P-08-14

Forsmark site investigation

Fracture mineralogy and $^{40}Ar/^{39}Ar$ ages of adularia in fracture filling and K-feldspar in breccia

Data from drill cores KFM01C, KFM01D, KFM02B, KFM04A, KFM06A, KFM06B, KFM07A, KFM08A, KFM08B, KFM08C, KFM08D, KFM09A, KFM09B, KFM10A and KFM11A

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March 2008

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ISSN 1651-4416
SKB P-08-14

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Keywords: Fracture mineralogy, Low temperature minerals, Stable isotopes, Calcite, Geochemistry, $^{40}Ar/^{39}Ar$ ages, Adularia, K-feldspar, Breccia, AP PF-400-07-047, AP PF-400-05-047.

This report concerns a study which was conducted for SKB. The conclusions and viewpoints presented in the report are those of the authors and do not necessarily coincide with those of the client.

Data in SKB's database can be changed for different reasons. Minor changes in SKB's database will not necessarily result in a revised report. Data revisions may also be presented as supplements, available at www.skb.se.

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Abstract

This report presents data obtained from detailed fracture mineral investigations of drill core samples from KFM01C, KFM01D, KFM02B, KFM08C, KFM08D, KFM09A, KFM09B, KFM10A and KFM11A from the Forsmark site investigation. Open as well as sealed fractures have been sampled. The data include mineralogy, geochemistry of fracture minerals, stable isotopes in calcite, XRD analyses, uranium series disequilibrium analyses (USD) and Mössbauer analyses. Complementary geochemical analyses of fracture minerals in KFM04A, KFM06A, KFM06B, KFM07A, KFM08A, and KFM08B are presented. Complementary $^{40}Ar/^{39}Ar$ data for fracture filling adularia and K-feldspar in breccia from KFM04A, KFM08A and KFM09A are also presented in this report.

Sammanfattning

Denna rapport presenterar data från detaljerade sprickmineralogiska undersökningar av borrkärnorna KFM01C, KFM01D, KFM02B, KFM08C, KFM08D, KFM09A, KFM09B, KFM10A och KFM11A från Forsmarks platsundersökning. Både öppna och läkta sprickor har provtagits. Resultaten inkluderar mineralogi, geokemi av sprickmineral, stabila isotoper i kalcit, XRD-analyser, uran-serie analyser (USD) och Mössbauer analyser. Kompletterande geokemiska analyser av sprickmineral från borrhålen KFM04A, KFM06A, KFM06B, KFM07A, KFM08A och KFM08B har utförts. Vidare har kompletterande $^{40}Ar/^{39}Ar$ dateringar av sprickmineralet adularia och kalifältspat i breccia från borrhålen KFM04A, KFM08A och KFM09A också utförts, och presenteras i denna rapport.

Contents

1 Introduction

This document reports the results gained by a detailed fracture mineralogy investigation, which is one of the activities performed within the site investigation at Forsmark. The work was carried out in accordance with activity plan AP PF-400-07-047 and AP PF-400-05-047 (the later for the $^{40}Ar/^{39}Ar$ dating of fracture minerals). In Table 1-1 controlling documents for performing the activity are listed. Both activity plans and method descriptions are SKB's internal controlling documents. This document presents the result from boreholes KFM01C, KFM01D, KFM02B, KFM08C, KFM08D, KFM09A, KFM09B, KFM10A and KFM11A. The locations of the boreholes studied are shown in Figure 1-1 together with the bedrock geology of the Forsmark area.

Mapping of fractures and fracture minerals is carried out on all cored boreholes within the site investigation program and this information serves as a basis for the fracture mineral study. However, identifying fracture minerals macroscopically can be very difficult, especially considering clay minerals and other very fine grained mineral coatings. X-Ray diffractometry (XRD), SEM-EDS analyses and conventional petrological microscopy are therefore used in the detailed fracture mineralogical study to determine unidentified or fine-grained fracture minerals in order to support the drill core mapping geologists.

The flow logs have been used as a tool for selection of samples of hydraulically conductive fractures, preferably for geochemical-, USD-, XRD-, and Mössbauer-analyses.

$^{40}Ar/^{39}Ar$ dating of fracture filling adularia and K-feldspar in breccia has also been carried out within the scope of this report.

Original data from the reported activity are stored in the primary database Sicada. Data are traceable in Sicada by the activity plan numbers (AP PF 400-07-047 and AP PF 400-05-047). Only data in databases are accepted for further interpretation and modelling. The data presented in this report are regarded as copies of the original data. Data in the database may be revised, if needed. However, such revision of the database will not necessarily result in a revision of this report.

In addition to the results from the above mentioned boreholes, a few complementary analyses of samples from KFM04A, KFM06A, KFM06B, KFM07A, KFM08A and KFM08B are included in this report. The full description of these samples, including thin sections and SEM-surfaces are shown in Appendix 1 in P-Report P-05-197 /Sandström and Tullborg 2005/ for borehole KFM04A and KFM06A, and in Appendix 1 in P-Report P-06-226 /Sandström and Tullborg 2006/ for boreholes KFM06B, KFM07A, KFM08A and KFM08B.

Table 1-1. Controlling documents for performance of the activity.

Activity plan	Number	Version
Sprickmineralogiska undersökningar	AP PF-400-07-047	1.0
Geokronologisk undersökning av sprickmineral	AP PF-400-05-047	1.0
Method descriptions	**Number**	**Version**
Sprickmineralogi	SKB MD 144.000	1.0
Åldersdateringar av mineral och bergarter	SKB MD 132.002	1.0

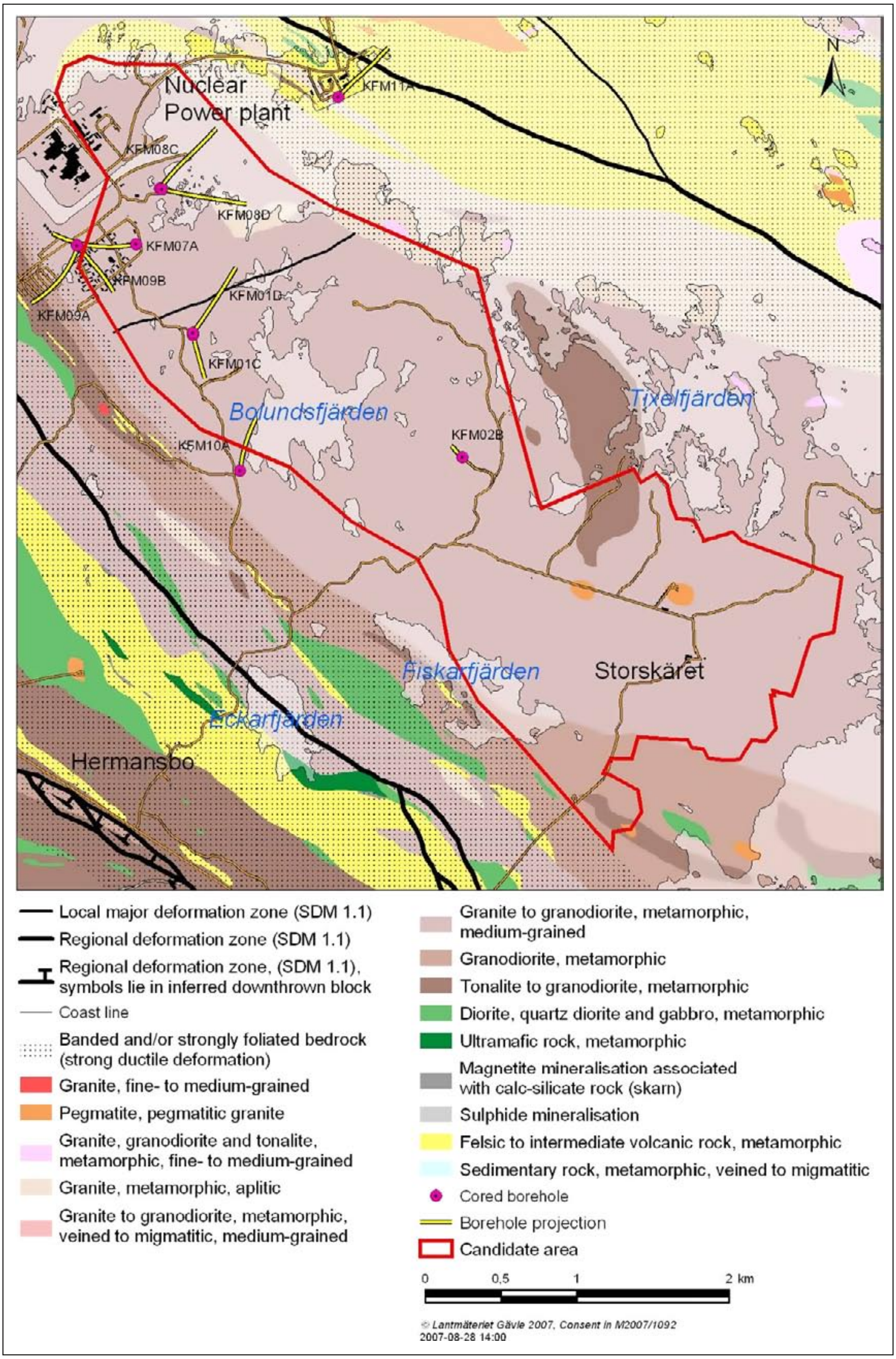

Figure 1-1. *Geological map over the Forsmark site investigation area with projections of the boreholes treated in this report /SKB GIS database 2007/.*

2 Objective and scope

The objective of this P-report is to report data obtained from detailed mineralogical studies. Further data evaluation (including the U-series analyses) will be carried out in an SKB R-report /Sandström et al. 2008/. The data presented in this report include mineralogy (based on optical microscopy and SEM-EDS), X-ray diffraction analyses, geochemistry, Mössbauer analyses, stable isotopes in calcite and U-series analyses. The report complements the data presented in /Sandström et al. 2004, Sandström and Tullborg 2005, Sandström and Tullborg 2006/. The conclusions regarding the fracture mineralogy in a geological evolution context (including the relative sequence of fracture minerals) presented in /Sandström and Tullborg 2006/ have been further strengthened and not modified in this report. For a detailed description of the relative sequence of fracture minerals, see /Sandström and Tullborg 2006/. New $^{40}Ar/^{39}Ar$ data of fracture filling adularia and K-feldspar in wall rock fragments in breccias are also presented in this report. The $^{40}Ar/^{39}Ar$ data complement the data presented in /Sandström et al. 2006/.

3 Equipment

3.1 Description of equipment/interpretation tools

The following equipment has been used for performance of this activity:

- Rock saw
- Steel knife
- Tweezers
- Hand lens
- Digital camera
- Petrographic Microscope (Leica DMRXP)
- Stereo microscope (Leica MZ12)
- Digital microscope camera (Leica DFC 280)
- Scanner (Epson 4180 Photo) and polarizing filters
- Computer software (Corel Draw 9, Microsoft Word 2003, Microsoft Excel 2003, BIPS Image Viewer 2.51)
- Analytical balance (Sartorius 2004 MP)
- Scanning electron microscope (Hitachi S-3400N) with EDS-detector (INCADryCool)
- Mass spectrometer (VG Prism Series II)

The listed equipment is located at the Department of Earth Sciences, University of Gothenburg, Sweden. For instruments used at other laboratories, see section 4.4.

4 Execution

4.1 General

Fracture filling samples suitable for microscopy were selected from the drill cores KFM01C, KFM01D, KFM02B, KFM08C, KFM08D, KFM09A, KFM09B, KFM10A and KFM11A. In addition a few samples were selected from previous drill cores (KFM04A, KFM06A, KFM06B, KFM07A, KFM08A and KFM08B) to supplement where data were missing. In total, 68 samples were chosen (6 from previously sampled drill cores) from representative fractures for different analyses. The selection of the samples was more based on the information expected to be yielded from each sample than to get a statistic overview of the drill cores (see section 4.2).

4.2 Selection of samples

Samples have been selected on different grounds:

- For mineralogical identification; the sampling has usually been initiated by the geologists carrying out the drill core logging. XRD and SEM-EDS analyses are performed on many of these samples, but they are also used for thin section preparation and subsequent microscopy.
- Samples selected for mineralogical studies (thin section preparation and surface samples); these samples often show a complex mineralogy and are usually chosen to represent several generations of fracture mineralization. Cross-cutting relations are preferably sampled for the construction of the sequence of fracture mineralizations.
- Fractures filled or coated with calcite are sampled since they can provide paleogeohydrological information. Some of these samples have been analysed for stable isotopes, ($\delta^{13}C$, $\delta^{18}O$ and $^{87}Sr/^{86}Sr$).
- Hydraulically conductive fractures are sampled based e.g. on the flow logging. Priority is given to fractures within the sections sampled for groundwater chemistry. These samples are mainly analysed for geochemistry, mineralogy (XRD), U-series and Mössbauer analyses.
- Adularia samples for were selected based on the relative sequence of fracture minerals in /Sandström and Tullborg 2006/. The selected samples were also examined in detail with binocular microscope and SEM-EDS prior to the geochronological analyses.
- Rock fragment samples from a calcite and laumontite sealed breccia were selected for $^{40}Ar/^{39}Ar$ age determination of the K-feldspars.

A problem encountered in the fracture filling studies is the small sample volumes. The representativity of the samples can therefore not be quantified which needs to be considered in the subsequent interpretations.

4.3 Preparations

All samples were photographed before any analyses were carried out.

4.4 Analytical work

Thin-sections with a thickness of 30 µm were prepared and analysed with optical microscope and scanning electron microscope (SEM) equipped with an energy dispersive spectrometer (EDS). In order to study minerals grown in the open space in some fractures, fracture surfaces were also prepared and examined by SEM-EDS. Additional fracture surfaces were only briefly examined with stereomicroscope. The SEM-EDS analyses were conducted at the Department of Earth Sciences, University of Gothenburg, with a Hitachi S-3400N equipped with an INCADryCool EDS detector.

The XRD analyses were performed by Dr. Erik Jonsson at SGU in Uppsala. The method is described in /Petersson et al. 2004/.

Fracture calcites were hand picked by tweezers or scraped by a steel knife and analysed for stable carbon, oxygen and for strontium isotope composition. Stable carbon and oxygen isotope analyses were carried out by Owe Gustavsson at the Department of Earth Sciences, University of Gothenburg and at the Institute for Energy Technology in Norway (IFE). The method is described in /Sandström et al. 2004/. The Sr isotope analyses were performed at IFE. The technique is described in /Sandström et al. 2004/.

Chemical analyses of powdered fracture filling material were made by Analytica AB in Luleå. The analytical technique is described in /Petersson et al. 2004/.

Mössbauer analyses were carried out by Prof. Hans Annersten at Uppsala University according to the method described in /Sandström and Tullborg 2005/.

The U-serie analyses were performed by A.B. MacKenzie at the Scottish Universities Environmental Research Centre (SUERC). The analytical technique is described in /Sandström and Tullborg 2006/.

The $^{40}Ar/^{39}Ar$ dating was carried out at the $^{40}Ar/^{39}Ar$ geochronology laboratory at Lund University according to the method described in /Sandström et al. 2006/.

4.5 Nonconformities

The activity has been performed according to the activity plan with additional presentation of four $^{40}Ar/^{39}Ar$ ages of fracture minerals to complement the results presented in /Sandström et al. 2006/. For controlling documents, see Table 1-1.

5 Results

The original results from the present study are presented in appendices to this report and stored in the primary data base (Sicada). Data are traceable in Sicada by the activity plan numbers (AP PF-400-07-047 and AP PF-400-05-047) and only data in SKB's data bases are accepted for further interpretation and modelling. The data presented in this report are regarded as copies of the original data. Data in the database may be revised if needed. However, such revisions will not necessarily result in a revision of this report, although the normal procedure is that major revisions entail a revision of the P-report. Minor data revisions are normally presented as supplements, available at www.skb.se. The appendices are:

Appendix 1: Sample description (Appendix 1 is stored as a file in the Sicada file archive)
Appendix 2: Calcite, stable isotopes
Appendix 3: Mössbauer analyses
Appendix 4: U-series analyses
Appendix 5: Geochemistry of fracture fillings
Appendix 6: $^{40}Ar/^{39}Ar$ data
Appendix 7: XRD analyses

5.1 Minerals identified

A list in alphabetic order, of the fracture minerals identified within the Forsmark area is presented below and the XRD and SEM-EDS data referred to is published in /Petersson et al. 2004, Sandström et al. 2004, Sandström and Tullborg 2005, Sandström and Tullborg 2006/. The abundance of different fracture minerals in Forsmark varies highly and the relative abundance can be summarized as follows: calcite and chlorite/corrensite > laumontite, quartz > adularia, albite, clay minerals, prehnite, epidote, hematite and pyrite. The rest of the minerals have only been found as minor occurrences but can be more common in particular zones, e.g. asphaltite.

Albite (Na-Plagioclase) ($NaAlSi_3O_8$) is often found in fracture fillings together with hydrothermal K-feldspar (adularia). The fillings can be brick-red due to hematite staining.

Allanite $(Ca,Mn,Ce,La,Y,Th)_2(Fe^{2+},Fe^{3+},Ti)(Al,Fe^{3+})_2O.OH[Si_2O_7][SiO_4]$ has been found in two fractures were it occurs as a thin beige coating in open fractures.

Analcime ($NaAlSi_2O_6{\cdot}H_2O$) has colourless, usually trapetzohedral crystals (like garnet). Analcime is stable at temperatures up to 200°C in the presence of quartz, but can in other assemblages exist at temperatures up to 600°C /Liou 1971/. In Forsmark, relatively large crystals have been found in some fractures (in the order of 5 to 10 mm).

Apophyllite ($(K,Na)Ca_4Si_8O_{20}F{\cdot}8H_2O$) is a hydrothermal sheet silicate with white to silvery surface. It is detected in some fractures at Forsmark. Based on a few SEM-EDS analyses it seems to be a relatively pure K-Ca-apophyllite.

Asphaltite ("bergbeck" in Swedish). The term is here used in a broad sense, meaning black, highly viscose to solid hydrocarbons with low U and Th contents.

Baryte ($BaSO_4$) has only been identified in a few samples, e.g. as small inclusions in galena.

Calcite ($CaCO_3$) occurs abundantly in Forsmark in different assemblages and with different crystal shape. The calcite generally shows low contents of Mg, Mn and Fe. No other carbonate minerals have been identified.

Chalcopyrite ($CuFeS_2$) occurs in Forsmark as small grains together with pyrite, galena and sphalerite.

Chlorite ($(Mg,Fe,Al)_3(Si,Al)_4O_{10}(OH)_2$) occurs abundantly in Forsmark as a usually dark-green mineral found in several associations. XRD identifies the chlorite as clinochlore but large variations in FeO/MgO ratios are indicated from SEM-EDS analyses (from 6 down to < 1). The occurrence of K, Na and Ca in many of the chlorite samples indicates possible ingrowths of clay minerals, mostly corrensite. The Mn and Ti contents in the chlorites are usually low but a few samples have TiO_2 values between 1 and 1.5%, possibly due to inclusions of titanite or illmenite.

Epidote ($Ca_2Al_2Fe(SiO_4)(Si_2O_7)(O,OH)_2$) occurs as a green filling in sealed fractures. According to the SEM-EDS analyses, the Fe-oxide content varies between 8 and 14% given as FeO. In reality, however, Fe in epidote is genererally Fe^{3+}. The lower temperature limit for epidote is ~ 200°C /Bird et al. 1984, Bird and Spieler 2004/.

Fluorite (CaF_2). Violet fluorite is found in a few mostly sealed fractures.

Galena (PbS) is mainly found on fracture surfaces and has cubic or octahedral crystals. The mineral occurs together with pyrite in Forsmark and some galena crystals have small inclusions of baryte.

