P-05-174

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Fracture mineralogy and wall rock alteration

Results from drill cores KAS04, KA1755A and KLX02

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ISSN 1651-4416
SKB P-05-174

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Keywords: Fracture minerals, Äspö, Laxemar, Formation temperatures, Ductile/brittle deformation, Mylonite, Wall rock alteration, Oxidation-reduction, Subsidence-uplift, Metamorphic facies, Burial metamorphism, Low-temperature minerals, Calcite.

Abstract

Two drill cores from Äspö, KAS04 and KA1755A, and one from Laxemar, KLX02, have been sampled for detailed fracture mineralogical studies and investigations of the wall rock alteration as part of SKB's site investigation programme. The area is situated in Precambrian crystalline rocks, at sites mainly granitoids belonging to the Transscandinavian Igneous Belt (TIB).

Overall, 28 samples have been collected from fractures, which mainly include fillings of several generations. The samples have been analysed using mainly polarised light microscope and scanning electron microscope (SEM-EDS). One sample of fracture calcite has been analysed for its stable isotope composition (C, O and Sr) and trace element content. The main aim of this study has been to test and upgrade the fracture filling model and the model of wall rock alteration from KSH01A+B /Drake and Tullborg, 2004/ with results from KAS04, KA1755A and KLX02. One focus has been to gain knowledge of the mylonites from the ductile Äspö Shear Zone, present in KAS04 and KA1755A, to be used in the characterisation of other fracture zones in the area and to upgrade the ductile constituent of the fracture filling model. Additional intentions of this study have been to find fracture minerals of well established generations that are suitable for direct dating. Fillings of special intrest for dating are those that can give chronological information of periods of oxidising conditions. This study will ultimately add to the understanding of the geological evolution of the area.

The fracture minerals identified in this study are chlorite, calcite, epidote, quartz, low temperature K-feldspar (adularia), prehnite, laumontite, albite, fluorite, harmotome, barite, pyrite, titanite, apatite, muscovite, hematite, apophyllite, REE-carbonate, ilmenite and clay minerals. All of these minerals have been identified in drill core KSH01A+B as well, where clay minerals were identified in detail using X-ray diffraction, a method that is not included in this study.

The results from this study reveal that the fracture filling model from KSH01A+B is valid for the drill cores investigated in this study with a few minor exceptions. One exception is that a generation of idiomorphic epidote and chlorite, that post dates the mylonites and preceeds the prehnite formation, are more common in the investigated drill cores than in KSH01A+B. Another exception is that the hematite-cataclasite and the paragenetic adularia and Mg-rich chlorite, which are common in KSH01A+B, are not that numerous in this study, although still abundant. The wall rock alteration and indications of oxidising and reducing conditions are escentially the same as in KSH01A+B. The fracture bound hematite fillings and the hydrothermal alteration of the wall rock, including oxidation, are of the same type as the one described from KSH01A+B, however, less frequent and extensive in the drillcores investigated in this study.

As in KSH01A+B, the textural/structural relationships and the mineralogy of different fracture filling generations reveal that conditions have been changing from early high temperature/ductile conditions to gradually more brittle and low temperature conditions. This is demonstrated by the early formation of mylonites with epidote and subsequent fillings of idiomorphic prehnite and ultimately zeolite mineralistions and clay minerals.

Sammanfattning

Sprickmineralogiska undersökningar och undersökningar av sidobergsomvandling har utförts på två borrkärnor från Äspö, KAS04 och KA1755A, och en från Laxemar, KLX02, inom ramen för SKB's platsundersökningar. Området är lokaliserat i pre-kambrisk kristallin berggrundsterräng tillhörande det Transskandinaviska Magmatiska Bältet (TMB/TIB).

Tjugoåtta prover har insamlats från sprickor som i huvudsak innehåller sprickmineraliseringar av flera generationer. Proverna har i huvudsak analyserats med polarisationsmikroskop och svepelektronmikroskop (SEM-EDS). Stabila isotopförhållanden (C, O och Sr) och spårämnessammansättning har analyserats hos ett sprickkalcitprov. Huvudsyftet med studien är att testa och uppgradera modellen för sprickmineraliseringar och sidobergsomvandling från KSH01A+B /Drake and Tullborg, 2004/ med result från KAS04, KA1755A och KLX02. Ett syfte med studien har varit att genom detaljerad undersökning av Äspöskjuvzonen, i KAS04 och KA1755A, öka förståelsen för den duktila historien i området. Studierna av Äspöskjuvzonen kommer också att vara till nytta vid karaktärisering av andra sprickzoner i området. Ett annat syfte har varit att hitta dateringsbara prover av sprickmineral från väldefinierade generationer. Speciellt fokus läggs på att hitta dateringsbara prover som kan ge kronologisk information om perioder under vilket reducerande respektive oxiderande förhållanden rått. Studien avser slutligen att öka förståelsen av områdets geologiska historia.

De sprickmineral som identifierats i denna undersökning är klorit, kalcit, epidot, kvarts, lågtemperatur-kalifältspat (adularia), prehnit, laumontit, albit, fluorit, harmotom, baryt, pyrit, titanit, apatit, muskovit, hematit, apophyllit, REE-karbonat, ilmenit and lermineral. Dessa mineral identifierades även i undersökningen av KSH01A+B där lermineral identifierades med röntgen diffraktion (XRD), vilket inte är fallet i denna undersökning där endast SEM-EDS analyser har använts för identifiering.

Resultaten visar att sprickmineraliseringsmodellen från KSH01A+B med viss modifikation är representativ även för borrkärnorna i denna studie. Ett undantag från modellen är att en fyllning bestående av idiomorf epidot och klorit, bildad efter myloniterna och före prehniten, är mycket mer vanligt förekommande här än i KSH01A+B. En annan avvikelse är att hematit-kataklasit och paragenetisk adularia och Mg-klorit, vilka är mycket vanliga i KSH01A+B, inte är lika vanligt förekommande i de undersökta borrkärnorna.

Sidobergsomvandlingen och indikatorerna på oxiderande och reducerande förhållanden följer ungefär samma mönster som i KSH01A+B. Hematit-mineraliseringar kopplade till sprickläkningar är inte lika vanliga i denna studie som i KSH01A+B. Den hydrotermala omvanlingen och oxideringen av sidoberget är av samma typ som i KSH01A+B men mindre omfattande i de nu undersökta borrkärnorna.

Precis som i KSH01A+B visar texturella/strukturella förhållanden och mineralogin i olika sprickfyllningsgenerationer att förhållandena har skiftat från högtemperatur-/duktila förhållanden till gradvis mer låga temperaturer med spröd deformation. Detta demonstreras av tidig epidot-mylonitbildning med efterföljande fyllningar av idiomorph prehnit och slutligen kristalliseringen av zeoliter och lermineral.

Contents

1 Introduction

The Swedish Nuclear Fuel and Waste Management Company (SKB) is currently doing a site investigation in the Simpevarp/Laxemar area in the Oskarshamns region. Three drill cores from previous investigations, KLX02 from the Laxemar area and KAS04 and KA1755A from Äspö HRL have been samples for detailed studies of fracture mineralogy, wall rock alteration and geochemistry. The results from this study have been compared to the detailed fracture filling study of the drill-core KSH01A+B from the Simpevarp pensinsula /Drake and Tullborg, 2004/. Both of the drill cores KAS04 and KA1755A are penetrating the Äspö Shear Zone.

A total number of 28 samples from which 28 thin-sections and 2 fracture surface samples have been analysed using polarised light microscope and scanning electron microscope (SEM-EDS). Additional fracture mineral identification has been made using stereomicroscope.

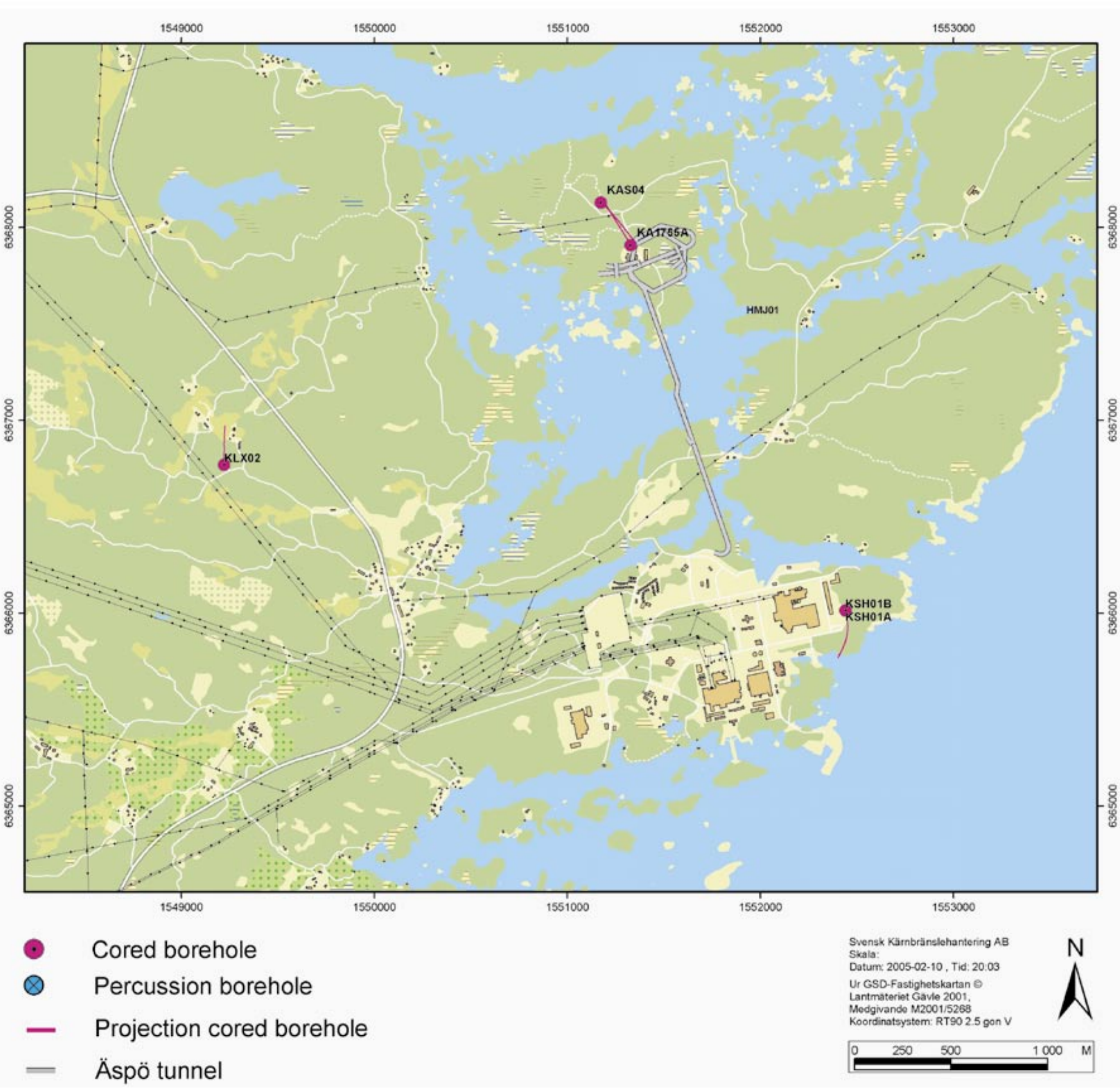

Figure 1-1. *Map showing the location and direction of the boreholes.*

The work was carried out in accordance with activity plan SKB PS 400-03-045. In Table 1-1 controlling documents for performing this activity are listed. Both activity plan and method descriptions are SKB's internal controlling documents.

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

Activity plan	Number	Version
Sprickmineralogiska undersökningar	AP PS 400-03-045	1.0
Method descriptions	**Number**	**Version**
Sprickmineralogy	SKB MD 144.000	1.0

2 Aim of the study

This study will upgrade and test the fracture filling model from KSH01A+B (Appendix A5) to be more valid for the whole Simpevarp/Laxemar area. The study of the Äspö Shear Zone will add to the knowledge and characterisation of the deformation history of different fracture zones in the region. It will be compared to a study of a fracture zone in drill-core KSH03A+B, a study that is currently being carried out by Drake and Tullborg. Another purpose is to find samples that are suitable for absolute dating. Fillings of special interest for dating are those that can give chronological information about periods of oxidising conditions.

This study is done as a part of a Fil.Lic. project at the Department of Geology, Earth Sciences Centre, Göteborg University.

3 Methods

Samples with fracture fillings suitable for microscopy and dating were selected from the drill-cores KLX02, KAS04 and KA17755A. Fractures that were assumed to have been filled with minerals of different generations and/or to provide chronological information of periods of oxidising conditions were selected. Twentyeight samples were chosen from representative fractures scattered over the drill core (see Table 3-1). The collecting of the samples was not supposed to give a statistic representation of the drill-core. 28 thin-sections with a thickness of 30 μm each were then prepared and analysed with optical microscope and scanning electron microscope (SEM) equipped with an energy dispersive spectrometer (EDS). Two "fracture surface samples" of freely growing minerals, one from an open fracture and one from a cavity were examined in detail with stereomicroscope and SEM-EDS. Clay mineral compositions have been determined in the samples where possible.

The thin-sections have been used to identify characteristic mineral parageneses from different fracture filling generations in the same manner as in the study of KSH01A+B /Drake and Tullborg, 2004/. The division into different generations has been based on textural and mineralogical observations. The results have than been compared to the results and conclusions from the study of KSH01A+B and an updated fracture filling model have been constructed. Textural observations also include the suggestion about the deformation type (ductile/brittle) inducing the fractures. Mineralogical observations include crystal morphology and chemical signatures. The comparison of chemical signatures, enabled by SEM-EDS-analyses in particular, makes the identification of different characteristic mineral compositions possible.

Indications of oxidising or reducing conditions have been recorded from the presence of hematite and pyrite, respectively. General information of the identified fracture minerals can be found in the "Facies and mineral characteristics" Chapter in /Drake and Tullborg, 2004/.

Wall rock alteration has only been studied briefly in this study. No attempt to link fracture filling generations to preferred fracture orientation has been made in this study.

