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Abstract

The deepening of the HDR GPK-2 borehole (Soultz-sous-Forêts, France) from 3880 to 5093 m gives access to an insight within a 3,6 km thick section at the top of the Soultz granite massif. More than 500 chip samples have been logged on site in order to characterize the granite petrography and to identify fracture zones. A core of fine-grained two-mica granite of 1,35 m long, collected at 5057 m depth, was evaluated. Conventional geophysical measurements (caliper log, gamma ray spectral log) and borehole image logs (UBI, ARI) were carried out on the upper granite section (3200-4600 m) and compared with the cutting analysis.

The granitic composition of the rock is well established in the upper part (3880-4860 m) where geophysical measurements were acquired. Two major fractured zones deduced from cutting analysis, were cross-cut by the well at 4580-4600 m and 4775 m.

Deeper (4860-5090 m), cutting analysis as well as core evaluation show that some petrographic facies variation occur at depth. They mainly correspond to fine-grained oriented two-mica granite, biotite-rich granite and xenolith-rich facies. The occurrence of the two-mica granite is related to a new granitic intrusion; the coexistence of biotite and primary muscovite implies that this fine-grained granite is peraluminous and thus clearly different from the magnesio-potassic calc-alkaline porphyritic standard granite.

About 100 thin-sections were evaluated that permits to check the cutting analysis done on site and to study the nature of the hydrothermal minerals (clays, carbonates).

36 X-ray diffraction analyses were carried out in order to specify the mineralogical composition of the clay minerals present. A comparison with the other hydrothermal alteration minerals encountered in other Soultz wells was also done. This deeper section of GPK-2 (3880-5093 m) shows the same secondary mineralogical phases that we already know at Soultz. In the unfractured zones, chlorite was mainly evidenced whereas in the hydrothermally altered and fractured zones, illite was present. Between 4580 and 4600 m depth, some traces of a sodium-bearing sulphate (natrojarosite) were found associated with calcite and illite. As in EPS-1 or in GPK-1, carbonates (represented mainly by calcite) were found both in fractured zones (vein alteration) and in unaltered granite facies (pervasive alteration).

The vertical thickness of the standard porphyritic granite is about 3,4 km (1420 to 4860 m) whereas the two-mica granite extends over 200 m deeper (4860-5093 m).

Content

List of figures

List of tables

List of annexes

Introduction

In the framework of the European Hot Dry Rock (HDR) project, the borehole GPK-2 was deepened from 3883 to 5093 m depth (driller reference) starting on the 15th February 1999 and completing on the 29th May 1999. As the well is slightly deviated in the deeper part, the actual vertical depth after the trajectory corrections is 5024 m (ground reference).

The Soultz site is located on the western side of the Rhine Graben at Soultz-sous-Forêts (France). The objective of this HDR project is to develop a heat exchanger within a granite massif overlain by a sedimentary cover (Baria et al., 1998). In 1995, the purpose of GPK-2 was to drill a second deep well that intersected the dominant fracture network created during the previous hydraulic experiments (Jung et al., 1995). This borehole is located about 500 m, south-south-east of GPK-1 (Figure 1).

The initial target of the deepening of GPK-2 well was to reach 4500-5000 m depth with an anticipated temperature of 195°C+-5°C. The drilling rig was supplied by ENEL. SOCOMINE assisted by Southern International Inc. acted as the operator for the drilling operations.

Geological monitoring was conducted on site by the geologists of BRGM and SWBU (Stadtwerke Bad Urach). This study was carried out as a part of BRGM scientific research programme applied to the HDR-Soultz project. The general objective of this research consists of the geological characterization of the deep granite massif dedicated to HDR experiments.

Due to borehole conditions (temperature, deviation, caves), the well logging operations were conducted at different times (10/04/99, 13/04/99, 12/05/99) in the deeper part of GPK-2 Well.

A core was taken between 5057,00 and 5059.90 m depth. During the drilling, several rock samples stuck into the roller reamers which were collected for petrographical study. They provided some direct evidences of the rock texture. These samples correspond generally to dark fine-grained xenolithes which probably are from a large cave located between 3875 and 3900 m depth.

This geological field report is organised into three different parts :

- the synthetic petrographic log of GPK-2 deduced from the examination of the chip samples in the upper part of the granitic section (3880-5093 m) as well as a petrographic core description,

- a microscopic description of thin sections of selected cutting samples as well as an interpretation of a series of X-ray diffraction patterns of selected samples,
- a first outlook of the new geophysical well loggings obtained in the granitic section (2000 - 4600 m).

GPK-2 was drilled in 8-1/2" diameter between 3880 and 5093 m (driller depth reference). The driller depth reference is based on the rotating table located at 8.80 m above the ground level (Baumgärtner et al., 1999). All the geological data (petrography, alteration, ROP, X-Ray diffraction, core) will be provided and plotted according to the driller depth references.

Schlumberger logs are depth matched according to the 9-5/8" casing shoe at 1427 m.

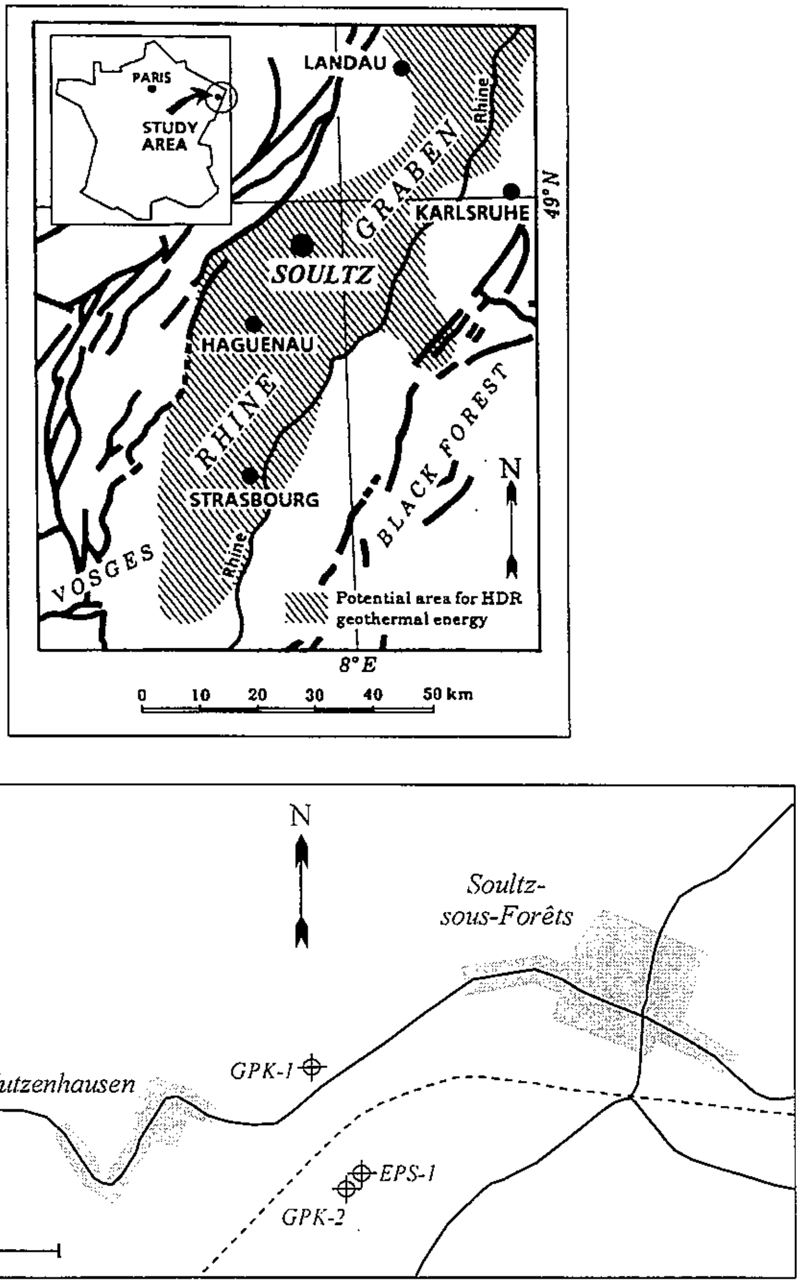

Fig. 1 - Locations of the Soultz site and the HDR borehole network

1. Synthetic petrographic log from chip samples

1.1. METHODS AND PROCEDURES

The drilled cuttings from the borehole GPK-2 were collected by ENEL every hour at two or three meter intervals from 3880 m to 5093 m. These cuttings were washed, cleaned and dried by BRGM to remove drilling mud (Ecolub), cement, iron or rust particles and lost circulation material. They were first logged in detail on site by conventional binocular microscope examination at 10-50 x magnification. Moreover, four cutting samples were packaged by BRGM as reference collection for further investigations.

Cuttings collected from GPK-2 are fine-grained, ranging between 0,1 and 1 mm with an average of about 0,5 mm. This small size hinders accurate characterization of grain size feature of coarse, medium or fine grained facies. It also prevents from recognizing fracture fillings accurately.

Because of the possible mixing of cuttings from neighbouring levels in the drilling mud during its ascent to the surface, the samples represent an average composition for a certain level. For instance, the volume of one meter long drilled section represents 36 litres for 8-1/2" borehole diameter.

Thus, examination of the chip samples can only show changes in petrographic facies and/or the type of alteration if it affects a reasonably thick layer of granite. It appears difficult to detect variations covering less than three or four meter.

The drilling rate (Rop, rate of penetration), expressed in meter per hour was not yet provided by ENEL. Therefore, an average value calculated by bit was plotted on the on-site geological log (Annex 1).

The geological data were processed with the GDM software package of BRGM as well as all the different geological profiles (geology, core description, geophysical measurements).

1.2. EXAMINATION OF CHIP SAMPLES

A binocular microscope examination of all chip samples was carried out on site.

Data log included the sample colour-facies, primary mineralogy, style and intensity of alteration and hydrothermal fillings. From the previous investigations (Genter, 1989), two alteration styles are known which occur within the Soultz granite. Pervasive (or so-called propylitic) alteration took place on a large scale within the granite without any macroscopic modification of the rock texture. Vein alteration is related to fracture zones where hydrothermal fluid circulation strongly modify the granite.

Colour : The small size of the cuttings gives a homogeneous sample colour which is a good indicator for characterizing facies variations. The colour is dark to grey, or white. No red, pink or orange colours were observed as in the upper part of GPK-2 (Genter and Tenzer, 1995).

Primary mineralogy : Abundance of quartz, K-feldspar, plagioclase and biotite was estimated providing a qualitative evaluation of the primary mineralogical content variation. According to the geological investigations previously performed on EPS-1 core sections (Genter et Traineau, 1991 and 1992), on GPK-1 cuttings (Genter and Traineau, 1993), and on GPK-2 cuttings (Genter and Tenzer, 1995), primary biotite content was used as the main indicator for showing petrographic variations and hydrothermal alteration types.

Style and intensity of alteration : Chloritization of primary biotite is used as an effective index for pervasive alteration. Primary, black coloured biotite is partially transformed into a green coloured chloritized biotite. Three degrees (weak, moderate and strong) of biotite replacement were defined.

Illitisation of primary biotite and plagioclase is used as an effective index for vein alteration. Biotite, partly chloritised, is replaced by pale yellow-green illite. Primary white coloured plagioclase is also replaced by green coloured illite. In this case, the illitised facies shows a prominent white hue.

As for chloritization, the intensity of illitisation includes three degrees (weak, moderate and strong). Hematization, developed on primary minerals (biotite, K-feldspar) and in fracture fillings, could also give evidence of vein alteration.

The occurrence of epidote, that is a hydrothermal mineral characterizing both high temperature in geothermal environment and pervasive alteration, was also described systematically.

The distinction between chlorite and illite is difficult by binocular examination because they are both green coloured minerals. X-ray diffraction patterns were carried out just after drilling and the results are integrated in this report. They are very useful for a more accurate characterization of these clay minerals. As a consequence, the alteration style deduced from the on site macroscopic examination may be regarded with caution.

1.3. PETROGRAPHY

We considered as a main assumption that the drilling of the GPK-2 borehole should cross the same granite massif as previously due to its large vertical and lateral extension. We also assumed that possible departures from the standard porphyritic granite facies should be ascribed to texture variations of the granite or vein alteration with associated fracturing.

So, petrographic units defined through the logging of the GPK-2 borehole have been tentatively correlated with rock types identified in the upper part of GPK-1 (Traineau et al, 1991), in the lower part of GPK-1 (Genter and Traineau, 1993), in the EPS-1 well (Genter and Traineau, 1992; Traineau et al., 1992) and in the upper part of GPK-2 (Genter and Tenzer, 1995). Correlation was accomplished primarily through comparison of GPK-2 chip samples with representative petrographic facies observed on the EPS-1 core sections. The following petrographic types encountered in GPK-2 between 3880 and 5093 m, listed below will be discussed : (a) standard porphyritic granite, (b) biotite-rich granite, (c) xenolith-rich granite, (d) two-mica granite, and (e) altered porphyritic granite related to fractured zones which are divided into four alteration grades (low, moderate, high and very high).

1.3.1. Standard porphyritic granite

Chip samples contain primary quartz, K-feldspar (orthoclase), plagioclase, biotite, amphibole and accessory minerals as magnetite, titanite, apatite and allanite. Their colour is dominantly grey to dark. The percentage of biotite grains is roughly estimated around 8%. This amount does not represent the true biotite content of the granite because it is probably higher in the chip samples than in the penetrated rock.

Small variations of biotite content are ascribed to slight changes in the granite texture, or to drilling features (variations in grinding at the drill bit, enrichment or impoverishment in the ascending mud column).

Individual grains, up to 1 mm long, of pink K-feldspar are indicative of the porphyritic texture of the granite. Biotite grains form well-shaped black flakes. They are sometimes partially altered to green chlorite. It is the dominant mafic constituent. Hornblende is scarcely observed in the chip samples by binocular observation, probably because it is more powdered by drill bit than biotite (Glenn et al., 1981); however green amphibole appears frequently in thin sections and is sometimes abundant. Quartz and plagioclase occur as anhedral grains. Titanite is quite common with its honey-like colour. Some white-milky minerals that could correspond to carbonates are also quite common.

1.3.2. Biotite-rich granite

Chip samples contain primary quartz, K-feldspar, plagioclase, biotite and amphibole. It is distinguished from standard porphyritic granite by its relatively high biotite content (> 25 %) leading to a darker colour. It is interpreted as reflecting textural variations like schlieren or mafic minerals rich granite. Biotite is partially replaced by secondary chlorite.

1.3.3. Xenolith-rich granite

Fragments of fine-grained xenoliths are very common from 3880 m to 5093 m depth. Their distinction is sometimes possible by binocular observation and is very easy in thin sections thanks to their small grain size (< 1 mm) and to their dark colour due to their relatively high content in mafic minerals: biotite and common green hornblende. The petrographic study of cuttings shows that are present in all the thin sections of samples collected in the following depth intervals: 4506 to 4645 m and 4744 to 4771 m. What is the size of these xenoliths ? nothing allows us to assume that their thickness does not exceed 25 cm as in the case of the EPS-1 cores.

Some rock samples were collected within the roller reamers which pulled them out from the hole wall at the following depths: about 3895 m, 4402-4085 m, 4541-4616 m. A sample from the latter interval shows even a xenolith and its enclosing standard porphyritic granite. 2 cm long pieces of xenoliths were also collected at about 4442,5 m depth.

Their microscopic study in thin sections shows petrographic characteristics which are analogous to those which were observed in EPS-1 cores. Grain size is heterogeneous: 1 to 3 mm long crystals are scattered within a 0.1 – 1 mm matrix. Texture displays frequently a planar orientation. The 1-3 mm long crystals are composed of one or several of the following minerals: plagioclase, green hornblende, biotite, rounded quartz, rare titanite. The matrix is made of (i) 25-35 % mafic minerals including green hornblende, biotite, titanite and magnetite and (ii) a assemblage of felsic minerals with variable proportions of plagioclase, K-feldspar and quartz giving a composition ranging from quartz diorite to syenite. All the samples contain apatite as countless very fine needles.

1.3.4. Two-mica granite

As described later (2.5.2), the cored part of GPK-2 is mainly made of a fine-grained two-mica granite with a planar magmatic fabric. Cross-hatched microcline and myrmekite are very interesting specific features which allow to recognise the presence of fine-grained two-mica granite in the thin sections corresponding to cuttings. In some samples the diagnosis is confirmed by the occurrence of primary muscovite flakes and/or of small pieces of fine-grained granite containing biotite and/or muscovite.

Microcline occurs in almost all the thin sections of cuttings and is relatively abundant in the lowest part of GPK-2 well, i.e. at a depth ≥ 5042 m.

1.3.5. Altered porphyritic granite related to fractured zones

The standard porphyritic granite has been more or less altered within and near fractured zones. The examination of chip samples leads to determination of four main grades of alteration and inferred fracturing. The determination of these four grades was based on the general trend to the argilization of the samples as previously stated in EPS-1 core sections and GPK-1 cuttings (Table 1). The most characteristic feature is the development of illite removing primary biotite and plagioclase. Altered granite is typically biotite free and cream-white coloured. It contains grains of colourless to pale green illite. Fragments of carbonate are sometimes observed. Occurrence of quartz veins with euhedral crystals reflects the highest grade of alteration. Some geodic quartz was observed during this geological survey. It corresponds to drilling events such as high rate of penetration value that indicate a very high alteration.

The small size of drill cuttings hinders determination of cataclasites. Therefore, the four grades of alteration probably represent the whole range of different cataclastic facies deduced from EPS-1 cores examination as breccia, microbreccia, argilised wall rock and oriented cataclasites (Genter et Traineau, 1992).

