49.9	7.70	189	90	2.10	18827	1279	*n.a.*	24.0	24.0	120	115	228	219
GPK3-04-I3	18/08/04 08:30	mixing	11.8	18	1.019	50.6	7.70	208	93	2.15	18486	1312	22	27.4	25.3	126	115	237	219
GPK3-04-I4	18/08/04 12:15	mixing	11.8	22	1.021	50.4	7.60	187	97	*n.a.*	19347	1336	*n.a.*	26.9	*n.a.*	128	*n.a.*	249	*n.a.*
GPK3-04-I5	18/08/04 19:11	mixing	11.8	21	1.020	52.0	7.51	131	90	*n.a.*	20769	1373	*n.a.*	34.2	*n.a.*	140	*n.a.*	262	*n.a.*
GPK3-04-I6	19/08/04 08:30	mixing	11.8	19	1.020	54.8	7.20	149	95	2.71	21166	1643	25	41.5	35.9	174	163	344	313
GPK3-04-I7	19/08/04 11:31	mixing	11.8	24	1.018	56.1	7.34	177	98	*n.a.*	21975	1600	*n.a.*	42.5	*n.a.*	190	*n.a.*	373	*n.a.*
GPK3-04-I8	19/08/04 19:15	mixing	11.8	23	1.020	56.3	7.36	182	97	*n.a.*	23080	1760	*n.a.*	42.5	*n.a.*	196	*n.a.*	370	*n.a.*
GPK3-04-I9	20/08/04 08:30	Fresh water	11.8	23	0.998	3.5	7.35	95	72	1.93	1079	121	*n.a.*	0.89	0.97	< 0.4	*n.a.*	< 0.4	*n.a.*
GPK3-04-I10	20/08/04 13:40	Fresh water	11.8	23	0.998	2.9	7.33	145	73	*n.a.*	954	106	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*
GPK3-04-I11	20/08/04 19:40	Fresh water	11.8	24	0.998	2.0	7.59	139	80	*n.a.*	539	83.1	5.9	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*
GPK3-04-I12	21/08/04 09:00	Fresh water	11.8	17	0.998	1.7	7.30	195	62	1.59	462	69.4	*n.a.*	0.2<x<0.5	0.18	0.4<x<1.0	0.32	0.4<x<1.0	0.27
GPK3-04-I13	21/08/04 13:45	Fresh water	11.8	20	0.998	1.6	7.33	184	62	*n.a.*	446	68.3	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*
GPK3-04-I14	21/08/04 19:40	Fresh water	11.8	19	0.998	1.8	7.33	150	62	*n.a.*	472	87.9	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*
GPK3-04-I15	22/08/04 12:40	Fresh water	17.8	18	0.998	1.8	7.31	136	70	2.92	472	99.7	5.9	0.2<x<0.5	0.20	0.4<x<1.0	0.33	0.4<x<1.0	0.13
GPK3-04-I16	22/08/04 19:40	Fresh water	17.8	20	0.998	2.0	7.38	177	76	*n.a.*	539	102	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*
GPK3-04-I17	23/08/04 08:45	Fresh water	23.8	22.5	0.998	2.2	7.32	195	72	2.45	589	99.9	5.7	0.2<x<0.5	*n.a.*	0.4<x<1.0	*n.a.*	0.4<x<1.0	*n.a.*

n.a.: not analyzed

Table 3a - Results obtained during the geochemical monitoring of the fluid injected into GPK-3 (from 17/08 to 23/08/2004).