The SEM-EDS analyses were carried out on an Oxford Instruments Link EDS mounted to a Zeiss DSM 940 SEM at the Earth Sciences Centre, Göteborg University. Polished thin-sections were coated with carbon and fracture surface samples were coated with gold for electron conductivity. The acceleration voltage was 25 kV, the working distance 24 mm (18 mm for fracture surface samples) and the specimen current was about 0.7 nA. The instrument was calibrated at least once an hour using a cobalt standard linked to simple oxide and mineral standards to confirm that the drift was acceptable. ZAF calculations were maintained by an on-line LINK ISIS computer system. The quantitative microprobe analyses supply mineral compositions but Fe (II) and Fe (III) are not distinguished and the H_2O content is not calculated. Detection limits for major elements are higher than 0.1 oxide %, except for Na_2O with a detection limit of 0.3%.

Table 3-1. Table of the samples in this study.

KAS04	Thin section*	Surface Sample**
17.70–17.85 m	x	
65.18–65.25 m	x	
70.60–70.80 m	x	
176.45–176.70 m	x	
177.90–178.34 m	x	
180.68–180.85 m	x	
181.75–182.07 m	x	
182.52–182.66 m	x	
185.15–185.20 m	x	
187.70–187.85 m	x	
194.80–195.03 m	x	
KA1755A	**Thin section***	**Surface Sample****
200.84–200.99 m	x	
203.95–204.38 m	x	
204.90–205.10 m	x	
206.50–206.55 m	x	
208.45–208.50 m	x	x
208.65–209.00 m	x	
211.70–211.75 m	x	
KLX02	**Thin section***	**Surface Sample****
218.40–219.10 m	x	
260.08–260.25 m	x	
268.20–268.35 m	x	
513.78–514.12 m	x	
525.06–525.66 m	x	
676.82–677.00 m		x
704.00–704.30 m	x	
898.90–899.10 m	xx	
948.39–948.56 m	x	
954.68–954.93 m	x	

* Thin section have been prepared mainly perpendicular to the fracture surfaces.

** Sample of the fracture surface.

4 Geological setting

The bedrock in the Simpevarp/Laxemar/Äspö area north of Oskarshamn is predominated by Småland granitoids belonging to the Transscandinavian Igneous Belt (TIB) /Gaál and Gorbatschev, 1987/. This belt is found between the older Svecofennian (c 1.9 Ga) crust in the east and the younger, Gothian rocks in the west /Larson and Berglund, 1992; Åhäll and Larson, 2000/. The TIB granitoids were emplaced and extruded during several pulses of magmatism between 1.85 and 1.66 Ga with the younger of these rocks in the west /Larson and Berglund, 1992; Åhäll and Larsson, 2000/. TIB is divided into three major magmatic events; TIB 1 (1.81–1.77 Ga), TIB 2 (1.72–1.69 Ga) and TIB 3 (1.69–1.66 Ga) /Larson and Berglund, 1992; Åhäll and Larsson, 2000/. The Småland granitoids in the Simpevarp/Laxemar/Äspö area belong to the TIB 1 and have been dated to 1,804+/–4 Ma (zircon) with U-Pb-dating /Kornfält et al. 1997/ and 1,802+/–4 Ma (zircon), 1,793+/–4 (titanite) and 1,800+/–4 Ma (titanite+zircon) /Wahlgren et al. 2004/. Another magmatic episode in the region was the intrusion of anorogenic granites, at e.g. Götemar /Kresten and Chyssler, 1976; Åberg et al. 1984/ and Uthammar. These coarse-grained granites were emplaced at 1,452 +11/–9 Ma (Götemar) and 1,441 +5/–3 Ma (Uthammar) /Åhäll 2001/.

4.1 Rock types

The dominating rocks in the area are TIB granitoids ranging in mineralogical compositions from true granites (Ävrö granite) to granodioritic to dioritic composition (Quartz monzodiorite) /Kornfält and Wikman, 1988/ and "fine-grained dioritoid" (Hermansson and Wahlgren, in press). Other rocks in the area are fine-grained Småland granites, anorogenic granites (e.g. Götemar), metavolcanics, greenstones and dikes of pegmatite, aplite and dolerite /Kornfält and Wikman, 1987/.

The granitoids were probably formed by a continuous magma-mixing process as indicated by the presence of basic enclaves /Wikström, 1989/. All the rock units, except the anorogenic granites, show a general foliation in approximately ENE-WSW.

Note that the present nomenclature and classification of the rock types in the region was established later than the mapping of the drill cores. This is the reason why old nomenclature is used to describe the rock samples in this study. The rock type classification from the different drill cores are taken from the reports and may not fit the updated nomenclature for the area. The Äspö diorite is a quartzmonzodiorite with porphyritic texture, which means that it is a sub-unite to the established Ävrö granite group described as granites to quartsmonzodiorites with porphyritic texture (Wahlgren and Hermansson, in press). The term Smålands granites used in the older core mapping from Äspö is however, a wider term used for granitic to granodioritic, medium grained or weakly porphyritic rocks. What is important is that all of these granites to quartz monzodiorites, porphyritic or non porphyritic, are of the same age and have the same metamorphic history. They are the result of complex magma mixing and mingling processes and both distinct and diffuse contacts between the varieties occur. There are no indications that the fracture mineralogy is different between the Äspö and Ävrö.

5 The drill-cores

5.1 KAS04

The KAS04 drill core was drilled in 1987 as a part of the planning for the Äspö Hard Rock Laboratory (ÄHRL). The aim of the drilling was to examine a mylonite zone, the Äspö Shear Zone that was detected on the surface at Äspö. KAS04 is the shortest (474.40 m) of the four drill cores from the early ÄHRL investigations. It is graded, with a plunge of 60° ESE.

Three main rock-groups plus one section of mylonite were distinguished in the mapping of the core, see below /Wikman and Kornfält, 1988/. The drill core in KAS04 generally shows signs of strong deformation.

Group 1: Greyish black to dark-grey, fine-grained greenstone, appears:

- 0–30 m.
- 120–150 m.

Group 3: Reddish grey, fine medium-grained to medium-grained mainly granitoids (granodiorite and tonalite). Occasionally with megacrysts of microcline. Subgroup 3a: Reddish grey, fine medium-grained to medium-grained granodiorite to quartz monzodiorite, appears:

- 65–120 m.
- 150–175 m.
- 230–330 m.
- 455–474 m.

Group 5: Fine-grained granites, occasionally foliated, appear:

- 30–65 m; signs of strong fracturing, almost altered to mylonite.
- 330–455 m.

Mylonite affecting mostly Group 3a, appear:

- 175–230 m.

According to /Riad and Munier, 1988/ the mylonite zone is built up of two fine-grained, epidot-rich mylonities at 176–182 m and 214–217 m, respectively with minor mylonite zones in between.

Earlier fracture mineral studies have been carried out by /Tullborg, 1988/.

5.2 KA1755A

This cored borehole was drilled after the excavation of the Äspö tunnel at level c 250–350 m. It is drilled sub horizontally from tunnel section 1,755 m and the total length of the hole is 320.58 m. Borehole diamter is 56 mm, the direction 339.60 and the inclination –19.80.

The main reason for drilling this borehole was to replace the cored borehole KAS04 as a borehole for monitoring pressure and for chemical sampling. Another reason was to get a new borehole through the fracture zone EW-1 (the norhern part of Äspö Shear Zone) in order to better characterize the zone.

EW-1 is a complex zone composed of highly fractured, more or less mineralogically altered, metre wide sections, seperated by Småland granite and up to metre wide mylonites. Initially the zone was characterized by early ductile-semiductile deformation. Local development of mylonites and epidote shear zones controlled the orientation of subsequent brittle deformation.

The distribution (%) of the main rock types in KA1755A is:

- Småland granite 20%
- Äspö diorite 50%
- Fine-grained granite 21%
- Greenstone 8%
- Mylonite < 1%

The dominating rock type in the first one hundred metres of the drill core is Äspö diorite. The fracture frequency in this section is low – very low. The southern branch of EW-1 is indicated between 95 and 140 metres in the drill core where the dominant rock types are fine-grained granite and mylonite (1–2 m wide). The fracture frequency in this section is mostly > 10 fractures/m. An approximately 60 metre wide section with Småland granite and fine-grained granite with low fracture frequency is present from 145 to 195 metres. The northern branch of EW-1 is present in section 195–215 metres, which comprise interchanging, highly fractured and altered Äspö diorite, mylonite and fine-grained granite. The section 215–320 m has a low fracture frequency and is made up of Småland granite, Äspö diorite, greenstone and small inclusions of mylonite and fine-grained granite.

Information about drill core KA1755a is from /Stanfors et al. 1994/.

5.3 KLX02

This 1,700.5 m long, near vertical, ø 76 cm core borehole was drilled during the autumn 1992 at Laxemar. The main objects of the drilling project, conducted by SKB, was to test core drilling teqnique for ø 76 cm to large depths and to enable geoscientific parameters at larger depths than had been possible in earlier core drilled boreholes. The length of the borehole (1,700.5 m) corresponds to a vertical depth of 1,660 m.

The distribution (%) of the main rock types in KLX02 is:

- Småland granite 63%
- Äspö diorite 25%
- Greenstone 10%
- Fine-grained granite 2%

The Småland granite dominates the following parts of the borehole:

- 65–540 m.
- 960–1,375 m.
- 1,405–1,450 m.

The following sections consist of Äspö diorite:

- 10–68 m.
- 920–928 m.
- 1,373–1,380 m.
- 1,450–1,532 m.
- 1,533–1,590 m.
- 1,609–1,613 m.
- 1,616–1,700.5 m.

Greenstone occurs in the core as a large number of 5–10 m wide dikes. A few dikes are wider than 10 m, e.g. at 1,380–1,405 m. Greenstone dikes are abundant in the section 540–960 m.

The most imorptant sections where dykes of fine-grained granite appear include:

- 0–10 m.
- 19–22 m.
- 169–175 m.
- 1,204–1,210 m.
- 1,590–1,600 m.

The core may be divided into four intervals regarding fracture frequency:

- 200–730 m – normal fracture frequency.
- 730–1,120 m – increased fracture frequency.
- 1,130–1,550 m – low fracture frequency.
- 1,550–1,700.5 m – highly fractured and altered interval.

Note that 0–200 m was percussion drilled and no core was produced of this part.
The information of KLX02 listed above is from a report compiled by /Ekman, 2001/.

6 Fracture minerals

The most common fracture minerals identified are chlorite and calcites which occur in several different varieties and are present in most of the open fractures. Other common minerals are epidote, prehnite, laumontite, quartz, adularia (low-temperature K-feldspar), fluorite, hematite, pyrite and clay minerals. Harmotome (Ba-zeolite), barite and apophyllite have been identified in some fractures.

7 Results/discussion

Although the results from different thin-sections may vary, a pattern of different characteristic parageneses has been recognized. The generations listed below consist of mineral parageneses that are considered to be the most characteristic for all the three drill-cores in this study and KSH01A+B. These conclusions are based on the number of observations and the abundance of the different minerals in each sample.

Thin section descriptions, surface sample descriptions along with pictures and SEM-EDS analyses can be found in the Appendix along with the fracture mineral model for KSH01A+B.

7.1 Quartz

This filling type was identified in the study of KSH01A+B as a coarse-grained quartz filling, associated with post-magmatic circulation. These early formed fillings are however very difficult to identify since the fractures often have been reactivated in several preceeding events. The re-crystallised quartz crystals in the mylonites may thus originate from earlier formed quartz fillings. Fragments of quartz crystals are found in mylonites and cataclasites. These quartz crystals may be remnants of earlier formed quartz fillings or derived from the wall rock. Early formed quartz fillings in this study have been observed in samples "KAS04: 70.6–70.80 m" and "KAS04: 182.52–182.66 m". In the latter sample the filling of quartz crystals cut the foliation and or mylonites. Overall it is hard to provide characteristic, detailed and confident information of this filling and it is therefore removed from the updated fracture filling model.

- KSH01A+B model:
  - Quartz, coarse-grained.
- Updated model:
  - Removed from model – too few observations.

7.2 Re-crystallised quartz and mylonites

In the study of KSH01A+B, where mylonites were not as numerous as in this study, a separation of two different mylonites, one epidote-rich and one quartz-rich, was made. Parts of the mylonites are more quartz-rich and other parts are more epidote-rich. Generally, however, quartz and epidote exist in paragenesis in most of the mylonites examined in this study. This is why the updated fracture filling model will make no distinction between different mylonite varieties. Other minerals that have been observed in the mylonites that were not included in the KSH01A+B model is titanite, albite and to a smaller extent apatite and K-feldspar. The K-feldspar and albite may be derived from the wall rock. The titanites may be derived from the wall rock or come from the alteration of biotite into chlorite and titanite. The mylonites of the Äspö Shear Zone show much more ductile signatures than those observed in KSH01A+B, which are more cataclasitic and epidote-rich. These mylonites/cataclasites from KSH01A+B also include more angular fragments of the wall rock or earlier formed fracture fillings.

- KSH01A+B model:
  - Re-crystallised quartz – idiomorhic pyrite, calcite.
  - Quartz-mylonite, muscovite, chlorite.
  - Epidote-mylonite, (Fe/Mg-chlorite), (calcite).
- Updated model:
  - Quartz/Epidote-mylonite, muscovite, titanite, Fe/Mg-chlorite, albite, (apatite) (calcite) (K-feldspar).

7.3 Idiomorphic epidote, chlorite, quartz, calcite, pyrite and fluorite

Coarse-grained quartz fillings that are partly re-crystallised have been found in this study in samples "KAS04: 70.6–70.80 m" and "KAS04: 182.52–182.66 m". No pyrite or calcite have however been found in paragenesis with this filling. No obvious relation between these fillings and the mylonites have been found in this study, but the quartz-filled fractures are cutting through the wall rock discordantly to the foliation/mylonites indicating that these fillings have been formed after the mylonites. Ongoing studies by the authors of drill cores KLX03 and KLX04, show that the quartz, pyrite and calcite filled fractures are younger than the mylonites and can be linked to fracture filling paragenesis of coarse-grained epidote, chlorite and quartz (see below), this is also supported by re-evaluated observation of KSH01A+B.