Altered porphyritic granite (low grade)

* Biotite in process of illitisation
* Plagioclase no modified

Altered granite (moderate grade)

* Biotite transformed in illite
* Plagioclase no modified

Altered granite (high grade)

* Biotite transformed in illite
* Plagioclase in process of illitisation

Altered granite (very high grade)

* Biotite transformed in illite
* Plagioclase transformed in illite
* Occurrence of geodic quartz +(total mud losses, high Rop)

Tab. 1 - Key for estimating the vein alteration grade in the altered granite facies observed in cutting samples of the GPK-2 borehole

1.4. LOG DESCRIPTION

The main objective of the on-site chip sample logging was both to recognize fractured and altered zones and significant petrographical facies variations within the Soultz granite massif while drilling was in progress and also to assist the drilling operation. The synthetic petrographic log of GPK-2 (Figure 2, Annex 1) includes all the geological data obtained from 3880 to 5093 m depth.
From a general point of view, the geological profile of Well GPK-2 could be summarised as follows:

- between 3900 and 4520 m, the well intersected an unaltered granite with a few hydrothermally altered and fractured zones. Grey-green to grey porphyritic granite facies were encountered. Quite scarce pink to reddish granite facies related to hematite were observed (4040, 4490 m). The vertical distribution of hematite seems more related to the fractures. Epidote is observed between 4200 and 4350 m depth within the unaltered granite facies. The petrographic variations encountered are dark fine grained xenolith (4080 m) and a grey two-mica granite facies observed at 4275 m depth. Between 3900 and 4520m, there is no major fractured zone. The intensity of the hydrothermal vein alteration seems quite low in the altered zones (4040, 4200-4220, 4260 ,4325, 4370, 4430, 4440, 4460 m) suggesting that the well cross-cut localised and spatially limited fractures. One cutting sample shows some geodic quartz (3940 m). The systematic occurrence of chlorite in all the samples tends to show that there is no intense hydrothermal alteration process controlled by fractures.

- between 4520 and 4860 m, the well penetrated several fractured and altered zones with the major features located between 4580 and 4600 m, and at about 4775 m. Unaltered facies is still a grey porphyritic granite but from 4720 to 4770 m, the large homogeneity of the granite is disrupted by a significant enrichment in primary fine-grained ferro-magnesian minerals (biotite, hornblende), probably due to the occurrences of numerous fine-grained dark xenoliths. In altered zones, the colour of the cuttings is grey-white, epidote is absent and chlorite too. However, numerous altered sections show low chlorite content that is thought to be related to vein alteration. Their occurrences assume that there are probably some facies mixing (fractured granite and unaltered granite) on short vertical distances. It means that cutting analysis resolution would be coarser (2 to 3 m) thanks to the petrographic variations.

- from 4860 m to the bottom depth, strong petrographical variations are evidenced and a few fractured zones are present. Epidote is present either in grey porphyritic granite and in dark-grey biotite-rich granite. Illite and hematite are quite scarce and match with the main structural features which are located at 4885, 4900, 5010, 5045 and 5060 m. Their vertical apparent thickness are quite low by comparison with the 2 major features encountered in the previous section. The grey porphyritic standard granite is not logged below 5045 m although the first sample of the cored section (5057 m) includes this facies. Some grey two-mica granite facies occur together with dark grey biotite-rich granite or grey porphyritic granite (4860 to 5045m). From 5047 to 5093 m, white-grey fine-grained two-mica granite and grey-dark biotite-rich granite occur. This deeper section seems also characterized by the occurrence of primary muscovite between 4860 and 4937 m. This overall depletion of K-feldspar has two consequences: (1) the porphyritic texture of the standard granite facies was lost, that means that some fine grained granitic rocks occur at depth and (2) a significant change in the mineralogical granite composition (some enrichment in the biotite content). In this deeper section of GPK-2, the well has penetrated a new intrusion characterized by fined grained texture and a different mineralogical composition (muscovite and biotite enrichment).

The precise characterization of the rock texture (size of the main crystals) is quite difficult to obtain with chip sample examination. Then, textural variations could occur in the upper part of the well but their analysis is quite problematic (see paragraph 2.5).

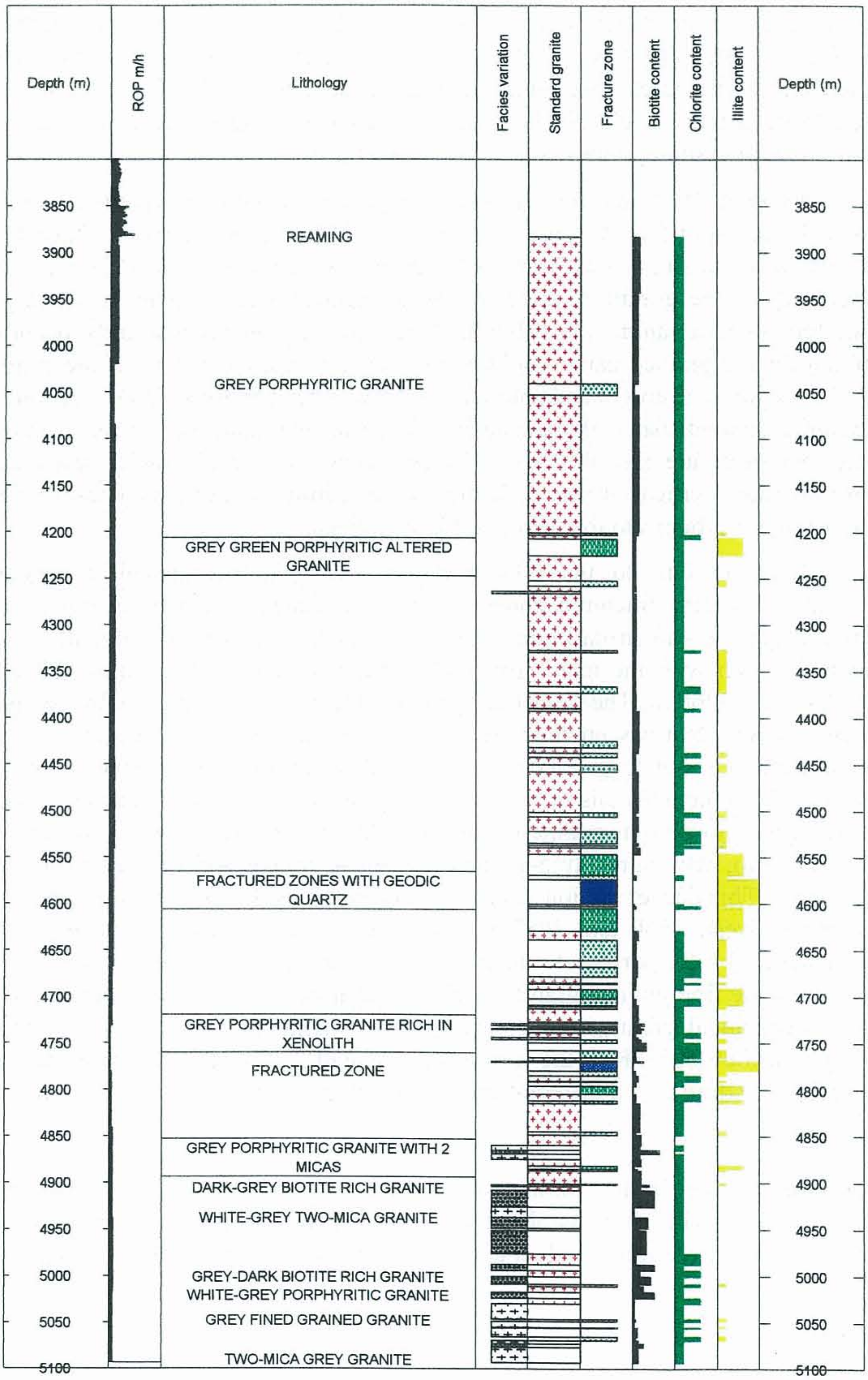

Fig. 2 - Synthetic log of GPK-2 between 3880 - 5090 m according to cutting analysis

1.5. CORE DESCRIPTION

1.5.1. Core presentation

Between 5757,00 and 5759,90 m depth, a core operation was achieved with a core barrel of 7-7/8''. About 1,35 m length of core was recovered that corresponds to a recovery rate of 47%. Sixty core pieces were identified. As it was the first and only core collected in GPK-2, this core was named K1. The core diameter is about 7 cm.

In terms of core quality, the samples are round-shaped indicating a bad quality. This assumes that during the coring, the samples in the core barrel rotated against each other, inducing a self-abrasion. A photograph of the bottom core sample is visible in annex 2.1.

Due to coring problems, it is not possible to reconstruct a clear continuous rock section within the cored interval. No reference line, useful for core reorientation, was drawn.

1.5.2. Core description

A schematic geological log of K1 is presented in Figure 3.

3 main petrographic facies can be distinguished:

At the top of the core, the first sample corresponds to a grey-pink porphyritic granite. K-feldspar crystals are pluricentimetric in size, the primary ferro-magnesian minerals (biotite, amphibole) are very dark and unaltered. The quartz-plagioclase assemblages are translucide to white coloured. There is no visible fracture or microfault as well as no vein alteration. The pervasive alteration is quite low. The most significant feature in terms of structure, is the occurrence of a preferential orientation of biotite as well as K-feldspar. This bulk foliation reflects the magma flowing during the intrusion emplacement.

Between, 5057,05 and 5057,08 m depth, a fine-grained dark coloured xenolith is present. The finest minerals are mainly biotite and amphibole. The white half centimetric minerals are K-feldspar. There is no apparent foliation, no vein alteration and no fracture. This fined-grained rock is a very unaltered rock.

Between 5057,08 and the bottom of the cored section, a fine-grained grey to green two-mica granite occurs. This facies is characterized by a clear preferential orientation of biotite. If we assume that the coring axis is close to the vertical, the foliation is nearly horizontal. The fracture content is quite low. Two small filled-joints were observed probably filled with calcite and greenish minerals (chlorite?). There is no major fault and no vein alteration.

The dominant facies seems affected by a core disking, that would be perpendicular to the borehole axis. The core disking induced by relaxation process could also explain why the quality of the cored samples is in bad-shape.

The petrographic study of the corresponding thin section shows hypidiomorphic texture and a grain size ranging between 0.1 and 2 mm with an average of 0.5-0.6 mm. The composition is typically granitic with about the same proportions of quartz, K-feldspar and plagioclase. The biotite content is about 10 % and the primary muscovite content 1-2 %.

K-feldspar crystals are anhedral to subhedral and display the cross-hatch twinning which is specific of microcline. Plagioclase is euhedral to subhedral, opacified by clay alteration minerals, and sometimes myrmekitic at the contact with microcline. Quartz is anhedral, more or less recrystallized and displays undulatory extinction. Biotite is rarely fresh, mainly altered into green chlorite plus sometimes epidote. Primary muscovite is associated with biotite or not. Secondary white mica occurs as a alteration mineral on some plagioclase crystals.

The presence of both biotite and primary muscovite implies that this granite is peraluminous and thus clearly different from the magnesio-potassic calc-alkaline porphyritic standard granite.

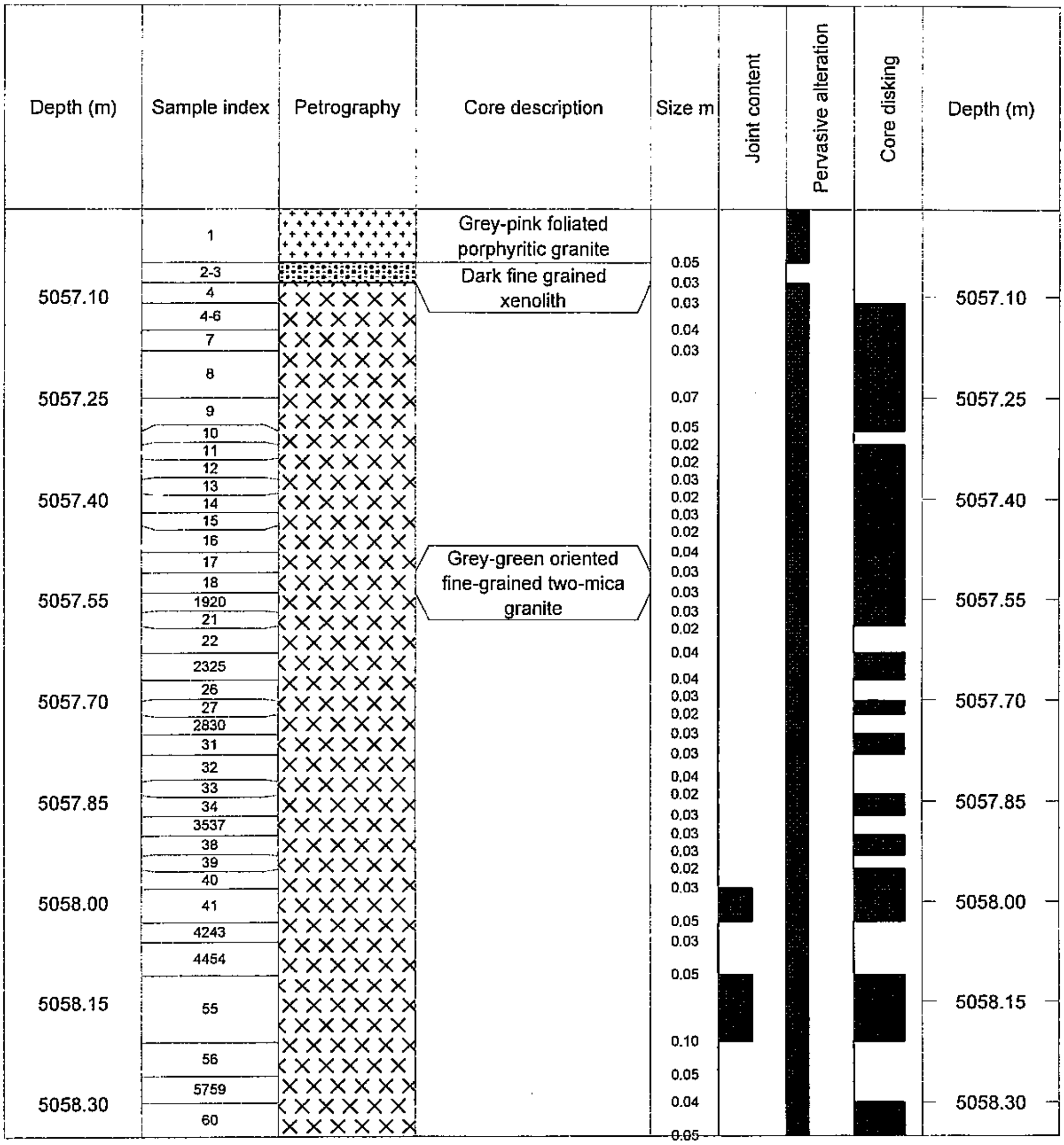

Fig. 3 - Schematic geological log of the core (K1) collected in GPK-2

1.5.3. Comparison with cuttings

The 3 different petrographic facies encountered between 5057 and 5058,35 m on the core K1 indicated that rapid petrographic facies variation could occur with depth. These modifications observed with a fine resolution scale provide a relevant example that it could be difficult to reconstruct a petrographical section with such a coarse resolution. As each cutting sample was collected every 2 or 3 meters (coarse resolution), some mixing of several crystalline facies could occur and then avoid to characterize the deep geology properly.

1.6. COMPARISON WITH OTHER DEEP SOULTZ WELLS

It is rather difficult to compare the GPK-2 well with the other Soultz data because GPK-2 was already the deepest. In terms of deep drilling reconnaissance, GPK-2 could be considered as an exploration well through the deep basement of the Rhine graben. However, the following drillhole depths could be compared:

GPK-2 (1420-2110 m)
Between 1420 and 2110 m, GPK-2 was drilled within the Soultz granite massif and is composed of a porphyritic granite, called standard granite. This granite is fairly petrographically homogeneous from the top of the basement to the major fault located at 2110 m, except in some zones of limited extension between 1757 and 2110 m where variations of the percentage of primary minerals (biotite and K-feldspar) are ascribed to magmatic heterogeneities.

EPS-1 (1410-2230 m) and GPK-1 (1376-3600 m)
The granite intersected by the closely EPS-1 borehole is also a fairly homogeneous porphyritic granite. Variations in K-feldspar-megacryst (MFK) content are seen throughout the 810 m of cores as MFK-rich granite or MFK cumulate, which rarely exceeds 1 to 2 m in thickness. Complete gradation occurs between these zones and the standard granite. MFK-depleted granite is also present. Xenoliths up to a decimeter in size are common; they are fine-grained, dark-coloured and rich in biotite. As a cumulative length of 80 metres of biotite-rich granite has been observed from drill cutting analysis between 1757 and 2100m in GPK-2 , it could be suggested that the granite composition is slightly different in GPK-2 than in EPS-1 in the same range of depth interval. In the upper part of GPK-1, the porphyritic granite is locally interrupted by leucogranites (Traineau et al., 1991). In the lower part of GPK-1, some biotite-rich granite zones were observed from drill cutting analysis at depths of 2125-2275 and 2985-3030m.

GPK-2 (2110-3880 m)
Between 2110 and 3880 m, no chip samples were available. Geophysical measurements were the only way for characterizing this depth interval. From 2110 down to 2960 m, GPK-2 has encountered a massive crystalline unit poorly fractured with some minor facies variation. From 2960 down to 3510 m, both vertical magnetic field component and Gamma ray measurements are variable. Abundant major fractured zones are visible on Rop, caliper data and sonic logs. From 3510 down to 3800 m, both radioactivity and magnetic field are variable whereas caliper, Rop and sonic logs are stable. It suggests that some facies variations occur within a massive granite which is probably poorly fractured. From 3820 down to 3880 m, no geophysical data were available. The Rop

data showed a high rate of penetration between 3850 and 3875 m depth suggesting that the well stopped in a faulted zone.

GPK-2 (3880-5093 m)
In the deepening part of GPK-2, the same porphyritic granite was penetrated between 3880 and 4860m and the petrographic variation corresponds mainly to xenolithes with numerous fractures. Deeper, a new mineralogical assemblage is evident characterizing a fine-grained two-mica granite with a low fracture occurrence (see paragraph 2.5).