Fluid sample	Date	$T_{sampling}$ °C	T_{labo} °C	Density	Cond. (25°C) mS/cm	pH	Eh mv	O_2 %	Cl mg/kg	Ca mg/kg	Alk. meq/l	SiO_2 mg/l	1,5-nds (BRGM) µg/l	1,5-nds (EGI) µg/l	2,7-nds (BRGM) µg/l	2,7-nds (EGI) µg/l	1,6-nds (BRGM) µg/l	1,6-nds (EGI) µg/l	2,6-nds (BRGM) µg/l
GPK3-04-P1	28/08/04 10:00	18.7	23.3	0.998	2.1	6.33	-14.3	9	618	97	2.24	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*
GPK3-04-P2	28/08/04 11:30		26.5		2.1	6.26	-34.2	13	645	121	1.93	104	< 0.2	0.36	< 0.4	0.52	< 0.4	0.32	*n.a.*
GPK3-04-P3	28/08/04 18:00	18.7	20.8		47.2	5.57	42.4	54	18596	1748	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*
GPK3-04-P4	28/08/04 00:00		20.8		47.6	5.56	40.9	53	18238	1804	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*
GPK3-04-P5	29/08/04 06:00		20.8		48.7	5.92	25.6	58	18994	1792	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*
GPK3-04-P6	29/08/04 11:00	119.3	20.3	1.020	48.9	6.20	-9.3	49	19259	1838	2.72	246	14.9	16.2	71.2	61.3	547	481	*n.a.*
GPK3-04-P7	29/08/04 18:00		20.2		50.5	5.44	70.4	65	18479	1926	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*
GPK3-04-P8	29/08/04 00:00		20.2		51.1	5.72	58.5	78	20244	2017	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*
GPK3-04-P9	30/08/04 06:00		20.2		53.5	5.59	59.2	77	20760	1928	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*
GPK3-04-P10	30/08/04 12:00	123.0	24.7	1.019	54.2	5.24	-20	16	22091	2025	*n.a.*	264	17.1	24.9	84.0	72.3	599	487	*n.a.*
GPK3-04-P11	30/08/04 18:00		19.1		56.0	5.26	-4.7	38	22449	2081	2.69	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*
GPK3-04-P12	30/08/04 00:00		20.1		57.3	5.40	86.2	73	21480	2103	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*
GPK3-04-P13	31/08/04 06:00	121.0	21.3		57.6	5.53	54.3	84	21803	2200	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*
GPK3-04-P14	31/08/04 09:00		21.3	1.019	57.8	5.75	23.4	68	22837	2246	2.67	*n.a.*	25.0	22.7	95.6	79.8	696	499	*n.a.*
GPK3-04-P15	19/09/04 13:07		20.5		63.1	5.88	*n.a.*	*n.a.*	25330	*n.a.*	2.55	*n.a.*	22.4	*n.a.*	121	*n.a.*	880	*n.a.*	< 10
GPK3-04-P16	20/09/04 00:00		20.2		70.1	5.61	*n.a.*	*n.a.*	28368	*n.a.*	2.52	*n.a.*	20.1	*n.a.*	112	*n.a.*	909	*n.a.*	< 10
GPK3-04-P17	20/09/04 11:55		20.5		70.7	5.86	*n.a.*	*n.a.*	28726	*n.a.*	2.42	*n.a.*	24.2	*n.a.*	135	*n.a.*	954	*n.a.*	< 10

n.a.: not analyzed

Table 3b - Results obtained during the geochemical monitoring of the fluid discharged from GPK-3 (from 28/08 to 31/08/2004 and from 19/09 to 20/09/2004).

Fluid sample	Date	Depth (m)	T_{WH} °C	$T_{meas.}$	Cond. 25°C (mS/cm)	pH	K mg/l	Ca mg/l	Mg mg/l	SiO_2 mg/l	Cl g/l	SO_4 mg/l	Li mg/l	Br mg/l	B mg/l
GPK4-03-P1	01/11/03	1804	68	22.8	31.4	7.59	*n.a.*	*n.a.*	*n.a.*	*n.a.*	11.39	*n.a.*	*n.a.*	*n.a.*	*n.a.*
GPK4-03-P2	04/11/03 16:40	1946	38	22.8	120.7	6.55	1870	3730	33.0	37.6	54.69	252	87.2	130	17.2

Fluid sample	Date	Depth (m)	Na-benzoate µg/l	1,5-nds (BRGM) µg/l	1,5-nds (EGI) µg/l	2,7-nds (BRGM) µg/l	2,7-nds (EGI) µg/l	1,6-nds (BRGM) µg/l	1,6-nds (EGI) µg/l
GPK4-03-P1	01/11/03	1804	< 15	< 5	2.2	< 25	41.5	244	231
GPK4-03-P2	04/11/03 16:40	1946	80	< 10	*n.a.*	< 50	*n.a.*	266	*n.a.*

n.a.: not analyzed

Table 4 - Chemical composition (pH, K, Ca, Mg, Cl, SO_4, SiO_2, Li, Br, B and organic tracers) of two fluid samples collected at depths of 1,804 and 1,946 m during the drilling of the well GPK-4. Major and trace species were analyzed using classical techniques (titration, ion chromatography, colorimetry, atomic absorption spectrometry, ICP-MS). Relative analytical uncertainty is lower than 5% for major species and lower than 15% for trace species.