Idiomorphic epidote and chlorite crystals have been found in many fractures. These fractures are sometimes cutting through the earlier mylonites and cataclasites in a brittle manner (e.g. "KLX02: 954.68–954.93 m"). In some places the epidote and chlorite are found in fractures cutting through coarse-grained quartz, but the idiomorphic quartz crystals are sometimes associated with this filling and are therefore thought to represent the same fracture-filling generation. The Fe/Mg-chlorite fillings are somewhat spherulitic, dark green, apart from the brighter green Fe/Mg-chlorite in the mylonites and in the altered wall rock (see analyses in Appendix A4). The idiomorphic epidote crystals are often growing from the fracture wall, which implies extensional conditions in the fractures. Microscopy studies show that the epidote crystals have a more intense yellow colour in plane polarised light than in the mylonites. This comes from the higher Fe-content (see analyses in Appendix A4) of the idiomorphic epidote /cf Tullborg, 1988/.

These epidote fillings have been described in earlier studies to be associated with fluorite and are thought to be related to the intrusion of the ~1.4 Ga Götemar granite /e.g. Tullborg, 1988/. Fluorite has been found by the authors in association with epidote in ongoing studies of KLX03 and KLX04, but no relation of this kind is found in this study. This epidote filling is far more abundant in the drill core investigated in this study than in KSH01A+B. This might support the theory that the epidote/ (fluorite) fillings originate from the Götemar granite since the drill cores in this study are drilled closer to the Götemar massif than KSH01A+B is.

- KSH01A+B model:
  – Re-crystallised quartz – idiomorhic pyrite, calcite, as a sub-division of the same generation as the mylonites.
- Updated model:
  – Idiomorphic epidote, chlorite, quartz, calcite, pyrite and fluorite.

7.4 Prehnite

The fillings of idiomorphic prehnite that were found along with some fluorite and Fe/Mg-chlorite in KSH01A+B have also been frequently observed. What might differ from earlier observations is that the connection between Fe/Mg-chlorite and prehnite is not that consistent in this study. The paragenesis of fluorite and prehnite is however verified even more strongly with this study. The prehnite crystals, that make up ~99% of these fillings are idiomorphic and are often growing from the fracture walls and show zonation, which implies slow growing rates and extensional conditions in the fractures. The prehnite filled fractures are found to be cutting through earlier formed idiomorphic epidote and mylonites (e.g. KLX02: 954.68–954.93 m).

- KSH01A+B model:
  – Prehnite (fluorite) (Fe/Mg-chlorite).
- Updated model:
  – Prehnite (fluorite) (Fe/Mg-chlorite).

7.5 Calcite

In some samples in KSH01 the calcite filled fractures cutting through earlier formed fillings like prehnite, were observed in paragenesis with adularia. This paragenesis is further established in this study. The fact that calcite fillings have been formed during several events makes this generation difficult to pin down. In some samples the calcites have been identified in paragenesis with fine-grained idiomorphic fluorite (KA1755A: 211.70–211.75 m). The connection between Fe/Mg-chlorite and calcite was more convincing in the KSH01 study than in this study.

An interesting observation is that the first appearance of fracture bound hematite seems to be in association with this calcite filling. This observation along with adularia-calcite paragenesis implies that the preceeding hematite-cataclasite might be formed shortly after these calcite fillings.

- KSH01A+B model:
  – Calcite (Fe/Mg-chlorite).
- Updated model:
  – Calcite, adularia (fluorite) (Fe/Mg-chlorite) (hematite).

7.6 Hematite-cataclasite

The observations of the hematite-cataclasite in this study differs only slighty from the observations from the KSH01A+B study. Generally, this fracture filling is found less frequently in the studied drill cores compared to KSH01A+B. Fine-grained epidote seems to be related to the hematite-cataclasite in some samples but these epidote crystals might originate from earlier formed fillings. The spherulitic Fe/Mg-chlorite found in a few samples in KSH01A+B has not been found in paragenesis with calcite and therefore it is removed in the updated model.

- KSH01A+B model:
  - Hematite-cataclasite: adularia, Mg-chlorite, hematite, (spherulitic Fe/Mg-chlorite).
- Updated model:
  - Hematite-cataclasite: adularia, Mg-chlorite, hematite.

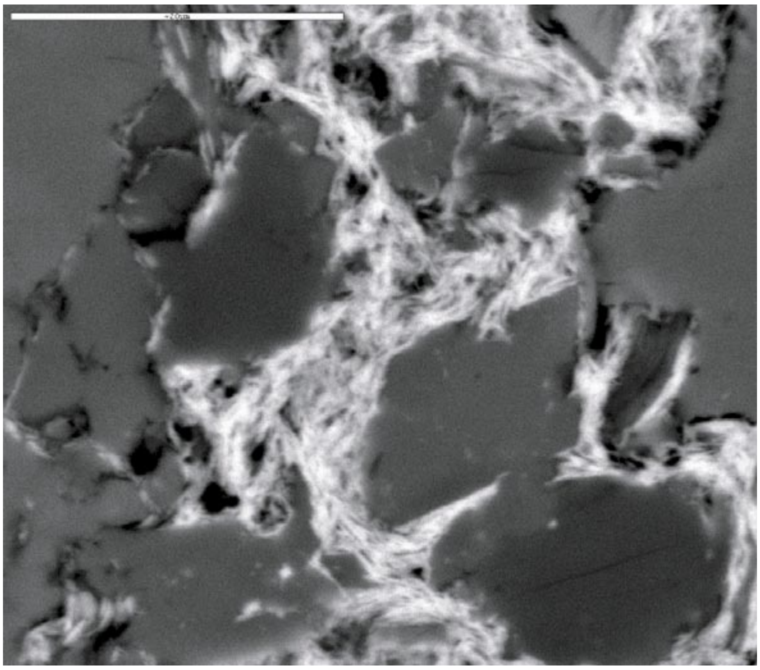

***Figure 7-1.** KAS 04: 17.70–17.85(1): Fine-grained hematite crystals are surrounding crystals of adularia in a micro-fracture. Back-scattered electron image. Scale bar is 20 µm.*

7.7 "Late" formed fillings

In the study of KSH01 a sequence of fine-grained fillings which represent mineral formed during zeolite facies to potentially ambient temperature condition was established. This type of mineralisations is also represented in this study. Differences are for example that quartz is found to be cutting through hematite-cataclasite in many more cases than in KSH01, adularia and especially Mg-rich chlorite are not as abundant as in KSH01, apatite is not found and laumontite is more frequent than in KSH01. The Ba-bearing minerals harmotome and barite are also found in thin sections in this study. The XRD-identification of apophyllite from KSH01 shows to be correct since the mineral has been identified in thin section as well as on a surface sample in this study. The REE-carbonate that was found on a surface sample in KSH01 has been found in a thin section in this study (KAS04: 65.18–65.25 m). Adularia is found to be in paragenesis with albite and quartz.

Pyrite and Fe-chlorite are often found, in paragenesis or unaccompanied, among the latest formed fracture fillings in the thin sections. The latest formed minerals in the thin section are however often clay minerals, apophyllite or mixed layer clay.

- KSH01A+B model:
  - Calcite.
  - Quartz (albite).
  - Fine grained adularia, Mg-chlorite, apatite, laumontite, (hematite) (calcite).
  - Hematite, Fe-chlorite, harmotome, pyrite, (adularia) (calcite) (fluorite).
  - Calcite, Mixed-layer clay (chlorite, illite, smectite), (REE-carbonate).
- Updated model:
  - Calcite.
  - Quartz (albite, adularia).
  - Fine grained adularia, Mg-chlorite, laumontite, calcite (hematite) (apatite).
  - Hematite, Fe-chlorite, harmotome, pyrite, (adularia) (calcite) (barite) (fluorite).
  - Calcite, Mixed-layer clay (chlorite, illite, smectite), apophyllite, (REE-carbonate).

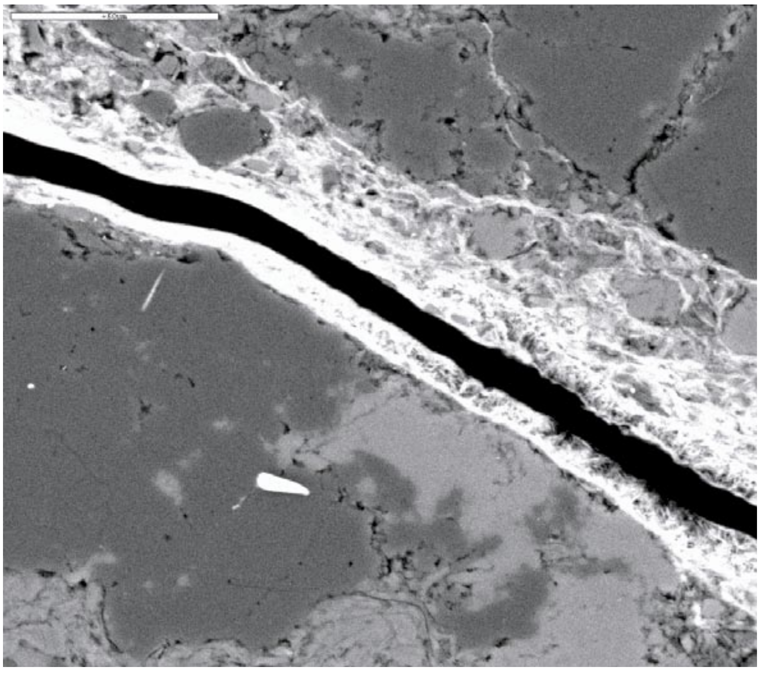

Figure 7-2. *Sample "KAS04: 65.18–65.25 m". Bright Fe-rich chlorite is penetrating through the matrix of the sample. No hematite crystals are visible in this back-scattered electron image. Scale bar is 50 µm.*

7.8 Detailed descriptions of the surface samples

Only two surface samples have been analysed in this study. Sample "KA1755A: 208.45–208.50 m" is from the surface of a wall of a cavity. The walls are covered with idiomorphic quartz and adularia (microcline ?) crystals. Later formed hematite crystals are present on the surfaces of the quartz and adularia crystals. Sample KLX02: 676.82–677.00 m is from an open fracture. The fracture wall is covered by apophyllite and barite. This sample was chosen because it was hard to identify the minerals in hand sample. Other fracture coatings like pyrite, chlorite, calcite and hematite are common in open fractures in the drill cores.

7.9 Wall rock alteration

The wall rock alteration shows a similar pattern throughout the drill cores and can be compared to the alteration in KSH01A+B. The most apparent alteration is the extensive red-staining of the host rock adjacent to a majority of the fractures. Other widespread alterations are the chloritization of biotite and saussuritization/sericitization of plagioclase and more rarely of K-feldspar. These alterations are evidently earlier than the formation of calcite, described in Chapter 7.5, and are thus considered to be a part of the earliest events in the geological record of the area.

The wall rock alteration generally increases closer to the fractures. Amphibole and biotite crystals are replaced by chlorite and titanite crystals. In most cases the transformation is pseudomorphic. The alteration of biotite into chlorite leaves some exsolved K^+, which has been participating in the formation of K-feldspar and sericite. Fluorine released from the biotite is incorporated in fluorite in the fracture fillings. The amount of epidote is also increasing in the wall rock close to the fractures. These epidote crystals seem to be coeval with the chlorite crystals in the wall rock.

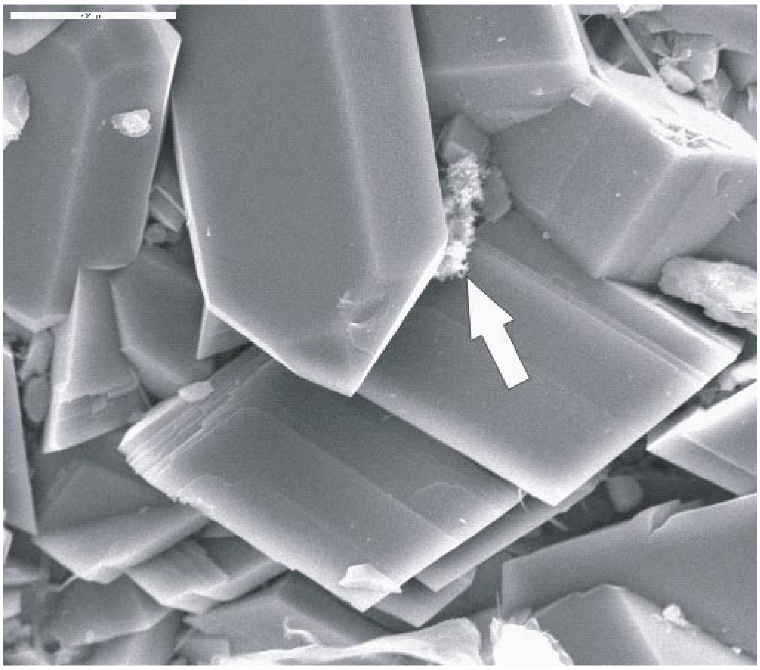

Figure 7-3. *Idiomorphic adularia crystals along with small aggregates of hematite crystals (arrow). Electron image of sample "KA1755A: 208.45–208.50 m". Scale bar is 20 µm.*

Saussuritisation of plagioclase crystals is widespread in the wall rock. Alteration of K-feldspar has also been observed but this alteration has not been as extensive as the alteration of plagioclase. The degree of alteration is as a rule increasing closer to the fractures.

The extensive red-staining of the plagioclase crystals that was noticed in the KSH01A+B study is also common in this study. The red colour comes from micro-crystals of hematite, or Fe-oxyhydroxides present within the plagioclase (clouded), in micro-fractures and along grain boundaries of the plagioclase crystals in particular /Eliasson, 1993; Drake and Tullborg, 2004/ and this study.

An interesting observation is that amphiboles in sample "KLX02: 704.00–704.30 m" do not reduce in number with decreasing distance to the fracture; they do not look affected at all. The wall rock is moderately red coloured from hydrothermal activity but the chloritization of amphiboles has not been as extensive as it commonly is.

A feature that was not observed in the KSH01A+B study is the rather common alteration of aggregates of ilmenite and other Ti-oxides to titanite along the rims of the aggregates (See Figure A2: 204.90–205.10 (3) in Appendix A2). This type of wall rock alteration has been observed in several samples of this study.

The quartz crystals in the wall rock are partially altered and are showing undulose extinction and sometimes sub-grain/granular appearance.