2. Petrography from thin sections and x-ray analyses

2.1. THIN SECTION EXAMINATION

About 100 thin sections of cutting samples were evaluated by microscopic examination (Annex 2.4). In order to compare with the upper part of GPK-2, some cutting thin sections were investigated between 1890 and 2100 m. From those, the primary mineralogical content was checked and compared with the petrographic description of chip samples done on-site. K-feldspar, plagioclase, biotite, hornblende and the accessory minerals were identified as well as their hydrothermal alteration (carbonates, clays).

Microphotographs of thin sections show the fine-grained two-mica granite facies from both the core K1 and some selected cutting samples (microphotographs 1 to 4). The most typical mineralogical feature is the cross hatched-twinning of the K-feldspar (microcline) that does not occur in the porphyritic biotite-granite.

Thin section evaluation shows that xenolith fragments are quite common with depth they seem more abundant between 3900 and 4860 m than deeper. Geologically, this depth interval corresponds to the porphyritic biotite granite facies.

Secondary carbonates, mainly represented by calcite, are present in all the samples. Chlorite is visible from biotite alteration and sericite (white mica) from plagioclase.

2.2. X-RAY DIFFRACTION RESULTS

From previous investigations (Genter, 1989; Ledésert et al., 1996 and 1999), two main hydrothermal styles occurred within the Soultz granite. The hydrothermal transformation of crystalline rocks begins with a pervasive isochemical alteration (or so-called propylitic facies) that took place on a large scale within the granite and without any macroscopic modification of the rock texture. X-ray diffraction was done on untreated and ethylene-glycol-saturated samples using an automatic Siemens D5000 diffractometer. This stage is followed by chemical leaching (dissolution) and clay enrichment process (precipitation) superimposed on the pervasive event. The latter style, is the so-called vein alteration because it is related to fractures in which hydrothermal fluid circulation strongly modified the mineralogical assemblage of the granite.

In order to confirm the occurrence of the hydrothermal minerals observed by binocular examination, some X-ray diffraction measurements were carried out in the BRGM laboratory (Pillard, 1999). The main goal is to detect chlorite minerals in the standard granite facies and illite minerals in the altered granite facies. We selected 36 cutting samples in GPK-2 well over the interval of 1893-5080 m depth (see annex 3.1) in order to understand the vertical distribution of the hydrothermal assemblages and to compare them with the geological on-site profile (annex 1).

For samples corresponding to the standard Soultz granite (pervasive alteration), chlorite was detected on the X-ray analysis (Fig. 4). With natural X-ray diffraction treatment, chlorite shows some typical peaks which are evidenced. As in such a facies, the primary biotite is partly altered into chlorite, and as a result some peaks corresponding to the biotite are visible.

For samples corresponding to altered and fractured granite (vein alteration), the X-ray diffraction spectra show illite minerals (Fig. 5). This means that the primary biotite, partly chloritised, is completely transformed into illite as well as the primary plagioclase. In some samples, the peaks of the chlorite are still present, indicating that some mixing is possible between massive granite and altered facies (Fig. 6).

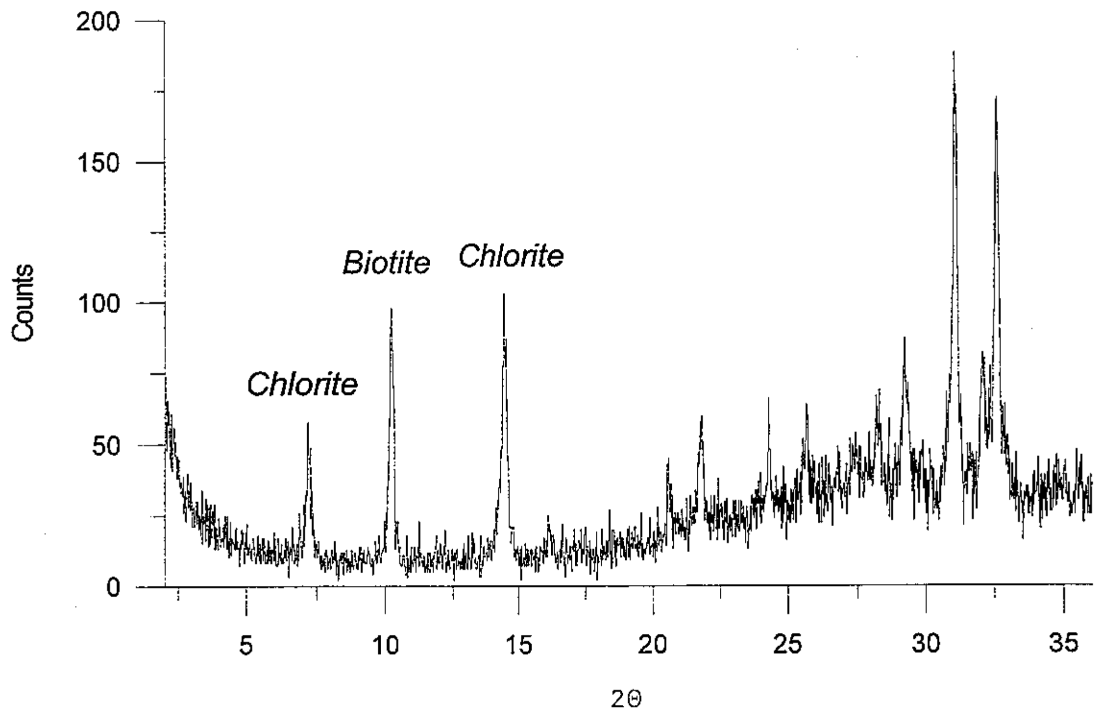

Fig. 4 - Example of X-ray diffraction pattern for a pervasive alteration facies (3600 m, untreated sample)

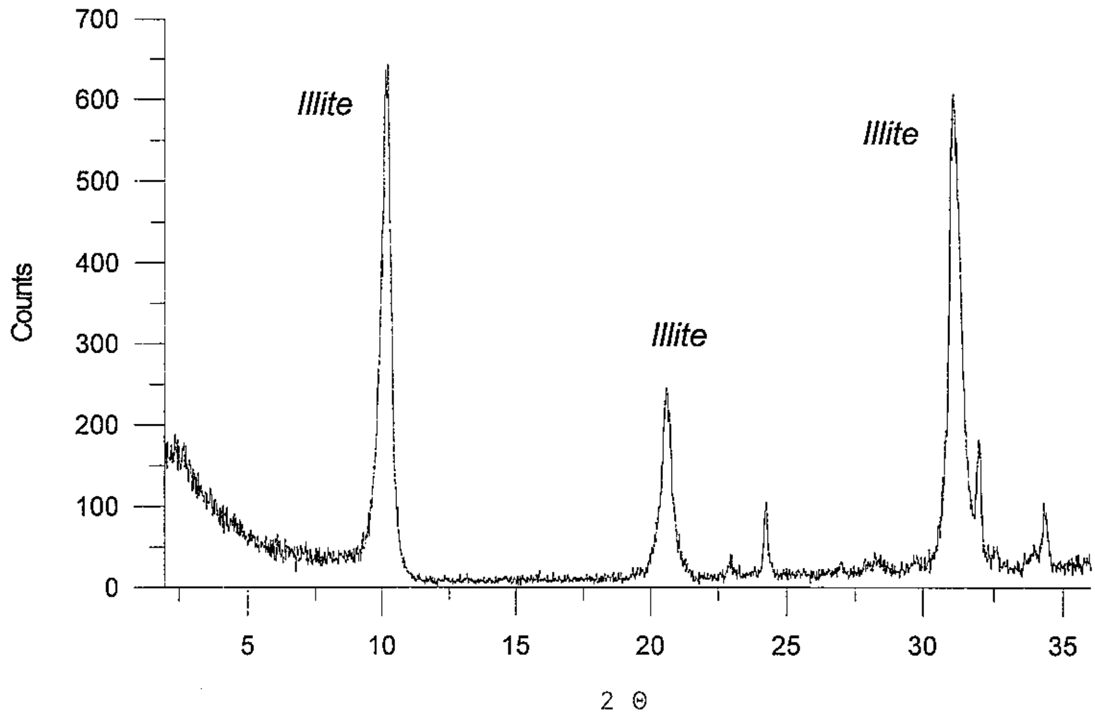

Fig. 5 - Example of X-ray diffraction pattern for a vein alteration facies (4586 m, untreated sample)

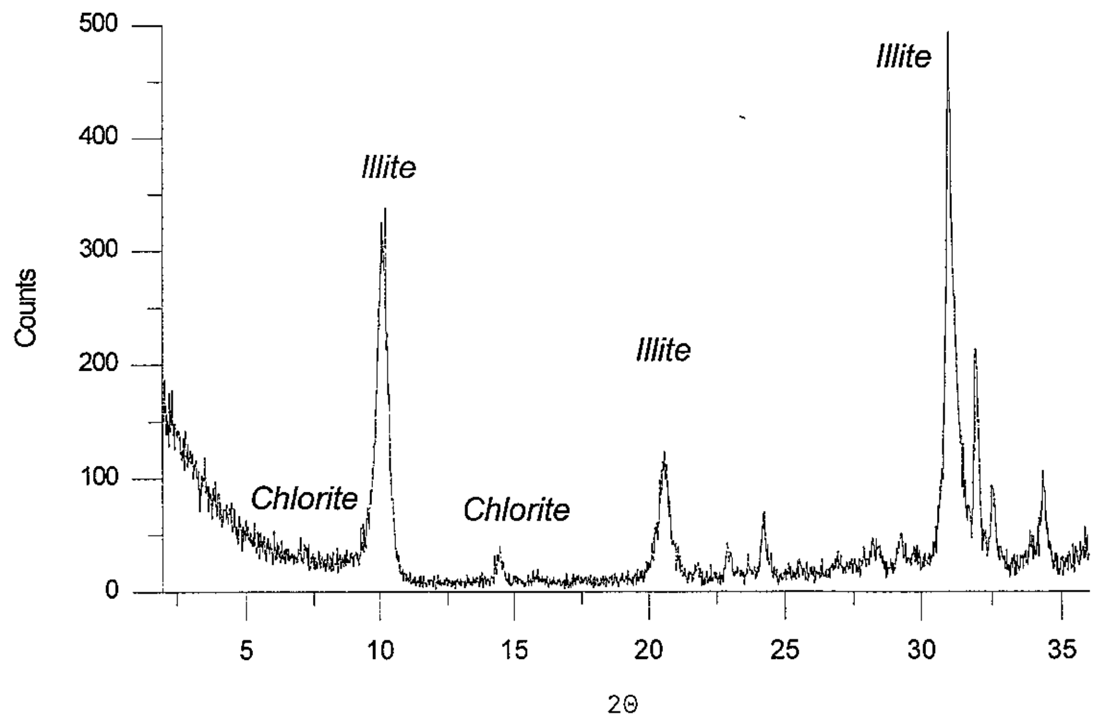

Fig. 6 - Example of X-ray diffraction pattern for a vein alteration facies (4598 m, untreated sample). The chlorite peaks are still visible indicating a low percentage of mixing

The distribution of the hydrothermal assemblage versus depth in the GPK-2 well based on X-ray diffraction analysis is plotted in Figure 7. The illite is dominating in the upper part (1900-2100 m) where a major permeable fault was cross-cut during the drilling. Illite is also present in altered facies at depth (4645, 4694, 4780, 4885). Generally, a small amount of chlorite is associated suggesting that some facies mixing occurred due to the coarse resolution of the cutting sample which is pluri-metric. Chlorite is also present in the upper part within the standard granite. Locally, a small quantity of smectite is observed together with illite at 1926 m and at 4694 m depth. No cutting samples were available between 2100 and 3850 m, except at about 3600 m whereas the depth is not guarantee. In the deeper part, illite is absent from 3855 to 4586 m whereas chlorite is quite abundant. Between 4600 and 5090 m, chlorite is less abundant suggesting a low pervasive alteration intensity. Some chlorite/smectite mixed-layer minerals corresponding probably to corrensite, are locally observed in GPK-2 well, in association with chlorite. Between 4586 and 4600 m, abundant calcite and a small amount of natrojarosite (Na-sulphate) are associated with illite and characterizes a major fracture zone.

The occurrence of epidote in the cuttings starts at 4200 m. Deeper, its vertical distribution is rather discontinuous (annex 1).

2.3. COMPARISON WITH OTHER SOULTZ WELLS

Occurrences of hydrothermal filling in fractures observed on EPS-1 cores is presented in Annex 3.2 (Genter & Traineau, 1996). This log shows that vein alteration is mainly characterized by the occurrences of illite and secondary quartz. Several generations of carbonates represented by calcite are associated with pervasive alteration (rock matrix) and also with vein alteration (fractures). Cuttings collected in GPK-2 represent a mixing volume of both granite matrix and fracture. Based on the EPS-1 results, the occurrence of illite in GPK-2, is related to the fractures whereas the occurrence of chlorite to the granitic matrix. The large amount of calcite at 4600 m in GPK-2 is clearly related to fractures.

A series of X-ray diffraction analysis has been conducted on selected samples of EPS-1 (Annex 3.3). The illite or I/S mineral (illite/smectite mixed layer) is symptomatic for vein alteration while chlorite or corrensite mineral is well correlated with pervasive alteration. Carbonates (calcite and dolomite) are associated with the two styles of hydrothermal alteration. The main difference to EPS-1 results, is the absence of tosudite (donbasite/beidellite mixed layer mineral, in Ledésert et al., 1996) in GPK-2 This clay mineral, bearing lithium, seems to characterize some present-day saline fluid circulations in fractures as it was observed at 2170 m in EPS-1.

A series of X-ray diffraction analysis has been conducted on selected samples of GPK-1 (Annex 3.4) between 2000 and 3600 m depth. The same kind of results are observed in GPK-1 and in GPK-2: the close relationship between the occurrence of illite and vein alteration as well as between the occurrence of chlorite or corrensite and pervasive alteration. As in EPS-1, the occurrence of tosudite, mainly related to permeable fractures, was not observed in GPK-2.

The overall comparison of hydrothermal mineral observed in the different Soultz wells is quite consistent. The illite mineral is symptomatic for vein alteration and the chlorite is clearly related to pervasive alteration. The absence of tosudite in GPK-2 could be interpreted as a lack of significant permeable joint below 3900 m. Carbonates detected by X-ray analysis characterized vein alteration. Natro-jarosite (Na-sulphate), that was never detected at Soultz, has been evidenced in a fractured zone at 4600 m in GPK-2.

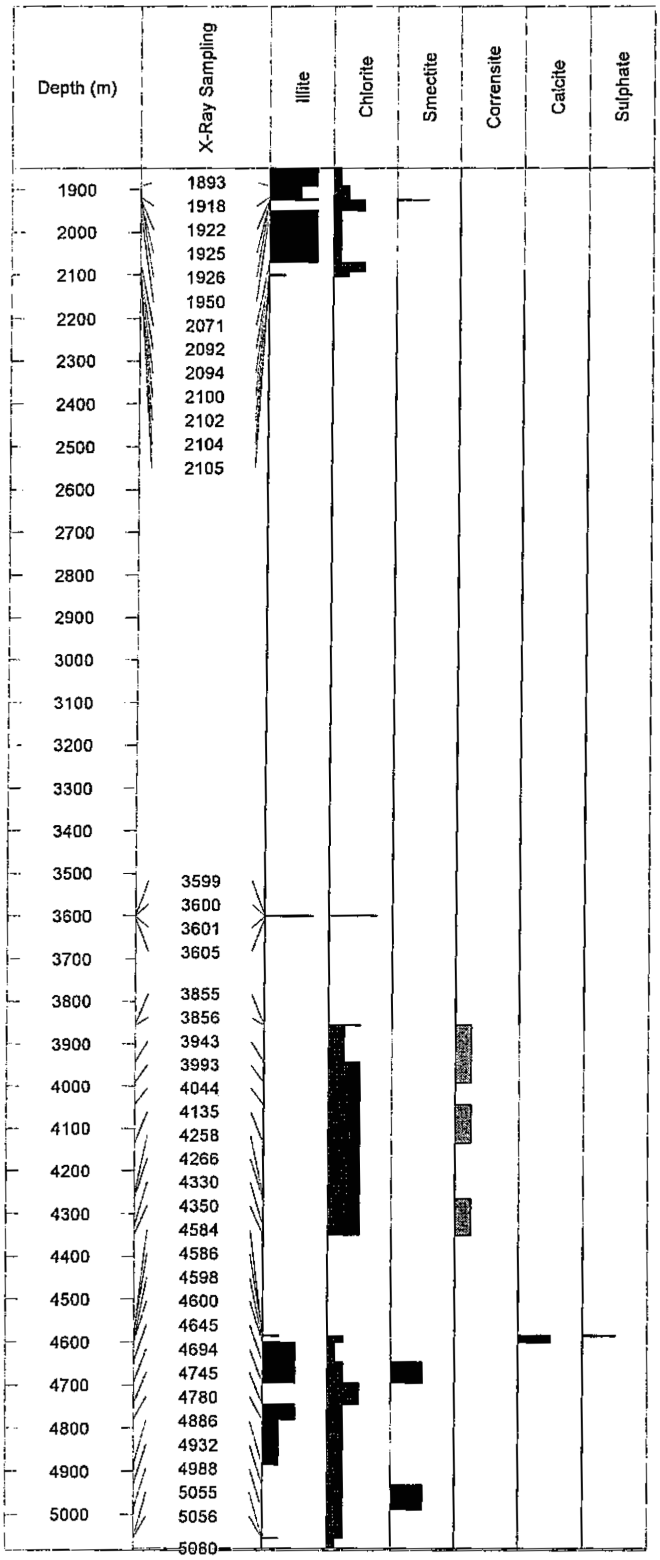

Fig. 7 - Distribution of hydrothermal assemblages versus depth in the GPK-2 well based on X-ray diffraction analysis on selected samples

3. First presentation of geophysical well logging and borehole imagery

3.1. WELL LOG DATA

Conventional well logs (gamma ray, 6-arm caliper) and electrical borehole imagery (UBI, ARI) were performed in GPK-2 by Schlumberger, with the Maxis-500 data acquisition system (Tab. 2).