Fluid sample	Date	Depth (m)	Cond. 25°C (mS/cm)		pH		Na g/l		K mg/l		Ca mg/l		Mg mg/l		Cl g/l		Li mg/l	
Drilling mud			In	Out	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out
GPK4-04-P1	17/02/04 09:00	4825	93.7	95.0	10.68	8.25	23.10	23.30	873	1020	1550	1840	< 2	66.5	38.798	39.345	47.5	56.4
GPK4-04-P2	18/02/04 09:00	4873	111.3	114.9	8.61	8.46	28.70	30.00	1070	1090	1760	1820	29.5	40.3	47.893	49.373	58.6	60.6
GPK4-04-P3	19/02/04 09:00	4905	111.8	117.0	11.51	11.89	29.50	31.80	970	972	1420	1510	< 2	< 2	47.855	50.875	51.9	52.4
GPK4-04-P4	22/02/04 09:00	4934	107.4	108.4	11.09	11.53	28.40	28.80	826	816	1200	1170	2.4	< 2	45.856	46.337	44.7	44.9
GPK4-04-P5	25/02/04 05:15	4960	114.6	111.9	11.99	11.94	30.90	29.90	759	789	985	1060	< 2	< 2	49.328	47.908	41.2	42.0
GPK4-04-P6	25/02/04 16:40	4970	109.5	111.7	9.40	11.01	29.00	30.20	717	750	933	969	81.1	< 2	46.442	48.431	39.9	41.2
GPK4-04-P7	27/02/04 11:30	4980	108.6	107.8	9.07	9.84	29.70	28.80	698	678	983	907	9.4	< 2	46.746	46.487	40.3	39.5
INFLUX	29/02/04 09:30			118.2		6.15		28.50		1720		3300		478		51.707		96.7
CO_2 4% circulation	04/03/04 09:00			117.9		6.02		26.90		2140		4820		658		51.997		129
GPK4-04-P8	08/03/04 12:00	5020	116.9	111.7	10.35	9.93	29.40	27.70	1440	1470	2550	2540	3.0	< 2	51.355	48.552	87.4	84.7
GPK4-04-P9	10/03/04 09:45	5060	121.2	121.5	9.75	10.83	31.50	31.40	1390	1420	2250	2370	33.6	< 2	52.686	53.444	79.3	81.1
GPK4-04-P10	05/04/04 11:00	5115		107.9		7.11		27.68		1262		1620		< 5		45.629		56.9
GPK4-04-P11	06/04/04	5142	131.5	130.2	11.67	10.71	35.47	36.04	1154	1169	1422	1430	< 5	< 5	57.921	57.891	53.4	53.3
GPK4-04-P12	08/04/04	5172	141.6	136.4	10.95	10.82	40.09	38.44	1145	1118	1051	1331	< 5	< 5	63.833	61.697	53.2	52.5
GPK4-04-P13	09/04/04	5181	142.1	139.8	10.86	10.70	40.60	38.87	1087	1130	1253	1257	< 5	< 5	64.059	63.942	52.5	50.7
GPK4-04-P14	10/04/04	5220	136.7	138.5	6.80	7.45	37.40	38.53	1101	1085	1208	1199	< 5	< 5	61.898	63.086	50.3	52.7
GPK4-04-P15	11/04/04	5259		139.0		8.26		37.71		1062		1026	< 5	< 5		63.523		51.9

Fluid sample	Date	Depth (m)	1,5-nds (BRGM) µg/l		1,5-nds (EGI) µg/l		2,7-nds (BRGM) µg/l		2,7-nds (EGI) µg/l		1,6-nds (BRGM) µg/l		1,6-nds (EGI) µg/l	
Drilling mud			In	Out	In	Out	In	Out	In	Out	In	Out	In	Out
GPK4-04-P1	17/02/04 09:00	4825	13	< 10	38	0	44	32	54	24	113	90	93	99
GPK4-04-P2	18/02/04 09:00	4873	18	< 10	0	0	35	29	48	31	93	80	107	57
GPK4-04-P3	19/02/04 09:00	4905	15	< 10	0	41	48	31	47	49	104	92	105	95
GPK4-04-P4	22/02/04 09:00	4934	14	< 10	0	0	43	34	54	50	109	94	117	100
GPK4-04-P5	25/02/04 05:15	4960	14	< 10	0	0	43	36	56	57	114	97	120	106
GPK4-04-P6	25/02/04 16:40	4970	17	< 10	0	0	50	30	57	57	111	104	122	108
GPK4-04-P7	27/02/04 11:30	4980	14	< 10	0	0	39	37	54	59	112	106	119	109
INFLUX	29/02/04 09:30			< 10		0		< 20		45		81		80
CO_2 4% circulation	04/03/04 09:00			< 10		*n.a.*		< 20		30		60		81
GPK4-04-P8	08/03/04 12:00	5020	13	< 10	0	0	37	25	37	46	81	74	83	84
GPK4-04-P9	10/03/04 09:45	5060	11	< 10	0	0	38	24	42	37	87	69	82	61
GPK4-04-P10	05/04/04 11:00	5115		27		*n.a.*		104		*n.a.*		253		*n.a.*
GPK4-04-P11	06/04/04	5142	30	26	*n.a.*	*n.a.*	91	79	*n.a.*	*n.a.*	211	213	*n.a.*	*n.a.*
GPK4-04-P12	08/04/04	5172	33	10<x<25	*n.a.*	*n.a.*	78	82	*n.a.*	*n.a.*	223	230	*n.a.*	*n.a.*
GPK4-04-P13	09/04/04	5181	10<x<25	10<x<25	*n.a.*	*n.a.*	72	76	*n.a.*	*n.a.*	202	205	*n.a.*	*n.a.*
GPK4-04-P14	10/04/04	5220	10<x<25	10<x<25	*n.a.*	*n.a.*	71	75	*n.a.*	*n.a.*	207	200	*n.a.*	*n.a.*
GPK4-04-P15	11/04/04	5259		27		*n.a.*		71		*n.a.*		195		*n.a.*