Figure 7-4. *Photo of sample "KLX02: 704.00–704.30 m" showing wall rock alteration/oxidation adjacent to a prehnite filled fracture. Width of view is 3 cm.*

7.10 Sequence of fracture filling events

Each fracture filling event represents a specific pressure-temperature condition. However, the fractures studied have commonly been reactivated. The relation between the different generations can therefore be hard to decide. This may also make the recognition of preferred orientation of fractures containing different fillings problematic. A common feature seems to be that there is a correlation between relative age and temperature such that younger fillings also represent lower temperature.

Early quartz filled fractures linked to post magmatic circulation may be traced as the earliest fracture filling event. However foliation, hydrothermal alteration and ductile as well as brittle deformation have affected the rock unit since then. The first major traceable fracture filling event, the formation of epidote/quartz dominated mylonite, shows that the rock unit has been subjected to ductile deformation at pressure-temperature conditions in accordance to greenschist facies. Further on, the rock has been exposed to periods of brittle deformation that induced fractures filled with epidote, Fe/Mg-chlorite, quartz, calcite, pyrite and fluorite and later by prehnite. The presence of prehnite infers formation conditions of prehnite-pumpellyite facies, < 400°C. The minerals of these two fracture fillings show idiomorphic and somewhat zoned crystals, showing that they have been growing slowly. The epidote/chlorite filling (Chapter 7.3) is more common than in KSH01A+B (Appendix A5). The prehnite generation marks the definite end of the extensive wall rock alteration, including chloritization of biotite and widespread oxidation causing red-staining of the wall rock. This period was followed by events which include hematite crystals in the fracture fillings and not in the wall rock. The first event connected to hematite formation is calcite and associated adularia. These fractures are cutting through the earlier formed fracture fillings and the oxidised wall rock. The connection between hematite and calcite of this generation is more evident than in KSH01A+B. In a subsequent period, semi-ductile to brittle deformation induced fractures filled with hematite-cataclasite in paragenesis with adularia and Mg-rich chlorite. This mineral-paragenesis is of lower temperature origin but the lack of prehnite and zeolites makes a more precise classification of the temperature-pressure conditions difficult to establish. The hematite-cataclasite is not as abundant as KSH01A+B. Especially adularia and Mg-rich chlorite appear less frequently in this study, although quite abundantly. As recorded in KSH01A+B, minerals of gradually lower formation temperatures began to occupy the fractures at one or more events postdating the "hematite-cataclasite". Barite and apophyllite was found to be more abundant than in the samples from KSH01A+B. The appearance of different zeolites confirms that the fillings were formed at zeolite facies conditions. The conditions shifted from oxidising to reducing, demonstrated by the growth of pyrite, postdating hematite crystallisation.

A summary of the updated mineral parageneses from this study in combination with the results from the study of KSH01A+B is listed below in Table 7-1.

Table 7-1. Fracture filling model for drill cores KSH01A+B, KAS04, KA1755A and KLX02.

(0): (Quartz, coarse-grained).

(Post-magmatic circulation).

1. Quartz/Epidote-mylonite, muscovite, titanite, Fe/Mg-chlorite, albite, (apatite) (calcite) (K-feldspar).

(Greenschist-facies).

2. Idiomorphic epidote, chlorite, quartz, calcite, pyrite and fluorite.

3. Prehnite (fluorite) (Fe/Mg-chlorite).

(Prehnite-pumpellyite facies).

4. Calcite, adularia (fluorite) (Fe/Mg-chlorite) (hematite).

5. Hematite-cataclasite: adularia, Mg-chlorite, hematite.

(Prehnite-pumpellyite/zeolite facies ?).

6-1: Calcite.

6-2: Quartz (albite, adularia).

6-3: Fine grained adularia, Mg-chlorite, apatite, laumontite, calcite (hematite).

6-4: Hematite, Fe-chlorite, harmotome, pyrite, (adularia) (calcite) (barite) (fluorite) (apophyllite), (REE-carbonate), (Mixed-layer clay).

6-5: Calcite, Pyrite, Mixed-layer clay (chlorite, illite, smectite, corrensite).

(Zeolite-facies to Surface Conditions ?).

8 Redox conditions

Indications of reducing and oxidising conditions are in this study partly demonstrated by the presence of pyrite (reducing conditions) and hematite (oxidising conditions). The model for oxidising/reducing conditions from KSH01A+B that was presented in /Drake and Tullborg, 2004/ is largely valid for the drill cores in this study as well. In order to trace the first and most widespread oxidising event of the wall rock one have to study fractures with only a single major fracture generation present. A brief overview shows that hematisised or red stained wall rock exists adjacent to fractures filled with solely: 1) mylonite, 2) idiomorphic epidote/chlorite or 3) prehnite, respectively. This suggests that the oxidising of the wall rock has been in progress for a long period. However, the lack of early formed pyrite in this study makes it hard to validify the model from KSH01A+B as a whole.

The suggested hematite formation in association with calcite formation (Chapter 7.5) shortens the time gap between the oxidation of the wall rock adjacent to fractures and the oxidation of the fracture fillings. This time gap was distinguished in the KSH01A+B study and showed that at least two different events of extensive oxidation have taken place in the fracture systems, separated into one wall rock oxidation and at least one fracture filling oxidation.

The observations of pyrite that is postdating hematite in thin sections and in hand samples from the drill core suggest reducing conditions. The reducing conditions are thought to represent the current conditions in the rock unit. This is in agreement with the results from the KSH01A+B study and U-series analyses from the Äspö area presented in /Tullborg et al. 2004/, where oxidising conditions were only detected in the uppermost 15–20 metres of the bed rock.

9 Relation to geological events

In the study of KSH01A+B a correlation of the different fracture filling generations to different geological events were constructed /Drake and Tullborg, 2004/. This model was based on geological interpretations from /Tullborg et al. 1996/ and is also valid for the drill cores in this study with one modification. This is the epidote/chlorite filling of generation 3, which is thought to be formed in relation to the intrusion of the ~1.4 Ga Götemar intrusion /e.g. Tullborg, 1988/. If this is correct then the prehnite fillings are formed later than 1.4 Ga. Direct datings of the fracture minerals are however crucial, to get as detailed information of the deformation events and oxidising/reducing conditions, as possible.

10 Summary

The studied drill cores shows several generations of mineralization. The fracture mineralogy in KLX02, KAS04 and KA17755A resembles that in KSH01A+B and with decreasing temperature conditions, from greenschist facies to zeolite facies, formed during successively younger events.

The mineral parageneses of the different generations in the drill cores of this study and KSH01A+B are esentially the same with a few exceptions. This may to some extent depend on the sample collection but it is thought to give representative results. One of the differences is that idiomorphic epidote and chlorite that are postdating the mylonites and are formed earlier than the prehnite fillings are more common in this study than in KSH01A+B. The indicators of oxidising and reducing conditions are also similar in this study to the KSH01A+B study, although early formed pyrite was lacking in the samples in this study and hematite-cataclasite appears less frequently in the samples of this study as compared to KSH01A+B. The paragenesis of Mg-rich chlorite and adularia also appear less frequently in this study than in KSH01A+B. The fracture fillings and the wall rock alteration in the different drill cores are very similar although the drill cores KAS04 and KA1755A have much wider and more numerous mylonite zones (Äspö Shear Zone) than KLX02 and KSH01A+B.

From the samples here studied it can be concluded that the Äspö Shear Zone generally shows the same characteristics as other structural elements, studied in the Simpevarp and Laxemar area /e.g. Drake and Tullborg, 2004/. A major difference is however that the Äspö Shear Zone dominantly shows signs of ductile deformation, with extensive mylonitisation, as oppose to the Simpevarp area, where semi-ductile cataclasites and repeated brittle fracturing are more frequent.

An attempt to relate the different generations to geological events was made in the KSH01A+B study /Drake and Tullborg, 2004/ by combining the characteristics of each mineral paragenesis (e.g. formation temperatures) with existing models of subsidence and uplift of the present land surface, as shown by /Tullborg et al. 1996/. This evaluation is in general also valid for the fracture fillings investigated in this study and gives suggestions of when the fracture fillings of the different generations could possibly have been formed. Dating of different fracture filling generations will, in combination with the recently conducted and forthcoming studies, give detailed, valuable knowledge of the geological evolution of the area.

11 Acknowledgement

We would like to thank the staff at the SKB Simpevarp site investigations for their support. Kjell Helge (Minoprep AB) and Ali Firoozan (Earth Sciences Centre, Göteborg University) are thanked for carrying out sample preparation. Fredirk Hartz SKB, kindly helped us with the map for the area.

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Appendix 1

Sample descriptions, KAS04

("*" = below detection limit of SEM-EDS).

17.70–17.85 m

Sample type: Thin section.
Rock type: Greyish black to dark-grey, fine-grained greenstone.
Fracture: Several closed micro fractures: < 1 mm.
Minerals: Calcite, Hematite, Adularia.

Order:

1) Calcite (MnO_2 = * –1.5%), and a fine-grained filling consisting of hematite, adularia and albite. The hematite was probably formed latest in the sample. Adularia seems to be formed later than calcite in places, and at least later than the calcite with undetectable MnO_2 amount. Hematite crystals are numerous.

Wall rock alteration: The wall rock is partly mylonitic and strongly red-stained. The plagioclases are fresh and the red colour comes from individual grains of Fe-oxide (hematite) that are present in micro-fractures, between grains, and along grain boundaries of earlier formed minerals. Calcite fillings are closely connected to the presence of hematite but hematite grains may as well appear without calcite association. There is practically no epidote/chlorite/sericite in the sample.

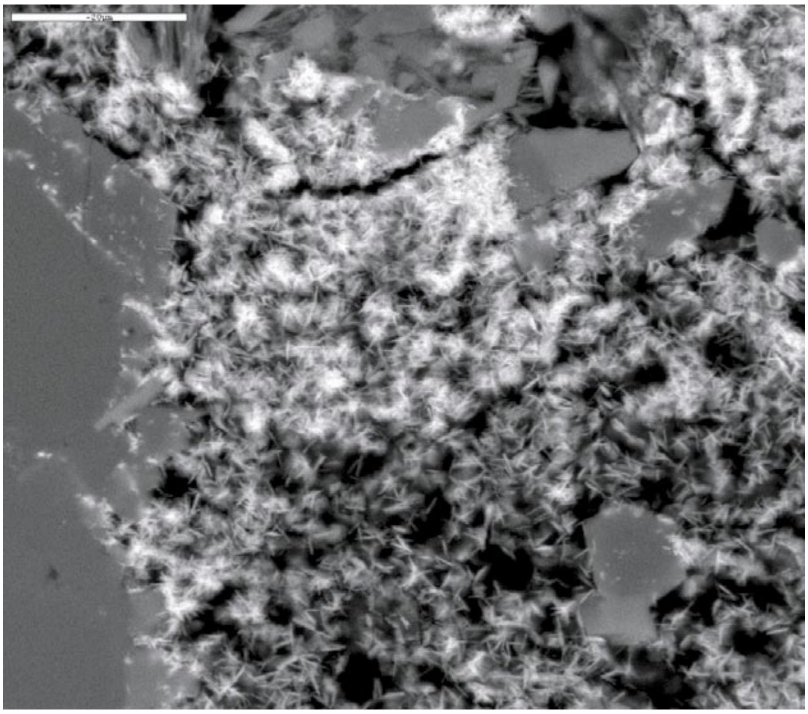

Figure A1. *17.70–17.85(1). Fine-grained hematite crystals (bright) present in a micro fracture along with earlier formed adularia. Back-scattered electron image. Scale bar is 20 µm.*

65.18–65.25 m:

Sample type: Thin section.
Rock type: Cataclasite/mylonite of fine-grained granite or of reddish grey, fine medium-grained to medium-grained granodiorite to quartz monzodiorite.
Fracture: Red coloured, cataclasite/mylonite.
Minerals: Hematite, REE-carbonate, K-feldspar, Quartz, Adularia, Chlorite.

As seen in Figure A1: 65.18–65.25 (1) the fracture filling is dark red/brown in colour. Microscopic studies suggest high hematite content for several parts of the sample since these parts are almost opaque. SEM-EDS studies show however that the hematite content is rather irregularly distributed in the sample. Some parts are intensively hematite stained while other parts that appear dark-red in microscope lack distinct hematite crystals when examined with SEM. The FeO-content (SEM-EDS) of the main minerals of the filling (K-feldspar and quartz), are however significantly high: > 1%. The red colour is the result of very fine-grained hematite crystals present in crystal lattices and between crystals, in micro-fractures and along grain boundaries of the filling. The fine-grained K-feldspar and quartz, might be derived from the wall rock and form together with later formed REE-carbonate in the fracture filling (Figure A1: 65.18–65.25 (2)). The red coloured filling is in some places cut by micro-fractures filled with adularia and Fe-rich chlorite.