In order to compare the various runs of well logs, it was necessary to match their depth with respect to absolute reference point. All the tools were run with the gamma-ray tool in order to correlate all geophysical data with each other.

Type	Tool	Parameters	Depth (m)
NGS	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 Imagery with coarse resolution (12 electrodes)	3500-4500
UBI	Ultrasonic Borehole Imager	Oriented Borehole Imagery with fine resolution	3200-3875

Tab. 2 - List of geophysical well logs and borehole imagery carried out in the deeper part of GPK-2 borehole

3.2. LOG RESPONSES

3.2.1. Presentation

Various standard open-hole well logs (caliper, resistivity and spectral gamma ray logs) were performed in the well in order to determine the main distribution of the petrographic facies in terms of facies variation, standard granite and hydrothermally altered and fractured zones. For a better understanding of the existing fracture network, Ultrasonic Borehole Imager (UBI) was run between 3200 and 3875 m depth providing fully processed images in real time on the Maxis 500 data acquisition imaging system. Further on, Azimuthal Resistivity Imager (ARI) was run between 3500 and 4500 m depth. The standard geophysical measurements (Spectral Gamma Ray) were run between 2000 and 4500 m, in order to overlap with the geophysical logs (sonic logs) acquired in the upper part of the well (Genter and Tenzer, 1995; Tenzer, 1995).

3.2.2. Conventional well-logging responses

Conventional geophysical well logging permit to distinguish several sections within the GPK-2 well (Fig. 8):

(1) from 2000 m down to 2915m, Gamma Ray curve shows a slight and regular decreasing trend versus depth as it was already mentioned in the other Soultz wells (Traineau et al, 1991). The different radioactive curves (GR, K_2O, U, Th) are very stable along this depth interval that could indicate a massive granitic rock composition. This is confirmed by the Rop data which are very stable with depth except in fault zones (2110 m). From 2000 to 2960 m, the standard granite displays a stable K_2O content at about 3.7% in average, a regular decreasing of Uranium with depth from 8 to 6 ppm, and a regular decreasing of Thorium with depth from 34 to 24 ppm. This regular decrease in radioactivity with depth that corresponds to a slight depletion of radioactive minerals bearing U and Th within the granite, is well-known in granitic plutons. A series of localised peaks mainly characterized by enrichment in Potassium content is observed at different depths (2110, 2310, 2340, 2420, 2550, 2615 m). This significant increase in K content could be easily interpreted as an increase of the illite content (clay mineral bearing K) assuming fracture zones as was shown by X-ray analyses. The fractures located at 2110, 2340 and 2420 m shows a larger illite enrichment underlined by a wider halo of the K increase. There is also an important variation in the Th content at 2655 m but without any significant effect on the K_2O content. At 2340, 2420 and 2655 m, Th increases at the margins and decreases at the centre or conversely. These Th variations (leaching and concentration) could be related to intense hydrothermal vein alteration and were previously observed in GPK-1 (Traineau et al., 1991).

(2) from 2915 to 3525 m, compared to the previous depth, Rop peaks are more intense in this section. Rop data show low values (hard rock) which are disrupted by high Rop values corresponding to fracture zones (2975-3005, 3055-3125, 3175-3205,

3260-3280, 3320-3400, 3420-3430, 3470, 3510 m). These zones had already been detected by sonic logs. Caliper data, which are available from 3200 m, indicate two kinds of different behaviours : (1) some values which are close to drillhole bit size diameter induced by hard crystalline rocks, (2) some values which are higher than borehole size and which could be related to the occurrence of cavities induced by hydrothermally altered and fractured zones (3325-3360, 3470, 3510 m). Radioactive curves (GR, K_2O) are very noisy and disturbed in this section. The increase of K_2O content (possibly illite deposition) in some selected zones, can be correlated with the high Rop values that indicated fracture zone occurrences. At 3360 m depth, the high depletion of both the K_2O content and the radioactivity could be interpreted as the occurrence of quartz vein. With low Rop values and low sonic velocities indicating massive rocks, K_2O values are about 4% in average. Between 3250 and 3310 m, K_2O varies alternatively from 4 to about 7%. These unusual high K-content could be interpreted as the occurrence of either a xenolith body rich in K_2O or a two-mica granite. However, previous chemical analyses of EPS-1 xenolith facies showed relatively high K_2O content (Chèvremont et al., 1992). The fine-grained two-mica granite observed on GPK-2 core, will be analysed chemically in order to compare its K_2O, Th and U-contents with the well-logging data. We might expect a high K_2O content because this fine-grained granite bears potassium in K-feldspar, biotite and muscovite. Uranium content is slightly decreasing with depth from 6 to 5 ppm with some minor fluctuations. The peak minimum of Uranium is visible at 3360 m, interpreted as the core of a major feature, e.g. a quartz vein. The maximum Uranium content value, located at 3100 m, corresponds exactly to a strong positive Rop value and consequently to a localised fracture. Thorium content is rather stable at about 24 ppm in average. The Th variation can be correlated with fracture zone location based on Rop data, and correspond to both leaching or concentration processes. At 3510 m, there is a very significant correlation between all the logs that indicate the occurrence of a major fracture zone. The stoneley wave log (Fig. 9) shows a peak maximum suggesting an open fault structure that limits the lower section (see below).

(3) from 3525 to 4625 m, caliper data indicate several values which are higher than borehole size and which could be related to the occurrence of caves (3875-3900, 3950-4145, 4218, 4360, 4505-4525). For those located at 4218, 4360, 4005-4025, 4590-4600 m, they could be interpreted as the occurrences of cavities induced by hydrothermally altered and fractured zones as it was observed on the geological profile. For those located between 3950 and 4145 m, there is no particular geological features detected in the cuttings. The size of the cave is not very large but the borehole wall is very rough over a large apparent vertical distance. The Rop values, which are very "smooth", are not helpful for more precise interpretation. The cave located between 3875 and 3900 m, has a complex origin. This zone corresponds to the ending point of the drilling of GPK-2 in 1995 and was characterized by very high Rop values suggesting the occurrence of a hydrothermally altered zone. Moreover, a cutting sample was collected at 3883 m (driller reference) and it shows a signature of a highly altered and fractured granite facies but the depth is not guaranteed. However, during the deepening of GPK-2, several rock pieces got stuck in the roller reamers and were then collected.

They correspond systematically to fine-grained dark xenolithes with no evidence of fractures. Possibly, the upper part of this zone is highly fractured while the lower part characterizes a xenolith facies. The location of this fracture zone is located at a contact between a granitic fractured facies and a larger xenolithic facies. The Gamma Ray Spectral logs are not helpful because the size of the cave at 3900 m, which is over 30 inches, did not allow to characterize the radioactive properties. One of the major fractured zone detected from cutting analysis (4580-4600 m), is not clearly evidenced by caliper data. However, the Gamma ray curve shows a significant decreasing indicating a probable leaching of the radioactive elements and the occurrence of quartz deposition. From 3525 and 4500 m, the raw resistivity data (ARI tool) is very noisy and though difficult to interpret. A filter has to be used to remove the disturbing noise to get a better electrical response. The raw data ranges from 10 to 10,0000 Ohm.m but with a more stable value at about 1,000 Ohm.m on a logarithmic scale. A few conductive zones fit with the occurrence of cavities (3875-3900, 4100, 4360 m) or detected fractures (4325,4425-4460 m) whereas a few of them don't fit with any features (4175 m).

3.2.3. Borehole imagery : ARI

Due to the occurrences of large caves at about 3900 m, it was impossible to log deeper with the UBI tool. In order to get minimum structural informations about fracture location at depth in the deeper part of GPK-2 Well, Azimuthal Resistivity Imager (ARI) was run between 3500 and 4500 m depth. This oriented tool has a coarser resolution than a classical borehole imagery tool (BHTV, FMI, UBI). However, this electrical tool is able to detect preferentially the most conductive fracture network that intersects the well. Then, it must provide the location as well as the geometry of the major structural features encountered at depth. ARI logs have to be interpreted through specific software when the numerical datas are available.

3.2.4. Borehole imagery : UBI

The drillhole GPK-2 was logged between 3900 and 3200 m depth by the UBI system. The 9 5/8" casing shoe was detected at 1427 m depth. With these acoustic measurements, the coverage of the borehole wall is up to 100 %. Therefore nearly-vertical fractures can be identified with high accuracy, in contrast to electrical imagery logs. This section was previously logged in 1995 but the quality of the acoustic signals was very poor in this 6 1/4" section. Due to the deepening of Well GPK-2, the 6 ¼ inches section was enlarged in 8 1/2" inches section. This new*
UBI run shows a very good borehole wall surface reflection and besides that a good fracture detection. As the ARI logs, UBI has to be analysed through specific software.

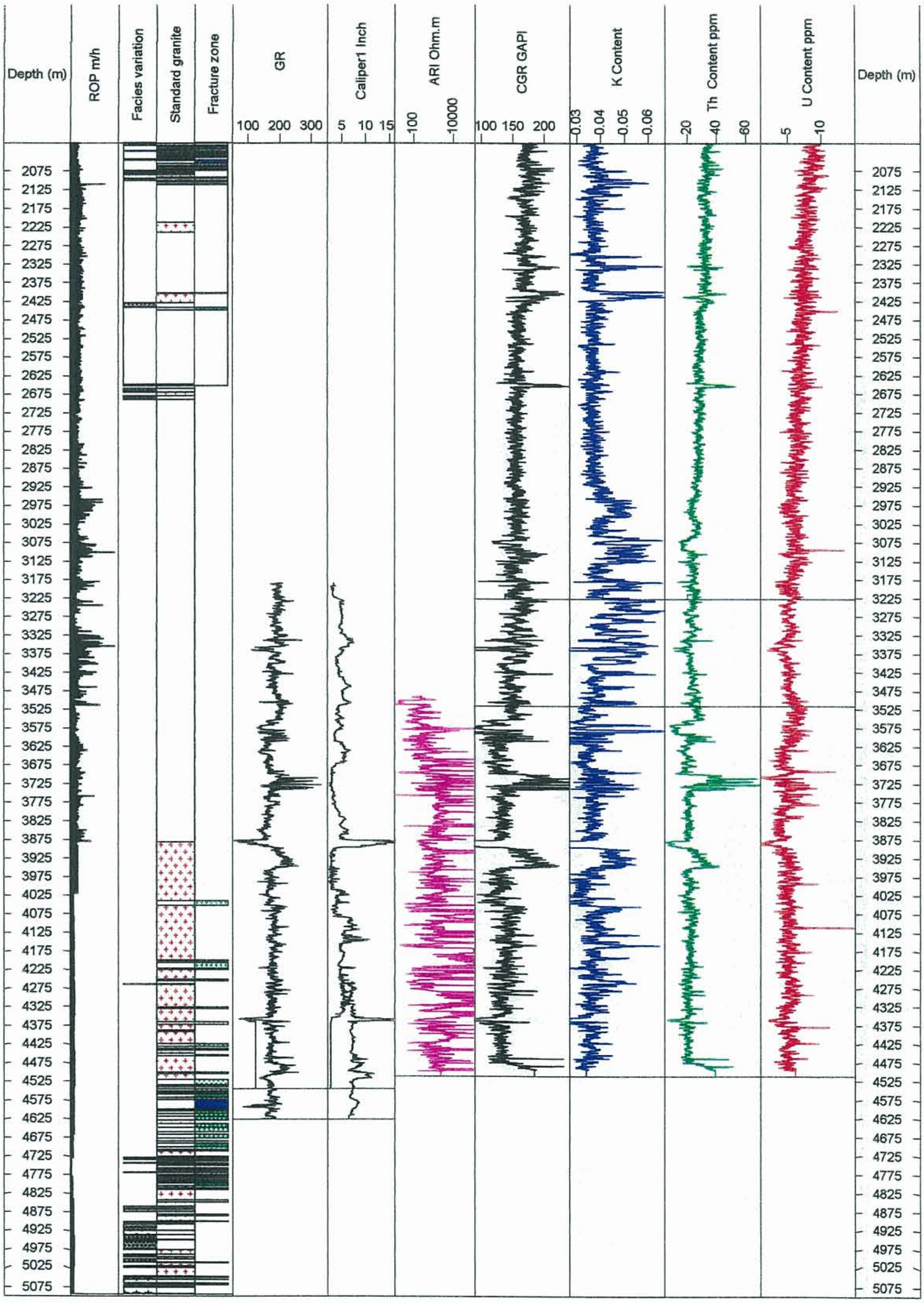

Fig. 8 - Synthetic composite log of GPK-2 between 3880-5090 m from cutting analysis and available well-logging measurements

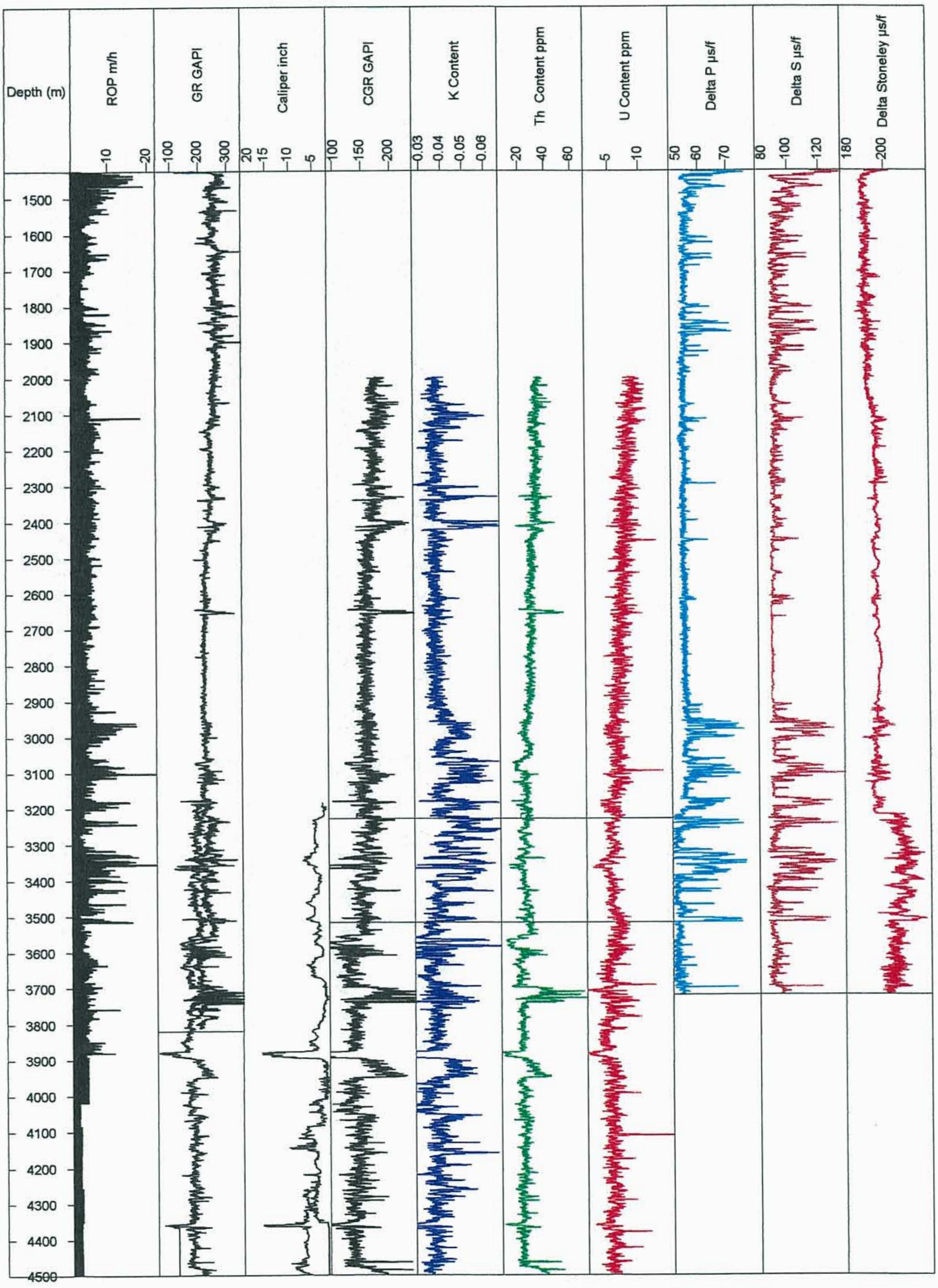

Fig. 9 - Well logging data collected between 1400 and 4500 m depth in GPK-2 Well

Conclusion

The evaluation of the geological profile from chip samples examination has been realised on-site during the deepening of HDR GPK-2 borehole between 3880 and 5093 m providing daily petrographic logs.

From cutting analysis, three main petrographic units were observed :
- from 3900 to 4520 m, GPK-2 penetrates a low fractured porphyritic granite section;
- from 4520 to 4860 m, the well intersects a fractured granite with two major fractured zones (4600, 4775 m).
- from 4860 to the bottom depth of 5093 m, a new facies, consisting a two-mica granite associated with xenolith-rich granite occurs with nearly no significant fractures. This fine-grained granite intrudes into the porphyritic granite.

An unfractured core section (K1), of 1,35 m length, was collected. Three main crystalline rock facies could be recognised : a piece of porphyritic granite (top of core), followed by xenolith pieces and dominated by a third facies of fine-grained oriented two-mica granite. The coexistence of biotite and primary muscovite implies that this granite is peraluminous and thus clearly different from the magnesio-potassic calc-alkaline porphyritic standard granite.