K-feldspar ($KAlSi_3O_8$) is usually present in its low temperature form named adularia but is also found as wall rock fragments in breccias showing typical microcline twinnings. Like in albite the colour can be brick-red due to hematite staining, but also greenish varieties occur in fine-grained mixtures with quartz.

Hematite (Fe_2O_3) is common in the Forsmark fractures but the amount is relatively low (does not often turn up in the diffractograms). However, micro-grains of hematite cause intense red-staining of many fracture coatings. Small spherical aggregates of hematite have also been found in a few fractures.

Laumontite ($CaAl_2Si_4O_{12}{\cdot}4H_2O$) is a common zeolite mineral in the Forsmark area. It shows a prismatic shape and is brittle. The mineral itself is white, but has at Forsmark a red staining due to micro-grains of hematite, although white varieties are observed as well. Zeolites have open structures suitable for ion exchange. Laumontite is stable at temperatures somewhere between ~ 150° and 250°C /Liou et al. 1985/.

Pitchblende (UO_2) is an usually massive, granular form of uraninite, in Forsmark so far only found in one fracture together with hematite and chlorite.

Prehnite ($Ca_2Al_2Si_3O_{10}(OH)_2$) occurs as a light greyish green to grey or white, hydrothermal mineral. The Fe content varies between 1 and 5.5 weight% (given as FeO). Like in epidote, most of the Fe is Fe^{3+}. The stability field for prehnite is somewhere between 200°C and 280°C at pressures below 3.0 kbars /Frey et al. 1991/.

Pyrite (FeS_2) is found in many fractures as small euhedral, cubic crystals grown on open fracture surfaces.

Quartz (SiO_2) has been identified in many of the analysed samples, often as very small and occasionally hematite stained, euhedral crystals covering the fracture walls. They often have a greyish sugary appearance but can also be transparent and then appear to have the colour of the wall rock.

Sphalerite (ZnS) has been found in a few fractures and is often associated with galena.

Talc ($Mg_6Si_8O_{20}(OH)_4$) has been identified in a few fractures in KFM11A.

Clay minerals:

Corrensite ($(Mg,Fe)_9(Si,Al)_8O_{20}(OH)_{10}\cdot H_2O$) is a chlorite-like mixed-layer clay with layers of chlorite and smectite/vermiculite, usually with a ratio of 1:1. Based on XRD analyses, some of the corrensite samples show irregular ordering in the layering, indicating either that they have not reached perfect corrensite crystallinity or that they are altered. Corrensite is the clay mineral most frequently found, and as mentioned above often found together with chlorite. This is a swelling type of clay like mixed-layer illite/smectite and saponite (see below).

Illite ($(K, H_2O)Al_2[(Al,Si)Si_3O_{10}](OH)_2$) occurs as micro- to cryptocrystalline, micaceous-flakes, and is usually light grey in colour. Illite is after corrensite the most common clay mineral in Forsmark.

Kaolinite ($Al_4[Si_4O_{10}](OH)_8$ has been identified by XRD in KFM01C. The XRD peaks indicate low crystallinity of the kaolinite.

Mixed-Layer clays. Mixed-layer clay with layers of illite and smectite has been identified in some fractures. XRD analyses show a 3:2 ratio of illite/smectite.

Saponite ($Mg_3(Si_4O_{10})(OH)_2\cdot nH_2O$). This is a variety of swelling smectite.

5.2 Fracture mineralogy

The relative sequence of fracture mineralization presented in /Sandström and Tullborg 2006/ has been strengthened by detailed mineralogical studies of samples from the drill-cores KFM01C, KFM01D, KFM02B, KFM08C, KFM08D, KFM09A, KFM09B, KFM10A and KFM11A. Detailed descriptions of mineralogy of the drill-core samples from these boreholes are presented in Appendix 1 (except for samples from KFM02B and KFM08D on which only XRD and geochemical analyses were carried out). For a description of the relative sequence of mineralizations, the reader is referred to SKB P-06-226 /Sandström and Tullborg 2006/. A summary of the sequence is presented in Table 5-1.

A few new features have however been identified in the drill cores treated in this report: Pyrite coeval with Generation 2 hematite has been identified in a few fractures. This indicates that during the precipitation of Generation 2 minerals, which normally are associated with oxidized iron occurring as hematite, local conditions in some fractures also made precipitation of reduced pyrite possible. Kaolinite has been identified by XRD in hydraulically conductive fractures/crushed zones in KFM01C and talc was identified by SEM-EDS in a fracture in KFM11A. It has not been possible to relate the talc to any of the four Generations of fracture mineralizations.

Table 5-1. Summary of fracture mineral generations presented with decreasing ages. Only the most common minerals in each generation are presented in this table.

Generation	Characteristic minerals
1	Epidote, chlorite, quartz
2	Adularia, prehnite, laumontite, hematite, calcite, chlorite
3	Quartz, calcite, pyrite, asphaltite
4	Clay minerals, calcite, chlorite

5.3 Stable isotopes in calcite

Data of the stable isotopic composition of calcite ($\delta^{18}O$, $\delta^{13}C$, $^{87}Sr/^{86}Sr$) are presented in Appendix 2. No significant deviations from the trends described in /Sandström and Tullborg 2006/ have been identified and further evaluation will be carried out in an R-report /Sandström et al. 2008/.

5.4 Mössbauer analyses

Mössbauer analyses on fracture filling material from preferentially hydraulically conductive fractures and crushed zones have been carried out and complement the data presented in /Sandström and Tullborg 2005/. The data are presented in Appendix 3. Further evaluation of the data will be carried out within the scope of an R-report and will be published during 2008 /Sandström et al. 2008/.

5.5 U-series analyses

Uranium series analyses (USD) have been conducted on fracture coating samples. The analyses have been carried out at SUERC (Scotish Universities Environmental Research Centre) by A.B McKenzie. The results are presented in Appendix 4. The samples selected for USD analyses were all chosen to represent hydraulically conductive structures and the sample material contained mixed fracture mineral-coatings including clay minerals and/or Fe(III)-oxide.

Basically, equilibrium (activity ratio ≈ 1) between the nuclides in the uranium decay series analysed ($^{238}U/^{234}U/^{230}Th$) indicate that no mobilisation or deposition have occurred during the last 1 Ma. The $^{234}U/^{238}U$ and $^{230}Th/^{234}U$ activity ratios against depth indicate that many of the fracture samples analysed have been open to uranium redistribution during this time period, and the redistribution seems to be more significant in the upper part of the bedrock (0–150 m) which is an expected result. However, many of the deep samples show a small increase in $^{230}Th/^{234}U$ activity ratios indicating a possible late mobilisation, which may be due to dissolution related to the drilling and handling of the drill cores. A thorough evaluation of the data will be carried out within the scope of an R-report /Sandström et al. 2008/.

5.6 Geochemistry of fracture fillings

The chemical composition of bulk fracture fillings are presented in Appendix 5. No significant divergences from the trends described in /Sandström and Tullborg 2005, Sandström and Tullborg 2006/ have been found in the analysed fracture fillings in this report. The discussion below considers both data of bulk fracture geochemistry from this report and previously reported data /Sandström and Tullborg 2005, Sandström and Tullborg 2006/.

K, Rb, Ba, Cs

These elements are mainly hosted in K-feldspar, mica and clay minerals. From the chemical analyses it is obvious that K correlates with Ba, which indicates that most K is hosted in K-feldspar which preferably contains Ba and to lesser degree Rb and Cs (Figure 5-1). The latter elements are instead hosted together with K in clay minerals. Especially illite and mixed layer clays of illite/smectite type tend to enrich Rb and even more Cs.

The mean Cs content in the host rock is 0.8 ppm /Drake et al. 2006/, whereas the values in the fracture coatings are significantly higher. The two samples with the highest Cs content (72.3 and 92.9 ppm) are samples which almost exclusively contain analcime indicating that analcime is the mineral with highest affinity for Cs in Forsmark.

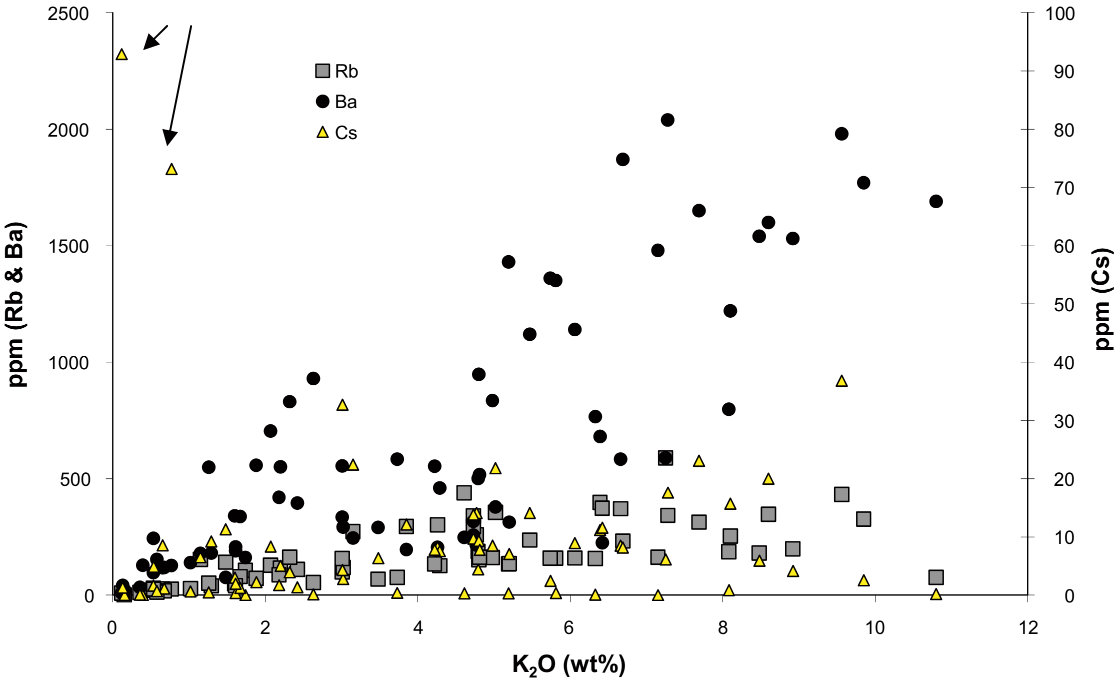

Figure 5-1. *Ba and Rb plotted versus K_2O for bulk samples of fracture fillings. Data from this report and /Sandström and Tullborg 2005, 2006/.*

Na, Ca, Sr

The Sr content in the analysed fracture fillings varies between 2 and 818 ppm. A positive correlation between Sr and Ca is observed for the samples with CaO contents < 5 wt% (Figure 5-2) whereas the samples with the highest CaO contents (15 to 50wt%) show relatively low Sr contents. The latter samples consist dominantly of prehnite, analcime and calcite, but also apophyllite samples are amongst these. From ICP-MS analyses on calcite it is known that the Sr/CaO ratio /Sandström and Tullborg 2005/ in the calcites is very low. The minerals hosting most Sr are epidote, laumontite and plagioclase.

Na shows a positive correlation with Sr in the samples with albite, whereas the analcime samples do not follow this trend.

Fe, Mg, Mn, Ti, V, Sc

Fe correlates with Mg in most samples (Figure 5-3), which is explained by the presence of chlorite and corrensite in the fracture fillings. As has been shown by SEM-EDS analyses, the Fe/Mg ratio in the chlorites of different generations varies /Sandström and Tullborg 2005/, which partly explains the variation in Fe/Mg ratio in the bulk samples. Additional contents of minerals containing Fe but no Mg is another explanation. The samples with highest Fe_2O_3 content often have high Cr and Ni contents as well (Figure 5-4). This indicates that part of the Fe in these samples can result from iron-rich debris produced during the drilling which may have soaked into the split-tube and penetrated the fractured drill core.

Mn shows a significant positive correlation with Fe indicating its presence in chlorite and clay minerals. Ti, V and Sc generally show a positive correlation with Fe except for some prehnite and pyrite rich samples, which in contrast display very low Ti, Sc and V contents.

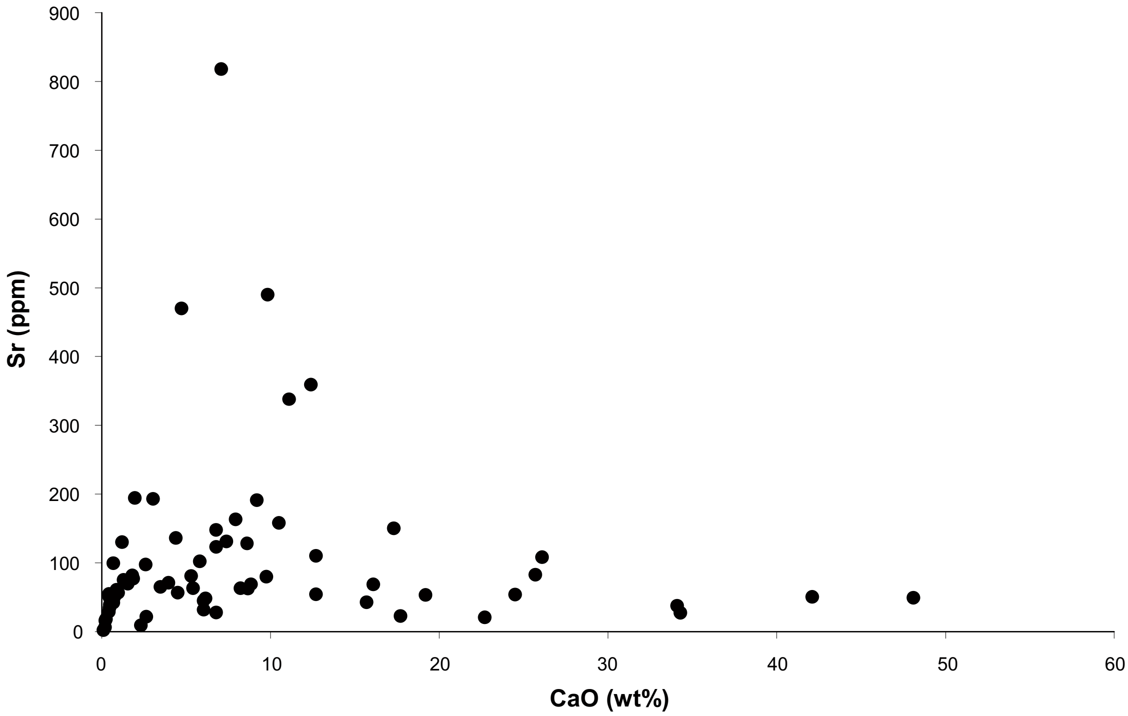

Figure 5-2. *CaO plotted versus Sr for bulk samples of fracture fillings. Data from this report and /Sandström and Tullborg 2005, 2006/.*

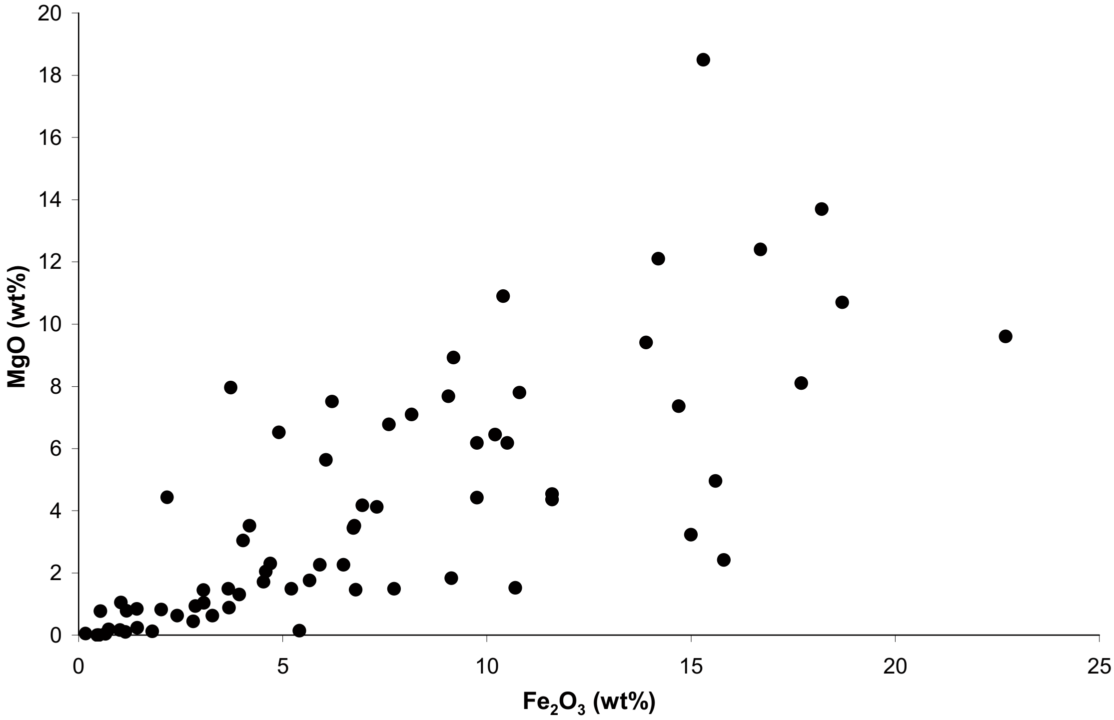

Figure 5-3. *Fe_2O_3 versus MgO for bulk samples of fracture fillings. Data from this report and /Sandström and Tullborg 2005, 2006/.*

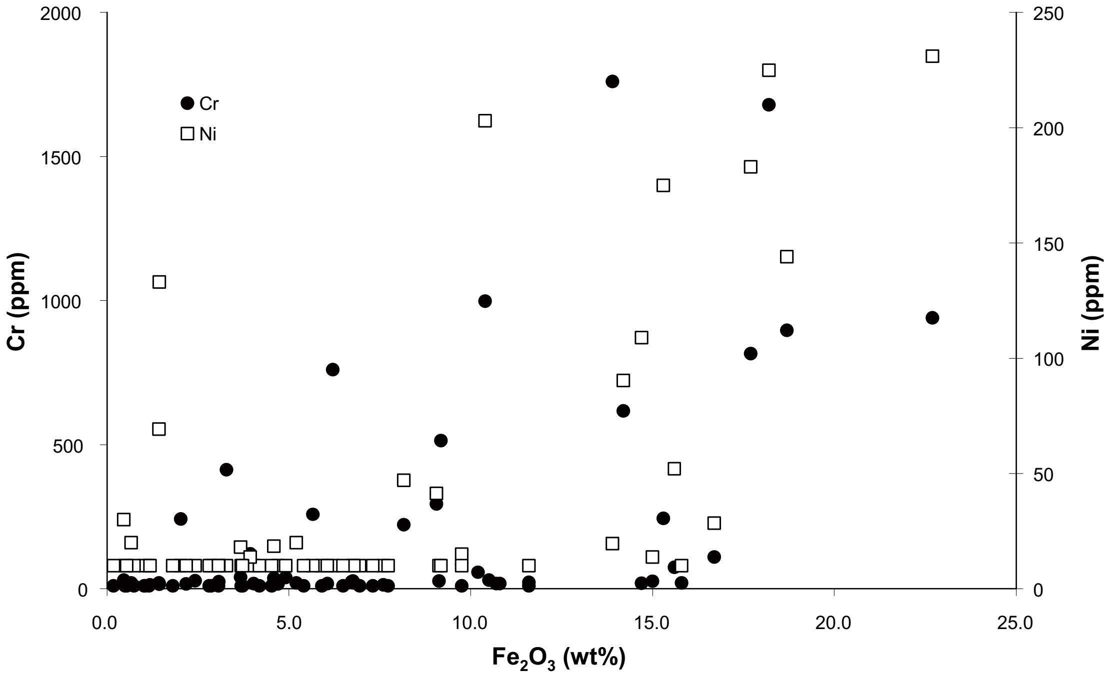

Figure 5-4. *Fe_2O_3 versus Cr and Ni in bulk samples of fracture fillings. Data from this report and /Sandström and Tullborg 2005, 2006/.*

U and Th

The U content varies between 0.1 and 164 ppm except in two samples from KFM03A 643.8–644.12 m and KFM03A 644.17 m which show U values of 2,200 and 2,310 ppm /Sandström and Tullborg 2005/. The Th values, in contrast, are all within the interval 0.2 to 36.4 ppm (Figure 5-5). The Th/U ratios are < 1 in 50 of 70 samples, indicating an enrichment of U in the most fracture coatings compared to the fresh rock (Th/U usually > 2) /Drake et al. 2006/. This U enrichment has taken place during different periods of time: The USD analyses (cf. section 5.3) show possible ongoing mobilisation/deposition of U in a number of samples from the site. From the U/Th ratio it is however indicated that U has been mobilised and inhomogenously deposited in the fracture system before the last 1 Ma detectable by the USD analyses. It is notable that the high U content in the fracture fillings correlate with high U content in water samples from the same depths /Drake et al. 2006/ indicating that at least part of the uranium is found in easily accessible sites.