n.a.: not analyzed

Table 5 - Chemical composition (pH, Na, K, Ca, Mg, Cl, Li and organic tracers) of drilling fluid samples collected during the drilling of the well GPK-4, between 4,825 and 5,260 m (for the analytical techniques and relative uncertainties, see comments in Table 4).

Fluid sample	Sampling in the tank	Date	2,6-nds g/l
GPK4-04-C1	after mixing	21/07/04	52.6
GPK4-04-C2	after mixing	21/07/04	50.4
GPK4-04-C3	after mixing	28/08/04	55.5
GPK4-04-C4	after mixing	28/08/04	31.1
GPK4-04-C5	after mixing	30/08/04 19:00	45.1
GPK4-04-C6	after mixing	31/08/04 10:30	44.2
GPK4-04-C7	before mixing	08/09/04	18.2
GPK4-04-C8	after mixing	08/09/04	44.8
GPK4-04-C9	before mixing	09/09/04	46.7
GPK4-04-C10	after mixing	09/09/04	49.4
GPK4-04-C11	before mixing	10/09/04	39.7
GPK4-04-C12	after mixing	10/09/04	47.4

Table 6 - Analytical control of the 2,6-nds solution (50 g/l) prepared and stored in a tank of 1 m^3.

Fluid sample	Date	T °C	Type of fluid	Injection flow rate (l/s)	Density	Cond. (25°C) mS/cm	pH	Eh mv	O_2 %	Cl mg/kg	Ca mg/kg	Alk. meq/l	SiO_2 mg/l	1,5-nds µg/l	2,7-nds µg/l	1,6-nds µg/l	2,6-nds µg/l
GPK4-04-I1	08/09/04 13:15	24.3	brine	0.77	*n.a.*	*n.a.*	7.11	122	83	163725	1377	*n.a.*	*n.a.*	*n.a.*	*n.a.*	472	5310
GPK4-04-I2	08/09/04 18:30	25.3	brine	0.77	*n.a.*	*n.a.*	7.14	126	89	167425	1406	*n.a.*	12.4	*n.a.*	*n.a.*	458	8140
GPK4-04-I3	09/09/04 11:15	19.8	brine	0.77	*n.a.*	*n.a.*	7.15	157	83	167975	1425	*n.a.*	24.2	*n.a.*	*n.a.*	462	795
GPK4-04-I4	11/09/04 11:00	21.2	brine	0.77	1.880	*n.a.*	7.18	162	85	178500	1389	*n.a.*	21.2	< 20	< 40	440	< 20
GPK4-04-I5	13/09/04 13:30	20.2	brine	30	1.780	*n.a.*	7.26	166	91	148000	1300	*n.a.*	10.4	< 20	< 40	457	1866
GPK4-04-I6	13/09/04 19:15	26.2	mixing	30	1.015	26.2	7.69	176	100	10521	723	*n.a.*	13.4	*n.a.*	*n.a.*	*n.a.*	*n.a.*
GPK4-04-I7	14/09/04 08:30	19.6	mixing	30	1.010	26.3	7.51	177	100	9374	788	*n.a.*	11.5	< 20	< 40	188	1652
GPK4-04-I8	14/09/04 19:30	20.0	mixing	30	1.010	26.4	7.49	161	100	6974	580	*n.a.*	*n.a.*	< 20	< 40	< 40	1613
GPK4-04-I9	15/09/04 12:00	22.5	mixing	45	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	< 20	< 40	< 40	1616
GPK4-04-I10	15/09/04 16:00	22.5	mixing	45	1.002	3.48	7.62	170	96	1034	122	2.21	5.9	< 20	< 40	< 40	1612
GPK4-04-I11	16/09/04 08:00	18.4	mixing	30	1.001	2.41	7.69	173	82	666	98	2.26	3.5	< 20	< 40	< 40	1981
GPK4-04-I12	16/09/04 15:35	21.8	mixing	30	0.999	2.39	7.79	245	*n.a.*	758	103	2.27	*n.a.*	< 20	< 40	< 40	1922

n.a.: not analyzed

Table 7 - Results obtained during the geochemical monitoring of the fluid injected into GPK-4 (from 8/09 to 13/09/2004 and from 13/09 to 16/09/2004).