The hydrothermal mineralogical assemblages deduced from X-ray analysis show consistent results with previous studies: the illite mineral is symptomatic of vein alteration and the chlorite is clearly related to pervasive alteration. The absence of tosudite in GPK-2 could be interpreted as a lack of significant permeable joints below 3900 m. Carbonates detected by X-ray analysis characterize mainly vein alteration. Natro-jarosite (Na-sulphate), that was never detected at Soultz, has been evidenced in a fractured zone at 4600 m in GPK-2.

Conventional well logs, acoustic borehole imagery (UBI system) and azimuthal resistivity imager (ARI system) were supervised on-site and preliminary compared with the synthetic petrographic log and geological results from closer deep wells (EPS-1, GPK-1) and the upper part of GPK-2. From the simultaneous interpretation of the geophysical well-logging response and the synthetic geological profile, three main sections were defined from 2000 and 4625 m:
- from 2000 to 2915 m a massive porphyritic granite with some significant faults (2100 m),
- from 2915 to 3520 m, a granite with a lot of petrographic facies variation. For example, between 3250 and 3310 m, the occurrence of either a xenolith body rich in K_2O or a two-mica granite is suspected. Several significant fractured zones are visible (3520 m).

- from 3520 m to 4625 m, GPK-2 intersected a low fractured porphyritic granite section with some localized faulted zones.

From 4860 m, the standard porphyritic granite is intruded by a peraluminous two-mica granite which occurs probably as dikes or sills between 4860 and 5093m.

Acknowledgements

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Annexes

ANNEX 1 : DETAILED PETROGRAPHIC LOG OF THE GPK-2 BOREHOLE FROM CHIP SAMPLE EXAMINATION. DEPTH: 3900 TO 5093 M (SOULTZ-SOUS-FORÊTS, FRANCE).

Scale 1:2000

BRGM

DEEPENING OF GPK-2 HDR BOREHOLE : GEOLOGICAL MONITORING

DEPTH: 3900 to 5093 m.

(02-06-1999)

EXPLANATION OF HEADINGS

Depth: Raw depth of the cutting samples from ENEL, not yet corrected from lag time.
ROP: Rate Of Penetration (meter/hour) not yet provided by ENEL.

Facies variation: Petrographic variations deduced from cuttings (variation of biotite and K-feldspar content).
Standard granite: Porphyritic granite with K-feldspar megacrysts, consistence with previous data acquired on GPK-1 and EPS-1 core sections.
Fracture zones: Fractured and altered granite facies deduced from cuttings.

Biotite: Estimated percentage of biotite from microscopic examination.
Chorite: Degree of chloritization of biotite, indicator of pervasive alteration.
(0: very weak; 1: weak; 2: moderate; 3: strong).
Epidote: Occurrence of epidote
(0: absent; 1: present)
Illite: Degree of illitisation of biotite and plagioclase, indicator of vein alteration
(same scale).
Hematite: Degree of hematization of primary minerals, and hematite hydrothermal filling
(same scale).

Pervasive alteration: Degree of pervasive alteration within the granite massif, such as chloritization of biotite. (0: very weak; 2: weak; 4: moderate; 6: strong).
Vein alteration: Degree of vein alteration, related to fracture zones and expressed as illitisation in cuttings samples. (0: very weak; 2: weak; 4: moderate; 6: strong).

HDR BOREHOLE GPK-2

Patterns of the petrographic log

Standard Granite

GRAN STANDARD GRANITE

Facies Variation

MELA BIOTITE-RICH PORPHYRITIC GRANITE

XENO XENOLITH-RICH GRANITE

GR2M FINE GRAINED TWO-MICA GRANITE

Hydrothermally Altered and Fractured Zone

HLOW LOW ALTERED GRANITE

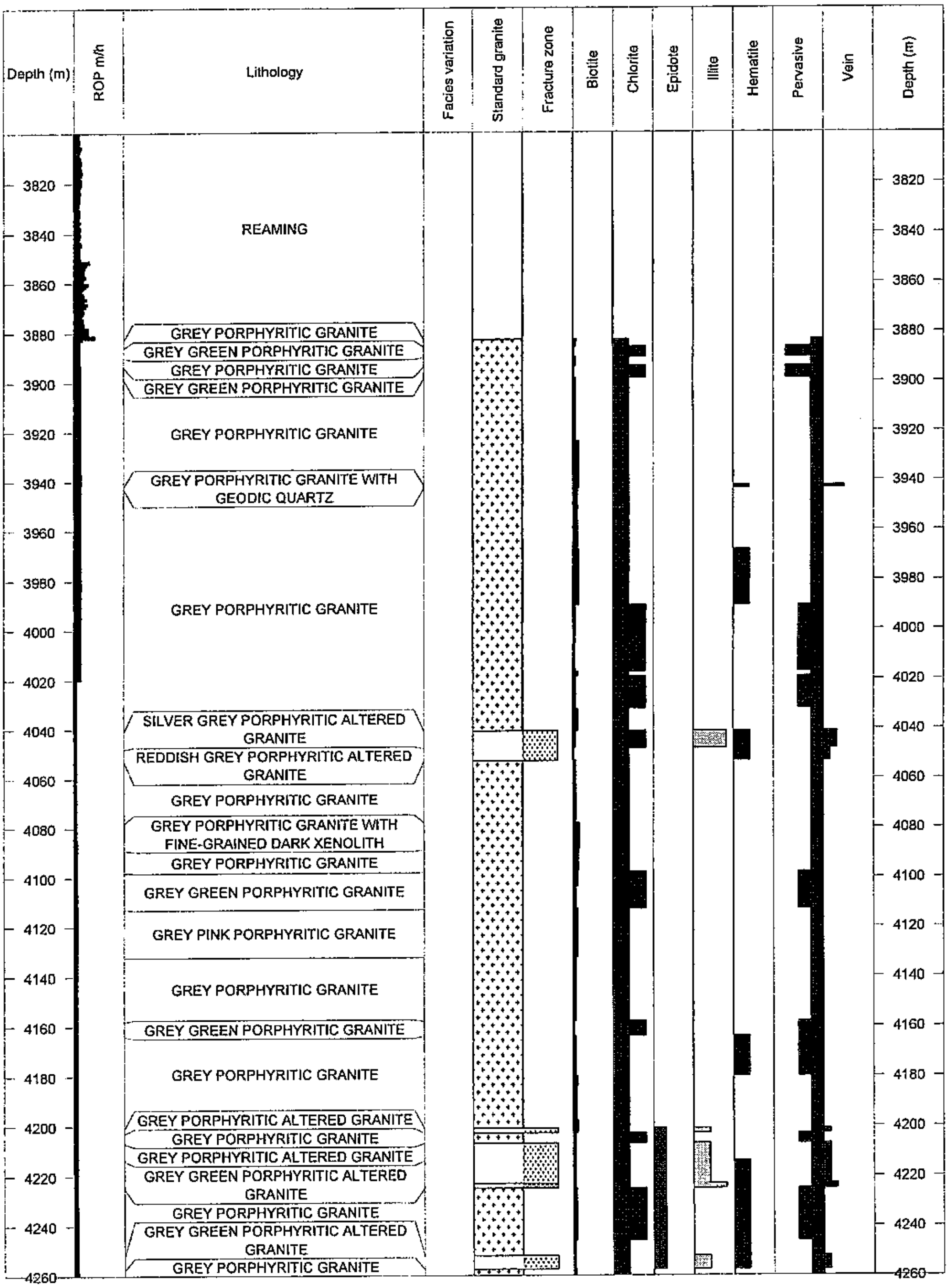
HMOD MODERATELY ALTERED GRANITE

HHIG HIGHLY ALTERED GRANITE

HEXT VERY HIGHLY ALTERED GRANITE

Alteration gradient

GPK-2 WELL


Depth (m)
ROP m/h
Lithology
Facies variation
Standard granite
Fracture zone
Biotite
Chlorite
Epidote
Illite
Hematite
Pervasive
Vein
Depth (m)
3820
3840
3860
3880
3900
3920
3940
3960
3980
4000
4020
4040
4060
4080
4100
4120
4140
4160
4180
4200
4220
4240
4260
REAMING
GREY PORPHYRITIC GRANITE
GREY GREEN PORPHYRITIC GRANITE
GREY PORPHYRITIC GRANITE
GREY GREEN PORPHYRITIC GRANITE
GREY PORPHYRITIC GRANITE
GREY PORPHYRITIC GRANITE WITH GEODIC QUARTZ
GREY PORPHYRITIC GRANITE
SILVER GREY PORPHYRITIC ALTERED GRANITE
REDDISH GREY PORPHYRITIC ALTERED GRANITE
GREY PORPHYRITIC GRANITE
GREY PORPHYRITIC GRANITE WITH FINE-GRAINED DARK XENOLITH
GREY PORPHYRITIC GRANITE
GREY GREEN PORPHYRITIC GRANITE
GREY PINK PORPHYRITIC GRANITE
GREY PORPHYRITIC GRANITE
GREY GREEN PORPHYRITIC GRANITE
GREY PORPHYRITIC GRANITE
GREY PORPHYRITIC ALTERED GRANITE
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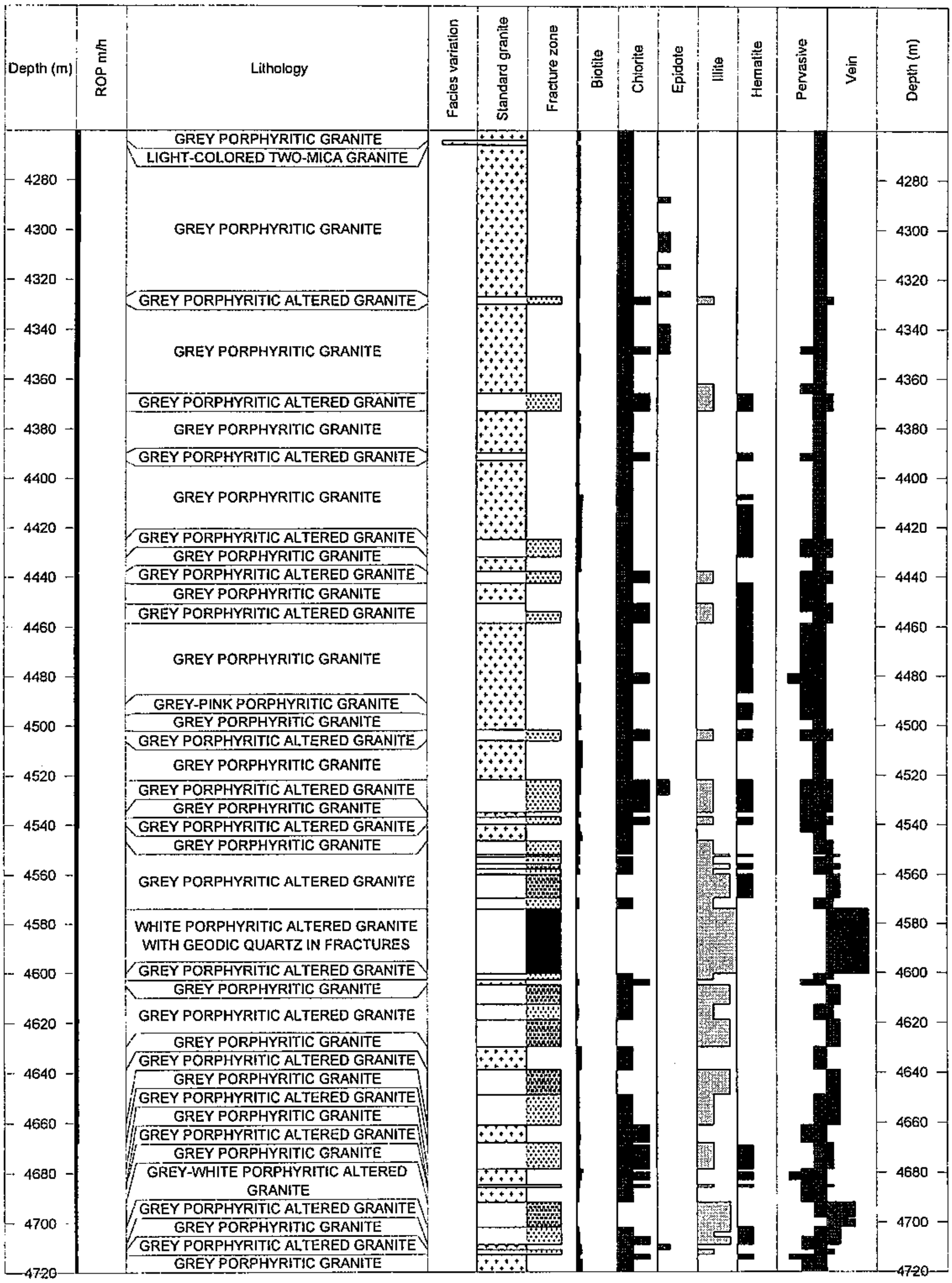
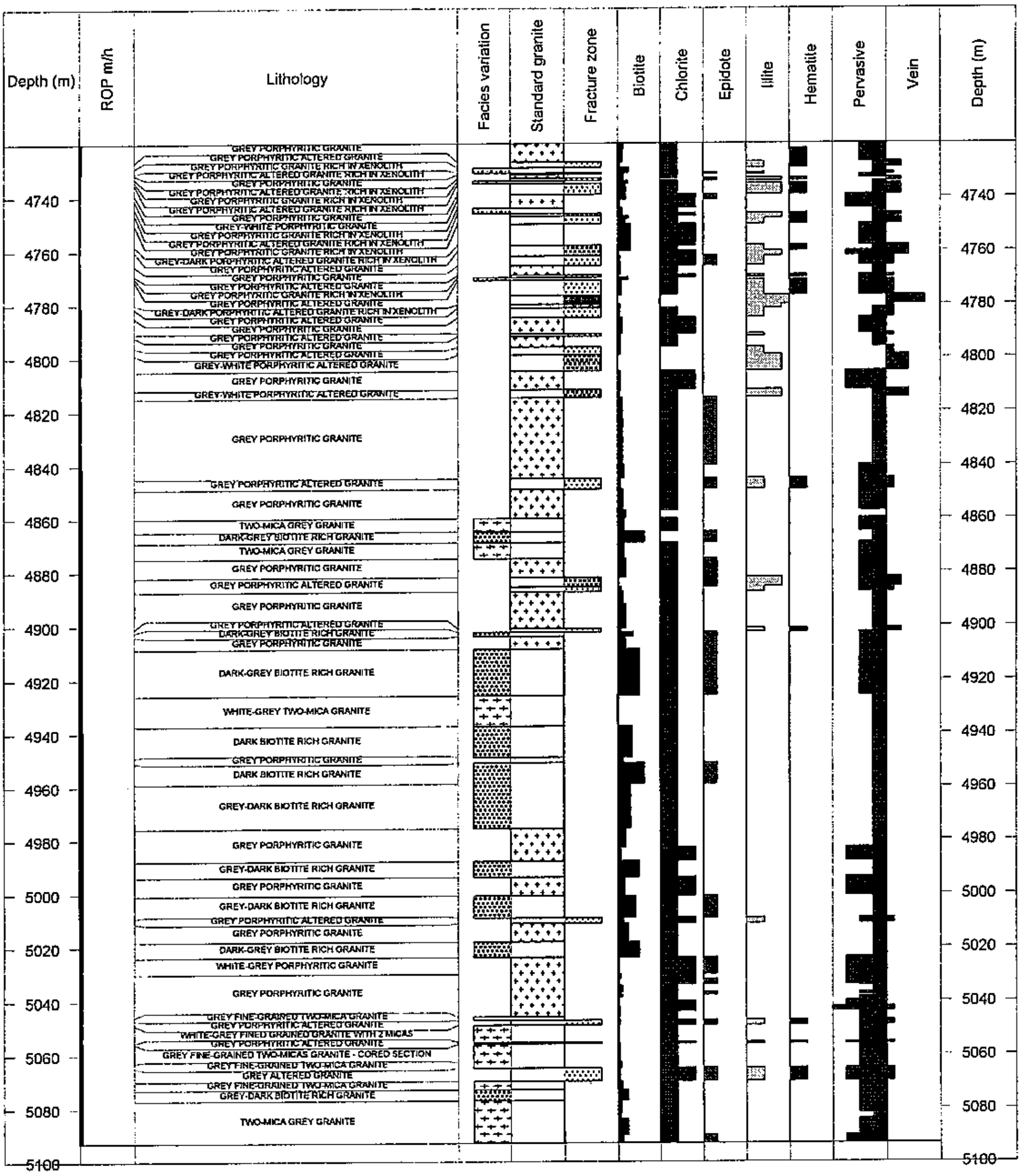
GREY PORPHYRITIC GRANITE
GREY GREEN PORPHYRITIC ALTERED GRANITE
GREY PORPHYRITIC GRANITE

GPK-2 WELL (Continuation)

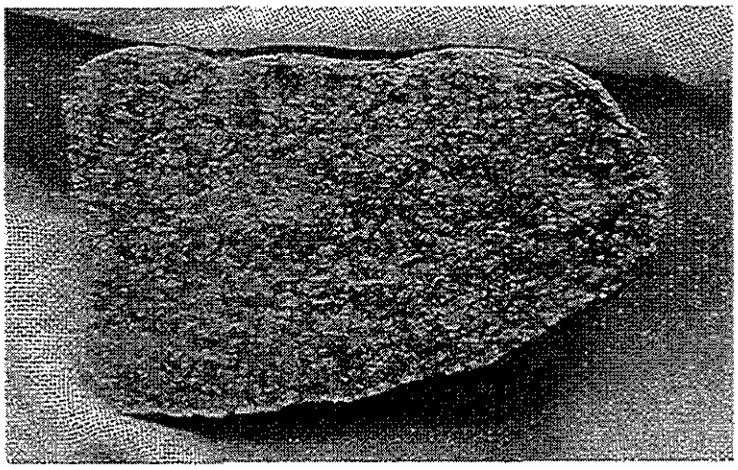


GPK-2 WELL (Continuation)

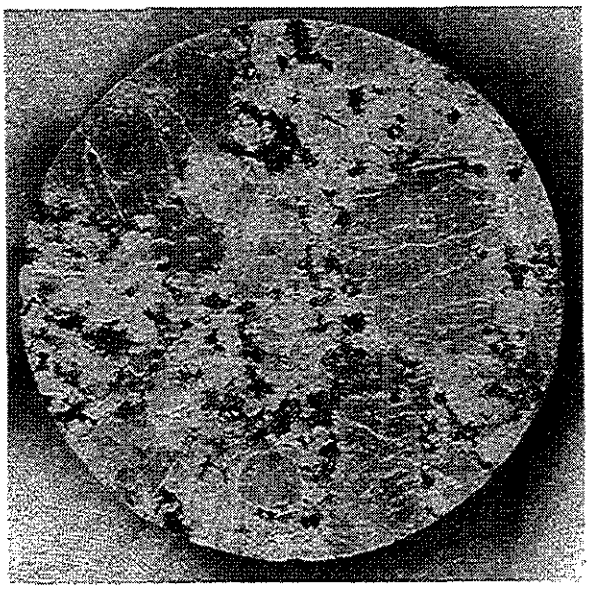


ANNEX 2. PETROGRAPHIC RESULTS

Annex 2.1. Core K1: 5057,00 to 5059,90 m depth (driller depth reference). Photograph of the core bottom piece (K1, Piece N°60, 5058,30 m). Fine-grained two-mica oriented granite. Abundant flakes of black biotite in a light-grey assemblage of quartz, feldspars and scattered muscovite. Sample scale: 7 cm



Annex 2.2. Core K21, GPK-1 well (3510 m). Porphyritic standard granite. K-feldspar (orthoclase) megacrysts are pink-coloured and 1 to 4 cm long. The matrix is made of white plagioclase, glassy quartz, and black biotite.