Concerning the U in the fracture coatings, no significant correlations with P, Ti or La can be seen.

REEs

Chondrite normalised REE curves from analysed fracture fillings are shown in Figure 5-6. The La/Yb ratios vary between 0.1 and 40, except for six samples with higher ratios out of 38 analysed samples. The higher ratios are 59, 63, 91, 128, 220 and 324. Most samples show negative Eu-anomalies, probably inherited from the host rock. A few samples show Ce-anomalies (either positive or negative) which probably are related to (hydrothermal?) oxidation in these fractures. The overall trend for the fracture fillings is enrichment in REEs compared to the host rock. This enrichment is generally more pronounced for the LREEs than the HREEs. However, four samples show significantly high Yb values (from 22.7 to 30 ppm). Two of these are the uranium rich samples from KFM03A 644 m. The other two samples (KFM06C 149.54 m and KFM08A 495.13 m) do not share the high U values. These samples in contrast, show La/Yb ratio < 1 and significantly high Y contents (520 to 600 ppm). Zr and Hf are not enriched in these samples.

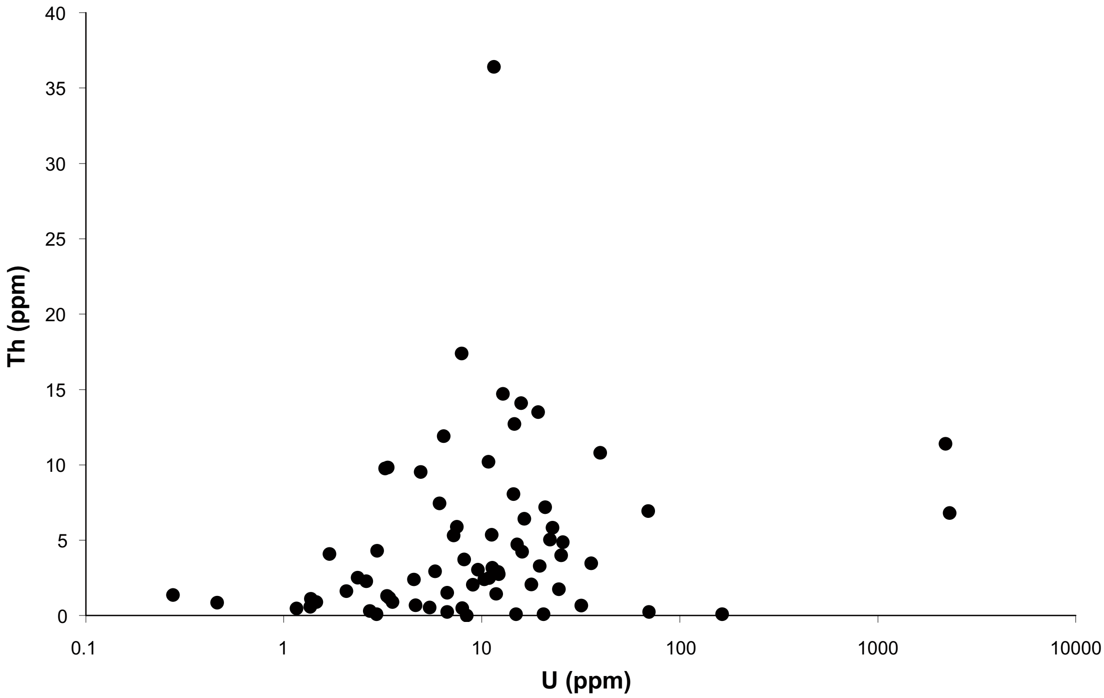

Figure 5-5. *U versus Th for bulk samples of fracture fillings. Data from this report and /Sandström and Tullborg 2005, 2006/.*

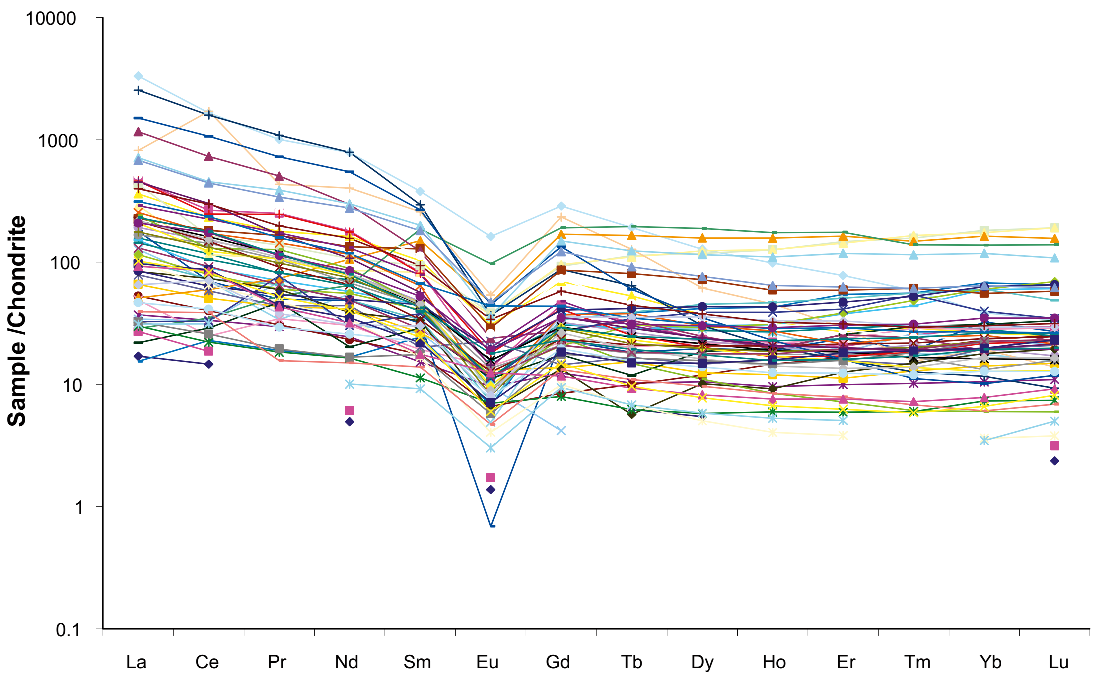

Figure 5-6. *Chondrite normalized REE curves for bulk samples of fracture fillings. Chondrite data from /Evansen et al. 1978/. Data from this report and /Sandström and Tullborg 2005, 2006/.*

5.7 $^{40}Ar/^{39}Ar$ dating

Raw data from the $^{40}Ar/^{39}Ar$ analyses are presented in Appendix 6.

5.7.1 Sample KFM04A 347.32–347.50 m

The drill core consists of a laumontite and calcite sealed breccia cut by a calcite vein (Figure 5-7). The analysed mineral is K-feldspar in rock fragments within the breccia. The laumontite belongs to Generation 2 in the relative sequence of fracture mineralizations (Table 5-1). The obtained plateau age of 1,354 ± 6 Ma in the step-heating spectrum (Figure 5-8) is consistent with $^{40}Ar/^{39}Ar$ ages obtained from K-feldspar in fresh rock samples from the Forsmark area /Page et al. 2007/, suggesting that the $^{40}Ar/^{39}Ar$ system in the analysed K-feldspar was not reset during the brecciation of the rock. The 1,354 ± 6 Ma age is therefore not interpreted as an age of the breccia formation but an age that represents cooling below the closing temperature of K-feldspar. The orientation of the calcite sealed fracture cutting the breccia is 230/74°.

Figure 5-7. *Laumontite and calcite sealed breccia from KFM05A 347.32–347.50 m. The diameter of the drill core is c 5 cm.*

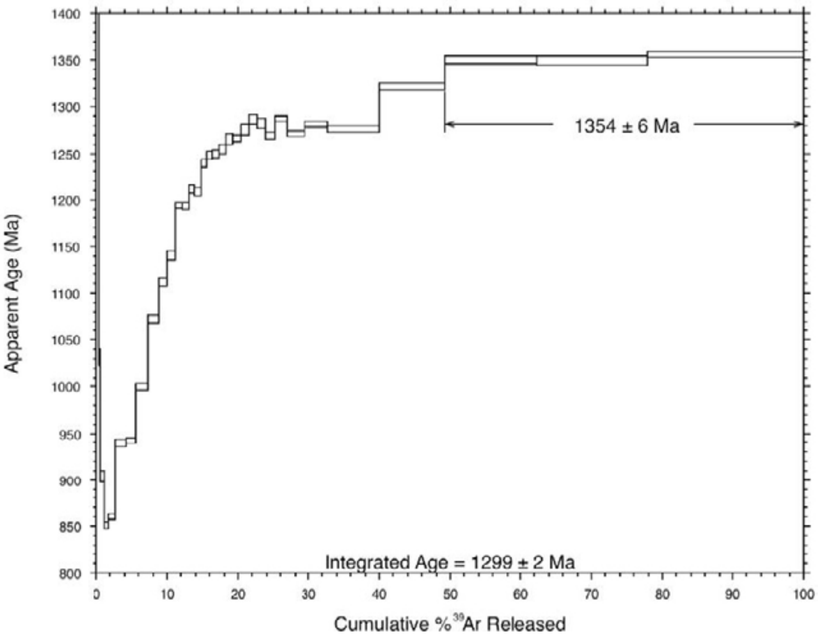

Figure 5-8. *$^{40}Ar/^{39}Ar$ K-feldspar step-heating spectrum for sample KFM04A 347.32–347.50 m.*

5.7.2 Sample KFM08A 183.77–183.88 m

Adularia occurs in this sample together with prehnite, calcite, quartz, fluorite and albite in the fracture (Figure 5-9). The adularia, prehnite, quartz and fluorite have been interpreted as coeval /Sandström and Tullborg 2006/. The adularia belongs to the sequence of hydrothermal fracture minerals classified as Generation 2 in Table 5-1. The plateau age defined on the $^{40}Ar/^{39}Ar$ step-heating spectrum is 1,093 ± 3 Ma (Figure 5-10), which is consistent with previously obtained ages of fracture filling adularia in Forsmark and corresponds to an early Sveconorwegian event /Sandström et al. 2006/. The orientation of the fracture is 026/75°.

Figure 5-9. *KFM08A 187.77–183.88 m; fracture sealed with adularia, quartz, prehnite, calcite, fluorite and albite. The diameter of the drill core is c 5 cm.*

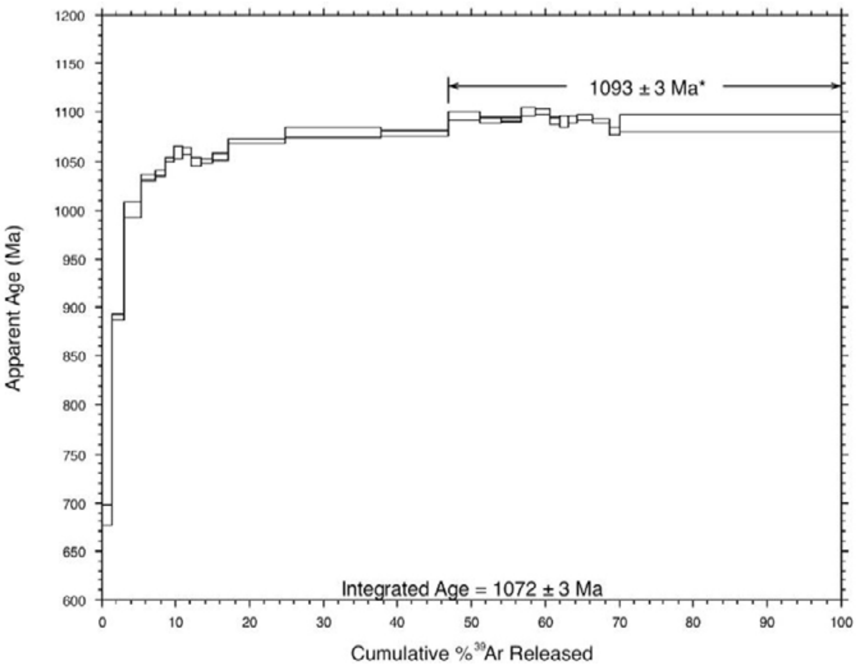

Figure 5-10. *$^{40}Ar/^{39}Ar$ adularia step-heating spectrum for sample KFM08A 183.77–183.88 m.*

5.7.3 Sample KFM09A 230.34–230.46 m

The drill core consists of a calcite and laumontite sealed breccia (Figure 5-11). The analysed mineral is K-feldspar in wall rock fragments in the breccia. The laumontite and calcite belongs to Generation 2 in the relative sequence of fracture mineralizations (Table 5-1). No plateau age can be defined on the $^{40}Ar/^{39}Ar$ step-heating spectrum which indicates that the $^{40}Ar/^{39}Ar$ system in the K-feldspar did not reset during the brecciation (Figure 5-12). No significant age has thus been obtained from this sample. The orientation of the breccia is 207/68°.

Figure 5-11. *KFM09A 230.34–230.46 m; calcite and laumontite sealed breccia. The diameter of the drill core is c 5 cm.*

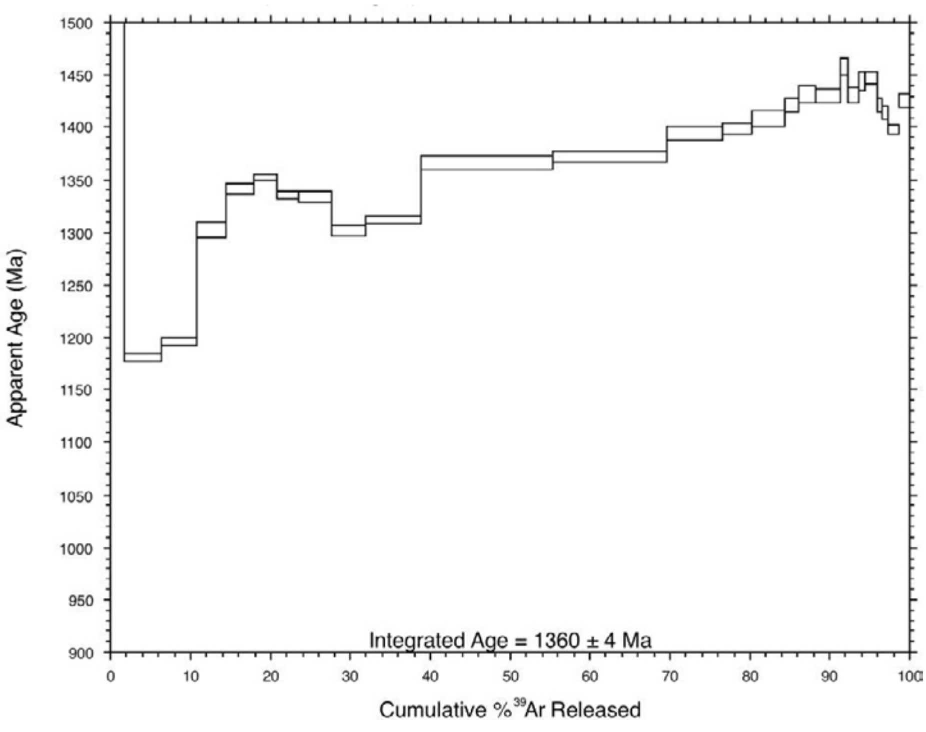

Figure 5-12. *$^{40}Ar/^{39}Ar$ adularia step-heating spectrum for sample KFM09A 230.34–230.46 m.*

5.7.4 Sample KFM09A 732.90–733.10 m

The drill core (Figure 5-13) consists of a laumontite and calcite sealed breccia belonging to Generation 2 in the relative sequence of fracture mineralizations (Table 5-1). The analysed mineral is K-feldspar in wall rock fragments within the breccia. The $^{40}Ar/^{39}Ar$ step-heating spectrum gives a plateau age of 1,107 ± 7 Ma (Figure 5-14). This is interpreted as a total resetting of the $^{40}Ar/^{39}Ar$ system in the K-feldspar during the time of brecciation and subsequent fluid circulation with associated laumontite precipitation. The obtained age of the K-feldspar in the breccia is thus interpreted as the age of the laumontite sealing.