Figure A1. *65.18–65.25(1). Photo of the drill-core sample. The red-coloured cataclasite in the centre of the sample was examined in thin section. Drill-core diameter is 50 mm.*

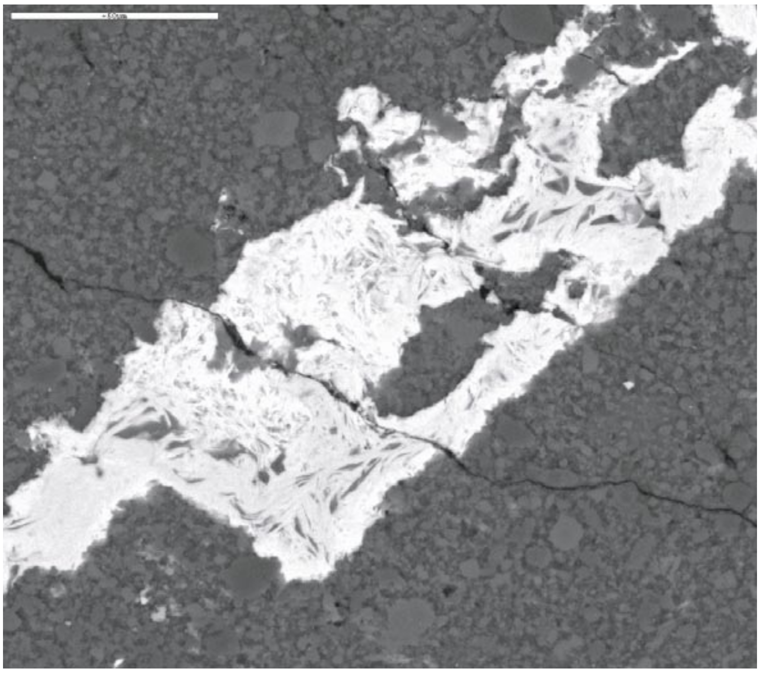

Figure A1. *65.18–65.25(2). Bright REE-carbonate in a cataclasitic matrix of more dark K-feldspar and quartz. The matrix is distinctly red coloured in handsample but few crystals of Fe-oxides are visible in this part of the sample with SEM. Back-scattered electron image. Scale bar is 20 µm.*

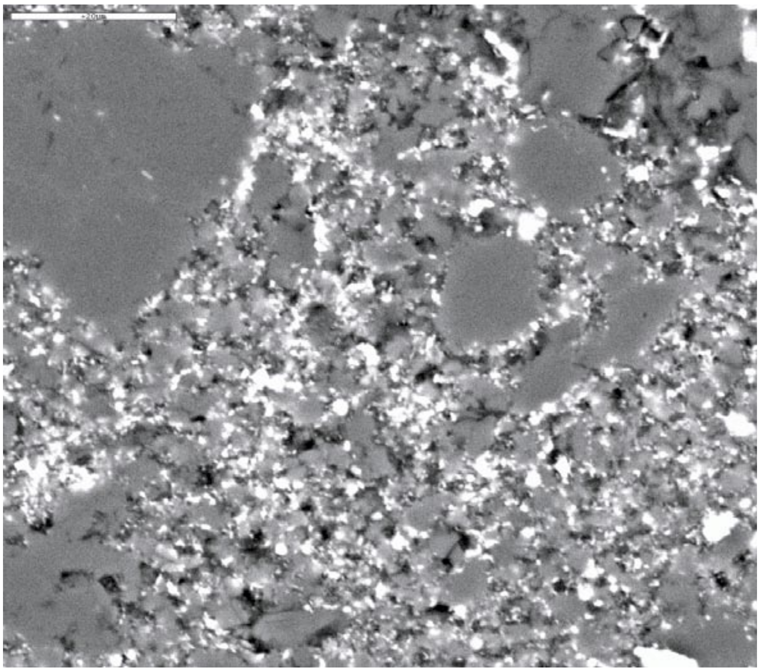

Figure A1. *65.18–65.25(3). Bright hematite between and in the crystal lattice of K-feldspar. This is a part of the sample were the red staining Fe-oxide is clearly visible with SEM. Back-scattered electron image. Scale bar is 20 µm.*

70.60–70.80 m:

Sample type: Thin section.
Rock type: Reddish grey, fine medium-grained to medium-grained granodiorite to quartz monzodiorite.
Fracture: 2–3 centimeter wide, closed.
Minerals: Quartz, Epidote, Adularia, Muscovite/Illite (?), Fluorite.

Order:

1) Coarse-grained quartz filling.
2) Idiomorphic epidote crystals penetrating the quartz crystals, this filling may be coeval with the quartz-filling.
3) Veins of adularia, muscovite/illite (?) and fluorite are cutting through and off-setting the earlier formed fillings.

176.45–176.70 m:

Sample type: Thin section.
Rock type: Mylonite/cataclasite affecting reddish grey, fine medium-grained to medium-grained granodiorite to quartz monzodiorite.
Fracture: Several sets of microfractures of different generations, giving the sample a mylonitic/cataclasitic appearance.
Minerals: Epidote, Chlorite, Laumontite, Calcite, Adularia, Pyrite.

Order:

1) Epidote and Chlorite formed in the altered wall rock.
2) Laumontite, calcite (MnO_2 = *), with lots of fluid inclusions and adularia are formed in fractures that are cutting through the epidote and chlorite-rich wall rock. Adularia is coating the calcite-filled fractures in places. The wall rock is more intensively red-coloured next to the fractures filled with laumontite.
3) Pyrite crystals are present in voids in the laumontite fillings.

Wall rock alteration: The wall rock is mylonitic and fine-grained. The plagioclase is brightly red coloured in thin section and the red colour/hematite-content increases when fractures are filled with laumontite. The hematite crystals can be found in microfractures, along grain boundaries and in the crystal lattice of laumontite. Numerous crystals of chlorite and epidote are present in the wall rock.

177.90–178.34 m:

Sample type: Thin section.
Rock type: Epidote/Quartz – mylonite affecting reddish grey, fine medium-grained to medium-grained granodiorite to quartz monzodiorite.
Fracture: ~15 cm wide, fine-grained mylonite.
Mineral: Epidote, Quartz, Titanite, Zircon, Apatite.

Epidote and quartz are the general minerals in this mylonite. Titanite crystals are present within epidote crystals. These two minerals look to be formed at the same event. There are several crystals of zircon in the mylonite but it is unclear if they are formed hydrothermally in the mylonite or derived from the wall rock. Some apatite is also present in the mylonite.

There are a couple of quartz filled fractures (and some epidote filled fractures), that are cutting through the mylonite, sometimes giving the mylonite a breccia-like appearance.

Figure A1. *176.45–176.70(1). Photo of the sawed drill-core sample showing the site of the thin section. Drill-core diameter is 50 mm.*

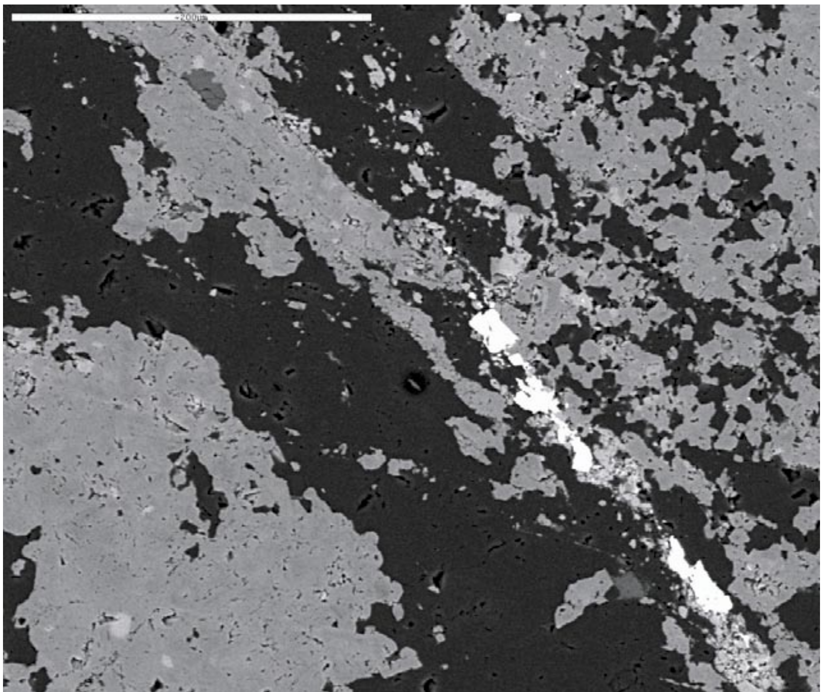

Figure A1. *177.90–178.34(1). Bright zircons in the mylonite consisting of quartz (dark) and epidote (medium dark). Brighterspots within the epidotes are titanites.Back-scattered electron image. Scale bar is 200 µm.*

180.68–180.85 m:

Sample type: Thin section.
Rock type: Mylonite affecting reddish grey, fine medium-grained to medium-grained granodiorite to quartz monzodiorite.
Fracture: Mylonite cut by a centimetre wide fracture.
Minerals: Epidote, Quartz, Calcite, Adularia, Albite, Apatite, Chlorite, Titanite.

Order:

1) Mylonite of epidote/quartz, and small amounts of fine-grained albite.
2) Epidote/quartz filling, with additional muscovite and minor amounts of apatite is cutting the mylonite. Fe/Mg-chlorite (MgO = 17–18%, FeO = 21%) and paragenetic titanite are cutting the mylonite is also cutting the mylonite but are difficult to relate to the Epidote/quartz filling.
3) Prehnite (few crystals) is cutting the mylonite.
4) Adularia and calcite (MnO_2 = 0.35–1.1%).

Wall rock alteration: Partly mylonitic and red-stained wall rock with several epidote and chlorite crystals with a preferred orientation. Some bigger crystals of quartz are present and the plagioclase is vaguely clouded by Fe-oxide.

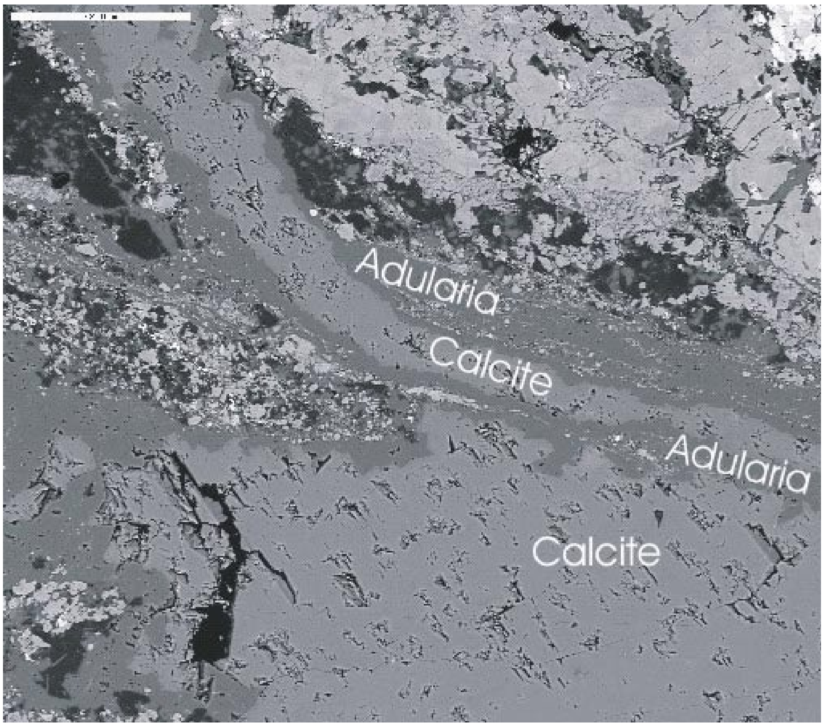

Figure A1. *180.68–180.85(1). Calcite crystals filling two fractures coated by adularia.Back-scattered electron image. Scale bar is 200 µm.*

181.75–182.07 m:

Sample type: Thin section.
Rock type: Quartz/Epidote – mylonite affecting reddish grey, fine medium-grained to medium-grained granodiorite to quartz monzodiorite.
Fracture: 20 centimetres of mylonite of different strain rates.
Minerals: Epidote, Quartz, Titanite, Zircon, Apatite, Chlorite, Harmotome, Albite.

Quartz-dominated mylonite and epidote-dominated mylonite are the dominating features of this filling. Veins of quartz penetrate into the epidote-rich mylonite and veins of epidote are penetrating into the quartz-rich mylonite. Titanite is present along with zircon in the epidote-rich mylonite. Albite and apatite are also present. Harmotome is found as two ~50 micron sized unaltered crystals that are clearly formed later than the mylonite.

182.52–182.66 m:

Sample type: Thin section.
Rock type: Altered reddish grey, fine medium-grained to medium-grained granodiorite to quartz monzodiorite.
Fracture: Two centimeter wide, open fracture.
Minerals: Quartz, Epidote, Chlorite, Laumontite.

Order:

1) Coarse-grained quartz crystals, Fe/Mg-chlorite (partly spherulitic) and epidote. Chlorite and epidote are filling smaller fractures cutting through the quartz filling but the fillings seem to be farly coeval.
2) Laumontite filled fractures cut through the chlorite – epidote and the quartz fillings.

Wall rock alteration: Zones of fine-grained quartz, muscovite, calcite and epidote are present in the red coloured wall rock. The plagioclase is saussuritized. There are few crystals of chlorite.

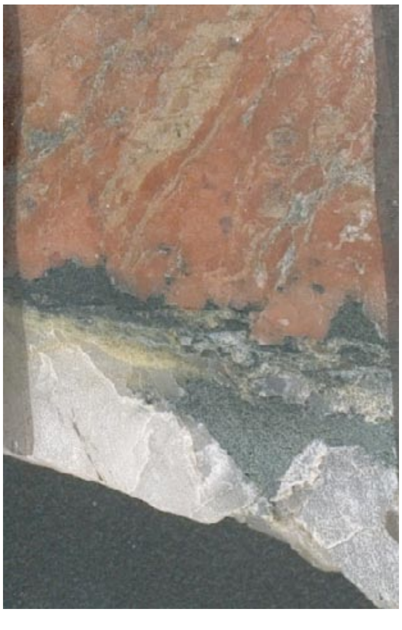

Figure A1. *182.52–182.66(1). Photo white quartz, dark-green chlorite and yellowish epidote as fracture coatings bordering red-stained wall rock, showing the orientation of the thin section. View is ~20 mm wide.*

185.15–185.20 m:

Sample type: Thin section.
Rock type: Mylonite affecting reddish grey, fine medium-grained to medium-grained granodiorite to quartz monzodiorite.
Fracture: Several thin mylonites and microfractures.
Minerals: Epidote, Quartz, Fluorite, Titanite, Albite, K-feldspar, Laumontite, Zircon, Apatite, Chlorite, Prehnite, Calcite.

Order:

1) Epidote/Quartz – mylonite with albite, K-feldspar, apatite, Fe/Mg-chlorite, titanite and zircons.
2) Fluorite; big crystals cutting the epidote-rich mylonite.
3 ?) Calcite, thin vein, (MnO_2 = 0.6–2%).
3 ?) Laumontite (thin vein).

Wall rock alteration: Not much of the original wall rock present. Everything is more or less mylonitic. No red colouration features in the sample.

Figure A1. *185.15–185.20(1). Back-scattered electron image of a zircon crystal from the mylonite. Scale bar is 20 µm.*

187.70–185.85 m:

Sample type: Thin section
Rock type: Mylonite affecting reddish grey, fine medium-grained to medium-grained granodiorite to quartz monzodiorite
Fracture: One centimetre wide mylonite and a set of several microfractures of different orientation from that of the mylonite.
Minerals: Epidote, Quartz, Fe-Mg-chlorite, Adularia, Laumontite, Pyrite, Calcite, Titanite, Albite, Monazite, Th-silicate.