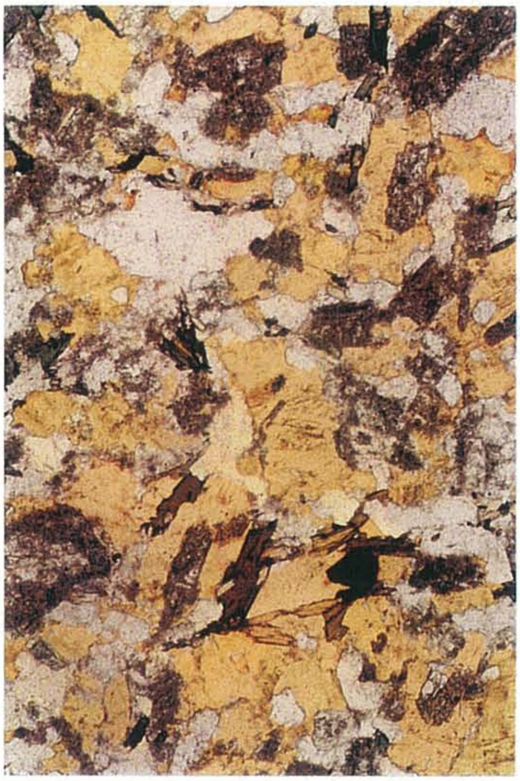
Annex 2.3. Thin section photographs of GPK-2 rock and cutting samples. PPL: plane-polarized light and CP: crossed polars

Microphotographs 1A (PPL: plane-polarized light) and 1B (CP: crossed polars).
Fine-grained two-mica granite, Core K1 at 5058,30 m.
Quartz: white anhedral crystals
K-feldspar: artificially-yellow coloured anhedral to subhedral crystals with specific cross-hatched twinning of microcline visible under polarized light
Plagioclase: brownish subhedral to euhedral crystals stained by microphyllites*
Biotite: brown flakes, locally altered into green chlorite
Muscovite: rare small white flakes, generally associated with biotite, displaying green to red polarization colours
Fe and/or Ti-oxide: one black (opaque) crystal

Microphotographs 2A (PPL) and 2B (CP).

In the upper part: a typical microcline (K-feldspar) of the same thin section as the previous, showing the cross-hatched twinning under crossed-polars.

In the lower part: a zoned-plagioclase invaded by secondary white mica adjacent on the left to two primary muscovite flakes with green to red polarization colours. In the right corner, one flake of chloritized pale green-coloured biotite.



1000 µm 1A, PPL

1000 µm 1B, CP

500 µm 2A, PPL

500 µm 2B, CP

Microphotographs 3A (PPL) and 3B (CP) . Fine-grained two-mica granite visible in a cutting sample at 5055,30 m.

Same mineralogy as for the microphotographs 1 and 2: quartz; microcline with the specific cross-hatched-twinning (CP); plagioclase stained by microphyllites; flakes of biotite and primary muscovite.

Microphotographs 4A (PPL) and 4B (CP). A biotite and hornblende-rich granite observed at 4867 m in a cutting sample.

Abundance of mafic minerals: flakes of brown biotite, crystals of green hornblende. In the upper right corner: fragment of black (opaque) magnetite.

500 µm 3A, PPL

500 µm 3B, CP

1000 µm 4A, PPL

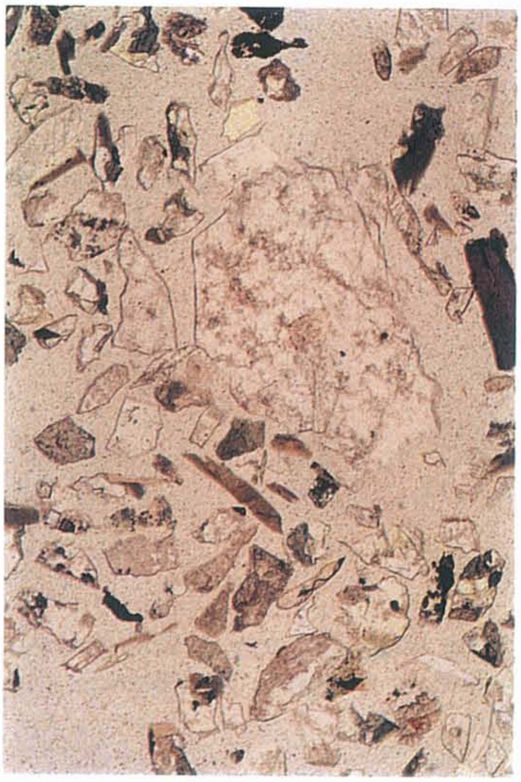
1000 µm 4B, CP

Microphotographs 5A (PPL) and 5B (CP). A Porphyritic biotite granite observed in a cutting sample at 3927 m

Quartz: white fragments.
K-feldspar: a large crystal of perthitic orthoclase, specific of the porphyritc texture, visible in the central part of the picture, and rare small fragments.
Plagioclase: white and twinned (CP) when it is fresh, and brownish, more or less stained by microphyllites when it is altered.
Biotite: brown flakes; rarely altered into chlorite.

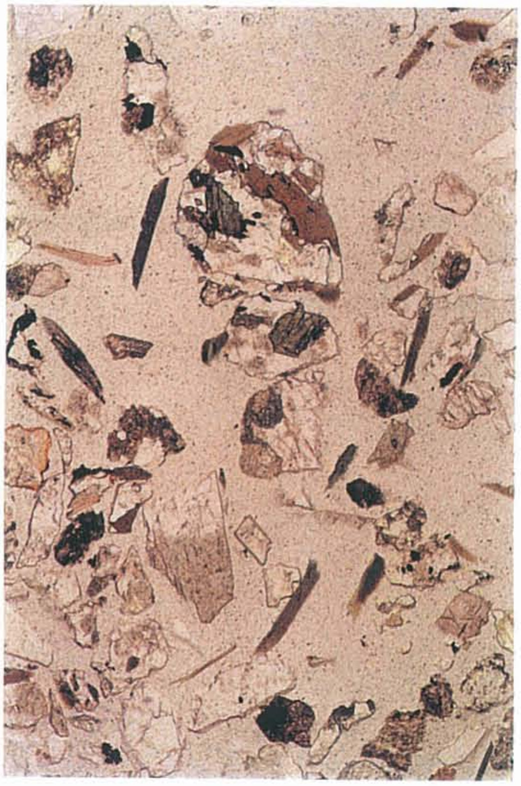
Microphotographs 6A (PPL) and 6B (CP). A xenolith fragment observed in a cutting sample at 3927 m.

In the centre of the upper part, a fragment of fine-grained xenolith with abundant mafic minerals: brown biotite and green hornblende.



1000 µm 5A, PPL

1000 µm 5B, CP



1000 µm 6A, PPL

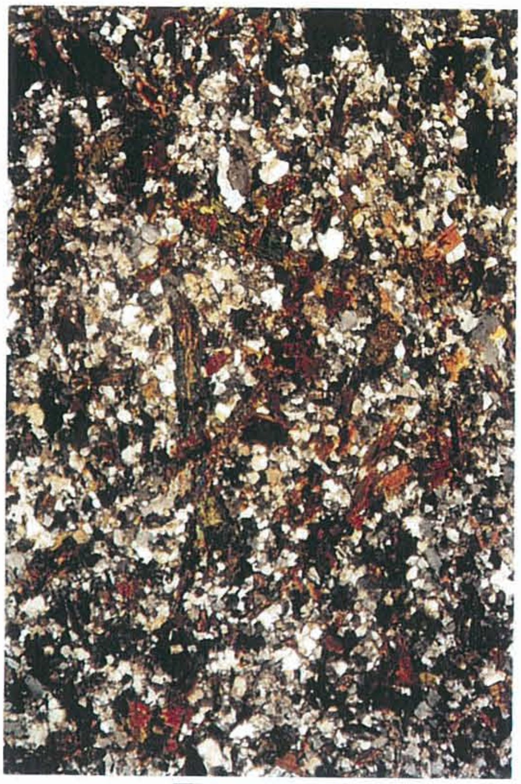
1000 µm 6B, CP

Microphotographs 7A (PPL), 7B (PPL), 8 (PPL) and 9 (PPL). A fragment of xenolith facies observed in a coarse cutting sample at about 4442,50 m.

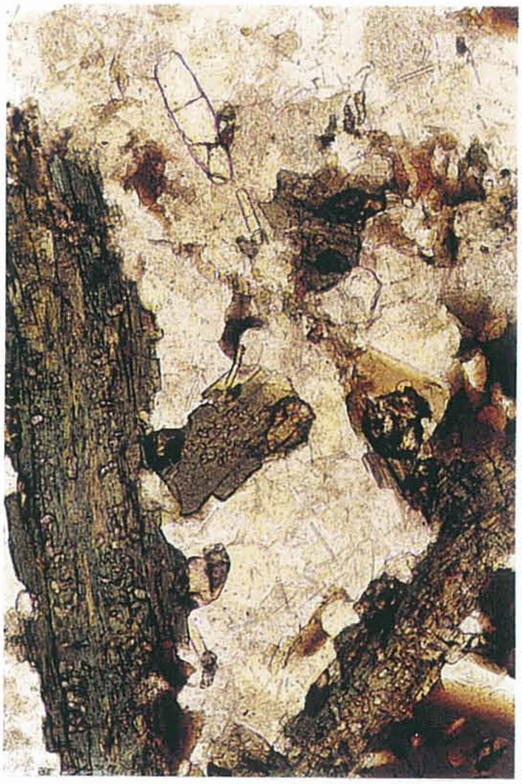
Microphotographs 7A (PPL) and 7B (PPL). The rock displays a fine-grained texture and abundant mafic minerals: small prisms of green hornblende and flakes of brown biotite.

Microphotographs 8 (PPL) and 9 (PPL). At larger magnification appears abundant white apatite as small needles or larger prisms.
Mafic minerals: green hornblende and rarely chloritized biotite.

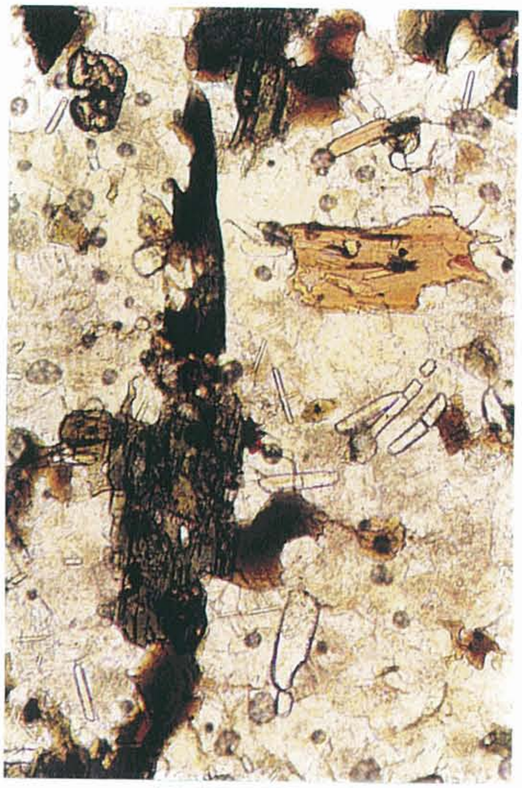
1000 μm 7A, PPL



1000 μm 7B, CP



500 μm 8, PPL



500 μm 9, PPL

Annex 2.4. Synthetic petrographic tables of the mineralogical content in GPK-2 cuttings from microscopic examination

N°	depth	type	thin section	K-feldspar	plagioclase	*alteration minerals*	biotite	*alteration minerals*	amphibole	accessory minerals	others	alteration type
	1893,0	HLOW	C28772	orthoclase, rare microcline	low to moderately altered	sericite, calcite	rare, generally altered	chlorite, carbonates, white mica	? completely altered if present	magnetite, rare allanite	some carbonate	pervasive, vein
	1918,0	HMOD	C28773	orthoclase	low to moderately altered	sericite, calcite	relatively abundant, 80-90 % altered	chlorite, carbonates, white mica	? completely altered if present	magnetite, leucoxene, rare allanite	some carbonate	pervasive, vein
	1922,0	HHIG	C28774	orthoclase	moderately to highly altered	sericite, calcite	relatively abundant, 90 % altered	chlorite, carbonates, white mica	? completely altered if present	magnetite	some carbonate	pervasive, vein
	1925,0	HLOW	C28775	orthoclase	low to moderately altered	sericite, calcite	relatively abundant, 30 % altered	chlorite, carbonates, white mica	completely altered into carbonates, chlorite…	magnetite	some carbonate	pervasive, vein
	1926,0	HHIG	C28776	orthoclase	low to moderately altered	sericite, calcite	not abundant, 90-95 % altered	chlorite, carbonates, white mica	? completely altered if present	magnetite	some carbonate	pervasive, vein
	1929,0	MELA	C28777	orthoclase	low to moderately altered	sericite, calcite	abundant, 90-95 % fresh	chlorite	present	magnetite, titanite, apatite	rare epidote, carbonate	pervasive
	1944,0	MELA	C28778	orthoclase	low to moderately altered	sericite, calcite	abundant, 99 % fresh, inclusions of hydrogarnet, zircon, apatite	rare chlorite	present	magnetite		low pervasive
	1950,0	GRAN	C28779	orthoclase	low to moderately altered	sericite, rare calcite	70-80 % fresh, some kinks	chlorite, rare calcite or white mica	present	magnetite, titanite		pervasive
	1965,0	MELA	C28780	orthoclase	low to moderately altered	sericite, some calcite	relatively abundant, 95-99 % fresh, some kinks	chlorite	rare	magnetite, rare allanite	rare epidote	low pervasive

N°	depth	type	thin section	K-feldspar	plagioclase	*alteration minerals*	biotite	*alteration minerals*	amphibole	accessory minerals	others	alteration type
	2071,0	HHIG	C28781	orthoclase	moderately to highly altered	sericite, calcite	rare, generally altered	white mica, rare chlorite	not observed	magnetite	some carbonate	vein
	2074,0	HLOW	C28782	orthoclase	low to highly altered	sericite, calcite	60-70% altered	chlorite, rare white mica	? completely altered if prese nt	magnetite, altered titanite	some carbonate	pervasive, vein
	2078,0	MELA	C28783	orthoclase	low to moderately altered	sericite, rare calcite	abundant, 70-80 % fresh, some kinks	chlorite, rare white mica	? completely altered if present	magnetite, altered titanite	rare carbonate	pervasive, vein ?
	2081,0	GRAN	C28784	orthoclase	low to moderately altered	sericite, rare calcite	abundant, 70-80 % fresh, some kinks	chlorite, rare white mica	? completely altered if present	magnetite	rare carbonate	pervasive, vein ?
	2090,0	MELA	C28785	orthoclase	low to highly altered	sericite, calcite	very abundant, 90-95 % fresh, inclusions of hydrogarnet, apatite	rare chlorite or white mica + calcite	rare	magnetite, allanite	some carbonate	low pervasive, vein ?
	2092,0	GRAN	C28786	orthoclase	low to moderately altered	sericite, calcite	70-80 % fresh	chlorite, rare white mica + calcite	present, +/- altered	magnetite	some carbonate, rare epidote	low pervasive, vein ?
	2094,0	HLOW	C28787	orthoclase	low to moderately altered	sericite, calcite	70-80 % altered	chlorite, some white mica +/- calcite	? completely altered if present	magnetite, titanite	rare carbonate	pervasive, vein
	2098,0	MELA	C28788	orthoclase	low to moderately altered	sericite, calcite	very abundant, 95 % fresh	rare chlorite	present	magnetite, rare allanite	rare carbonate	low pervasive