Figure 5-13. *KFM09A 732.90–733.10 m; laumontite and calcite sealed breccia. The diameter of the drill core is c 5 cm.*

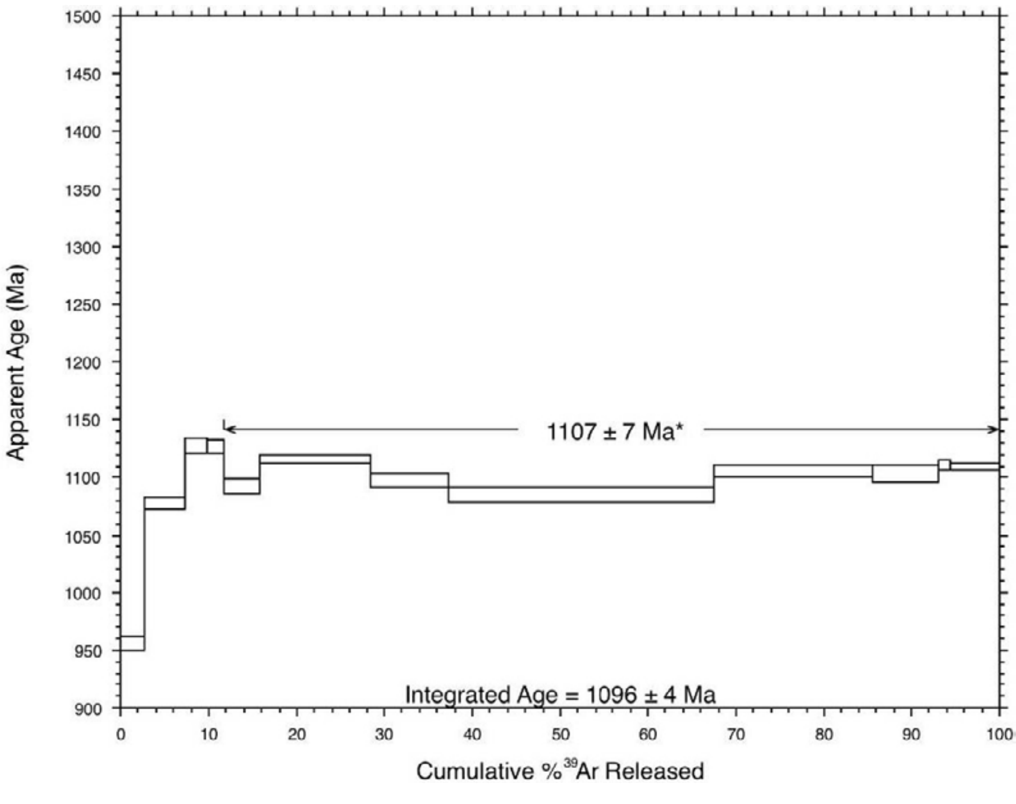

Figure 5-14. *$^{40}Ar/^{39}Ar$ adularia step-heating spectrum for sample KFM09A 732.90–733.10 m.*

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Sample descriptions

Sample: **KFM01C 6.45–6.72 m**
Fracture: Open fracture
Orientation: not in BIPS
Deformation zone: n.a.
Fracture orientation set: n.a.
Fracture minerals: Quartz, calcite, clay mineral

Sample: **KFM01C 6.97–7.08 m**
Fracture: Open fracture
Orientation: not in BIPS
Deformation zone: n.a.
Fracture orientation set: n.a.
Fracture minerals: Quartz, chlorite

Sample: **KFM01C 9.18–9.25 m**
Fracture: Open fracture
Orientation: not in BIPS
Deformation zone: n.a.
Fracture orientation set: n.a.
Fracture minerals: Chlorite, calcite, clay mineral

Sample: **KFM01C 12.43–12.51 m**
Fracture: Open fracture
Orientation: 043/10°
Deformation zone: Not in zone
Fracture orientation set: Gently dipping
Fracture Domain : FFM02
Fracture minerals:

Sample: **KFM01C 14.81–14.97 m**
Fracture: Open fracture
Orientation: 106/07°
Deformation zone: No zone
Fracture Domain: FFM02
Fracture orientation set: Gently dipping
Fracture minerals: Calcite

Sample: **KFM01C 17.22–17.40 m**
Fracture: Open fracture
Orientation: 174/45°
Deformation zone: No zone
Fracture Domain: FFM02
Fracture orientation set: SSE
Fracture minerals: (XRD) biotite, calcite, chlorite, illite, K-feldspar, plagioclase, quartz

Sample: **KFM01C 26.43–26.55 m**
Fracture: Open fracture
Orientation: 250/06°
Deformation zone: ZFMA2, ZFMENE1192
Fracture orientation set: Gently dipping
Fracture minerals: Quartz, calcite, chlorite

Sample: **KFM01C 34.47–34.67 m**
Fracture: Open fracture
Orientation: 016/24°
Deformation zone: ZFMA2, ZFMENE1192
Fracture orientation set: Gently dipping
Fracture minerals: (XRD) biotite, chlorite, illite, K-feldspar, mixed layer clays, plagioclase, quartz

Sample: **KFM01C 39.75–40.02 m**
Fracture: Open fracture
Orientation: 244/03°
Deformation zone: ZFMA2, ZFMENE1192
Fracture orientation set: Gently dipping
Fracture minerals: (XRD) chlorite, illite, K-feldspar, kaolinite, mixed layer clays, quartz, smectite

Sample: **KFM01C 41.15–41.25 m**
Fracture: Open fracture
Orientation: 075/06°
Deformation zone: ZFMA2, ZFMENE1192
Fracture orientation set: Gently dipping
Fracture minerals: (XRD) illite, K-feldspar, kaolinite, mixed layer clays, plagioclase, quartz

Sample: **KFM01C 43.00–43.20 m**

Fracture: Open fracture

Orientation: 064/12°

Deformation zone: ZFMA2, ZFMENE1192

Fracture orientation set: Gently dipping

Fracture minerals: (XRD) illite, K-feldspar, kaolinite, mixed layer clays, plagioclase, quartz, smectite

Sample: **KFM01C 78.31–78.48 m**

Fracture: Open fracture

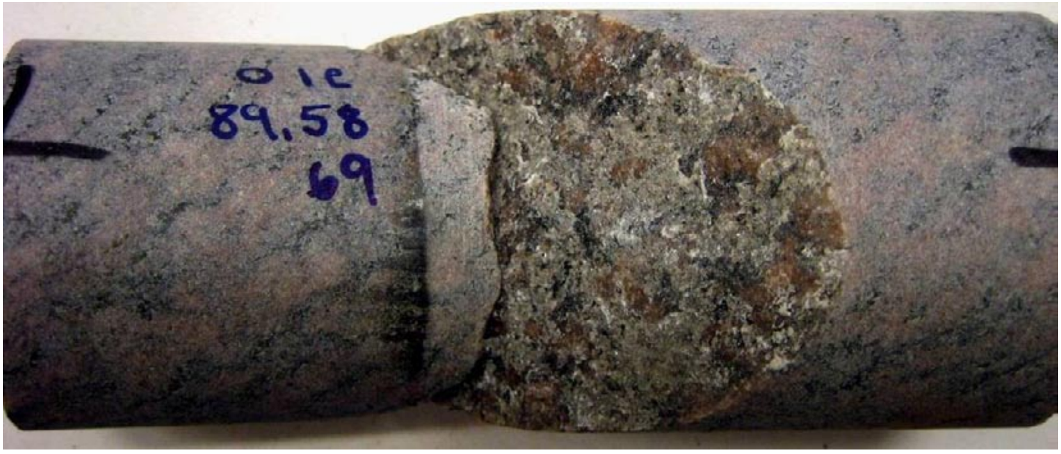
Orientation: 108/70°

Deformation zone: ZFMA2

Fracture orientation set: ESE

Fracture minerals: Chlorite, goethite, calcite, clay mineral

Sample: **KFM01C 89.58–89.69 m**
Fracture: Open fracture
Orientation: 053/86°
Deformation zone: ZFMA2
Fracture orientation set: NE
Fracture minerals: Calcite, quartz, asphaltite

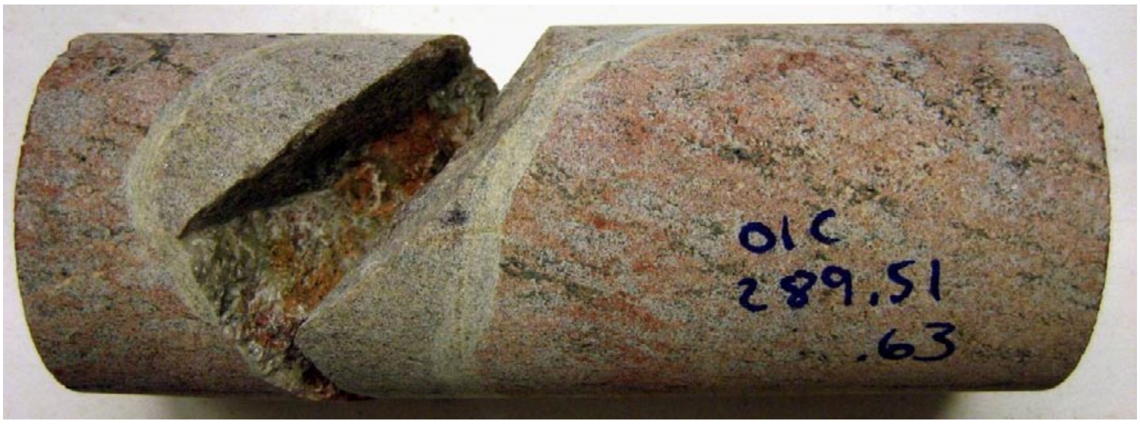


Sample: **KFM01C 90.63–90.73 m**
Fracture: Open fracture
Orientation: 088/86°
Deformation zone: ZFMA2
Fracture orientation set: E
Fracture minerals: Calcite, quartz

Sample: **KFM01C 97.33–97.40 m**
Fracture: Open fracture
Orientation: a) 232/68° and b) 106/14°
Deformation zone: ZFMA2
Fracture orientation set: SW and Gently dipping
Fracture minerals: a) Clay mineral, b) calcite

Sample: **KFM01C 253.38–253.62 m**
Fracture: Sealed fracture
Orientation: 084/62°
Deformation zone: No zone
Fracture domain: FFM01
Fracture orientation set: ENE
Fracture minerals: Prehnite, laumontite, calcite, hematite

Sample: **KFM01C 289.51–289.63 m**
Fracture: Open fracture
Orientation: 209/79°
Deformation zone: No zone
Fracture domain: FFM01
Fracture orientation set: SSW
Fracture minerals: Prehnite, laumontite, calcite



Sample: **KFM01C 322.05–322.23 m**
Fracture: Sealed fracture
Orientation: 216/80°
Deformation zone: ZFMENE0060C
Fracture orientation set: SW
Fracture minerals: Prehnite, laumontite, calcite

Gradual transition between prehnite + calcite and laumontite + calcite

Sample: **KFM01C 332.51–332.72 m**
Fracture: Sealed fractures
Orientation: 103/14°
Deformation zone: No zone
Fracture domain: FFM01
Fracture orientation set: Gently dipping
Fracture minerals: Epidote

Sample: **KFM01C 404.71–404.81 m**
Fracture: Open fracture
Orientation: 220/87°
Deformation zone: No zone
Fracture domain: FFM01
Fracture orientation set: SW
Fracture minerals: Prehnite, laumontite

Sample: **KFM01D 571.06–571.10 m**
Fracture: Open fracture
Orientation: 036/20°
Deformation zone: No zone
Fracture domain: FFM01
Fracture orientation set: Gently dipping
Fracture minerals: Chlorite/corrensite

Sample: **KFM08C 148.16–148.26 m**
Fracture: Open fracture
Orientation: Not in BIPS
Deformation zone: No zone
Fracture domain: FFM01
Fracture orientation set: n.a.
Fracture minerals: Calcite, quartz, asphaltite, pyrite

Sample: **KFM08C 161.02–161.36 m**
Fracture: Sealed fracture
Orientation: 055/87°
Deformation zone: DZ not modelled
Fracture orientation set: ENE
Fracture minerals: Adularia, calcite, quartz, hematite

Sample: **KFM08C 224.89–224.98 m**
Fracture: Open fracture
Orientation: 033/10°
Deformation zone: No zone
Fracture domain: FFM01
Fracture orientation set: Gently dipping
Fracture minerals: Clorite, clay mineral, calcite

Sample: **KFM08C 282.73–282.79 m**
Fracture: Open fracture
Orientation: 046/11°
Deformation zone: No zone
Fracture domain: FFM01
Fracture orientation set: Gently dipping
Fracture minerals: Chlorite, corrensite, calcite

Sample: **KFM08C 470.45–470.60 m**
Fracture: Open fracture
Orientation: 190/82°
Deformation zone: ZFMNNE2312
Fracture orientation set: SSW
Fracture minerals: Chlorite, corrensite, clay minerals, calcite

Sample: **KFM08C 523.47–523.73 m**
Fracture: Not identified in BIPS
Orientation: Not identified in BIPS
Deformation zone: ZFMNNE2312
Fracture orientation set: n.a.
Fracture minerals: (XRD) corrensite, illite, K-feldspar, plagioclase, quartz

Sample: **KFM08C 524.11–524.34 m**
Fracture: Open fracture
Orientation: 237/67°
Deformation zone: ZFMNNE2312
Fracture orientation set: WSW
Fracture minerals: Quartz, adularia, clay mineral

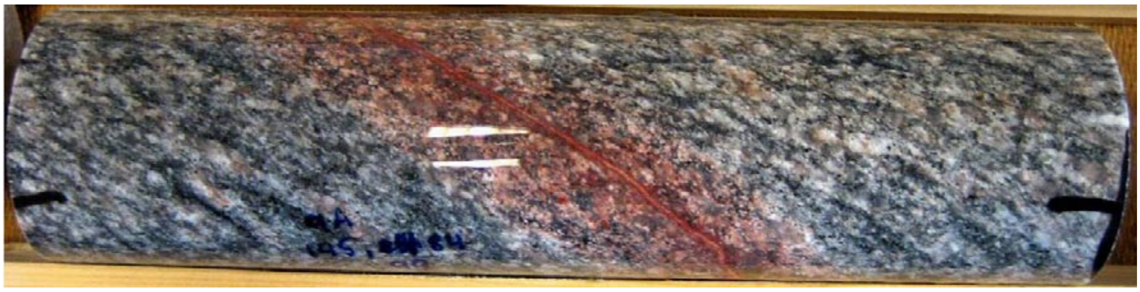
Sample: **KFM08C 683.57–683.66 m**
Fracture: Open fracture
Orientation: 045/56°
Deformation zone: ZFMWNW2225
Fracture orientation set: NE
Fracture minerals: (XRD) corrensite, chlorite, K-feldspar, plagioclase, quartz, biotite

Sample: **KFM08C 829.94–830.02 m**
Fracture: Open fracture
Orientation: 066/58°
Deformation zone: ZFMENE1061A, ZFMENE1061B
Fracture orientation set: ENE
Fracture minerals: (XRD) amphibole, calcite, chlorite, corrensite, illite, K-feldspar, plagioclase, quartz

Sample: **KFM08C 904.06–904.13 m**
Fracture: Open fracture
Orientation: 064/54°
Deformation zone: No zone
Fracture domain: FFM01
Fracture orientation set: ENE
Fracture minerals: (XRD) chlorite, corrensite, quartz

Sample: **KFM09A 135.67–135.81 m**
Fracture: Sealed fracture
Orientation: 245/82°
Deformation zone: No zone
Fracture domain: FFM01
Fracture orientation set: WSW
Fracture minerals: Chlorite, prehnite

Sample: **KFM09A 150.67–150.83 m**
Fracture: Sealed fracture
Orientation: 350/77°
Deformation zone: No zone
Fracture domain: FFM01
Fracture orientation set: NNW
Fracture minerals: Laumontite, hematite



Sample: **KFM09A 229.09–229.31 m**
Fracture: Sealed fracture
Orientation: 220/66°
Deformation zone: ZFMENE0159A, ZFMNNW0100
Fracture orientation set: SW
Fracture minerals: Laumontite, adularia, chlorite, quartz, pyrite, calcite

Sequence of mineralizations:

1. Adularia + laumontite + chlorite + hematite
2. Quartz
3. Calcite + pyrite

Sample: **KFM09A 230.34–230.46 m**
Fracture: Sealed fracture
Orientation: 207/68°
Deformation zone: ZFMENE0159A, ZFMNNW0100
Fracture orientation set: SSW
Fracture minerals: Adularia, hematite, calcite, hematite

Sample: **KFM09A 234.16–234.41 m**
Fracture: Sealed fracture
Orientation: 052/87°
Deformation zone: ZFMENE0159A, ZFMNNW0100
Fracture orientation set: NE
Fracture minerals: Feldspar, quartz, calcite, pyrite

Sample: **KFM09A 239.07–239.33 m**
Fracture: Sealed fracture
Orientation: 034/77°
Deformation zone: ZFMENE0159A, ZFMNNW0100
Fracture orientation set: NNE
Fracture minerals: Adularia, albite, hematite, pyrite, chlorite, titanite, laumontite

Sequence of mineralizations:

1. Adularia, albite, hematite, pyrite, chlorite, titanite, laumontite
2. Calcite, quartz, pyrite

Sample: **KFM09A 241.37–241.82 m**
Fracture: Open fracture
Orientation: 024/83°
Deformation zone: ZFMENE0159A, ZFMNNW0100
Fracture orientation set: NNE
Fracture minerals: Laumontite, hematite, calcite, pyrite, chlorite, titanite, quartz, adularia, analcime

Sequence of mineralizations:

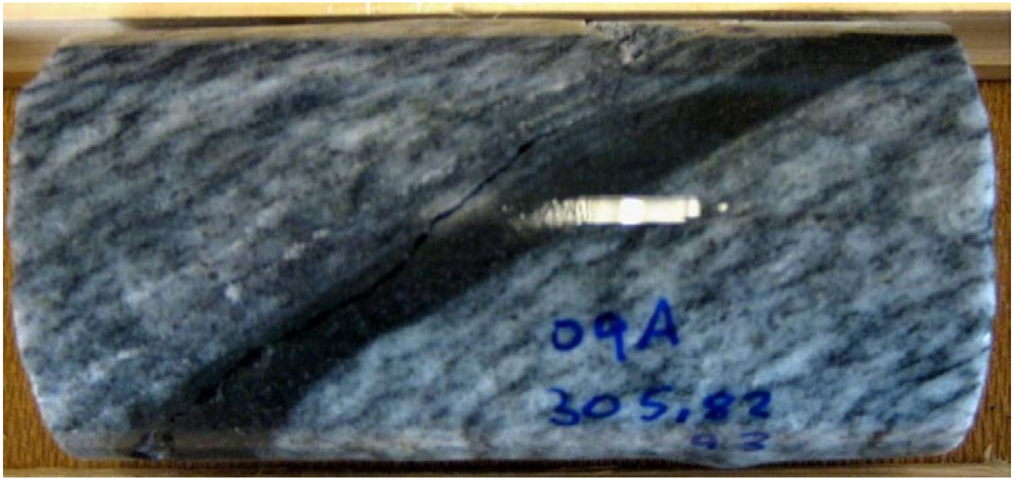
1. Laumontite, adularia, quartz, hematite, calcite, pyrite, chlorite, titanite
2. Quartz
3. Calcite
4. Analcime

Sample: **KFM09A 244.96–245.06 m**
Fracture: Open fracture
Orientation: 244/82° and 227/89°
Deformation zone: ZFMENE0159A, ZFMNNW0100
Fracture orientation set: WSW and SW
Fracture minerals: (244/82°) Chlorite, Adularia, hematite; (227/89°) quartz, pyrite, calcite

Sample: **KFM09A 276.26–276.40 m**
Fracture: Open fracture
Orientation: 310/86°
Deformation zone: ZFMENE0159A, ZFMNNW0100
Fracture orientation set: NW
Fracture minerals: Pyrite, quartz

Sample: **KFM09A 305.82–305.93 m**
Fracture: Open fracture
Orientation: 332/86°
Deformation zone: No zone
Fracture domain: FFM05
Fracture orientation set: NNW
Fracture minerals: No mineral

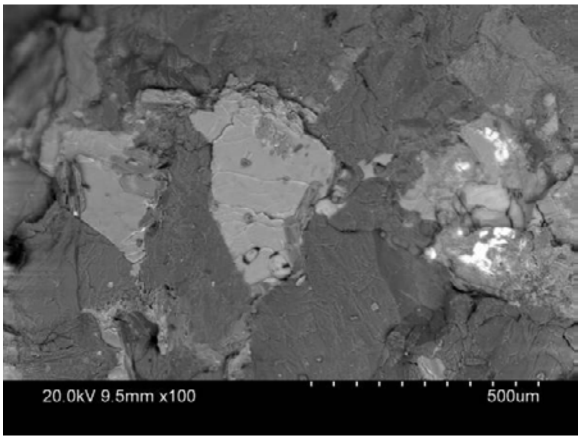
The fracture surface is fresh with unaltered biotite and well preserved crystals from the wall rock.



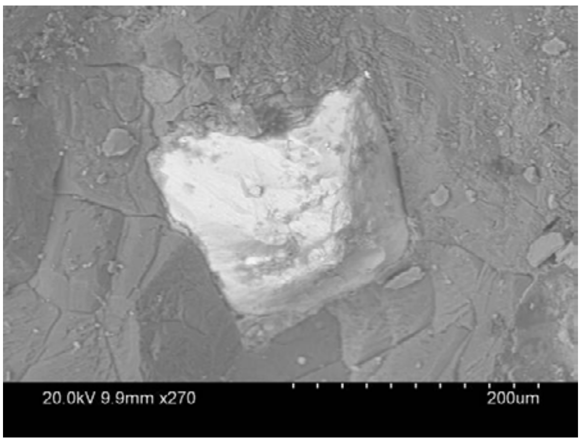
Sample: **KFM09A 350.72–350.78 m**
Fracture: Sealed fracture
Orientation: 047/13°
Deformation zone: No zone
Fracture domain: FFM05
Fracture orientation set: Gently dipping
Fracture minerals: Prehnite

Sample: **KFM09A 369.96–370.02 m**
Fracture: Sealed fracture
Orientation: 283/86°
Deformation zone: No zone
Fracture domain: FFM05
Fracture orientation set: WNW
Fracture minerals: No minerals

The fracture surface is fresh and biotite is unaltered and the plagioclase has an oligioclase composition. Unaltered euhedral octahedral crystals of magnetite are also found and are interpreted as belonging to the wall rock.