Order:

1) Epidote/Quartz – mylonite. Veins of pure quartz and pure epidote cutting the mylonite. Albite, Fe/Mg-chlorite and titanite are present in the mylonite. Some small Fe/Mg-chlorite filled fractures are cutting through the mylonite.

1 ?) Calcite crysts in the mylonite with lots of related Th-silicate (?) crystals, monazite and pyrite.

2) Thin vein of epidote and Fe/Mg-chlorite.

3) Thin vein of adularia.

3 ?) Thin vein of laumontite.

4) Pyrite crystals are present in the earlier formed laumontite vein.

Wall rock alteration: The wall rock shows a slightly mylonitic-foliated appearance, dominated by quartz/epidote and is altered (epidote/chlorite etc) and red coloured.

194.80–195.03 m:

Sample type: Thin section.
Rock type: Mylonite/cataclasite affecting reddish grey, fine medium-grained to medium-grained granodiorite to quartz monzodiorite.
Fracture: Several sets of closed fractures of different generations with different orientations. Some fracture fillings show mylonitic/cataclastic characteristics.
Minerals: Calcite, Prehnite, Quartz, Epidote, Chlorite, Harmotome, Laumontite.

Order:

1) Several fine-grained fillings consisting of epidote/quartz/chlorite and albite (?).

2) More coarse-grained epidote with some quartz.

3) Prehnite.

4) Calcite (MnO_2 = 0.5%), quartz, laumontite and harmotome are present in voids in the prehnite. Laumontite and quartz may be contemporaneous with calcite but harmotome is probably formed later.

Wall rock alteration: Saussuritised plagioclase. The plagioclase crystals are also clouded by minute hematite crystals. There are severeal fractures and micro fractures in the wall rock. Epidote crystals are common.

Appendix 2

Sample descriptions, KA1755A

(* = below detection limit of SEM-EDS).

200.84–200.99 m:

Sample type: Thin section.
Rock type: –
Fracture: One centimetre-wide fracture and one centimetre-wide mylonite.
Minerals: Epidote, Muscovite, Quartz, Chlorite, Prehnite, Fluorite, Calcite, Adularia.

Order:

1) Muscovite-epidote-quartz mylonite.
2) Fe/Mg-chlorite and coarse-grained epidote seem to be formed later than the mylonite. The chlorite can be coeval with the prehnite of generation 3.
3) Idiomorphic prehnite and fluorite.
4) Calcite, adularia, Mg-rich chlorite (probably coeval). The calcite is the most prominent mineral in this generation and is filling numerous distinct thin fractures that are cutting through the prehnite.

Prehnite, fluorite, calcite etc in generations 3–4 might be formed slightly contemporaneous.

Wall rock alteration: The wall rock and especially the plagioclase crystals are strongly saussuritized. Some plagioclase crystals show signs of deformation. The wall rock is red coloured, originating from slightly clouded plagioclase crystals. Crystals of epidote and chlorite are also present in the wall rock.

Figure A2. *200.84–200.99(1). Photomicrograph (+nic) of calcite filled fractures cutting through earlier formed prehnite.*

204.20–204.38 m:

Sample type: Thin section.
Rock type: –
Fracture: Two closed fractures (1 cm/ 0.5 cm wide) through heavely altered and foliated wall rock. One of the closed fractures borders to an open fracture.
Minerals: Laumontite, Epidote, Quartz, Calcite, Fe/Mg-Chlorite, Adularia.

Order:

1) Epidote-rich mylonite. This filling is present in the wall rock as a set of fine-grained, parallel bands between more unaltered wall rock and these bands are cut discordantly by later formed fractures.
2) A centimetre wide filling of poly-crystalline quartz. The crystals in the filling are even grained.
3) Epidote and Fe/Mg-chlorite (FeO = 23%, MgO = 16%) is formed later than the quartz filling. Epidote is filling microfractures that are cutting through the quartz filling.
4) In order: laumontite – adularia – calcite (MnO_2 = * –0.35%). These minerals are filling a 5 mm wide fracture that is parallel to the quartz filling in “2”.

Wall rock alteration: The wall rock is heavily altered by sericite and is mylonitic in parts. The plagioclase crystals are saussuritized and show signs of deformation (deformed twins). The red colouration of the wall rock due to hematite clouded plagioclase is increasing with decreasing distance from the main fractures. Fine-grained chlorite and some epidote have replaced minerals of the wall rock. Ilmenite has been partly replaced by titanite.

204.90–205.10 m:

Sample type: Thin section.
Rock type: –
Fracture: A 5 mm wide mylonite is cut by a 5 mm wide fracture. The fracture is closed and cut the mylonite perpendicular.
Minerals: Quartz, Epidote, Muscovite, Calcite, Chlorite, Adularia, Hematite, Titanite, Zircon.

Order:

1) Epidot-rich mylonite and muscovite-rich mylonite with flow textures. Included in the epidote-mylonite are quartz, titanite and some zircon. The muscovite-mylonite contains Fe/Mg-chlorite and titanite. The two mylonites appear next to each other and the muscovite variety might be youngest.
2) Calicte (MnO_2 = *) with numerous fluid inclusions is filling a fracture cutting the earlier formed mylonites.
3) Fine grained fillings of adularia, Mg-rich chlorite (FeO: 7%, MgO: 13%) and Fe-ox (hematite) (+ small amounts of albite), are present in dissolved parts or voids in the calcite fillings. A thin fracture filled with less calcite than in generation 2, is cutting the calcite of generation 2 and the mylonite. This fracture is bordered by adularia and chlorite.

Wall rock alteration: The wall rock is strongly oxidised and red coloured. The plagioclase is sericitezed/saussuritized and vaguely clouded by hematite. The wall rock is also rich in microfractures and aggregates with chlorite and some epidote. Aggregates of ilmenite and Ti-ox have been altered to titanite along the grain-boundaries.

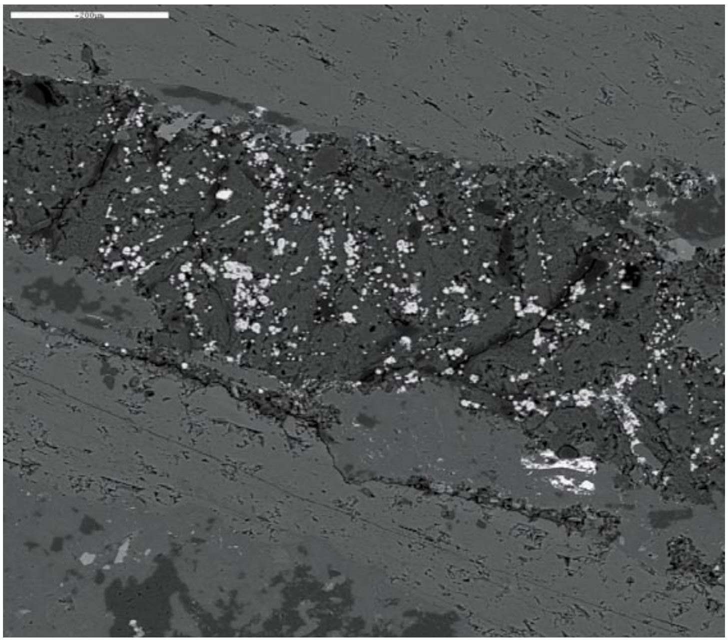

Figure A2. *204.90–205.10(1). Calcite (lighter grey) is penetrated by a filling (dark grey with bright spots) consisting of Mg-rich chlorite, adularia and hematite.Back-scattered electron image. Scale bar is 200 µm.*

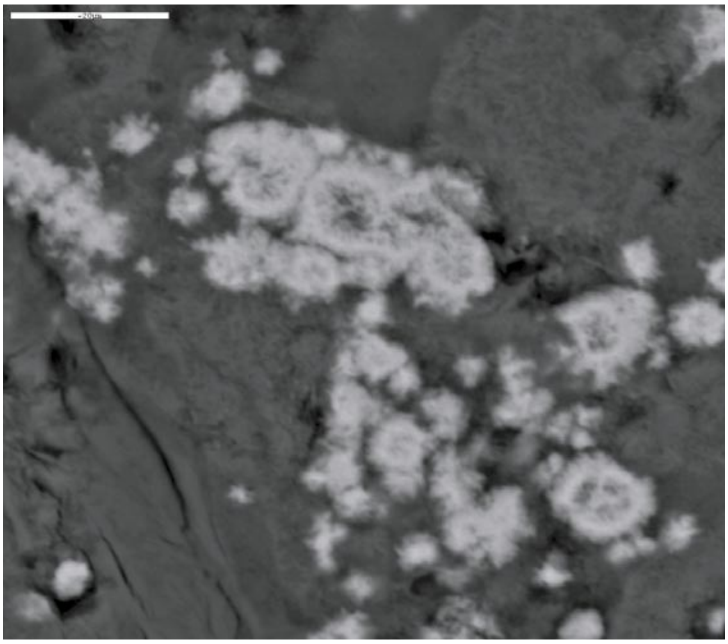

Figure A2. *204.90–205.10(2). A close-up of the Mg-rich chlorite, adularia and hematite from the figure above (1). The bright spots are hematite crystals. Back-scattered electron image. Scale bar is 20 µm.*

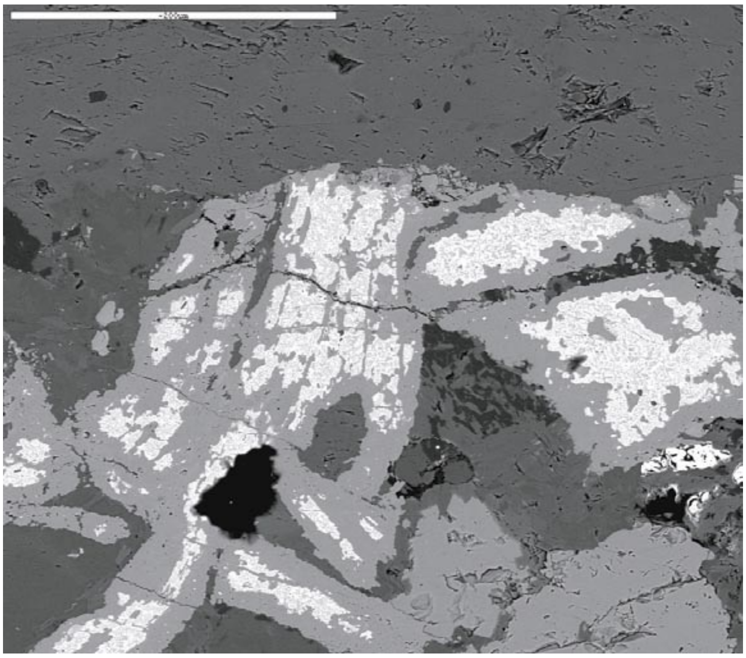

Figure A2. *204.90–205.10(3). Back-scattered electron image showing aggregates of ilmenite and Ti-ox (bright crystals) which have been altered to titanite (light grey) along their grain-boundaries. Scale bar is 200 µm.*

206.50–206.55 m:

Sample type: Thin section.
Rock type: –
Fracture: Thin, 2–3 mm thick, fracture coating that is bordering a later formed open fracture. The wall rock adjacent to the coating is altered and penetrated by numerous micro-fractures with a preferred orientation that is parallel to a foliation/"mylonitisation".
Minerals: Epidote, Chlorite, Quartz, Calcite, Hematite, Adularia, Chalcopyrite, Pyrite, Illite (Mixed-layer clay).

Order:

1) Epidote, Fe/Mg-chlorite and quartz fill parallel fractures. These fractures strike parallel to foliation/mylonitisation.
2) Calcite (MnO_2 = *) is filling a fracture coated by adularia, hematite and Fe/Mg-chlorite. This fracture is cutting the foliation/mylonitisation discordantly.
3) Adularia, chalcopyrite, pyrite, illite (Mixed-layer clay) and Fe-rich chlorite (FeO: 30%, MgO: 3%) are coating a fracture, partly filled with calcite (MnO_2 = *).

Notable: A calcite filled fracture (MnO_2 = *, different from the one in "2") is penetrating through an illite/hematite-filling. Fe-rich Chlorite is formed later than all of these fillings.

Wall rock alteration: Strongly altered and deformed (foliated/mylonitic) wall rock that is faintly red coloured and penetrated by micro-fractures. Some parts of the wall rock are enriched in fine-grained quartz/muscovite and some epidote. The plagioclase is sericitezed/saussuritized and vaguely clouded by minute hematite crystals.

208.45–208.50 m:

Sample type: Thin section.
Rock type: –
Fracture: 2–5 mm wide and 20 mm long cavities caused by dissolution. See Figure "A2: 208.45–208.50 (1)". The cavities have been studied in both thin section and surface sample using SEM-EDS.
Minerals: Quartz, Epidote, Muscovite, Albite, K-feldspar, Adularia, Chlorite, Hematite.

Order:

1) Fine-grained red-stained matrix of quartz and feldspars in the wall rock. These minerals are oriented in a preferred orientation (foliation).
2) Fracture-network filled by fine-grained epidote, albite, muscovite, (+quartz and K-feldspar) is penetrating through this early foliation.
3) Quartz is filling a fracture coated by the minerals in 2. Big eudhedral epidote crystals and lesser amounts of Fe/Mg-chlorite (FeO: 21%, MgO: 17%) are coating a fracture filled with quartz crystals.
4) Big euhedral crystals of contemporaneous adularia and albite have grown from the walls of the cavity.
5) Hematite crystals are present between the adularia and albite crystals ("4") and on their surfaces.

Wall rock alteration: The wall rock is mylonitic with lots of fine-grained quartz and feldspar. The plagioclase crystals are clouded by hematite. Micro-fractures with dark red hematite are present.

208.45–208.50 m:

Sample type: Surface sample.
Rock type: –
Fracture: Same as in the thin section description. The surface sample displays one wall of a cavity.
Minerals: Quartz, Adularia, Hematite.

Order:

Idiomorphic quartz and adularia (or microcline ?) are coeval and the hematite is present as small crystals on their surfaces. This suggests that the hematite is younger.