N°	depth	type	thin section	K-feldspar	plagioclase	*alteration minerals*	biotite	*alteration minerals*	amphibole	accessory minerals	others	alteration type
	2100,0	MELA	C28789	orthoclase	low to highly altered	sericite, calcite	(very) abundant, 90 % fresh, some kinks	chlorite	present	magnetite	rare carbonate	pervasive
	2102,0	HHIG	C28790	orthoclase	low to highly altered	sericite, calcite	95 % altered, some kinks	chlorite, white mica, carbonates	? completely altered if present	magnetite	some carbonate	vein
	2104,0	HLOW	C28791	orthoclase	low to highly altered	sericite, calcite	50 % fresh	chlorite	? completely altered if present	magnetite, altered titanite, rare zircon	rare carbonate	pervasive, vein ?
7	3856,0	GRAN	C28792	orthoclase, rare microcline	fresh to moderately altered	sericite	generally fresh	some chlorite, rare white mica	present	magnetite, titanite	rare carbonate, muscovite	low pervasive
27	3927,0	GRAN	C28793	orthoclase	low to highly altered	sericite, calcite	generally fresh	chlorite, rare white mica	relatively abundant, +/- altered	magnetite, altered titanite	some carbonate, fine-grained xenoliths	low pervasive, vein ?
33	3943,1	GRAN	C28794	orthoclase	low to highly altered	sericite, calcite	generally fresh	chlorite	abundant	magnetite, titanite	some carbonate, fine-grained xenoliths	vein
39	3971,6	GRAN	C28795	orthoclase, rare microcline	low to highly altered	sericite, calcite	60-70% altered	chlorite, rare white mica	present	magnetite, titanite	some carbonate, fine-grained xenoliths (sometimes altered)	vein
	2100,0	MELA	C28789	orthoclase	low to highly altered	sericite, calcite	(very) abundant, 90 % fresh, some kinks	chlorite	present	magnetite	rare carbonate	pervasive
	2102,0	HHIG	C28790	orthoclase	low to highly altered	sericite, calcite	95 % altered, some kinks	chlorite, white mica, carbonates	? completely altered if present	magnetite	some carbonate	vein

N°	depth	type	thin section	K-feldspar	plagioclase	*alteration minerals*	biotite	*alteration minerals*	amphibole	accessory minerals	others	alteration type
	2104,0	HLOW	C28791	orthoclase	low to highly altered	sericite, calcite	50 % fresh	chlorite	? completely altered if present	magnetite, altered titanite, rare zircon	rare carbonate	pervasive, vein ?
7	3856,0	GRAN	C28792	orthoclase, rare microcline	fresh to moderately altered	sericite	generally fresh	some chlorite, rare white mica	present	magnetite, titanite	rare carbonate, muscovite	low pervasive
27	3927,0	GRAN	C28793	orthoclase	low to highly altered	sericite, calcite	generally fresh	chlorite, rare white mica	relatively abundant, +/- altered	magnetite, altered titanite	some carbonate, fine-grained xenoliths	low pervasive, vein ?
33	3943,1	GRAN	C28794	orthoclase	low to highly altered	sericite, calcite	generally fresh	chlorite	abundant	magnetite, titanite	some carbonate, fine-grained xenoliths	vein
39	3971,6	GRAN	C28795	orthoclase, rare microcline	low to highly altered	sericite, calcite	60-70% altered	chlorite, rare white mica	present	magnetite, titanite	some carbonate, fine-grained xenoliths (sometimes altered)	vein
44	3993,0	GRAN	C28796	orthoclase, rare microcline	fresh to moderately altered	sericite, some calcite	50 % altered	chlorite, rare white mica	present	magnetite, titanite	some carbonate, fragments of xenoliths and of fine-grained muscovite granite	pervasive
66	4044,0	HLOW	C28797	orthoclase, rare microcline	low to highly altered	sericite, calcite	60-70% altered	chlorite, some white mica	present	magnetite, altered titanite	some carbonate, recristallized quartz	pervasive, vein

N°	depth	type	thin section	K-feldspar	plagioclase	*alteration minerals*	biotite	*alteration minerals*	amphibole	accessory minerals	others	alteration type
84	4080,0	GRAN	C28798	orthoclase, rare microcline	fresh to moderately altered	sericite, some calcite	generally fresh	chlorite	present	magnetite, titanite	some carbonate; fine-grained xenoliths	pervasive, vein ?
105	4135,0	GRAN	C28799	orthoclase, rare microcline	fresh to moderately altered	sericite, some calcite	50 % altered	chlorite	present	magnetite, apatite, allanite	some carbonate, rare xenolith	pervasive
131	4203,0	HLOW	C28800	orthoclase, more microcline	fresh (one fragment with myrmekite) to highly altered	sericite, calcite	generally fresh, some kinks and hydrogarnet inclusions	chlorite, rare white mica	present	magnetite, titanite	rare epidote and carbonate, rare xenolith	pervasive, vein ?
142	4227,0	GRAN	C28801	orthoclase, rare microcline	fresh to moderately altered	sericite, some calcite	50 % altered some kinks	chlorite, rare white mica	present	magnetite, titanite, zircon	some carbonate, rare xenolith	pervasive
153	4257,5	HLOW	C28802	orthoclase, rare microcline	low to highly altered	sericite, calcite	60-70% altered, some kinks	chlorite, some white mica	present	magnetite, altered titanite	some carbonate, fine-grained xenoliths, fragment of muscovite granite	pervasive, vein
156	4266,0	GR2M	C28803	orthoclase, rare microcline	fresh to moderately altered	sericite, some calcite	less abundant, 30-40% altered, apatite inclusions	chlorite, some white mica	rare	rare magnetite	some carbonate, muscovite, fragment of muscovite granite	pervasive
172	4309,0	GRAN	C28804	orthoclase, rare microcline	fresh to moderately altered	sericite, some calcite	generally fresh, some kinks	chlorite	present	magnetite, titanite, allanite	some carbonate, rare fragments of xenolith and of muscovite granite	pervasive

N°	depth	type	thin section	K-feldspar	plagioclase	*alteration minerals*	biotite	*alteration minerals*	amphibole	accessory minerals	others	alteration type
180	4330,0	HLOW	C28805	orthoclase, rare microcline	low to highly altered	sericite, calcite	60-70% altered	chlorite, some white mica, rare epidote	rare	magnetite, altered titanite	some carbonate, muscovite	pervasive, vein
188	4350,0	GRAN	C28806	orthoclase, rare microcline	low to highly altered	sericite, calcite	generally fresh, some kinks	chlorite	present	magnetite, titanite	some carbonate, fine-grained xenoliths, muscovite	pervasive
193	4366,0	GRAN	C28827	orthoclase, more microcline	low to highly altered	sericite, calcite	60-70 % altered	chlorite, rare white mica	present	magnetite, titanite	some carbonate; muscovite	pervasive
195	4372,0	HLOW	C28828	orthoclase, more microcline	low to highly altered	sericite, calcite	70-80 % altered	chlorite, some white mica	present, +/- altered	magnetite, altered titanite	some carbonate	pervasive, vein ?
204	4393,0	HLOW	C28829	orthoclase, more microcline	low to highly altered	sericite, calcite	generally fresh, some kinks	chlorite, rare white mica	present	magnetite	some carbonate	pervasive, vein
215	4420,0	GRAN	C28830	orthoclase, rare microcline	fresh (one crystal with myrmekite) to moderately altered	sericite, some calcite	generally fresh, some hydrogarnet or apatite inclusions	chlorite, rare white mica	more abundant	magnetite, titanite, allanite	rare carbonate	pervasive
250	4506,0	HLOW	C28836	orthoclase, rare microcline	low to highly altered	sericite, calcite	30-40 % altered, some hydrogarnet inclusions	chlorite, rare white mica	present	magnetite, titanite	some carbonate, fine-grained xenoliths	pervasive, vein
270	4546,4	GRAN	C28837	orthoclase, rare microcline	fresh to moderately altered	sericite, some calcite	generally fresh, some kinks	chlorite, rare white mica	more abundant	magnetite, titanite	fine-grained xenoliths	pervasive
272	4552,0	HLOW	C28834	orthoclase, more microcline	low to highly altered	sericite, rare calcite	10-20 % altered	chlorite	present	magnetite, titanite	some carbonate, rare epidote, fine-grained xenoliths	pervasive, vein ?

N°	depth	type	thin section	K-feldspar	plagioclase	*alteration minerals*	biotite	*alteration minerals*	amphibole	accessory minerals	others	alteration type
277	4558,0	HMOD	C28835	orthoclase, more microcline	low to highly altered	sericite, rare calcite	10-20 % altered	chlorite, rare white mica	present	magnetite, titanite, zircon	rare carbonates, fine-grained xenoliths, one fragment of muscovite granite	pervasive, vein ?
280	4564,0	HMOD	C28838	orthoclase, rare microcline	low to highly altered	sericite, rare calcite	20-30 % altered, some kinks, rare hydrogarnet inclusions	chlorite, rare white mica	present, sometimes altered	magnetite, titanite	rare carbonate, fine-grained xenoliths	pervasive, vein ?
282	4569,7	HMOD	C28839	orthoclase, rare microcline	low to highly altered	sericite, rare calcite	10-20 % altered	chlorite, rare white mica	present, sometimes altered	magnetite, altered titanite	rare carbonate, fine-grained xenoliths	pervasive, vein ?
283	4574,0	HLOW	C28840	orthoclase, rare microcline	one piece with myrmekite, low to highly altered	sericite, calcite	10-20 % altered, some kinks	chlorite, rare white mica	present, sometimes altered into carbonates	magnetite, altered titanite	some carbonate, fine-grained +/- altered xenoliths	
284	4579,0	HEXT	C28841	orthoclase, rare microcline	very altered	sericite, abundant calcite	relatively rare, 70-80 % altered	chlorite	present, +/- altered	magnetite, altered titanite	abundant carbonate, fine-grained xenolith with a planar fabric	

N°	depth	type	thin section	K-feldspar	plagioclase	*alteration minerals*	biotite	*alteration minerals*	amphibole	accessory minerals	others	alteration type
288	4592,0	HEXT	C28842	orthoclase, rare microcline	very altered	sericite, abundant calcite	relatively rare, 50-60 % altered	chlorite, rare white mica	present, +/- altered	magnetite, altered titanite	abundant carbonate, altered fine-grained xenoliths	vein >>
290	4598,0	HEXT	C28843	orthoclase, rare microcline	very altered	sericite, abundant calcite	relatively rare, 70-80 % altered	abundant white mica, chlorite	present, +/- altered	magnetite, altered titanite	abundant carbonate, altered fine-grained xenoliths	vein >>
292	4602,3	HLOW	C28844	orthoclase, more microcline	low to highly altered	sericite, calcite	50-60 % altered, some apatite inclusions	chlorite, some white mica	present, +/- altered	magnetite, titanite	some carbonate, fine-grained xenoliths	pervasive, vein ?
293	4605,0	GRAN	C28845	orthoclase, more microcline	fresh to highly altered	sericite, some calcite	20-30 % altered	chlorite, some white mica	present	magnetite, titanite, allanite, apatite	rare carbonate, fine-grained xenoliths, one fragment of muscovite granite	pervasive
315	4645,0	HMOD	C28846	orthoclase, rare microcline	fresh to highly altered	sericite, some calcite	10-20 % altered	chlorite, some white mica	present	magnetite, titanite	rare carbonate, muscovite; fine-grained xenoliths, one fragment of muscovite granite	pervasive, vein ?
322	4662,0	GRAN	C28953	orthoclase, rare microcline	fresh to highly altered	sericite, some calcite	10-20 % altered	chlorite	present	magnetite, titanite	rare carbonate	pervasive

N°	depth	type	thin section	K-feldspar	plagioclase	*alteration minerals*	biotite	*alteration minerals*	amphibole	accessory minerals	others	alteration type
330	4677,0	HLOW	C28954	orthoclase, rare microcline	low to highly altered	sericite, calcite	80-90 % altered, one hydrogarnet inclusion	chlorite, some white mica	rare	magnetite, titanite, allanite	rare carbonate	pervasive, vein ?
339	4694,0	HMOD	C28955	orthoclase, rare microcline	low to moderately altered	sericite, rare calcite	90 % altered	chlorite, some white mica	rare	magnetite	rare muscovite	pervasive
343	4702,0	HMOD	C28967	orthoclase, more microcline	low to moderately altered; one crystal with myrmekite	sericite, calcite	less abundant, 95 % altered	chlorite, rare white mica	present, generally altered	magnetite	some carbonate, muscovite, fine-grained xenolith, fragments of muscovite granite	pervasive, vein ?
354	4722,0	GRAN	C28956	orthoclase, rare microcline	fresh to moderately altered; one crystal with myrmekite	sericite	rarely altered, some kinks	rare chlorite	present	magnetite, titanite, zircon	one fragment of muscovite granite	low pervasive
371	4744,0	GRAN	C28957	orthoclase, rare microcline	low to highly altered	sericite, some calcite	50-60 % altered	chlorite	abundant	magnetite, titanite, apatite	some carbonate, fine-grained xenoliths	pervasive, vein ?
383	4760,0	HMOD	C28958	orthoclase, very rare microcline	low to highly altered	sericite, some calcite	rarely altered	rare chlorite	abundant	magnetite, abundant titanite, apatite	fine-grained xenolith, one fragment of fine-grained biotite granite	pervasive, vein ?

N°	depth	type	thin section	K-feldspar	plagioclase	*alteration minerals*	biotite	*alteration minerals*	amphibole	accessory minerals	others	alteration type
391	4771,0	XENO	C28959	orthoclase, rare microcline	low to moderately altered	sericite, rare calcite	rarely altered	rare chlorite	abundant	magnetite, titanite, apatite	rare carbonate, some fine-grained xenoliths	pervasive
395	4780,0	HHIG	C28960	orthoclase, very rare microcline	moderately to highly altered	sericite, some calcite	90-95 % altered	chlorite, some white mica	present	magnetite, titanite	abundant carbonate, important recrystallisa-tion of quartz	vein
403	4792,0	HLOW	C28961	orthoclase, rare microcline	low to moderately altered	sericite, rare calcite	5-10 % altered, some kinks	chlorite	present	magnetite, titanite	some calcite and muscovite	pervasive, vein
411	4801,0	HMOD	C28962	orthoclase, rare microcline	fresh to moderately altered	sericite	5-10 % altered	chlorite, rare white mica	present	magnetite	rare calcite, muscovite, xenolith, one fragment of muscovite granite, important recrystallis-ation of quartz	pervasive, vein ?
417	4813,0	HMOD	C28963	orthoclase, more microcline	fresh to moderately altered	sericite, some calcite	rarely altered	rare chlorite	present	magnetite, titanite	rare calcite, muscovite	pervasive, vein ?
431	4840,0	GRAN	C28964	orthoclase, rare microcline	fresh to moderately altered	sericite, rare calcite	rarely altered	rare chlorite	present	magnetite, titanite	rare calcite, epidote, some muscovite	pervasive
434	4846,0	HLOW	C29074	orthoclase, rare microcline	low to highly altered	sericite, some calcite	10-15 % altered	chlorite	present	magnetite, titanite	rare carbonate, fine-grained xenolith	pervasive, vein ?

N°	depth	type	thin section	K-feldspar	plagioclase	*alteration minerals*	biotite	*alteration minerals*	amphibole	accessory minerals	others	alteration type
443	4865,0	GR2M	C29075	orthoclase, rare microcline	fresh to highly altered	sericite, calcite ?	rarely altered, some kinks	rare chlorite	abundant	magnetite, titanite	some carbonate, rare epidote, fine-grained xenolith	low pervasive
444	4867,0	MELA	C29076	orthoclase	low to highly altered	sericite, some calcite	rarely altered, some hydrogarnet inclusions	rare chlorite	abundant	magnetite, titanite, apatite, allanite		low pervasive
451	4885,5	HMOD	C29077	orthoclase, very rare microcline	fresh to highly altered	sericite, calcite	rarely altered	rare chlorite	present , sometimes altered	magnetite, titanite, allanite	abundant carbonate	low pervasive, vein
457	4901,0	GRAN	C29078	orthoclase, more microcline	low to moderately altered	sericite	40-50 % altered, some kinks	chlorite, some white mica	present , sometimes altered	magnetite, titanite	rare carbonate and epidote, one fragment of muscovite granite	pervasive
458	4902,4	HLOW	C29079	orthoclase, more microcline	low to highly altered	sericite, calcite	20-30 % altered	chlorite, rare white mica	present	magnetite, titanite	some carbonate, muscovite fragments of muscovite granite	pervasive, vein

N°	depth	type	thin section	K-feldspar	plagioclase	*alteration minerals*	biotite	*alteration minerals*	amphibole	accessory minerals	others	alteration type
471	4931,7	GR2M	C29080	orthoclase, more microcline	fresh to moderately altered	sericite, calcite	rarely altered	rare chlorite	present	magnetite, titanite	abundant primary muscovite sometimes kinked; some carbonate; fragment of fine-grained biotite granite	pervasive, vein ?
481	4956,0	MELA	C29081	orthoclase, some microcline	low to highly altered	sericite, calcite	abundant, rarely altered, some kinks	rare chlorite	rare	magnetite, titanite	some carbonate, rare muscovite	pervasive, vein ?
494	4988,0	GRAN	C29082	orthoclase, some microcline	low to highly altered	sericite, calcite	10 % altered	chlorite	present	magnetite, titanite	muscovite associated with quartz, rare epidote	pervasive
501	5011,0	HLOW	C29083	orthoclase, rare microcline	low to highly altered	sericite, calcite	20-30 % altered	chlorite	present , sometimes altered	magnetite, titanite, allanite	rare carbonate	pervasive, vein ?
514	5030,0	GRAN	C29392	orthoclase, rare microcline	low to moderately altered	sericite	30-40 % altered	chlorite	present	magnetite, titanite, apatite	rare carbonate, muscovite, fragments of muscovite granite	pervasive
525	5042,1	GRAN	C29393	orthoclase, more microcline	low to moderately altered	sericite	40-50 % altered	chlorite	present	magnetite, titanite	muscovite, fragments of fine-grained granite	pervasive