BSE image of the fresh fracture surface. The light grey minerals are unaltered biotite.

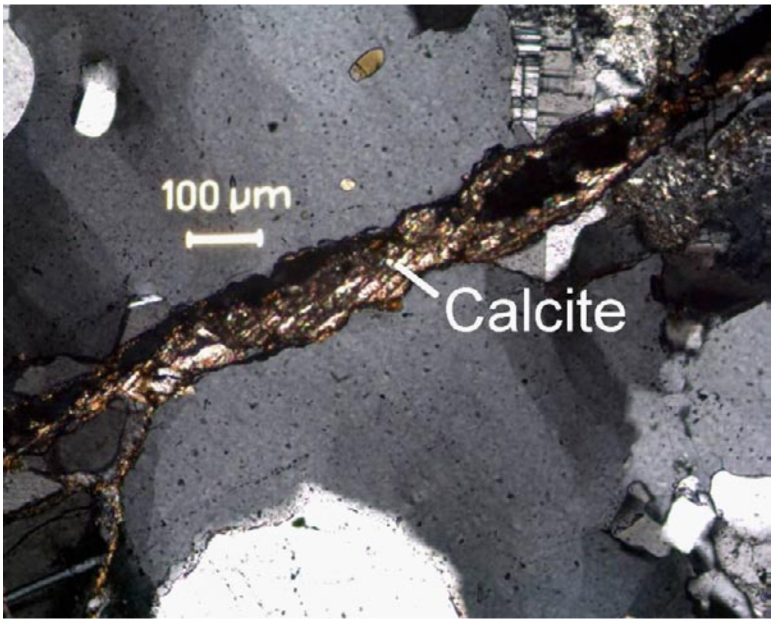


BSE image of euhedral magnetite crystal.

Sample: **KFM09A 424.27–424.37 m**
Fracture: Sealed fracture
Orientation: 149/06° + 316/70° cut each other
Deformation zone: No zone
Fracture domain: FFM05
Fracture orientation set: Gently dipping and NW
Fracture minerals: Prehnite, chlorite, corrensite (in both fractures)

Sample: **KFM09A 443.35–443.43 m**
Fracture: Open fracture
Orientation: 242/63°
Deformation zone: No zone
Fracture domain: FFM05
Fracture orientation set: WSW
Fracture minerals: No mineral

Sample: **KFM09A 447.73–447.91 m**
Fracture: Sealed fracture
Orientation: 249/86°
Deformation zone: No zone
Fracture domain: FFM05
Fracture orientation set: WSW
Fracture minerals: Prehnite, adularia, calcite

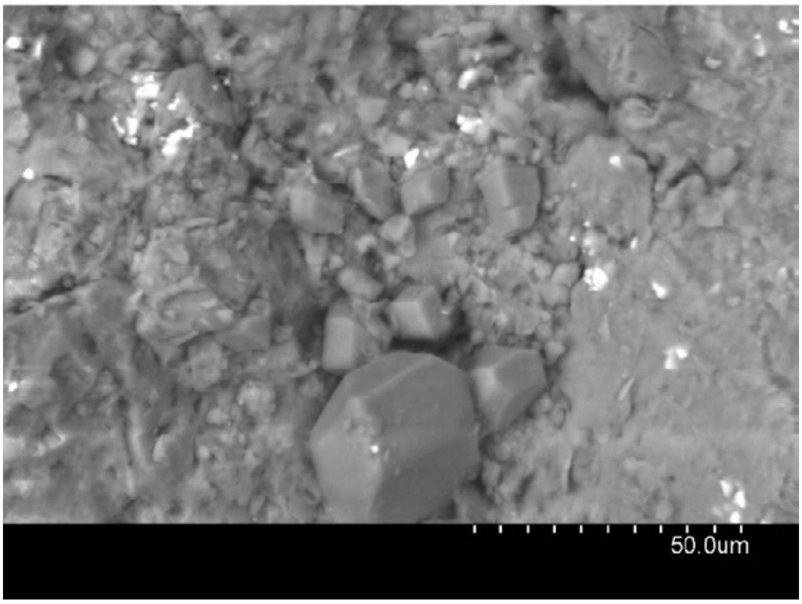


Sample: **KFM09A 475.92–475.99 m**
Fracture: Sealed fracture
Orientation: 241/86°
Deformation zone: No zone
Fracture domain: FFM05
Fracture orientation set: WSW
Fracture minerals: Adularia

Sample: **KFM09A 478.39–478.72 m**
Fracture: Sealed fracture
Orientation: 060/87°
Deformation zone: No zone
Fracture domain: FFM05
Fracture orientation set: ENE
Fracture minerals: Quartz, calcite, adularia, pyrite, chlorite

Sample: **KFM09A 502.04–502.14 m**
Fracture: Sealed fracture
Orientation: 272/62°
Deformation zone: No zone
Fracture domain: FFM05
Fracture orientation set: W
Fracture minerals: Chlorite/corrensite, apophyllite, calcite, allanite

The coating consists of chlorite/corrensite, apophyllite and calcite. Small crystals of allanite are also found on the surface. A few equant calcite crystals have also precipitated on the surface.



BSE image of equant calcite crystals on the fracture surface. The bright white minerals in the BSE image are small allanite crystals.

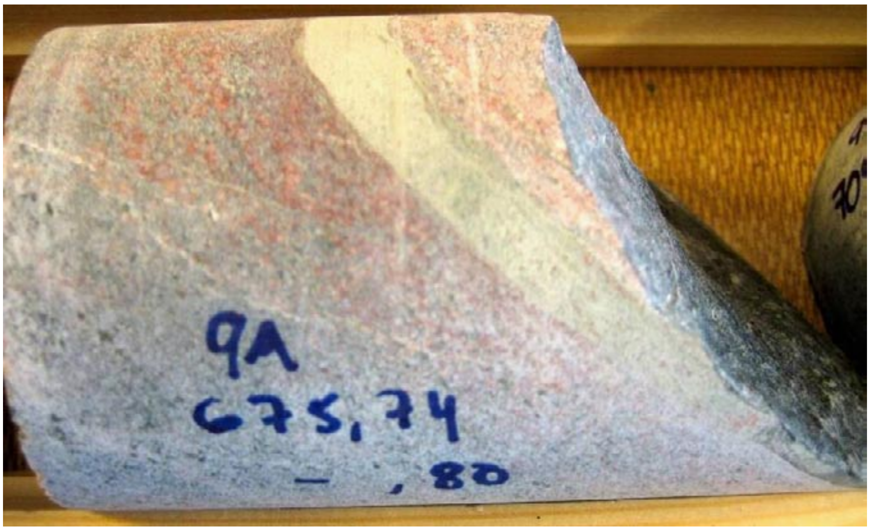
Sample: **KFM09A 514.64–514.71 m**
Fracture: Open fracture
Orientation: 294/72°
Deformation zone: No zone
Fracture domain: FFM05
Fracture orientation set: WNW
Fracture minerals: No mineral

Sample: **KFM09A 543.68–543.93 m**
Fracture: Sealed fracture
Orientation: Not identified in BIPS
Deformation zone: No zone
Fracture domain: FFM01
Fracture orientation set: n.a.
Fracture minerals: Epidote, laumontite, calcite, hematite

Sequence of mineralizations:

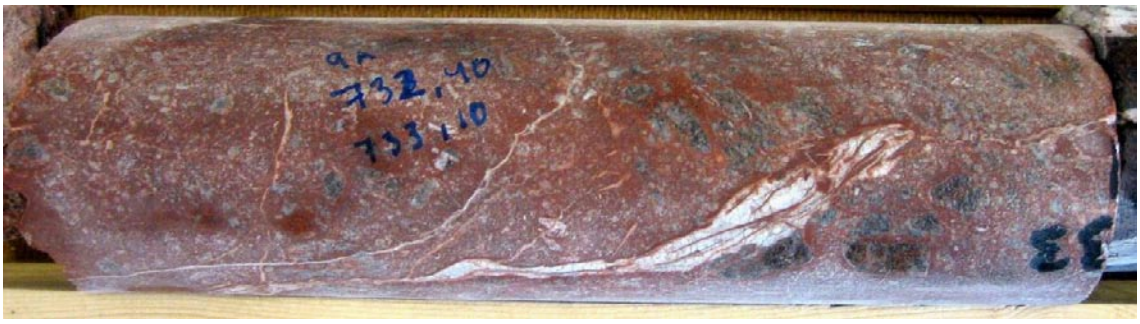
1. Epidote
2. Laumontite + hematite
3. Calcite

Sample: **KFM09A 675.74–675.80 m**
Fracture: Sealed fracture
Orientation: 156/86°
Deformation zone: No zone
Fracture domain: FFM04
Fracture orientation set: SSE
Fracture minerals: Epidote



Sample: **KFM09A 709.02–709.09 m**
Fracture: Open fracture
Orientation: 338/74°
Deformation zone: No Zone
Fracture domain: FFM04
Fracture orientation set: NNW
Fracture minerals: No mineral

Sample: **KFM09A 732.90–733.10 m**
Fracture: Sealed fracture
Orientation: n.a. (cataclastite, sealed network)
Deformation zone: ZFMNW1200
Fracture orientation set: n.a.
Fracture minerals: Laumontite, calcite, hematite



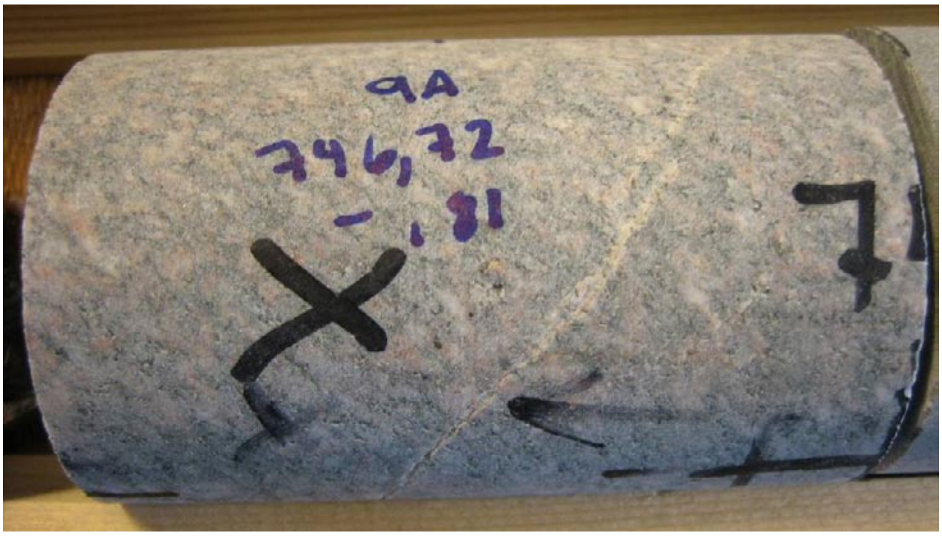
Sample: **KFM09A 740.35–740.63 m**
Fracture: Sealed fracture
Orientation: 036/86° cut by 223/72°
Deformation zone: ZFMNW1200
Fracture orientation set: NE and SW
Fracture minerals: Laumontite, clay minerals, adularia, pyrite, calcite, hematite

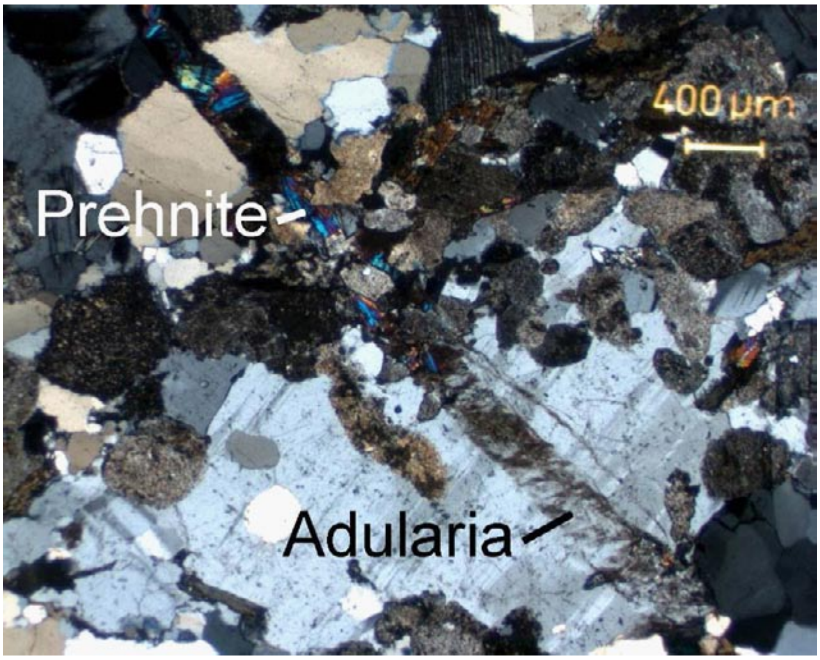
Sequence of mineralizations:

1. Laumontite + adularia + pyrite + hematite + clay minerals
2. Calcite

Sample: **KFM09A 744.14–744.19 m**
Fracture: Sealed fracture
Orientation: 056/84°
Deformation zone: ZFMNW1200
Fracture orientation set: ENE
Fracture minerals: Laumontite, calcite

Sample: **KFM09A 746.72–746.81 m**
Fracture: Sealed fracture
Orientation: 147/89°
Deformation zone: ZFMNW1200
Fracture orientation set: SSE
Fracture minerals: Prehnite, adularia

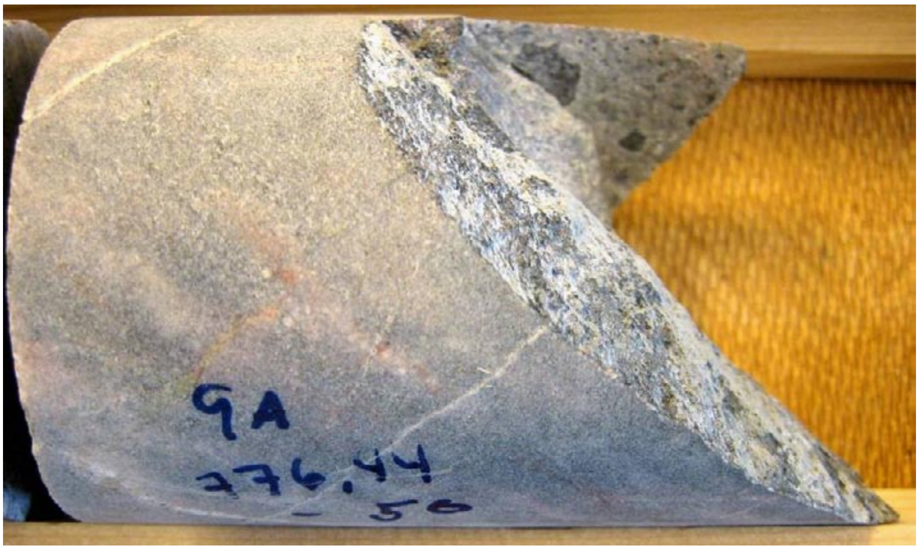


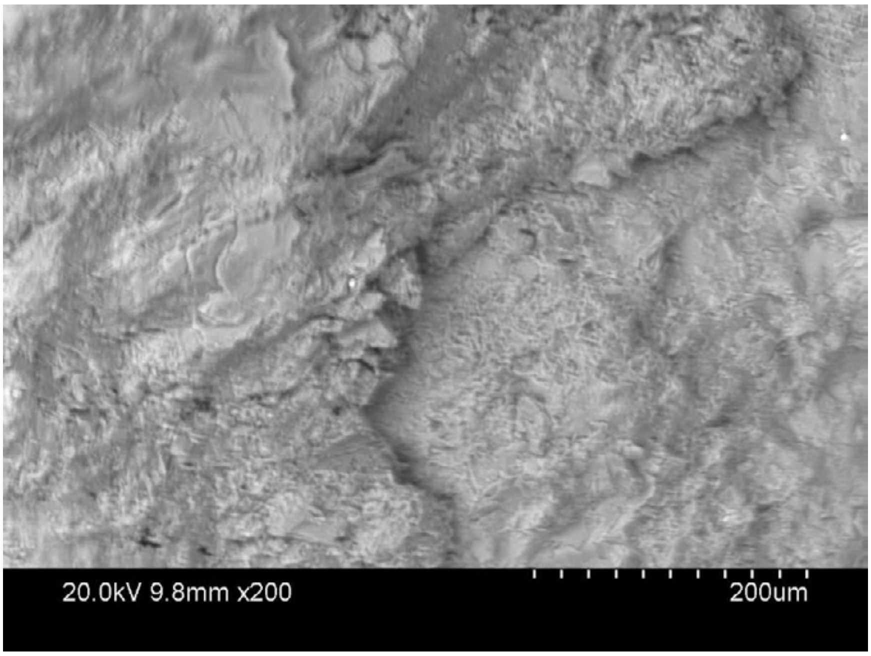


Photomicrograph of sealed fracture sealed with prehnite and adularia (crossed polars).

Sample: **KFM09A 776.44–776.50 m**
Fracture: Sealed fracture
Orientation: 255/79°
Deformation zone: ZFMNW1200
Fracture orientation set: WSW
Fracture minerals: Chlorite, clay minerals, quartz, calcite, galena

The fracture coating consists mainly of chlorite and clay minerals. The lighter greenish coating consists of more quartz and calcite and small scattered occurrences of galena.





SEM image of chlorite on the fracture surface.

