P-09-15

Oskarshamn site investigation

Investigations of goethite-bearing fractures in cored boreholes Laxemar subarea

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Abstract

This report presents a detailed study of possible goethite-bearing fracture coatings/fillings from the Laxemar subarea. The study focused on drill core samples from depths greater than –150 m above sea level. The distribution and characteristics of goethite and other redox sensitive minerals can be used to reveal the depth limit of penetration of oxidising groundwater in the bedrock fractures.

Goethite occurrences mapped during the routine Boremap mapping have been reinvestigated and analysed using microscope and scanning electron microscope (SEM-EDS). Mapping data from all cored boreholes in the Laxemar subarea, have been extracted from the SKB database Sicada, for open fractures, sealed fractures, crush zones, sealed network and rock alteration (including comment files). These data showed that 34 goethite occurrences have been mapped from depths greater than –150 m above sea level.

The results from microscope investigations (mainly SEM-EDS) show that only three of the 34 mapped occurrences may possibly contain fracture coating goethite (present before drilling). The other mapped occurrences are recommended to be removed from the mapping data as it is evident that they are either drilling induced (often as a fine-grained powder on the fracture coating and/or at the side of the drill core) or incorrectly identified. In the former case, the drill core section around the mapped goethite occurrence commonly shows signs of drill wear (parallel, often corroded metallic markings on the drill core side or sheared drill core pieces). There are also indications that some of the goethite-like coatings are actually stains of HCl used during the mapping procedure.

The three probable goethite occurrences are from open fractures, either from a deformation zone (ZSMNE107A in KLX16A) or from a possible deformation zone (in KLX15A), but not in any presently water-conducting sections ("PFL"-anomalies). The deepest of these occurrences are from –316.20 m above sea level (KLX16A).

These three occurrences comprise quite large-grained goethite (up to some tens µm). They thereby differ from potentially recently precipitated X-ray amorphous cryptocrystalline goethite in the area (only identified in near-surface drill core samples). Therefore, it is less probable that the goethite occurrences identified in the present study have been formed recently.

Suggested further studies to obtain a more detailed characterisation of the three remaining probable goethite occurrences from open fractures include U-series disequilibrium of the whole coatings and Fe-oxide analyses (X-ray diffraction, detailed SEM, Mössbauer spectroscopy and Fe isotopes). However, the amount of fracture material needed is a critical issue, as well as the post-drilling handling of the samples.

Sammanfattning

Denna rapport presenterar en detaljerad undersökning av sprickor med möjlig förekomst av götit i delområde Laxemar. Undersökningen fokuserade på borrkärneprover från större djup än –150 m över havet. Utbredningen av götit och dess karaktärsdrag kan avslöja hur djupt syrerikt grundvatten har trängt ner i sprickorna.

Götitförekomster som tidigare identifierats vid den konventionella Boremapkarteringen har här undersökts återigen, med hjälp av mikroskop och svepelektronmikroskop (SEM-EDS). Karteringsdata för öppna sprickor, läkta sprickor, krosszoner, nätverk av läkta sprickor och omvandling (inkluderande kommentarsfilerna till varje kartering) från alla kärnborrhål i delområde Laxemar har extraherats från SKB:s databas Sicada. Karteringsdatan innehöll 34 götitförekomster från djup större än –150 m över havet.

De nya detaljerade mikroskopiska undersökningarna, huvudsakligen SEM-EDS, visade att endast tre av de ursprungligen 34 karterade förekomsterna, möjligen kan innehålla götit som sprickmineral bildat innan borrningen. De andra förekomsterna bör tas bort ur databasen då de med mycket stor sannolikhet är antingen borrinducerade (syns ofta som ett finkornigt mjöl på de befintliga sprickmineralen och/eller på sidan av borrkärnan) eller för att de inte är korrekt identifierade. I det förra fallet visar ofta borrkärnesektionen runt den aktuella förekomsten tydliga tecken på onormalt stor påverkan av borrningen, såsom parallella, ofta korroderade, metalliska spår på sidan av borrkärnan, eller att borrkärnan har skjuvats. Det finns även indikationer på att några av de götitliknande sprickmineralen är fläckar av HCl, som använts vid karteringen.

De tre möjliga götitförekomsterna är alla från öppna sprickor, antingen från en deformationszon (ZSMNE107A i KLX16A) eller från en möjlig deformationszon (i KLX15A), men inte från någon nu vattenförande zon (”PFL”-anomali). Den djupaste förekomsten är från –316,20 m över havet (KLX16A). De tre förekomsterna består av relativt grovkornig götit (upp till några tiotals µm) och avviker därför från potentiellt nyligen bildad götit (kryptokristallin och amorf vid röntgen diffraktion) som identifierats i borrkärneprover nära markytan i området. Det är därför mindre troligt att götitförekomsterna som identifierats i den här studien är bildade nyligen.

För att uppnå en mer detaljerad karaktärisering av de tre kvarvarande möjliga götitproverna, föreslås vidare undersökningar med hjälp av uranserieanalyser (hela sprickfyllnaden) och en serie Fe-oxidanalyser (röntgen diffraktion, detaljerad SEM, Mössbauer spektroskopi och Fe-isotoper). Dock kan både provmängden och hanteringen av borrkärnorna efter borrningen begränsa vidare undersökningar av proverna.