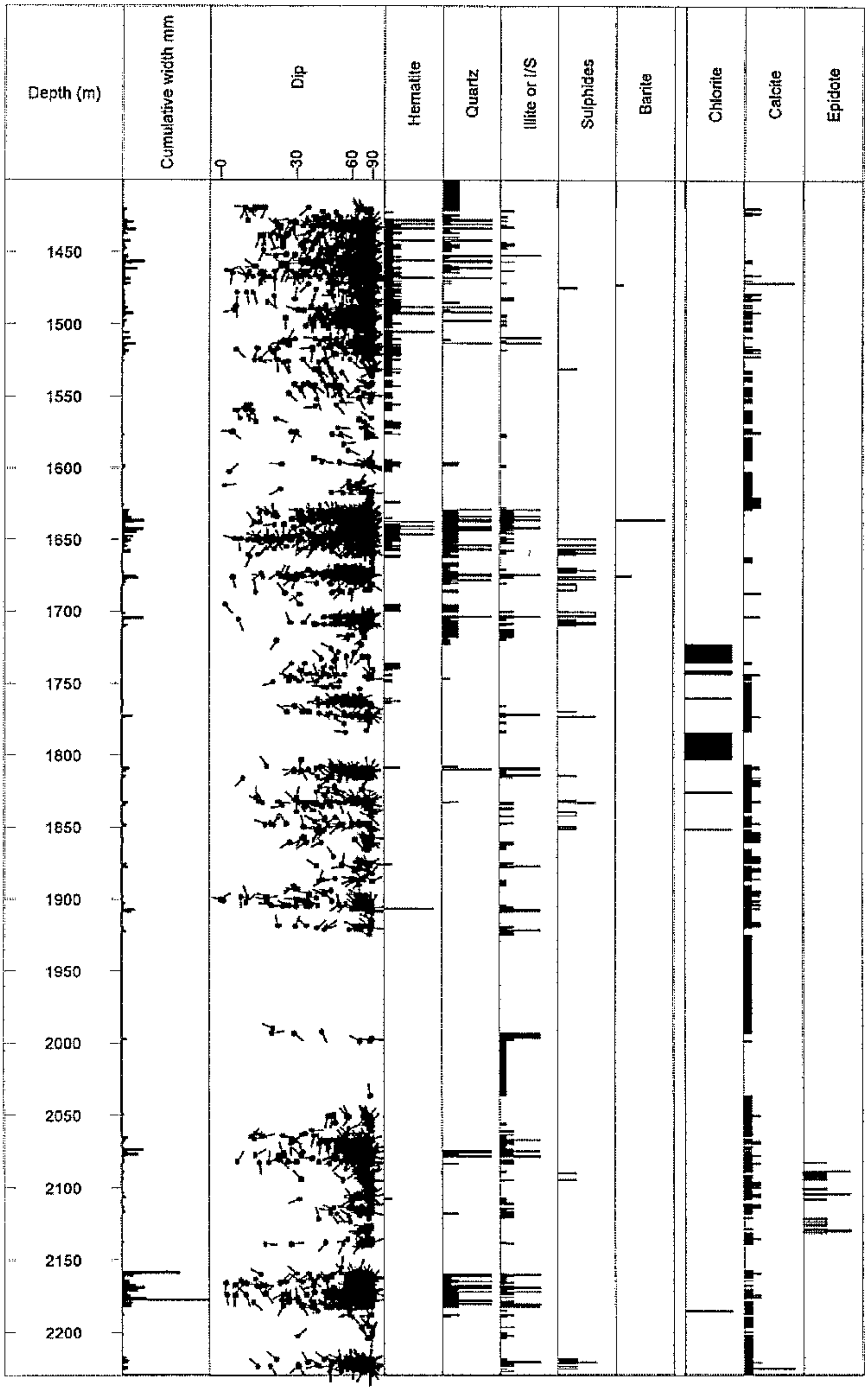
N°	depth	type	thin section	K-feldspar	plagioclase	*alteration minerals*	biotite	*alteration minerals*	amphibole	accessory minerals	others	alteration type
534	5055,3	GR2M	C29394	orthoclase, abundant microcline	low to moderately altered	sericite	10-20 % altered	chlorite	present	magnetite, titanite	muscovite, fragments of fine-grained granite	pervasive
537	5056,0	HLOW	C29395	orthoclase, microcline	low to moderately altered	sericite	20-30 % altered	chlorite, rare epidote	relatively abundant	magnetite, titanite	rare carbonate, muscovite, fragments of fine-grained granite and xenolith	pervasive
548	5080,4	GR2M	C29397	orthoclase, microcline	low to moderately altered	sericite	10-20 % altered, hydrogarnet inclusion	chlorite	present	magnetite, titanite	muscovite, fragments of fine-grained granite	pervasive
554	5093,0	GR2M	C29398	orthoclase, microcline	low to moderately altered	sericite	10-20 % altered, hydrogarnet inclusion	chlorite	present	magnetite, titanite	rare carbonate, epidote; muscovite, fragments of fine-grained granite and xenolith	pervasive

ANNEX 3. X-RAY RESULTS

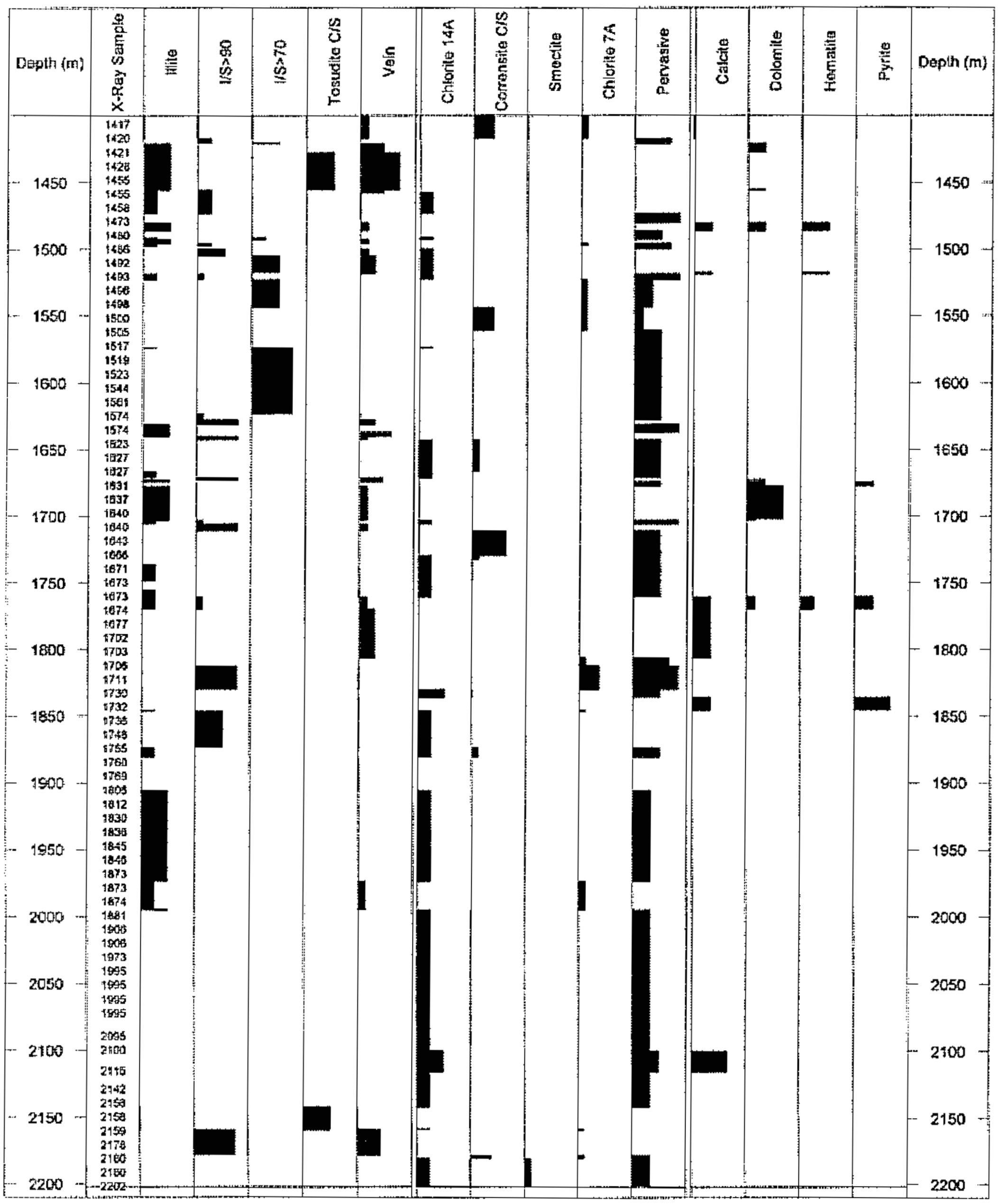
Annex 3.1. List of X-Ray analyses in Well GPK-2

N°Sample	Petrographic facies	Depth (m)
GPK-2-1	Altered Granite, white minerals, HEXT	4586-4600
GPK-2-2	Altered Granite, green minerals, HEXT	4586-4600
GPK-2-3	Altered Granite, raw cutting, HEXT	4598
GPK-2-4	Altered Granite, raw cutting, HHIG	1893
GPK-2-5	Altered Granite, raw cutting, HMOD	1918
GPK-2-6	Altered Granite, raw cutting, HHIG	1922
GPK-2-7	Altered Granite, raw cutting, HLOW	1925
GPK-2-8	Altered Granite, raw cutting, HHIG	1926
GPK-2-9	Massive Granite, raw cutting, GRAN	1950
GPK-2-10	Altered Granite, raw cutting, HHIG	2071
GPK-2-11	Massive Granite, raw cutting, GRAN	2092
GPK-2-12	Altered Granite, raw cutting, HLOW	2094
GPK-2-13	Biotite rich Granite, raw cutting, MELA	2100
GPK-2-14	Altered Granite, raw cutting, HHIG	2102
GPK-2-15	Altered Granite, raw cutting, HLOW	2104
GPK-2-16	Massive Granite, rock piece, GRAN	3600
GPK-2-17	Altered Granite, rock piece, HEXT	3601
GPK-2-18	Massive Granite, raw cutting, GRAN	3856
GPK-2-19	Massive Granite, raw cutting, GRAN	3943.10
GPK-2-20	Massive Granite, raw cutting, GRAN	3993
GPK-2-21	Altered Granite, raw cutting, n°66, HLOW	4044
GPK-2-22	Massive Granite, raw cutting, GRAN	4135
GPK-2-23	Altered Granite, raw cutting, n°153, HLOW	4257.50
GPK-2-24	Massive Granite, raw cutting, n°156, LCGR	4266
GPK-2-25	Altered Granite, raw cutting, n°180, HLOW	4330
GPK-2-26	Massive Granite, raw cutting, GRAN	4350
GPK-2-27	Altered Granite, raw cutting, 315, HMOD	4645
GPK-2-28	Altered Granite, raw cutting, 339, HLOW	4694
GPK-2-29	Massive Granite, raw cutting, 371, GRAN	4744,50
GPK-2-30	Altered Granite, raw cutting, 395, HHIG	4780
GPK-2-31	Altered Granite, raw cutting, 451, HMOD	4885,50
GPK-2-32	Massive Granite 2 micas, raw cutting, 471, GRAM	4931,70
GPK-2-33	Massive Granite, raw cutting, 494, GRAN	4988
GPK-2-34	Massive Granite 2 micas, raw cutting, 534, GRAM	5055,30
GPK-2-35	Altered Granite, raw cutting, n°537, HLOW	5056
GPK-2-36	Massive Granite, 2 micas, raw cutting, 548, GRAM	5080,40

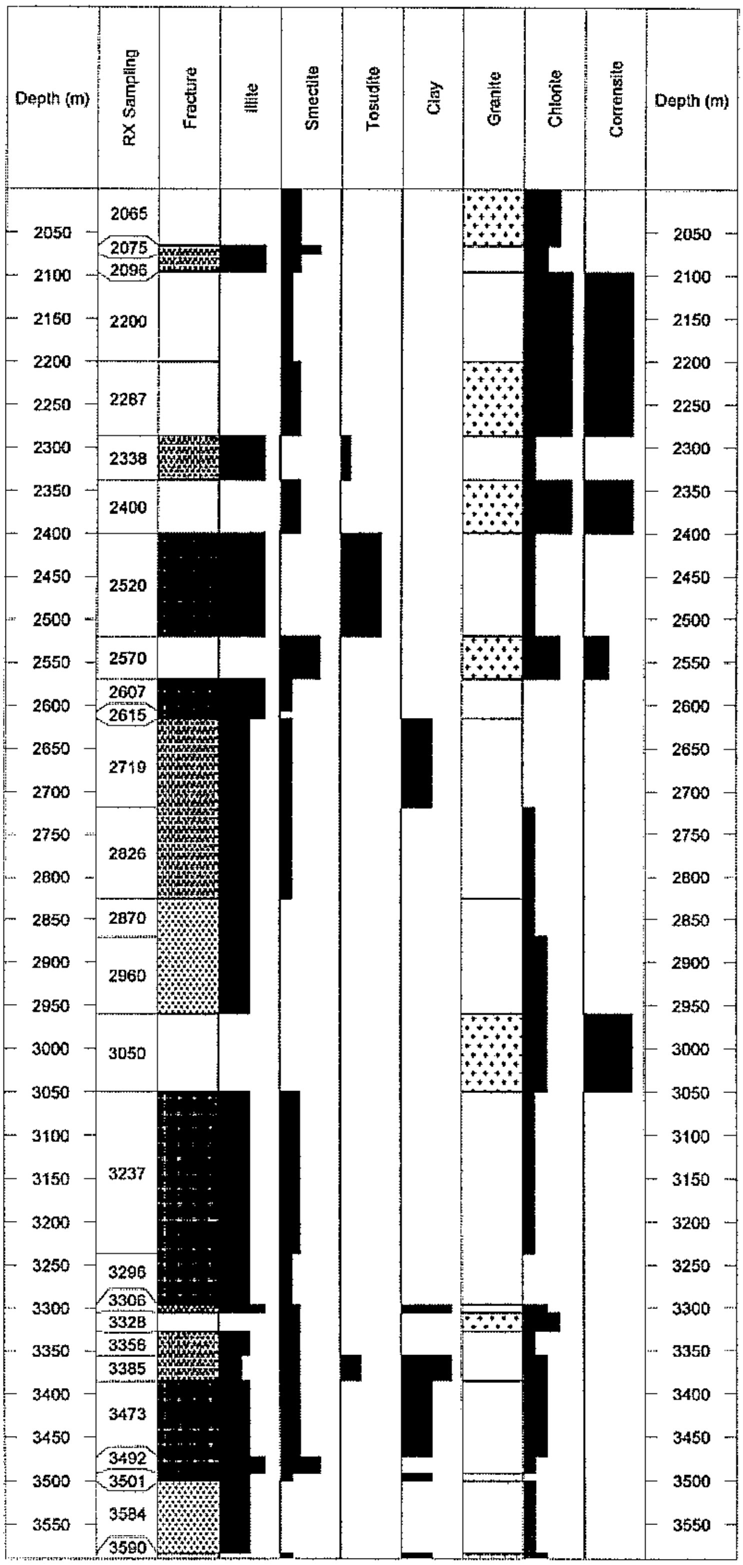
Annex 3.2. Hydrothermal alteration log in EPS-1 Well from fracture examination (Genter & Traineau, 1996)



Annex 3.3. Hydrothermal alteration log in EPS-1 Well from X-ray analyses (Genter & al., 1997)

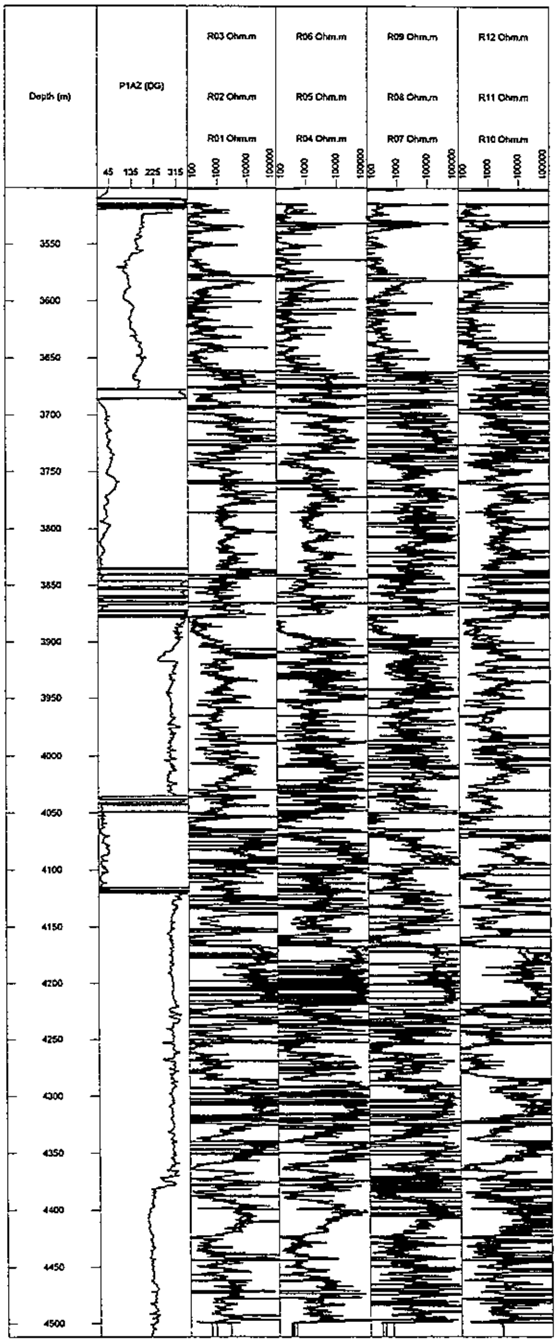


Annex 3.4. Hydrothermal alteration distribution versus depth in GPK-1 Well from X-ray analyses between 2000 and 3600 m (Genter et al., 1997)



ANNEX 4. ARI DATA COLLECTED IN WELL GPK-2

Annex 4.1 Log of the twelve resistivity curves (ARI) acquired between 3500 and 4500 m depth in Well GPK-2.



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