Sample: **KFM09A 776.75–776.91 m**
Fracture: Sealed fracture
Orientation: 147/75°
Deformation zone: ZFMNW1200
Fracture orientation set: SSE
Fracture minerals: Prehnite, laumontite, calcite

Sample: **KFM09A 789.13–789.43 m**
Fracture: Sealed fracture
Orientation: 070/68°
Deformation zone: ZFMNW1200
Fracture orientation set: ENE
Fracture minerals: Prehnite, calcite

Sample: **KFM09A 796.00 m (No secup-seclow available due to not in BIPS)**
Fracture: Sealed fracture
Orientation: Not in BIPS
Deformation zone: No zone
Fracture domain: FFM04
Fracture orientation set: n.a.
Fracture minerals: Epidote, pyrite

Sample: **KFM09B 9.40–9.57 m**
Fracture: Open fracture
Orientation: 150/67°
Deformation zone: ZFMENE1208A
Fracture orientation set: SSE
Fracture minerals: Chlorite/corrensite, calcite, pyrite

Sample: **KFM09B 16.89–17.01 m**
Fracture: Open fracture
Orientation: 334/19°
Deformation zone: ZFMENE1208A
Fracture orientation set: Gently dipping
Fracture minerals: Chlorite, clay mineral, calcite

Sample: **KFM09B 19.37–19.57 m**
Fracture: Open fracture / crushed zone
Orientation: 331/23°
Deformation zone: ZFMENE1208A
Fracture orientation set: Gently dipping
Fracture minerals: (XRD) calcite, chlorite, hematite, illite, K-feldspar, mixed layer clays, plagioclase, quartz

Sample: **KFM09B 19.81–20.18 m**
Fracture: Open fracture / crushed zone
Orientation: 086/19°
Deformation zone: ZFMENE1208A
Fracture orientation set: Gently dipping
Fracture minerals: (XRD) calcite, chlorite, illite, K-feldspar, mixed layer clays, plagioclase, quartz

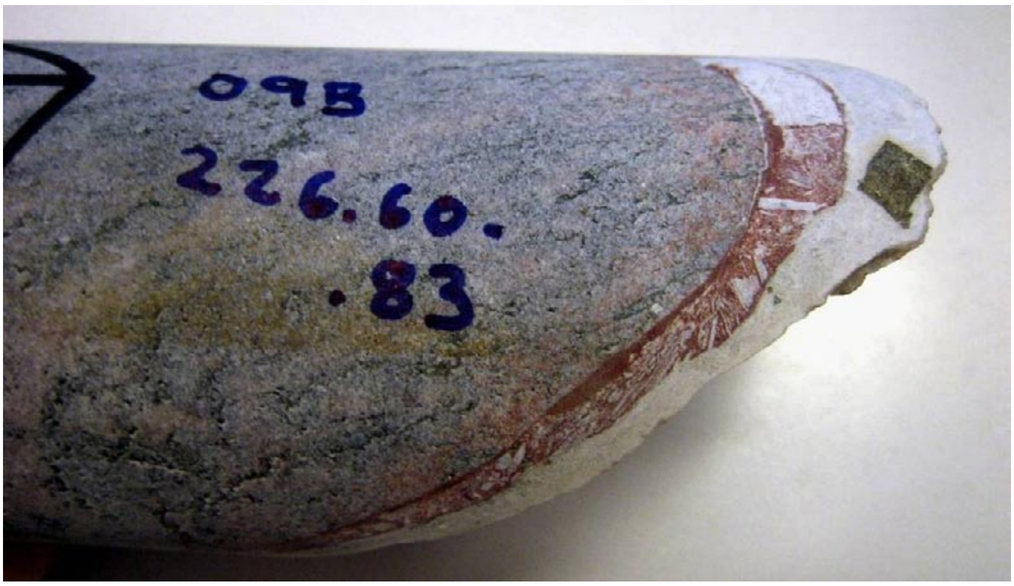
Sample: **KFM09B 49.73–50.10 m**
Fracture: Open fracture
Orientation: 085/16°
Deformation zone: No zone
Fracture domain: FFM02
Fracture orientation set: Gently dipping
Fracture minerals: Calcite, quartz, asphaltite, chlorite/corrensite

Sample: **KFM09B 50.74–50.85 m**
Fracture: Open fracture
Orientation: 078/13°
Deformation zone: No zone
Fracture domain: FFM02
Fracture orientation set: Gently dipping
Fracture minerals: Quartz, calcite, asphaltite

Sample: **KFM09B 121.56–121.98 m**
Fracture: Open fracture
Orientation: 200/78°
Deformation zone: ZFMENE0159A
Fracture orientation set: SSW
Fracture minerals: Adularia, hematite, chlorite, corrensite

Sample: **KFM09B 168.87–169.06 m**
Fracture: Open fracture
Orientation: 239/30°
Deformation zone: No zone
Fracture domain: FFM01
Fracture orientation set: Gently dipping
Fracture minerals: (XRD) calcite, quartz, K-feldspar, plagioclase, illite, chlorite, mixed layer clay.

Sample: **KFM09B 226.60–226.83 m**
Fracture: Open fracture
Orientation: 063/87°
Deformation zone: No zone
Fracture domain: FFM01
Fracture orientation set: ENE
Fracture minerals: Laumontite, calcite, pyrite, quartz



Sample: **KFM09B 242.60–242.79 m**
Fracture: Open fracture
Orientation: 070/13°
Deformation zone: No zone
Fracture domain: FFM01
Fracture orientation set: Gently dipping
Fracture minerals: Chlorite/corrensite, clay mineral, calcite, pyrite

Sample: **KFM09B 310.61–310.83 m**
Fracture: Open fracture
Orientation: 255/86°
Deformation zone: DZ not modelled
Fracture orientation set: WSW
Fracture minerals: (XRD) Quartz, plagioclase, laumontite, pyrite, epidote

Sample: **KFM09B 326.18–326.27 m**
Fracture: Open fracture
Orientation: 056/87°
Deformation zone: DZ not modelled
Fracture orientation set: ENE
Fracture minerals: Calcite, pyrite, quartz

Sample: **KFM09B 391.28–391.37 m**
Fracture: Open fracture
Orientation: 103/75° and 227/61°
Deformation zone: ZFMENE2320
Fracture orientation set: ESE and SW
Fracture minerals: Laumontite, chlorite/corrensite, clay mineral, calcite, hematite

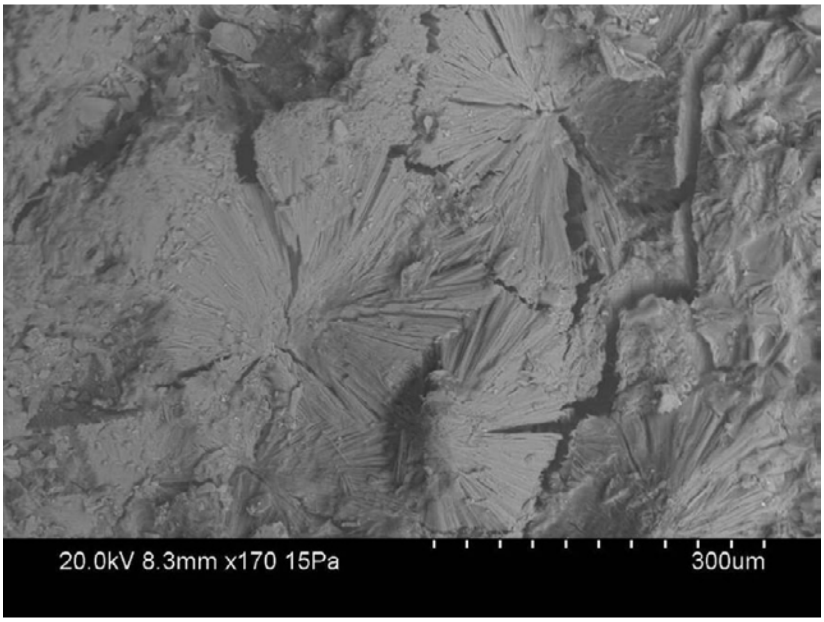
Sample: **KFM10A 105.79–106.08 m**
Fracture: Open fracture
Orientation: 121/61°
Deformation zone: ZFMWNW0123
Fracture orientation set: ESE
Fracture minerals: (XRD) calcite, chlorite, corrensite, adularia, plagioclase, quartz

Sample: **KFM10A 107.27–107.34 m**
Fracture: Open fracture
Orientation: 126/64°
Deformation zone: ZFMWNW0123
Fracture orientation set: SE
Fracture minerals: Chlorite, calcite, quartz, hematite, pyrite

Sample: **KFM10A 216.99–217.19 m**
Fracture: Open fracture
Orientation: 029/87°
Deformation zone: No Zone
Fracture domain: FFM03
Fracture orientation set: NNE
Fracture minerals: Laumontite, chlorite, calcite, hematite

Sample: **KFM10A 299.35–299.46 m**
Fracture: Open fracture
Orientation: 228/27°
Deformation zone: ZFMENE2403
Fracture orientation set: Gently dipping
Fracture minerals: Chlorite, clay minerals, pyrite, adularia, quartz, calcite

Sample: **KFM10A 87.41–87.43 m**
Fracture: Open fracture
Orientation: 215/09°
Deformation zone: ZFMWNW0123
Fracture orientation set: Gently dipping
Fracture minerals: Chlorite, talc, calcite



SEM-image of talc on fracture surface.

Sample: **KFM11A 178.78–178.81 m**
Fracture: Open fracture
Orientation: 048/05°
Deformation zone: No zone
Fracture orientation set: Gently dipping
Fracture minerals: (XRD) quartz, laumontite, chlorite, K-feldspar, plagioclase, epidote, corrensite

Sample: **KFM11A 376.43–376.60 m**
Fracture: Open fracture
Orientation: Not identified in BIPS
Deformation zone: No zone
Fracture orientation set: n.a.
Fracture minerals: (XRD) quartz, calcite, feldspars, prehnite, chlorite, corrensite

Sample: **KFM11A 381.17–381.25 m**
Fracture: Open fracture
Orientation: 164/35°
Deformation zone: n.a.
Fracture orientation set: Gently dipping
Fracture minerals: Chlorite, corrensite

Sample: **KFM11A 390.33–390.36 m**
Fracture: Open fracture
Orientation: 074/52°
Deformation zone: n.a.
Fracture orientation set: ENE
Fracture minerals: Chlorite, clay mineral, calcite

Sample: **KFM11A 394.20–394.41 m**
Fracture: Open fracture
Orientation: 349/66°
Deformation zone: n.a.
Fracture orientation set: NNW
Fracture minerals: Adularia, pyrite, calcite, quartz

Sample: **KFM11A 407.97–408.22 m**
Fracture: Open fracture
Orientation: 298/23°
Deformation zone: n.a.
Fracture orientation set: Gently dipping
Fracture minerals: Calcite, chlorite, clay mineral

Sample: **KFM11A 426.07–426.21 m**
Fracture: Open fracture
Orientation: 063/32°
Deformation zone: n.a.
Fracture orientation set: Gently dipping
Fracture minerals: (XRD) calcite, prehnite, laumontite, plagioclase, K-feldspar, quartz, chlorite, corrensite

Sample: **KFM11A 464.23–464.46 m**
Fracture: Open fracture
Orientation: 321/84°
Deformation zone: n.a.
Fracture orientation set: NW
Fracture minerals: Chlorite, corrensite, calcite, hematite

Appendix 2

Calcite, stable isotopes

Borehole	Secup	Seclow	Sub sample	$\delta^{13}C$ ‰ PDB	$\delta^{18}O$ ‰ PDB	$^{87}Sr/^{86}Sr$
KFM01C	253.38	253.62	1	–3.2	–15.4	0.70849
KFM01C	253.38	253.32	2	–3.1	–11.5	0.70732
KFM01C	322.05	322.23	1	–3.9	–21.2	0.71507
KFM01C	90.63	90.73	1	7.2	–12.4	
KFM04A	347.32	347.50	1	–13.6	–13.6	
KFM06B	68.96	69.06	1	–25.5	–12.5	
KFM07A	193.77	193.90	1			0.71940
KFM08A	410.60	411.04	1			0.71181
KFM08B	14.30	14.37	1			0.71375
KFM08B	91.36	91.58	1			0.71568
KFM08C	829.94	830.02	1	–4.5	–11.5	
KFM08C	148.16	148.26	1	–16.9	–12.9	
KFM08C	148.16	148.26	2	–19.0	–10.0	
KFM08C	161.02	161.36	1	–16.0	–14.1	
KFM08C	282.73	282.79	1	–3.5	–11.3	
KFM08C	523.47	523.73	1	–16.6	–12.7	
KFM09A	732.90	733.10	1	–3.6	–18.5	
KFM09A	241.37	241.82	1	–18.2	–12.8	0.71491
KFM09A	230.34	230.46	1	–5.5	–14.2	
KFM09A	789.13	789.43	1	–4.1	–16.8	
KFM09A	789.13	789.43	2	–4.3	–16.8	0.70978
KFM09A	234.16	234.41	1	–12.3	–12.8	
KFM09B	168.87	169.06	1	–2.3	–10.6	
KFM09B	11.35	11.42	1	–3.0	–14.9	
KFM09B	19.81	20.18	1	–8.7	–9.5	
KFM10A	105.79	106.08	1	–8.0	–12.3	
KFM10A	485.08	485.21	1	–7.9	–9.0	
KFM10A	216.99	217.19	1	–2.5	–14.6	
KFM10A	216.99	217.19	2	–14.4	–13.3	
KFM10A	299.38	299.45	1	–9.2	–10.1	
KFM10A	107.27	107.34	1	–6.3	–8.3	
KFM11A	394.20	394.41	1	–19.7	–14.4	

Appendix 3

Mössbauer analyses

Borehole	SecUp (m)	Fe-mineral	Oxid fact (sil)*	Oxid fact (tot) **
KFM01C	12.43	chlorite	0.37	0.37
KFM01C	39.75	chlorite, hem, tr. mag	0.43	0.57
KFM01C	41.15	chlorite, hem	0.37	0.72
KFM08C	683.57	chlorite	0.15	0.15
KFM08C	829.94	chlorite. tr. mag	0.21	0.27
KFM08C	904.06	chlorite	0.07	0.07
KFM09B	121.56	chlorite	0.12	0.12
KFM10A	105.79	chlorite, epidote	0.29	0.29

* Oxidation factor silicates (Fe^{3+}_{sil} / $(Fe^{2+} + Fe^{3+})_{sil}$
** Total oxidation factor (Fe^{3+}_{tot} / Fe_{tot})
tr = trace amount, mag= magnetite,
hem= hematite

Appendix 4

U-series analyses

Borehole	Secup (m)	Seclow	^{238}U Bq	±	^{234}U Bq	±	^{230}Th Bq	±	^{232}Th Bq	±	$^{234}U/^{238}U$	±	$^{230}Th/^{234}U$	±
KFM01C	43.00	43.20	83	1	111	1	125	2	60	1	1.33	0.02	1.12	0.020
KFM06A	357.81	357.87	65	1	70	1	89	4	31	2	1.07	0.02	1.27	0.060
KFM08C	683.57	683.66	78	1	101	1	118	6	55	4	1.29	0.02	1.16	0.060
KFM08C	829.94	830.02	69	1	71	1	121	2	14	1	1.02	0.02	1.71	0.004
KFM08C	904.06	904.13	109	1	116	1	117	4	21	2	1.07	0.02	1.01	0.040
KFM09B	19.81	20.18	111	1	117	1	119	6	20	2	1.05	0.01	1.02	0.050
KFM10A	105.79	106.08	355	2	450	2	450	9	16	1	1.27	0.01	1.00	0.020

Appendix 5

Chemical composition

Borehole		KFM01C	KFM01C	KFM01C	KFM01C	KFM01C	KFM01C	KFM08A
Length (m)		12.43	17.22	34.47	41.15	39.75	43.00	246.22
Comment								
Minerals		Ca,Chl,Ill, K-fsp,MLC Pl,Qz,Ti	Bi,Ca,Chl Ill,K-fsp,Pl Qz	Bi,Chl,Ill, K-fsp,MLC Pl,Qz	Ill,K-fsp Kao,MLC Pl,Qz	Chl,Ill,Qz K-fsp,Kao MLC,Sme	Ill,K-fsp Kao,MLC Pl,Qz,Sme	Ana
SiO_2	%	56.4	59.3	70.3	67.3	58.4	62.3	55.5
Al_2O_3	%	14.1	12.9	13.8	15.0	17.1	14.1	19.5
CaO	%	7.39	6.79	0.685	0.468	0.597	0.482	<0.2
Fe_2O_3	%	3.67	3.94	3.07	3.69	6.79	7.73	0.462
K_2O	%	6.06	4.8	5.47	8.6	9.56	7.69	0.77
MgO	%	1.49	1.31	1.03	0.88	1.46	1.49	<0.06
MnO	%	0.0444	0.0604	0.0198	0.0117	0.0191	0.0390	<0.0080
Na_2O	%	1.800	2.320	2.230	0.619	0.293	0.485	11.500
P_2O_5	%	0.0927	0.0895	0.0439	0.0353	0.0373	0.0505	0.0074
TiO_2	%	0.343	0.371	0.177	0.107	0.110	0.222	<0.006
Summa	%	91.4	91.9	96.8	96.7	94.4	94.6	87.7
Ba	mg/kg	1,140	947	1,120	1,600	1,980	1,650	127
Be	mg/kg	2.8	2.58	2.82	1.9	2.18	3.17	<1
Co	mg/kg	<6	5.78	<6	<6	<6	<6	<10
Cr	mg/kg	40.4	121	23.7	<10	19.7	<10	<30
Cs	mg/kg	8.96	9.34	14.1	20	36.8	23.1	73.2
Cu	mg/kg	<6	8.59	12.2	23.5	<6	<6	<10
Ga	mg/kg	7.85	6.33	8.52	9.46	14.3	11.1	<3
Hf	mg/kg	12.7	14.3	11.5	7.72	11.8	13.5	4.27
Mo	mg/kg	3.88	3.88	<2	<2	5.36	<2	<6
Nb	mg/kg	12.3	16.6	13.5	3.22	5.53	11.7	<0.6
Ni	mg/kg	18.1	13.8	<10	<10	<10	<10	<30
Rb	mg/kg	159	152	236	347	432	313	26
Sc	mg/kg	7.49	13.6	8.94	2	6.95	7.51	<3
Sn	mg/kg	3.2	4.04	13.5	4.52	3.18	2.41	<3
Sr	mg/kg	131	123	99.6	34.4	41.2	39	<6
Ta	mg/kg	1.08	1.25	1.42	0.438	0.372	0.495	0.23
Th	mg/kg	12.7	13.5	6.42	3.72	5.83	10.2	1.37
U	mg/kg	14.6	19.3	16.4	8.14	22.8	10.8	0.276
V	mg/kg	45.4	37.9	9.68	35.8	18.5	22.7	<6
W	mg/kg	1.62	2.58	2.91	1.81	1.84	3.85	1.11
Y	mg/kg	29.1	48.8	24.3	12	40.3	24.3	1.45
Zn	mg/kg	72.3	108	114	199	53.3	51.9	<30
Zr	mg/kg	179	228	170	129	170	221	22.8
La	mg/kg TS	52.9	126	113	58.6	369	50.8	6.62
Ce	mg/kg TS	103	230	158	82.6	683	78.3	11.9
Pr	mg/kg TS	11.2	25.1	23.8	12.2	69.9	10.2	<3
Nd	mg/kg TS	37.3	94.4	83.6	41.9	260	36.8	2.89
Sm	mg/kg TS	6.91	17.3	12.5	6.92	41.2	7.13	<0.8
Eu	mg/kg TS	0.914	1.51	1.05	0.537	2.6	0.566	<0.1
Gd	mg/kg TS	6.03	14.9	8.44	4.92	27.4	5.97	<0.8
Tb	mg/kg TS	0.919	1.72	0.944	0.554	2.24	0.867	<0.2
Dy	mg/kg TS	5.46	9.42	5.11	2.81	8.9	4.99	<0.2
Ho	mg/kg TS	1.08	1.77	0.954	0.479	1.3	0.966	<0.2
Er	mg/kg TS	3.05	4.64	2.83	1.19	2.67	2.59	<0.3
Tm	mg/kg TS	0.424	0.62	0.469	0.156	0.286	0.354	<0.3
Yb	mg/kg TS	2.68	3.9	3.58	0.988	1.68	2.1	<0.6
Lu	mg/kg TS	0.403	0.574	0.569	0.151	0.3	0.33	<0.08