Figure A2. *208.45–205.50(1). Photo of the drill-core sample showing the cavities formed by dissolution. Drill-core diameter is 50 mm.*

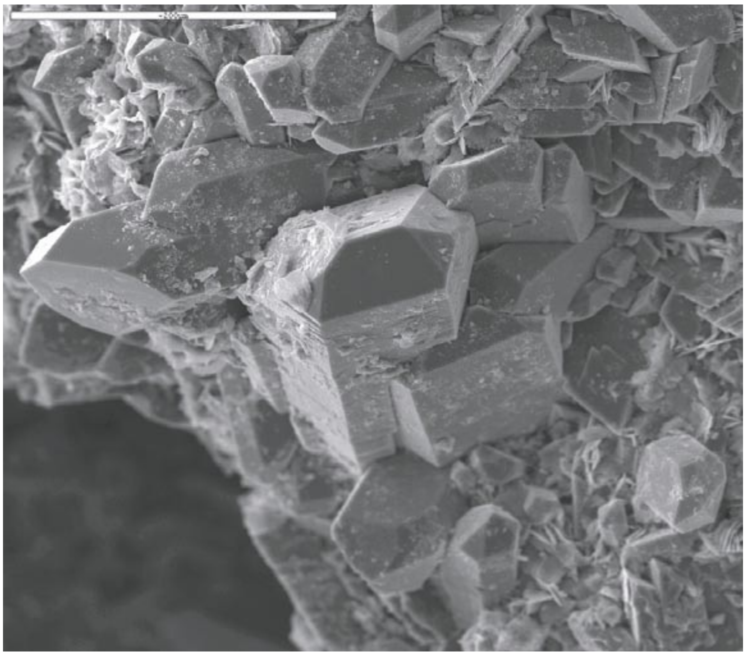

Figure A2. *208.45–208.50(2). Electron image showing idiomorphic quartz crystals growing from the walls of the cavity. Scale bar is 200 µm.*

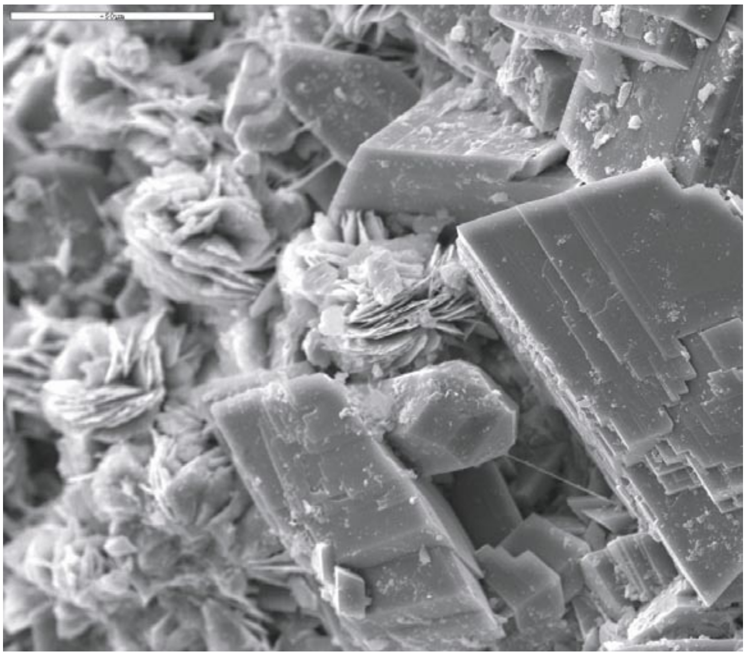

Figure A2. *208.45–208.50(3). Electron image showing idiomorphic adularia and quartz crystals (dark grey crystals, predominantly on the right hand side of the picture) growing from the walls of the cavity. Aggregates of tabular hematite crystals (brighter, on the left hand side) are growing on and in between the adularia and quartz crystals. Scale bar is 50 µm.*

208.65–208.90 m:

Sample type: Thin section.
Rock type: Mylonite.
Fracture: 5–10 cm wide mylonite. Pale green in colour, fine-grained.
Minerals: Epidote, Quartz, Chlorite, Albite, Adularia, Clay mineral (Illite/Chlorite ?), Titanite, Zircon.

Order:

1) Epidote – mylonite consisting of epidote, quartz and Fe/Mg-chlorite (FeO: 21%, MgO: 18%). Titanite crystals are present within the epidote crystals. A few crystals of zircon are also present in the thin-section.
2) Polycrystalline quartz in fractures cutting through the mylonite.
3) Idiomorphic albite, adularia and clay mineral (illite/chlorite mixed-layer clay ? – see analysis in A4).

211.70–211.75 m:

Sample type: Thin section.
Rock type: Mylonite.
Fracture: 5–10 cm wide mylonite. Pale green/gray in colour, fine-grained, cut perpendicularly by a 1–2 mm wide calcite fracture.
Minerals: Muscovite, K-feldspar, Calcite, Fluorite, Epidote, Chlorite, Quartz, Hematite.

Order:

1) Mylonite consisting of muscovite, quartz, epidote, K-feldspar, albite and titanite (apatite is present as well). Parts of the mylonite are red/brown coloured caused by restricted high concentration of titanite. There are titanite and the epidote crystals in the mylonite which look idiomorphic. The idiomorphic epidote crystals have dissolved cores that have been occupied by Fe-rich chlorite probably formed at a later event.
2) Fe/Mg-chlorite (FeO = 20%, MgO = 17%) along with some Fe-oxide in stress-shadow behind crysts of K-feldspar/albite.
3) Calcite (MnO_2 = 1.3–2%), big crystals in a vein that is cutting the mylonite discordantly. Idiomorphic (~50 micron) crystals of fluorite are present along with the calcite.

3–4 ?) Fine-grained filling, next to the calcite filling, consists of calcite, fluorite and hematite. This filling may be contemporaneous with the calcite filling. The fluorite crystals are only 1/10 of the size of the idiomorphic ones.

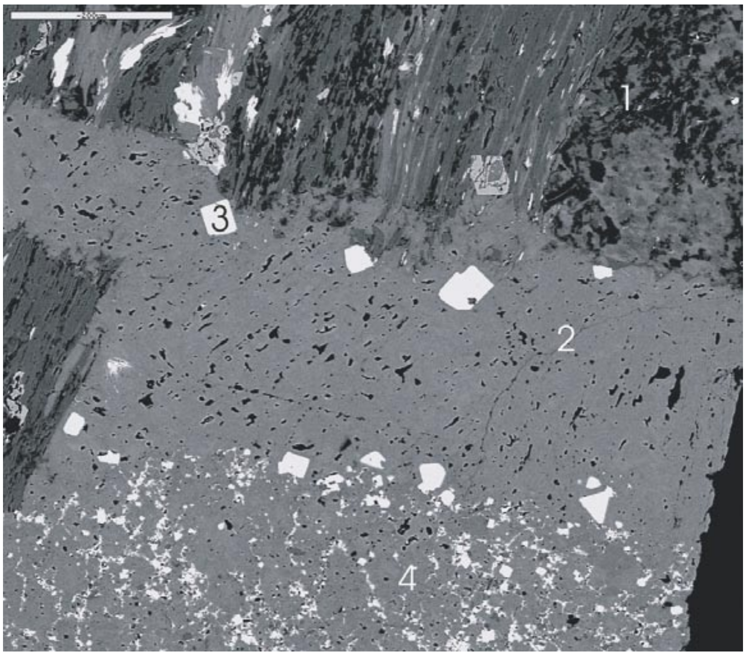

Figure A2. *211.70–211.75(3). Back-scattered electron image showing mylonite (1) that is cut by a fracture filled with calcite (2) with numerous fluid inclusions and idiomorphic fluorite (3). Lower part of the picture shows a fine-grained calcite/fluorite/hematite filling (4) that might be coeval with (3). Scale bar is 200 µm.*

Appendix 3

Sample descriptions, KLX02

(* = below detection limit of SEM-EDS).

218.40–219.10 m:

Sample type: Thin section.
Rock type: Småland granite.
Fracture: Three closed, parallel 2–5 mm wide fractures. All are filled with fracture fillings and one of these is bordering an open fracture.
Minerals: Quartz, Epidote, Prehnite, Adularia, Chlorite.

Order:

1) Fine-grained quartz-crystals as fragments in epidote cataclasite.
2) Epidote cataclasite.
3) Euhedral-subhedral epidote.
4) Prehnite.
5) Calcite, two types (MnO_2 = * and MnO_2 = 1.7%, hard to distinguish the order), with numerous fluid inclusions, together with Mg-rich chlorite (FeO: 17%, MgO: = 21%) and adularia.

The calcite with MnO_2 = * is present in prehnite-voids.

Wall rock alteration: Red coloured from oxidation. The plagioclase crystals are sericitzed/saussuritzed and partly and unevenly clouded by minute hematite crystals. Some plagioclase crystals are fresh. No signs of deformation/mylonitisation. Some chlorite is present in the wall rock but epidote is more or less abscent.

260.08–260.25 m:

Sample type: Thin section.
Rock type: Småland granite.
Fracture: Open fracture coated by a thin 0.5 mm wide calcite filling.
Minerals: Calcite (MnO_2 = 0.75–2%).

Wall rock alteration: This sample was studied because of the successive change of alteration with increasing distance from the fracture rim. This can be seen by the naked eye in that the red colour close to the fracture disappears about a centimetre from the fracture rim. Minute crystals of hematite, sericite and saussurisite in plagioclase crystals of the wall rock increase towards the fracture rim. The most extensive hematite staining of plagioclase in this sample is however much less than in other samples in this study. Biotite that is present in the unaltered part of the wall rock is replaced by chlorite, with some titanite, closer to the open fracture.

268.08–268.20 m:

Sample type: Thin section.
Rock type: Småland granite.
Fracture: Several closely spaced coeval fractures, < 1–2 mm wide each. The fractures are subparallel and filled with a dark filling.
Minerals: Illite (mixed-layer clay), Adularia, Calcite, Chlorite.

Order:

1) Adularia and calcite (MnO_2 = < 2%) fill the parts of the fractures coated by mixed-layer clay, illite and Fe-rich chlorite (FeO: 32%, MgO: 11%). It is hard to distinguish if the chlorite/illite were formed prior to or after the calcite/adularia. Fe-rich chlorite is either way slightly younger than Illite.

Wall rock alteration: The wall rock present in the thin section is evenly red coloured. The plagioclase crystals are clouded by minute hematite crystals in a much more intense way than in sample "KLX02: "260.08–260.25 m". Coarse-grained quartz crystals show undulose extinction in places and numerous micro fractures are shattering the wall rock.

513.78–514.12 m:

Sample type: Thin section.
Rock type: Småland granite.
Fracture: One closed reactivated fracture with a thickness of 3–4 mm.
Minerals: Epidote, Prehnite, Calcite, Pyrite, Chlorite, Barite.

Order:

1) Epidote mylonite/cataclasite.
2) Epidote, more coarse-grained and pure than in "1".
3) Prehnite is coating a void in the epidote filling ("2").
4) Calcite is filling the void that is coated by prehnite.
5) Fe-rich chlorite (FeO: 33%, MgO: 10%), barite and pyrite are coating the fracture walls of an open fracture that is penetrating through prehnite/epidote fillings.

Wall rock alteration: Vaguely clouded plagioclase crystals with minute grains of hematite give the sample a red coloured appearance. The red colour in hand sample suggests a larger amount of hematite than is visible in thin section. The plagioclases are intensively seritised and partly saussuritised. Dark minerals are practically abscent in the wall rock and only a few crystals of chlorite and epidote are found. No sign of mechanical deformation is visible in the wall rock.

525.06–525.66 m:

Sample type: Thin section.
Rock type: Småland granite.
Fracture: One closed fracture with a thickness of 5–10 mm.
Minerals: Epidote, Chlorite, Quartz, Titanite, Calcite.

Order:

1) Idiomorphic epidote crystals are growing from the fracture wall. Also present is Fe/Mg-chlorite with some small amounts of titanite.
2) Quartz and calcite are filling the epidote coated fracture along with some Fe/Mg-chlorite. This filling is probably contemporaneous with "1".
3) Fe-rich chlorite (FeO: 30–33%, MgO: 10–14%) is present in voids in the epidote crystals.

Figure A3. *525.06–525.66(1). Photomicrograph in plain polarised light showing the epidote (yellow) filled fracture with some chlorite (green) and quartz (white).Width of view is ~1 cm.*

Wall rock alteration: Red coloured close to the fracture. Plagioclase crystals are sericitised and partly saussuritised. The clouded appearance of plagioclase crystals originating from minute hematite crystals increase with decreasing distance from the fracture rim but are vague in this sample. There are numerous epidote and chlorite crystals in the wall rock, often as big crystals.

676.82–677.00 m:

Sample type: Surface sample.
Rock type: Småland granite.
Fracture: Open fracture.
Minerals: Apophyllite, Barite, Clay mineral (see analysis in A4).

Apophyllite and Barite are formed relatively contemporaneous in an open fracture. Both minerals are formed as idiomorphic crystals. An unidentified clay mineral (mixed –layer clay ? - see analysis in A4 and Figure 2 below) is present on the surfaces of barite and apophyllite.