Contents

1 Introduction

This document reports results from a detailed study of goethite-bearing fracture coatings/fillings from the Laxemar subarea. Only mapped occurrences from depths greater than –150 m above sea level have been investigated. Detailed investigations of shallower goethite occurrences in the Laxemar subarea are presented in /Drake and Tullborg 2008d, Dideriksen et al. submitted/. As shown in these studies, the distribution and characteristics of redox sensitive minerals (e.g. goethite) can be used to reveal the depth limit of penetration of oxidising groundwater in the bedrock fractures. /Drake and Tullborg 2008d/ used the distribution and geochemistry of secondary minerals in boreholes KLX09B-G and KLX11B-F to show that the redox transition zone (redox front) in the bedrock fractures between the fracture zones, is located at about 20 m depth, and that this zone corresponds the present conditions in the bedrock. The redox front location was e.g. shown by the presence of Fe(III) minerals (FeOOH; e.g. goethite) and absence of Fe(II) mineral pyrite above the redox front indicating oxidizing conditions. Below the redox front, pyrite was preserved and only scattered goethite occurrences were identified. The latter were associated with highly flowing sections (PFL-anomalies) and/or sections of high fracture frequency.

Another redox sensitive mineral is hematite, which indicates past oxidizing conditions. Because most of the fracture filling hematite in the Laxemar area is interpreted to have been formed under different conditions than those at present, based on its paragenesis of relatively high-temperature minerals /Drake and Tullborg 2005/ and its Fe-isotope values and degree of crystallinity /Dideriksen et al. 2007, Dideriksen et al. submitted/, interpretation of recent redox conditions based on Fe(III)-minerals is mainly based on goethite in this report. Mapped goethite occurrences from great depths may indicate the presence of O_2-rich water at these depths recently. It is therefore important to reinvestigate and further characterise these occurrences (e.g. to determine if the mapping is correct, or to give indications on timing of precipitation).

All goethite occurrences from the Boremap mapping of cored boreholes (files: open, sealed and partly open fractures: p_fract_core; crush zones: p_fract_crush; sealed network: p_fract_sealed_nw and the Boremap comment file: bm_comment for boreholes KLX02 through KLX29A) were extracted from the SKB database Sicada (data delivery: Sicada_08_062).

Activity plan and method description are listed in Table 1-1 and are SKB's internal controlling documents.

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

Activity plan	Number	Version
Kompletterande undersökning av götit i sprickor	AP-PS-400-08-26	1.0
Method descriptions	**Number**	**Version**
Sprickmineralogianalys	SKB MD 144.001	1.0

2 Objective and scope

The objective and scope is to investigate the mineralogy (using microscopy, SEM-EDS) of goethite occurrences from depths greater than –150 m above sea level in cored boreholes from the Laxemar subarea. The task is to give a more detailed description of the occurrences mapped as goethite than what is provided in the conventional drill core mapping. This characterization will give an indication on whether the mapping is correct, because:

1. Correct identification of Fe-oxyhydroxides may be difficult to assess without adequate equipment (e.g. microscope, SEM-EDS or X-ray diffraction).
2. There is a possibility that goethite is emplaced in the fracture during drilling, e.g. as drilling residue (either from metallic iron fragments from drill wear or as a fine-grained drilling induced mixture of rock powder in which iron is oxidized during drilling).

If the mapping of goethite is interpreted to be incorrect it is recommended to be removed from the database. If the mapping of goethite is interpreted to be correct or probable, then suggestions for further analyses of these samples are presented, each based on the characterization of the samples, e.g. amount of fracture coating and grain size.

3 Equipment

3.1 Description of equipment

The following equipment is used in the investigations:

- Scanning electron microscope (Hitachi S-3400N) with EDS (IncaDryCool).
- Stereo microscope (Leica MZ12).
- Digital camera (Canon S3 IS).
- Rock saw.
- Magnifying lens –10x.
- Scanner (Epson 3200).

4 Execution

4.1 Sample collection and preparations

All of the 34 mapped goethite occurrences listed in Table 4-1 through Table 4-4 were examined using hand lens and stereo microscope at the SKB drill core storage in Oskarshamn. Figure 4-1 shows the depth distribution of the mapped occurrences. The occurrences are from boreholes KLX04, KLX05, KLX07A, KLX08, KLX09, KLX10, KLX12A, KLX13A, KLX15A, KLX16A and KLX19A, and are from open fractures (21 occurrences), sealed fractures (5), crush zones (2), sealed network (5) and rock alteration (1). Four of these open fractures are from water conducting sections ("PFL" in Figure 4-1), although they are not the "best choice" flowing fracture in this interval.

During the sampling and initial examination in the drill core storage, 14 of the mapped occurrences were interpreted to be incorrect (corroded metallic markings on the core resulting from drill wear or complete lack of goethite or other Fe-oxyhydroxides) and these were not sampled (brief descriptions are found in Appendix 1). The other twenty mapped occurrences required more detailed investigations before any interpretations could be made. Therefore, these occurrences were sampled and examined in greater detail, and are described in detail in Chapter 5.