Borehole		KFM08C	KFM08C	KFM08C	KFM08C	KFM09B	KFM09B	KFM09B
Length (m)		**523.47**	**683.57**	**829.94**	**904.06**	**11.35**	**19.37**	**19.81**
Comment								
Minerals		Corr,Ill K-fsp,Pl,Qz	Bi,Chl Corr,K-fsp Pl,Qz	Amp,Ca,Pl Chl,Corr, Ill,K-fsp,Qz	Chl,Chl Corr,Qz		Ca,Chl,Hm Ill,K-fsp MLC,Pl,Qz	Ca,Chl,Ill K-fsp,MLC Pl,Qz
SiO_2	%	67.1	41.2	49.5	36.7	70.8	63.2	45.4
Al_2O_3	%	15.1	16.4	12.6	13.0	11.3	12.8	15.7
CaO	%	2.65	1.21	6.78	4.5	0.97	5.3	8.23
Fe_2O_3	%	1.15	16.7	10.4	18.2	2.17	2.86	7.31
K_2O	%	3.73	2.42	2.32	1.15	5.74	6.69	5.02
MgO	%	0.10	12.40	10.90	13.70	4.43	0.93	4.12
MnO	%	0.0069	0.2690	0.2540	0.4220	0.0366	0.0274	0.1030
Na_2O	%	6.540	0.802	2.880	0.282	1.890	1.380	0.448
P_2O_5	%	0.0246	0.0545	0.0909	0.1840	0.0199	0.0225	0.0594
TiO_2	%	0.385	0.499	0.323	0.714	0.170	0.131	0.261
Summa	%	96.8	92.0	96.0	88.9	97.5	93.3	86.7
Ba	mg/kg	584	395	830	179	1,360	1,870	378
Be	mg/kg	3.37	6.25	2.99	7.81	1.93	2.93	5.14
Co	mg/kg	<6	19	43.3	53.8	<6	<6	13.7
Cr	mg/kg	<10	110	998	1,680	17	<10	<10
Cs	mg/kg	0.375	1.36	3.95	6.48	2.43	8.17	21.8
Cu	mg/kg	<6	<6	<6	12.7	<6	21.7	<6
Ga	mg/kg	1.61	32	6.96	25.8	5.96	2.01	19.2
Hf	mg/kg	30	3.97	2.6	3.82	12.5	6.16	5.26
Mo	mg/kg	<2	<2	<2	<2	<2	<2	<2
Nb	mg/kg	73.3	22	4.07	36.8	25.8	8.27	8.07
Ni	mg/kg	<10	28.4	203	225	<10	<10	<10
Rb	mg/kg	75.2	111	162	153	158	232	355
Sc	mg/kg	11.3	19.7	32.3	65.1	6.9	5.72	22.3
Sn	mg/kg	6.37	11.9	5.3	24	9.84	8.57	6.6
Sr	mg/kg	21.6	130	148	56.5	56.3	80.7	62.9
Ta	mg/kg	6.94	1.1	0.282	2.96	3.09	0.875	0.634
Th	mg/kg	36.4	2.27	0.681	1.44	11.9	5.36	2.93
U	mg/kg	11.5	2.61	4.63	11.8	6.41	11.2	5.82
V	mg/kg	5.29	157	169	334	5.05	41.8	74.3
W	mg/kg	0.58	1.11	0.508	1.06	1.69	4.52	1.57
Y	mg/kg	170	32.8	9.5	66.9	29.4	31.5	33.8
Zn	mg/kg	93.2	167	121	301	69.5	78.9	162
Zr	mg/kg	442	29.3	21.7	44.7	203	108	66.6
La	mg/kg TS	175	52.7	7.33	20.7	43.2	70.9	35.2
Ce	mg/kg TS	290	94.7	14.1	40.7	84.4	143	67.1
Pr	mg/kg TS	37.4	8.73	1.77	5.23	9.49	16.7	7.93
Nd	mg/kg TS	142	30.9	7.8	23.4	35.3	62	30.4
Sm	mg/kg TS	30.8	5.2	1.74	6.92	6.65	12.1	6.1
Eu	mg/kg TS	2.1	0.736	0.407	1.11	0.474	1.16	0.661
Gd	mg/kg TS	30.5	4.79	1.63	8.27	5.84	9.79	5.91
Tb	mg/kg TS	4.63	0.79	0.233	1.56	0.805	1.13	0.925
Dy	mg/kg TS	29.3	5.24	1.47	11	4.98	6.03	5.96
Ho	mg/kg TS	6.25	1.17	0.338	2.44	1.05	1.17	1.29
Er	mg/kg TS	19.6	3.54	0.98	7.82	3.21	3.33	3.91
Tm	mg/kg TS	2.94	0.559	0.154	1.34	0.512	0.475	0.618
Yb	mg/kg TS	19.5	3.92	1.21	10.4	3.72	3.19	4.35
Lu	mg/kg TS	2.75	0.624	0.188	1.66	0.579	0.492	0.662

Borehole		KFM09B	KFM09B	KFM09B	KFM09B	KFM09B	KFM10A	KFM02B
Length (m)		49.73	121.56	168.87	310.61	391.28	105.79	471.49
Comment								
Minerals				Ca,Chl,Ill K-fsp,MLC Pl,Qz	Epi,Lau MLC,Pl Qz,Py		Ca,Qz,Chl K-fsp,Pl Corr	Ca,Chl,Ill Corr,Hm K-fsp,MLC Pl.Qz.SC
SiO_2	%	21.9	56.8	31.1	67.1	53.5	37.7	48.6
Al_2O_3	%	1.13	14.3	9.98	10.5	16.4	8.43	11.7
CaO	%	34.3	0.532	24.5	9.2	10.5	16.1	8.67
Fe_2O_3	%	1.81	15.8	4.53	5.41	2.81	6.21	8.16
K_2O	%	0.674	3.15	4.81	0.532	1.88	1.67	4.29
MgO	%	0.12	2.42	1.71	0.14	0.45	7.51	7.09
MnO	%	0.0375	0.1140	0.1020	0.0591	0.0242	0.1330	0.126
Na_2O	%	0.119	0.166	0.709	1.540	1.810	0.838	1.28
P_2O_5	%	0.0076	0.0127	0.0095	0.0250	0.0083	0.1340	0.0856
TiO_2	%	0.018	0.067	0.131	0.109	0.032	0.451	0.344
Summa	%	60.1	93.4	77.6	94.6	87.4	79.2	90.3
Ba	mg/kg	118	245	517	96.7	557	337	460
Be	mg/kg	<0.6	4.89	3.43	1.47	1.61	2.31	3.42
Co	mg/kg	<6	6.93	<6	<6	<6	7.01	10.9
Cr	mg/kg	<10	19.9	<10	<10	<10	760	222
Cs	mg/kg	1.11	22.4	7.79	1.63	2.25	1.23	7.54
Cu	mg/kg	<6	<6	<6	<6	10.3	<6	23.8
Ga	mg/kg	<1	17.4	9.87	10.2	6.44	6.72	20.1
Hf	mg/kg	4.53	3.65	4.05	8.93	6.03	3.96	3.87
Mo	mg/kg	5.43	<2	<2	<2	<2	<2	2.58
Nb	mg/kg	1.53	4.09	10.3	6.57	2.09	4.15	10.8
Ni	mg/kg	<10	<10	<10	<10	<10	<10	47
Rb	mg/kg	18.1	272	162	29.7	72.3	79.1	126
Sc	mg/kg	2.84	11.1	15.5	3.78	2.24	24.6	13.8
Sn	mg/kg	<1	6.9	5.09	56.5	1.56	<1	9.68
Sr	mg/kg	27.3	50.7	53.8	191	158	68.6	62.2
Ta	mg/kg	0.306	0.519	0.459	1.14	0.227	0.549	0.953
Th	mg/kg	1.62	0.902	3.46	4.24	4.31	1.75	3.99
U	mg/kg	2.07	3.54	35.7	16	2.96	24.5	25.2
V	mg/kg	8.39	25	17.1	19.1	5.04	70.1	56.1
W	mg/kg	2.42	0.865	1.72	0.752	37.3	2.22	5.01
Y	mg/kg	20.4	22.3	99.6	29.3	6.34	19.1	30.5
Zn	mg/kg	43.6	75.6	101	36.7	38.3	558	512
Zr	mg/kg	20	7.24	38.5	113	62.9	58	88.2
La	mg/kg TS	53.3	7.92	166	31.9	23.8	11.4	111
Ce	mg/kg TS	98.1	16.5	283	58.7	41.4	26.3	192
Pr	mg/kg TS	10.5	1.88	32.7	6.29	4.51	2.83	16.2
Nd	mg/kg TS	38.1	7.91	131	23.1	16.3	12.2	51.1
Sm	mg/kg TS	6.98	2.7	27.9	4.38	2.56	3.45	8.73
Eu	mg/kg TS	0.521	0.334	2.73	0.676	0.235	0.454	0.835
Gd	mg/kg TS	5.38	3.6	24.9	4.25	2.03	4	7.33
Tb	mg/kg TS	0.731	0.617	3.42	0.686	0.253	0.583	1.08
Dy	mg/kg TS	4.1	3.98	19.4	4.55	1.28	3.53	6.1
Ho	mg/kg TS	0.799	0.83	3.66	1.01	0.229	0.708	1.18
Er	mg/kg TS	2.25	2.61	10.4	3.24	0.635	2.05	3.3
Tm	mg/kg TS	0.353	0.466	1.56	0.494	<0.1	0.306	0.493
Yb	mg/kg TS	2.75	3.68	10.6	3.72	0.598	2.12	3.25
Lu	mg/kg TS	0.417	0.576	1.57	0.592	0.0964	0.323	0.542

Borehole		KFM02B	KFM11A	KFM11A	KFM11A	KFM11A	KFM02B	KFM02B
Length (m)		**500.36**	**178.78**	**376.43**	**426.07**	**450.28**	**499.84**	**500.72**
Comment								
Minerals		Ca,Chl Corr,Ill K-fsp,MLC Mus.Qz	Chl,Corr Epi,K-fsp Lau,Pl,Qz	Ca,Chl Corr,K-fsp Pl,Pre,Qz	Ca,Chl K-Fsp,Lau MLC,Pl Pre.Qz	Ana,Ca Chl,K-fsp Lau,Pl,Qz Sme	Ca,Chl Corr,K-fsp Pl,Qz	Ca,Chl Corr,Ill K-fsp,MLC Mus.Pl.Qz
SiO_2	%	27.0	60.7	56.4	33.2	44.9	9.86	17.8
Al_2O_3	%	5.48	13.5	17.5	15.9	14.2	2.21	2.97
CaO	%	34.1	7.08	15.7	26.1	17.3	48.1	42.1
Fe_2O_3	%	1.04	6.06	1.18	6.49	3.06	0.742	0.538
K_2O	%	3.48	0.577	2.63	0.129	0.534	1.02	1.61
MgO	%	1.05	5.64	0.778	2.26	1.45	0.184	0.772
MnO	%	0.0151	0.0771	0.0464	0.0673	0.0408	0.047	0.009
Na_2O	%	0.246	0.966	1.67	0.616	1.64	0.286	0.153
P_2O_5	%	0.0073	0.0767	0.013	0.0042	0.0217	0.0024	<0.002
TiO_2	%	0.0214	0.229	0.0516	0.0247	0.072	0.0147	0.0105
Summa	%	72.4	94.9	96.0	84.8	83.2	62.5	66.0
Ba	mg/kg	290	153	930	40.9	243	140	190
Be	mg/kg	1.34	2.51	11.8	5.1	1.62	<0.6	1.02
Co	mg/kg	<6	9.66	<6	<6	<6	<6	<6
Cr	mg/kg	<10	17.7	13.9	<10	<10	<10	<10
Cs	mg/kg	6.37	0.711	0.16	1.3	4.89	0.642	1.97
Cu	mg/kg	11.9	35.9	<6	29.6	15.1	34.6	46.2
Ga	mg/kg	12.7	21.4	19.4	25.8	11.2	4.61	8.64
Hf	mg/kg	2.61	4.34	1.2	1.19	1.52	0.728	0.983
Mo	mg/kg	<2	<2	<2	<2	2.84	<2	<2
Nb	mg/kg	2.55	10.7	4.22	5.77	2.71	1.48	1.54
Ni	mg/kg	<10	<10	<10	<10	<10	<10	<10
Rb	mg/kg	68	13.1	53.9	7.46	25.5	27.6	40.1
Sc	mg/kg	3.2	12.7	1.82	<1	3.42	<1	1.83
Sn	mg/kg	2.65	3.55	1.93	7.75	1.99	1.98	1.75
Sr	mg/kg	37.6	818	42.8	108	150	49.1	50.3
Ta	mg/kg	0.192	0.748	1.08	0.447	0.162	<0.06	0.0813
Th	mg/kg	2.52	4.86	3.16	0.673	2.05	0.468	0.899
U	mg/kg	2.36	25.7	11.3	31.8	9.03	1.16	1.46
V	mg/kg	20.3	110	27.3	33.5	12.3	6.64	8.26
W	mg/kg	<0.4	1.3	1.5	1.11	0.5	0.484	<0.4
Y	mg/kg	14.9	46.5	65.3	32.8	13.1	11.1	11.4
Zn	mg/kg	26.9	53.2	19.3	17.6	25.4	30.9	44.2
Zr	mg/kg	40.5	105	9.22	11.1	37.6	9.75	16.8
La	mg/kg TS	9.65	76.4	16	23.7	22.6	25	7.61
Ce	mg/kg TS	24.7	151	45.4	55.3	53.9	52.4	20
Pr	mg/kg TS	1.51	15.3	3.66	4.26	4.16	5.01	<1
Nd	mg/kg TS	7.1	56	14.6	16.6	15.1	19	4.77
Sm	mg/kg TS	2.13	10.3	4.62	3.38	2.71	3.75	1.42
Eu	mg/kg TS	0.273	2.55	0.473	0.412	0.724	0.348	0.176
Gd	mg/kg TS	2.69	8.93	7.33	3.75	2.4	3.04	1.92
Tb	mg/kg TS	0.41	1.31	1.32	0.561	0.348	0.361	0.255
Dy	mg/kg TS	2.45	7.96	9.11	3.78	2.09	1.97	1.48
Ho	mg/kg TS	0.478	1.62	1.89	0.899	0.43	0.379	0.301
Er	mg/kg TS	1.31	4.84	5.48	3	1.26	1.04	0.841
Tm	mg/kg TS	0.175	0.687	0.778	0.48	0.185	0.15	<0.1
Yb	mg/kg TS	1	4.44	4.88	3.26	1.29	1.09	0.573
Lu	mg/kg TS	0.175	0.669	0.744	0.587	0.233	0.207	0.127

Borehole		KFM11A	KFM11A	KFM11A	KFM09A	KFM09B	KFM09B
Length (m)		540.19	624.45	685.56	241.37	570.92	571.13
Comment						Episyenite	Episyenite
Minerals		Chl,Ill K-fsp,Mus Pl,Qz	Ca,Chl,Hm Ill,K-fsp MLC,Mus Pl.Qz	Chl,Ill K-fsp,Lau Mus,Qz,SC	Analcime	Bi,Corr,Epi Fl,K-fsp,Qz Sme	Chl,Corr Epi,K-fsp Pl,Qz
SiO_2	%	61.3	46.0	55.2	57.6	55.8	53.9
Al_2O_3	%	17.8	20.0	18.2	21.5	18.2	18.4
CaO	%	0.434	4.73	1.97	<0.1	8.65	9.42
Fe_2O_3	%	3.73	9.18	4.91	0.174	4.92	5.7
K_2O	%	4.22	4.73	8.92	0.116	9.15	8.42
MgO	%	7.96	8.92	6.52	0.0468	0.21	0.27
MnO	%	0.0491	0.188	0.128	<0.004	0.1370	0.1650
Na_2O	%	0.445	0.178	0.185	12.6	0.293	0.266
P_2O_5	%	0.0287	0.28	0.0594	0.0049	0.0497	0.0354
TiO_2	%	0.231	0.844	0.294	0.0024	0.195	0.220
Summa	%	96.2	95.1	96.4	92.0	97.6	96.8
Ba	mg/kg	553	257	1,530	9.22	1,330	1,150
Be	mg/kg	5.03	11.3	3.58	<0.6	3.14	3.21
Co	mg/kg	<6	23.1	<6	<6	<6	<6
Cr	mg/kg	<10	514	38.6	<10	24.1	16.8
Cs	mg/kg	7.78	13.8	4.16	92.9	0.595	0.596
Cu	mg/kg	20.3	23.7	24	<6	<6	<6
Ga	mg/kg	18.3	29.5	22.5	1.91	21.1	27.4
Hf	mg/kg	9.72	4.2	5.29	0.315	13.4	20.7
Mo	mg/kg	<2	<2	<2	<2	<2	<2
Nb	mg/kg	19.5	12.1	13.3	0.977	19	18.9
Ni	mg/kg	<10	110	<10	<10	<10	<10
Rb	mg/kg	134	295	198	7.81	244	236
Sc	mg/kg	10.9	30.5	9.06	<1	10.7	9.57
Sn	mg/kg	4.23	4.18	3.36	1.44	5.72	6.42
Sr	mg/kg	54.5	470	194	<2	1,290	1,440
Ta	mg/kg	1.92	0.636	1.01	<0.06	2.87	3.28
Th	mg/kg	17.4	3.29	9.53	0.246	103	62
U	mg/kg	7.92	19.6	4.92	0.109	45.9	39.9
V	mg/kg	2.49	101	28.7	<2	55.7	63.3
W	mg/kg	1.54	3.13	1.5	0.55	1.39	1.41
Y	mg/kg	44.9	53.2	23	<0.6	55	53.3
Zn	mg/kg	66.5	119	139	<10	27.6	30.2
Zr	mg/kg	303	119	150	2.74	169	274
La	mg/kg TS	51.1	97.6	56.6	4.62	137	130
Ce	mg/kg TS	111	190	113	19.2	182	150
Pr	mg/kg TS	10.9	19.1	11.1	<1	25.4	22.5
Nd	mg/kg TS	40.3	74.3	37.6	<0.8	97	88.2
Sm	mg/kg TS	8.09	14.4	6.51	<0.4	18.2	16.7
Eu	mg/kg TS	1.1	1.98	1.04	<0.05	1.46	1.45
Gd	mg/kg TS	7.17	11.8	4.73	<0.4	14.9	14.4
Tb	mg/kg TS	1.16	1.66	0.724	<0.1	1.87	1.78
Dy	mg/kg TS	7.66	9.55	4.43	<0.1	10.5	9.93
Ho	mg/kg TS	1.65	1.83	0.89	<0.07	1.91	1.8
Er	mg/kg TS	5.06	5.18	2.67	<0.1	5.29	5.07
Tm	mg/kg TS	0.793	0.749	0.436	<0.1	0.753	0.773
Yb	mg/kg TS	5.76	4.98	3.2	<0.2	5.27	5.64
Lu	mg/kg TS	0.884	0.802	0.503	0.0432	0.817	0.911

Ab=albite. Amp=amphibole Ana=analcime. Apo=apophyllite. Asph=asphaltite. Ca=calcite. Chl=chlorite. Corr=corrensite. Epi=epidote. Hm=hematite. Ill=illite. Kao=kaolinite. K-fsp=K-feldspar. Lau=laumontite.MLC=Mixed layer clay. Mus=muscovite. Pl=plagioclase. Pre=prehnite. Py=pyrite. Qz=quartz. SC=swelling clay. Sme=smectite