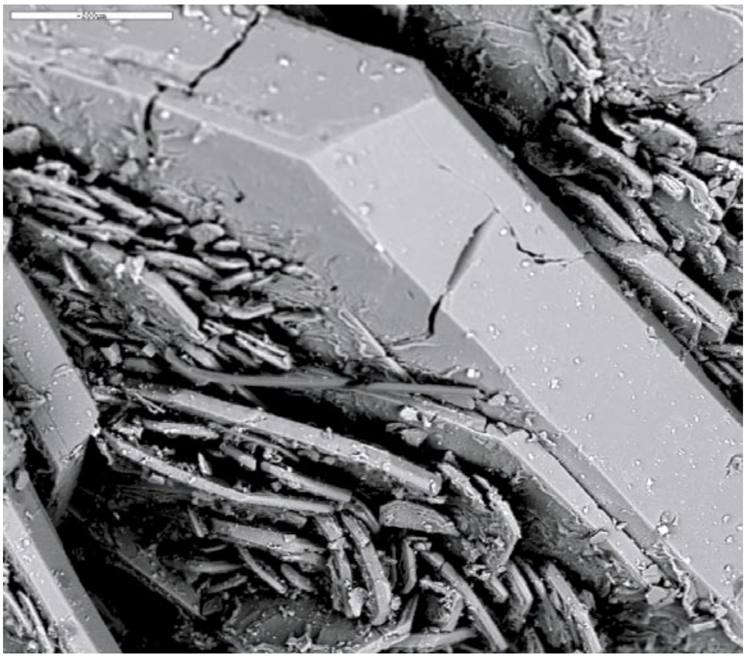

Figure A3. *676.82–677.00(1). Electron image showing idiomorphic apophyllite crystals growing from the fracture wall. Scale bar is 200 µm*

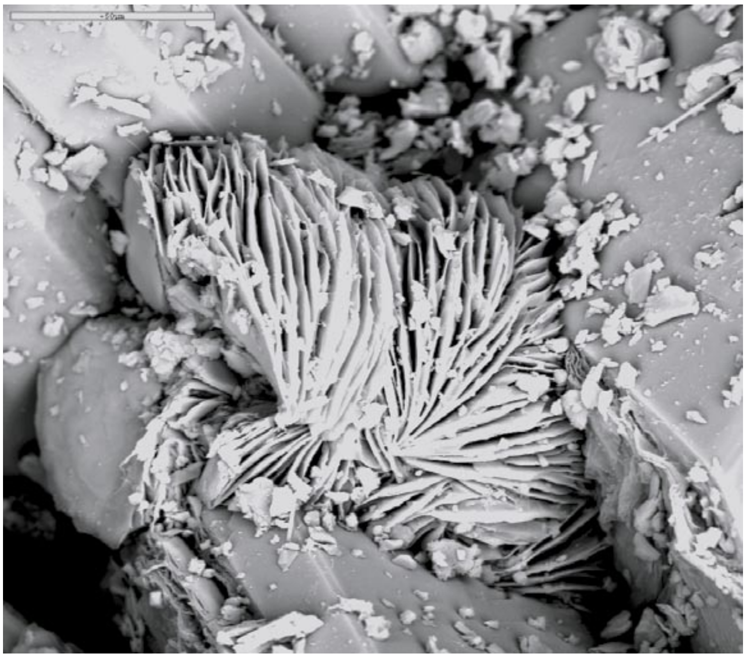

Fig A3. *676.82–677.00(2). Electron image showing clay mineral crystals (mixed-layer clay?) growing on the surface of apophyllite crystals. Scale bar is 50 µm*

704.00–704.30 m:

Sample type: Thin section.
Rock type: Greenstone (?).
Fracture: One closed fracture with a thickness of 2–3 mm.
Minerals: Prehnite, Epidote, K-feldspar, Apophyllite, Clay mineral (?).

Order:

1) Epidote (idiomorphic) filled fracture coated by idiomorphic K-feldspar.
2) Prehnite filled fracture is formed later than the epidote ffilled fracture above.
3) Apophyllite and a clay mineral, which might be apophyllite mixed with chlorite (see analyses in A4 (the Al_2O_3 might however be to low), and Figure 1 below), are present in microfractures through the prehnite filling.

Wall rock alteration: As in "KLX 260.08–260.25 m" the successive change in wall rock alteration/oxidation can be seen in the thin section. The plagioclase is moderately and only partly clouded with hematite, when compared to heavily altered samples in this study. The plagioclase crystals are sericitised. Epidote and chlorite are present in the wall rock along with some biotite and numerous amphibole crystals which is uncommon in oxidised wall rock. Noteworthy is also that amphiboles, that usually are altered to chlorite close to the fractures, are present very close to the fracture rim and do not look intensively altered.

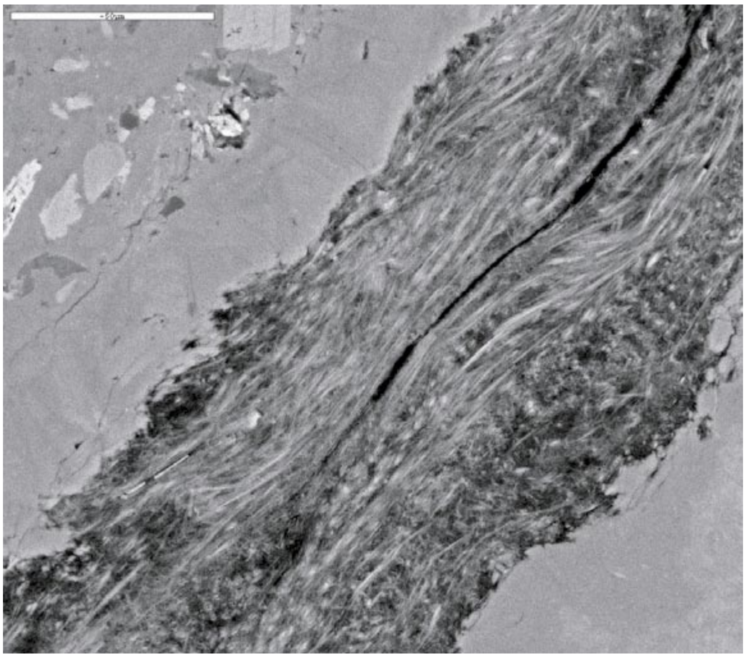

Figure A3. *704.00–704.30(1). Back-scattered electron image showing apophyllite mixed with chlorite (? – see analysis in A4) in a micro fracture cutting through prehnite. Scale bar is 50 µm.*

898.90–899.10 m:

Sample type: Thin section.
Rock type: Heavy altered fine-grained rock.
Fracture: Some microfractures. The main feature in the sample is however the different rates of oxidation/alteration in the wall rock. The sample is very porous in parts, possibly from removal of dissolved quatz crystals. This phenomenon is most prominent in the bright red part of the sample.

The few fractures in this sample are filled with epidote.

Wall rock alteration: The whole sample is intensively red coloured from hematite clouded plagioclase. There are two different types of alteration in this sample. One part of the sample is dark with amphibole, chlorite, opaques and some epidote. The plagioclase is heavily (almost extremely) altered in this part and quartz is almost abscent. The absence of quartz crystals probably originates from the dissollution of quartz crystals (episyenite ?), leaving numerous small voids in the rock. The other part of the sample is more brightly red coloured (although extensive). The dark minerals are fewer and epidote and quartz are more frequent.

948.39–948.56 m:

Sample type: Thin section.
Rock type: Småland granite.
Fracture: Several fracture sets of fractures and microfractures give the sample a breccia-like appearance. Some of the fracture fillings are cataclasitic.
Minerals: Epidote, K-feldspar, Quartz, Albite, Titanite, Apatite, Fluorite.

Order:

1) Epidote – mylonite /cataclasite consisting of fine-grained epidote and slightly smaller crystals of K-feldspar, albite and some titanite and apatite.
2) Veins of poly-crystalline quartz are cutting through the epidote-mylonite. Idiomorphic epidote crystals are occasionally coating the quartz-filled fractures.

Thin veins filled with fluorite are also present in the thin-section.

Wall rock alteration: Strong epidote alteration in the wall rock. Almost 50% of the wall rock consists of epidote crystals. The plagioclase is saussuritised and vaguely and partly clouded by hemtatite micro-grains. The wall rock is breccia-like and dark minerals and chlorite are basically absent.

954.68–954.93 m:

Sample type: Thin section.
Rock type: Småland granite.
Fracture: One major closed fracture, which has been reactivated. There are several micro-fractures within the major fracture. The major fracture is about 2 cm in wide.
Minerals: Epidote, Albite, K-feldspar, Prehnite, Quartz.

Order:

1) Epidote mylonite/cataclasite consisting of epidote, albite and K-feldspar.
2) Epidote, more coarse grained and pure than in 1 in sealed fractures through the mylonite/cataclasite.
3) Prehnite is sealing a breccia of the former fillings. Quartz is present along with prehnite but it is formed slitghly earlier than the prehnite. The prehnite crystals are more or less idiomorphic but the fillings are not equigranular.

Wall rock alteration: The wall rock is more strongly red coloured with decreasing distance from the fracture. The plagioclase is intensively clouded by hematite close to the fracture rim. The plagioclase is also saussuritised. Epidote and chlorite crystals are numerous in the wall rock.

Appendix 4

SEM-EDS analyses

* = below detection limit (< 0.3% Na_20, < 0.1% other oxides).

Clay minerals	**Na_2O**	**MgO**	**Al_2O_3**	**SiO_2**	**K_2O**	**CaO**	**FeO**	**Total**
KLX02: 268 – Illite (ML-clay)	*	3.08	23.39	56.9	7.68	0.36	5.78	97.19
KLX02: 704 – Apoph/chl	*	13.22	0.34	51.52	0.07	10.99	13.46	90.34
KLX02: 676 – Clay mineral	1.53	12.74	4.39	37.51	1.12	2.51	16.82	76.62
KA17755A – 208 Illite/chl	*	3.37	18.14	49.5	6.86	0.36	5.47	83.7
Apophyllite	**Al2O3**	**SiO_2**	**K_2O**	**CaO**	**FeO**	**Total**		
KLX02: 676 – Apophyllite	*	49.79	3.96	19.23	0.23	73.21		
KLX02: 704 – Apophyllite	0.65	51.98	4.23	23.75	*	80.61		
Chlorite	**MgO**	**Al_2O_3**	**SiO_2**	**MnO**	**FeO**	**Total**		
KLX02 – 525 Fe/Mg-Chl	18.11	19.91	26.2	0.6	20.83	85.65		
KAS04 – 182 Fe/Mg-Chl	17.42	20.27	25.89	0.55	21.39	85.52		
KAS04 – 182 Fe/Mg-Chl	17.15	20.74	25.32	0.63	21.25	85.09		
KA17755A – 211 Fe/Mg-Chl (1)	17.1	17.5	30.45	0.42	19.87	86.32		
KAS04 – 65 Fe-Chl (2)	1.76	13.94	24.66	0.15	40.39	81.44		
(1) = incl. 0.64 K_20, 0.18 CaO and 0.16 TiO_2								
(2) = incl. 0.26 K_20 and 0.28 CaO								
Prehnite	**Al_2O_3**	**SiO_2**	**CaO**	**FeO**	**Total**			
KLX02 – 704 Prehnite	21.92	42.88	26.38	3.76	94.94			
KLX02 – 954 Prehnite	20.12	43.09	26.17	5.73	95.11			
KLX02 – 954 Prehnite	22.96	43.25	26.72	2.53	95.46			
KLX02 – 954 Prehnite	24	43.88	27.07	1.21	96.16			
Epidote	**MnO**	**MgO**	**Al_2O_3**	**SiO_2**	**CaO**	**FeO**	**Total**	
KLX02 – 525 Epidote	*	*	20.97	37.06	22	14.99	95.02	
KLX02 – 704 Epidote	0.19	*	21.65	37.36	22.3	14.2	95.7	
KLX02 – 948 Epidote	*	*	24.02	38.72	22.77	11.82	97.33	
KLX02 – 954 Epidote	*	*	20.71	37.47	22.43	15.3	95.91	
KLX02 – 954 Epidote	*	*	21.55	37.51	22.58	14.67	96.31	
KAS04 – 70 Epidote	0.25	0.63	23.44	36.56	21.62	11.52	94.02	
KAS04 – 70 Epidote	0.19	*	22.77	37.39	22.67	12.7	95.72	
KAS04 – 177 Epidote (1)	*	*	25.63	37.53	22.91	8.94	95.01	
KAS04 – 177 Epidote (1)	0.15	*	23.68	36.95	22.52	10.81	94.11	
KAS04 – 177 Epidote (1)	0.13	*	23.48	37.23	22.69	11.7	95.23	
KAS04 – 182 Epidote	0.27	*	22.89	37.46	22.57	12.9	96.09	
KA1755A: 211 – Epidote	0.25	*	23.67	37.71	22.92	12.05	96.6	
(1) = in mylonite								
Muscovite	**Na_2O**	**MgO**	**Al_2O_3**	**SiO_2**	**K_2O**	**TiO_2**	**FeO**	**Total**
KA1755A – 211 Muscovite (1)	0.51	1.77	31.12	45.48	10.87	0.41	3.86	94.11
KA1755A – 211 Muscovite	0.27	2.12	29.39	46.31	10.8	0.7	3.39	92.98
(1) = incl. 0.09 CaO								
Laumontite	**Na_2O**	**Al_2O_3**	**SiO_2**	**K_2O**	**CaO**	**FeO**	**Total**	
KAS04 – 182 Laumontite	1.34	21.8	51.93	0.69	10.19	0.66	86.61	
REE-carbonate	**Al_2O_3**	**CaO**	**FeO**	**Y_2O_3**	**La_2O_3**	**Ce_2O_3**	**Nd_2O_3**	**Total**
KAS04 – 65 REE-carb (1)	1.03	12.84	0.91	2.32	9.19	23.37	7.88	58.6
KAS04 – 65 REE-carb (2)	0.28	16.48	0.25	3.02	7.61	24.17	7.18	59.28
(1) = incl. 0.43 SiO_2 and 0.63 Sm_2O_3								
(2) = incl. 0.29 MgO								

Appendix 5

Fracture filling model from KSH01A+B

1. Quartz, coarse-grained. *(Post-magmatic circulation).*
2.
I) Re-crystallised quartz – idiomorhic pyrite, calcite.
II) Quartz-mylonite, muscovite, chlorite.
III) Epidote-mylonite, (Fe/Mg-chlorite), (calcite) (Greenschist-facies).
3. Prehnite (fluorite) (Fe/Mg-chlorite). *(Prehnite-pumpellyite facies).*
4. Calcite (Fe/Mg-chlorite).
5. Hematite-cataclasite: adularia, Mg-chlorite, hematite, (spherulitic Fe/Mg-chlorite).
(Prehnite-pumpellyite/zeolite facies ?).
6-1: Calcite.
6-2: Quartz (albite).
6-3: Fine grained adularia, Mg-chlorite, apatite, laumontite, (hematite) (calcite).
6-4: Hematite, Fe-chlorite, harmotome, pyrite, (adularia) (calcite) (fluorite).
6-5: Calcite, Mixed-layer clay (chlorite, illite, smectite), (REE-carbonate).
(Zeolite-facies to Surface Conditions ?).

From /Drake and Tullborg, 2004/.