Appendix 6

$^{40}Ar/^{39}Ar$ data

Sample ID/Run ID#[a]	Power (W)	Ca/K	$^{36}Ar/^{39}Ar$	$\%^{36}Ar(Ca)$	$^{40}Ar^{*}/^{39}Ar$	^{39}Ar (Mol-14)	$\%^{39}Ar$	Cum. $\%^{39}Ar$	$\%^{40}Ar^{*}$	Age (Ma)	± 2σ
KFM08A 183.77–183.88, Run ID# 1707-01 (J = 0.01129 ± 0.00001):											
1707-01A	2.2	0.50699	0.335049	0	41.06197	0.2601	1.3	1.3	29.3	687.15872	5.18725
1707-01B	2.4	0.28456	0.023639	0.2	56.49668	0.3729	1.8	3.1	89	890.10089	1.5424
1707-01C	2.6	0.373	0.023982	0.2	65.61952	0.4723	2.3	5.4	90.3	1000.12673	3.94764
1707-01D	2.8	1.77595	0.026849	0.9	68.44398	0.3857	1.9	7.2	89.7	1032.8742	1.5038
1707-01E	3	5.75255	0.023074	3.4	68.83451	0.3058	1.5	8.7	91.2	1037.35564	1.46499
1707-01F	3.2	11.97317	0.016358	9.9	70.05221	0.2248	1.1	9.8	94.1	1051.25819	1.34412
1707-01G	3.4	24.05531	0.016731	19.4	70.75421	0.2305	1.1	10.9	94.6	1059.22443	3.21112
1707-01H	3.6	29.43979	0.014409	27.5	70.83292	0.2296	1.1	12	95.8	1060.11546	1.79969
1707-01I	3.8	33.77802	0.012869	35.4	69.89618	0.2852	1.4	13.4	96.6	1049.48276	2.02366
1707-01J	4	28.35438	0.009699	39.4	69.92821	0.3316	1.6	15	97.6	1049.8473	1.22368
1707-01K	4.2	23.1624	0.005843	53.4	70.33323	0.4142	2	17	98.9	1054.45137	1.60015
1707-01L	4.4	3.68169	0.001549	32	71.74449	1.6132	7.8	24.9	99.6	1070.40279	1.10424
1707-01M	4.6	0.46946	0.001437	4.4	72.56601	2.6541	12.9	37.8	99.4	1079.62379	2.73908
1707-01N	4.8	0.79111	0.002667	4	72.44114	1.8982	9.2	47	99	1078.22524	1.44311
1707-01O	•4.9	0.60377	0.00347	2.3	74.04012	0.8576	4.2	51.1	98.7	1096.05241	1.98471
1707-01P	•5.0	0.49986	0.003852	1.7	73.64401	0.6093	3	54.1	98.5	1091.6526	1.23225
1707-01Q	•5.1	0.63493	0.004367	2	73.76992	0.5621	2.7	56.8	98.3	1093.05228	1.08046
1707-01R	•5.2	0.48509	0.004498	1.5	74.44828	0.3819	1.9	58.7	98.3	1100.57499	2.35536
1707-01S	•5.3	0.72158	0.004755	2	74.40813	0.3898	1.9	60.6	98.2	1100.13061	1.36794
1707-01T	•5.4	0.63018	0.004756	1.8	73.58564	0.2804	1.4	61.9	98.2	1091.00326	1.92358
1707-01U	•5.5	0.44975	0.004663	1.3	73.54986	0.2332	1.1	63	98.2	1090.60523	2.76505
1707-01V	•5.6	0.47816	0.004846	1.3	73.69705	0.2255	1.1	64.1	98.1	1092.24233	1.76821
1707-01W	•5.8	1.03258	0.005905	2.4	73.8989	0.4475	2.2	66.3	97.7	1094.48509	1.43543
1707-01X	•6.0	1.11482	0.005573	2.7	73.59664	0.4755	2.3	68.6	97.9	1091.12567	1.33746
1707-01Y	•10.0	1.02671	0.005379	2.6	72.69765	0.287	1.4	70	97.9	1081.09696	1.69477
1707-01Z	•14.0	1.38625	0.006121	3.1	73.38052	6.1802	30	100	97.7	1088.71978	4.35753
Integ. Age=										1072	3
(•) Plateau Age =							53			**1093**	**3**

Sample ID/Run ID#[a]	Power (W)	Ca/K	$^{36}Ar/^{39}Ar$	%$^{36}Ar(Ca)$	$^{40}Ar^{*}/^{39}Ar$	^{39}Ar (Mol-14)	%^{39}Ar	Cum. %^{39}Ar	%$^{40}Ar^{*}$	Age (Ma)	± 2σ
KFM04A 347.32-347.50, Run ID# 1708-01 (J = 0.01129 ± 0.00001):											
1708-01A	2.2	0.49749	0.109982	0.1	817.86403	0.0269	0.1	0.1	96.2	4195.71481	10.09092
1708-01B	2.4	0.33495	0.013366	0.3	117.39616	0.0311	0.2	0.3	96.8	1522.44847	6.92544
1708-01C	2.6	0.25171	0.006006	0.6	68.30018	0.0567	0.3	0.6	97.5	1031.22117	4.07945
1708-01D	2.8	0.3444	0.002382	1.9	57.64966	0.093	0.5	1.1	98.8	904.38248	2.82091
1708-01E	3	0.62732	0.001511	5.6	53.39039	0.1381	0.7	1.8	99.2	851.05188	1.89927
1708-01F	3.2	0.79517	0.000771	13.9	54.1146	0.1664	0.9	2.7	99.6	860.23177	1.48181
1708-01G	3.4	0.90198	0.001029	11.8	60.57259	0.2896	1.5	4.2	99.6	940.08931	1.94414
1708-01H	3.6	0.78527	0.000527	20.1	60.73029	0.2642	1.4	5.6	99.8	941.99579	1.65254
1708-01I	3.8	0.51903	0.00043	16.2	65.59771	0.3301	1.7	7.3	99.8	999.8716	1.5572
1708-01J	4	0.27019	0.000251	14.5	71.90469	0.2909	1.5	8.8	99.9	1072.20463	2.16773
1708-01K	4.1	0.14484	0.000265	7.4	75.45239	0.2383	1.2	10.1	99.9	1111.65281	2.30539
1708-01L	4.2	0.16587	0.00033	6.8	78.0201	0.2092	1.1	11.2	99.9	1139.67555	2.56782
1708-01M	4.3	0.14538	0.000252	7.8	83.08591	0.1998	1	12.2	99.9	1193.7166	1.69139
1708-01N	4.4	0.09487	0.000159	8	83.00462	0.1733	0.9	13.1	99.9	1192.86204	1.53333
1708-01O	4.5	0.0447	0.000187	3.2	84.75857	0.1555	0.8	13.9	99.9	1211.21046	2.33796
1708-01P	4.6	0.05285	0.000728	1	84.51968	0.1536	0.8	14.7	99.7	1208.72237	2.18113
1708-01Q	4.7	0.04496	0.000776	0.8	87.41271	0.1553	0.8	15.5	99.7	1238.62597	2.22766
1708-01R	4.8	0.03634	0.000516	0.9	88.31168	0.1629	0.9	16.4	99.8	1247.81805	2.46458
1708-01S	4.9	0.03307	0.000427	1	88.47414	0.1796	0.9	17.3	99.9	1249.47422	2.25519
1708-01T	5	0.0241	0.000414	0.8	88.96634	0.1843	1	18.3	99.9	1254.48262	2.65398
1708-01U	5.1	0.02739	0.000357	1	90.03625	0.1955	1	19.3	99.9	1265.32189	2.59571
1708-01V	5.2	0.02248	0.000263	1.1	90.10038	0.2039	1.1	20.4	99.9	1265.96949	1.70732
1708-01W	5.3	0.0046	0.000088	0.7	91.10182	0.2041	1.1	21.5	100	1276.05284	3.03107
1708-01X	5.4	0.01541	0.000382	0.5	92.11297	0.2228	1.2	22.6	99.9	1286.17705	2.48231
1708-01Y	5.5	0.01934	0.000595	0.4	91.6495	0.2304	1.2	23.8	99.8	1281.5436	2.56176
1708-01Z	5.6	0.01957	0.000739	0.4	90.39113	0.2598	1.4	25.2	99.8	1268.90281	1.65117
1708-01AA	5.8	0.021	0.000559	0.5	92.22825	0.327	1.7	26.9	99.8	1287.32778	1.77809
1708-01AB	6	0.0143	0.00044	0.4	90.66795	0.4689	2.5	29.3	99.9	1271.69124	1.38217
1708-01AC	6.3	0.0129	0.00044	0.4	91.66917	0.6455	3.4	32.7	99.9	1281.74045	1.53823
1708-01AD	6.6	0.00994	0.000488	0.3	91.16481	1.4015	7.3	40.1	99.8	1276.68518	1.98729
1708-01AE	6.9	0.00527	0.000451	0.2	95.68788	1.7629	9.2	49.3	99.9	1321.52246	1.64547
1708-01AF	•7.3	0.00609	0.00046	0.2	98.64395	2.5105	13.1	62.4	99.9	1350.23512	2.49752
1708-01AG	•7.7	0.00555	0.00045	0.2	98.56383	2.9538	15.4	77.8	99.9	1349.4629	2.32036
1708-01AH	•8.5	0.00549	0.000442	0.2	99.32403	4.2356	22.2	100	99.9	1356.77662	1.44674
Integ. Age=										1299	2
(•) Plateau Age =							50.7			1354	6

Sample ID/Run ID#[a]	Power (W)	Ca/K	^{36}Ar/^{39}Ar	%^{36}Ar(Ca)	^{40}Ar*/^{39}Ar	^{39}Ar (Mol-14)	%^{39}Ar	Cum. %^{39}Ar	%^{40}Ar*	Age (Ma)	± 2σ
KFM09A 230.34-230.46, Run ID# 1710-01 (J = 0.01129 ± 0.000018):											
1710-01A	2.2	0.55928	0.028508	0.3	129.826	0.161	1.8	1.8	93.9	1628.16189	2.91068
1710-01B	2.4	0.25647	0.008169	0.4	81.78473	0.4071	4.5	6.3	97.1	1179.98957	1.95537
1710-01C	2.6	0.1371	0.00078	2.4	83.32838	0.4087	4.5	10.8	99.7	1196.26312	1.74235
1710-01D	2.8	0.13933	0.0006	3.1	93.76779	0.3289	3.6	14.4	99.8	1302.6245	3.40525
1710-01E	3	0.14611	0.000623	3.2	97.74529	0.3103	3.4	17.8	99.8	1341.55459	2.71088
1710-01F	3.2	0.12036	0.000522	3.1	98.85696	0.2598	2.9	20.7	99.8	1352.28661	1.68441
1710-01G	3.4	0.0894	0.000646	1.9	97.14789	0.2611	2.9	23.6	99.8	1335.76081	1.81783
1710-01H	3.6	0.11346	0.00078	2	96.96558	0.3823	4.2	27.8	99.8	1333.98901	2.61244
1710-01I	3.8	0.08369	0.000905	1.2	93.69834	0.3832	4.2	32	99.7	1301.93727	2.41257
1710-01J	4	0.04064	0.00115	0.5	94.77515	0.613	6.8	38.8	99.6	1312.56384	1.78824
1710-01K	4.2	0.02868	0.001022	0.4	100.26973	1.5036	16.6	55.3	99.7	1365.8339	3.32275
1710-01L	4.4	0.01166	0.00068	0.2	100.95586	1.2917	14.2	69.6	99.8	1372.37678	2.55166
1710-01M	4.6	0.02146	0.000838	0.3	103.18219	0.6333	7	76.5	99.8	1393.44511	3.37853
1710-01N	4.8	0.02712	0.001255	0.3	103.69501	0.3347	3.7	80.2	99.6	1398.26334	2.89429
1710-01O	5	0.02034	0.000992	0.3	104.85923	0.3756	4.1	84.4	99.7	1409.15438	3.97106
1710-01P	5.2	0.02709	0.001153	0.3	106.23572	0.1584	1.7	86.1	99.7	1421.94691	3.40538
1710-01Q	5.4	0.01777	0.000811	0.3	107.33952	0.1923	2.1	88.2	99.8	1432.14001	3.76779
1710-01R	5.6	0.02595	0.000643	0.5	107.17961	0.2888	3.2	91.4	99.8	1430.66694	3.06539
1710-01S	5.8	0.03726	0.001188	0.4	110.21059	0.0868	1	92.4	99.7	1458.38656	3.83134
1710-01T	6	0.0342	0.000681	0.7	107.22995	0.1224	1.3	93.7	99.8	1431.13081	3.78931
1710-01U	6.2	0.04899	0.000718	0.9	108.67716	0.0646	0.7	94.4	99.8	1444.41595	4.49696
1710-01V	6.4	0.00012	0.000423	0	108.99838	0.1332	1.5	95.9	99.9	1447.3514	3.13088
1710-01W	6.6	0.01667	0.000416	0.5	106.25594	0.055	0.6	96.5	99.9	1422.13412	3.39617
1710-01X	6.8	0.14919	0.000996	2	105.41828	0.0649	0.7	97.2	99.7	1414.36088	3.08309
1710-01Y	7	0.00101	0.000113	0.1	103.69329	0.1246	1.4	98.6	100	1398.2472	2.21736
1710-01Z	7.2	0.313	0.005274	0.8	100.1202	0.0042	0	98.7	98.5	1364.40485	24.25803
1710-01AA	7.4	0.00023	0.003092	0	105.04113	0.0069	0.1	98.7	99.1	1410.85008	14.28831
1710-01AB	15	0.00201	0.001602	0	106.65447	0.1154	1.3	100	99.6	1425.82066	3.4684
Integ. Age=										1360	4

Sample ID/Run ID#[a]	Power (W)	Ca/K	$^{36}Ar/^{39}Ar$	$\%^{36}Ar(Ca)$	$^{40}Ar^{*}/^{39}Ar$	^{39}Ar (Mol-14)	$\%^{39}Ar$	Cum. $\%^{39}Ar$	$\%^{40}Ar^{*}$	Age (Ma)	± 2σ
KFM09A 732.90-733.10, Run ID# 1711-01 (J = 0.01129 ± 0.000018):											
1711-01A	2.2	0.41197	0.103107	0.1	61.90984	0.5572	2.8	2.8	67	956.19254	2.93226
1711-01B	2.4	1.59742	0.027861	0.8	72.37482	0.9183	4.6	7.4	89.9	1077.48198	2.47205
1711-01C	2.6	9.51101	0.015411	8.3	76.91551	0.4717	2.4	9.7	94.8	1127.67394	3.03999
1711-01D	2.8	22.73926	0.009912	30.9	76.82155	0.3913	2	11.7	97.4	1126.6493	3.06623
1711-01E	•3.0	11.25911	0.003079	49.2	73.72607	0.8313	4.1	15.8	99.4	1092.56498	3.34337
1711-01F	•3.2	0.37812	0.000755	6.7	75.88642	2.5226	12.6	28.4	99.7	1116.42031	1.80121
1711-01G	•3.4	0.27567	0.001326	2.8	74.19474	1.7714	8.8	37.2	99.5	1097.76704	3.1248
1711-01H	•3.6	0.78454	0.003751	2.8	73.09727	6.0804	30.3	67.6	98.5	1085.56185	3.15014
1711-01I	•0.0	0.44094	0.005335	1.1	74.93958	3.6187	18.1	85.6	98	1106.00379	2.66803
1711-01J	•3.8	0.40123	0.006166	0.9	74.71471	1.4818	7.4	93	97.6	1103.52102	3.45655
1711-01K	•3.9	0.61828	0.006806	1.2	75.31792	0.295	1.5	94.5	97.4	1110.17327	2.15392
1711-01L	•7.0	0.84192	0.006586	1.7	75.21637	1.1067	5.5	100	97.5	1109.05503	1.26128
Integ. Age=										1096	4
(•) Plateau Age =							88.3			**1107**	**7**

Borehole	Secup	Seclow	Fraction	Ca	Chl	Corr	Epi	Hm	Ill	K-fsp	Kao	Lau	MLC	Mus	Plag	Qz	Clay	X
KFM01C	12.430	12.51	Whole sample	**	*				*	*					*	**		
			Fine fraction	*	**				**	*			*		*	*		Ti(*)
KFM01C	17.22	17.40	Whole sample	*	*					**					**	**		Bi(*)
			Fine fraction	**	**				**	*					*	**		
KFM01C	34.47	34.67	Whole sample						*	*					*	**		Bi(*)
			Fine fraction		*				*	*			**		*	*		
KFM01C	39.75	40.02	Whole sample		*				*	**	*					**		Sme(*)
			Fine fraction								*		**					
KFM01C	41.15	41.25	Whole sample						*	*	*				*	**		
			Fine fraction						*		*		**					
KFM01C	43.00	43.20	Whole sample							**	*				**	**		Sme(*)
			Fine fraction						*		*		**					
KFM09B	19.37	19.57	Whole sample	**	*				*	*					*	**		
			Fine fraction	*	*			*	*				**			*		
KFM09B	19.81	20.18	Whole sample	**	*				*	*					*	**		
			Fine fraction	*	**				*				**			*		
KFM09B	168.87	169.06	Whole sample	**	*				*	*					*	*		
			Fine fraction		**				*				*					
KFM09B	310.61	310.83	Whole sample				*					**			**	**		Py(*)
			Fine fraction				*					**	*		**	**		
KFM09B	570.92	571.05	Whole sample				*			**						**		Fl(*),Sme(*)
			Fine fraction			**	*			*								Bi(*),Fl(*)
KFM09B	571.13	572.19	Whole sample			*	*			**					*	**		Fl(*)
			Fine fraction		*	*	**			**								
KFM02B	471.49	471.69	Whole sample	**	*			*		*					**	**	*	
			Fine fraction	*	*	**		*	*				*					SC(**)

**= main minerals, * = minor minerals, Amp = Amphibole, Apo = Apophyllite, Bi = Biotite, Ca = Calcite, Chl = Chlorite, Corr = Corrensite, Fl=Fluorite, Hm = Hematite, Ill = Illite, Kao= Kaolinite, K-fsp = K-feldspar, Lau = Laumontite, MLC = Mixed layer clay, Mus = Muscovite, Plag = Plagioclase, Pre = Prehnite, Sme = Smectite, SC= Swelling clay, Qz = Quartz., Clay= unidentified clay mineral.

Appendix 7

XRD analyses of fracture fillings

Borehole	Secup	Seclow	Fraction	Ca	Chl	Corr	Epi	Hm	Ill	K-fsp	Kao	Lau	MLC	Mus	Plag	Qz	Clay	X
KFM02B	499.84	499.95	Whole sample	**						*					*	**		
			Fine fraction	**	*	**				*					*	*		
KFM02B	500.36	500.47	Whole sample	**					*	**				*		**		
			Fine fraction	*	*	**			*				*			*		
KFM02B	500.72	500.84	Whole sample	**	*				*	*				*	*	*		
			Fine fraction	**		**				**			*		**	*		
KFM11A	178.78	178.81	Whole sample		**		*			*		**			*	**	*	
			Fine fraction		**	**				**		**			**	**		
KFM11A	376.43	376.60	Whole sample	**	*					**					**	**		Pre(**)
			Fine fraction	**	**	**				**					**	**		Pre(*)
KFM11A	426.07	426.21	Whole sample	**	*					*		*			*	*	*	Pre(**)
			Fine fraction	**								**	**					
KFM11A	450.28	450.64	Whole sample	**	**					*		**			*	**		Ana(*)
			Fine fraction	**	**					*		**			*			Ana(*),Sme(*)
KFM11A	540.19	540.27	Whole sample		**				**	*				**	*	**		
			Fine fraction		**				**									
KFM11A	624.45	624.71	Whole sample	*	**			*	**	*				**	*	**		
			Fine fraction		**			*	**	*			*			*		
KFM11A	685.56	685.94	Whole sample		**				*	**		*		*		**		
			Fine fraction		**				**			*						SC(*)
KFM08C	523.47	523.73	Whole sample							*					**	*		
			Fine fraction			**			*	**					**	**		
KFM08C	683.57	683.66	Whole sample			**				*					*	**		Bi(*)
			Fine fraction		*	**												
KFM08C	829.94	830.02	Whole sample	*		*				*					**	*		Amp(*)
			Fine fraction		**	**			*									Amp(*)
KFM08C	904.06	904.13	Whole sample		**	**										**		
			Fine fraction		**	**												
KFM09A	502.00	502.14	Whole sample	**	**	*										**		Apo(*)
			Fine fraction			**												Apo(*)
KFM10A	105.79	106.08	Whole sample	**	**					*					*	**		
			Fine fraction		**	**										*		

**= main minerals, * = minor minerals, Amp = Amphibole, Apo = Apophyllite, Bi = Biotite, Ca = Calcite, Chl = Chlorite, Corr = Corrensite, Fl=Fluorite, Hm = Hematite, Ill = Illite, Kao= Kaolinite, K-fsp = K-feldspar, Lau = Laumontite, MLC = Mixed layer clay, Mus = Muscovite, Plag = Plagioclase, Pre = Prehnite, Sme = Smectite, SC= Swelling clay, Qz = Quartz., Clay= unidentified clay mineral.