All of the samples were photographed and examined with stereo microscope. A subsample for scanning electron microscopy (SEM-EDS) investigation from each sample was prepared by sawing, using a rock saw. The subsample was scanned using a scanner and then investigated using SEM-EDS, in order to identify and characterize the fracture minerals.

Table 4-1. Mapping information of mapped goethite-bearing open and sealed fractures (from p_fract_core in data delivery Sicada_08_062).

Sampled (Y/N)	IDCODE (Borehole)	FRACT_ MAPPED	FRACT_ INTERPRET	Adj. SecUp	MIN1	MIN2	MIN3	MIN4	STRIKE	DIP	Deformation zone	Elevation m.a.s.l.
N	KLX05	Broken	Sealed	518.300	Hematite	**Goethite**	Chlorite					–449.44
N	KLX05	Broken	Open	602.397	Hematite	**Goethite**	Calcite		297.1	3.6		–525.47
N	KLX07A#	Broken	Open	311.414	**Goethite**	Chlorite					Possible DZ	–222.98
Y	KLX07A	Broken	Sealed	432.144	Calcite	Chlorite	**Goethite**		140.7	75.2		–309.57
Y	KLX08	Broken	Open	388.349	Calcite	Chlorite	Pyrite	**Goethite**	194.7	48.3		–311.36
Y	KLX08	Broken	Open	388.561	Chlorite	Calcite	Clay Minerals	**Goethite**	232.4	29.5		–311.54
Y	KLX09	Broken	Open	437.210	Pyrite	**Goethite**			356.1	7.0		–410.62
N	KLX09	Broken	Open	574.242	Chlorite	**Goethite**			74.4	11.3		–546.66
Y	KLX10	Broken	Open	331.987	Calcite	Chlorite	Quartz	**Goethite**	358.0	32.1	ZSMNE942A	–311.10
Y	KLX10	Broken	Open	332.012	Calcite	Chlorite	Hematite	**Goethite**	316.5	21.5	ZSMNE942A	–311.13
Y	KLX10#	Broken	Open	704.339	Calcite	Clay Minerals	**Goethite**		92.4	9.9	ZSMEW946A	–680.99
N	KLX12A	Unbroken	Sealed	313.853	Epidote	Pyrite	**Goethite**	Calcite	335.4	78.9		–282.47
Y	KLX12A	Broken	Open	332.221	Calcite	Chlorite	**Goethite**		280.7	13.4		–300.17
N	KLX13A	Broken	Open	394.712	Chlorite	**Goethite**	Pyrite		321.8	7.2		–367.46
Y	KLX13A#	Broken	Open	550.762	**Goethite**	Chlorite	Clay Minerals		10.3	38.7	ZSMEW120A	–522.31
Y	KLX13A#	Broken	Open	550.766	**Goethite**	Chlorite	Clay Minerals		327.4	20.1	ZSMEW120A	–522.32
Y	KLX13A	Broken	Open	551.406	Clay Minerals	Chlorite	**Goethite**		358.2	69.7	ZSMEW120A	–522.95
Y	KLX15A	Broken	Open	379.524	Chlorite	Calcite	**Goethite**	Hematite	193.9	25.4	Possible DZ	–279.44
Y	KLX16A	Broken	Open	348.067	Calcite	Epidote	Hematite	**Goethite**	44.5	34.9	ZSMNE107A	–294.91
Y	KLX16A	Broken	Open	348.173	Calcite	Hematite	**Goethite**		290.3	37.0	ZSMNE107A	–295.00
Y	KLX16A	Broken	Open	371.851	Calcite	**Goethite**	Hematite		18.1	61.7	ZSMNE107A	–316.20
N	KLX16A	Broken	Open	406.842	Calcite	Hematite	**Goethite**		269.5	56.0	ZSMNE107A	–347.53
Y	KLX16A	Unbroken	Sealed	408.237	Hematite	**Goethite**			45.7	23.3	ZSMNE107A	–348.78
Y	KLX16A	Unbroken	Sealed	408.241	Hematite	**Goethite**			320.2	47.3	ZSMNE107A	–348.79
Y	KLX19A	Broken	Open	229.510	Chlorite	Calcite	**Goethite**		286.4	32.9		–176.68
Y	KLX19A	Broken	Open	414.363	Calcite	Chlorite	**Goethite**		93.9	14.0	Possible DZ	–331.53

Fracture is in water conductive section (PFL anomaly) but is not listed as best choice fracture in the Sicada data.

Table 4-2. Mapping information of goethite-bearing crush zones (from p_fract_crush in data delivery Sicada_08_062).

Sampled (Y/N)	IDCODE (Borehole)	Adj. SecUp	Adj. SecLow	MIN1	MIN2	MIN3	MIN4	Deformation zone	Elevation (Adj. SecUp)
N	KLX04	894.446	895.104	Calcite	Chlorite	Clay Minerals	**Goethite**	klx04_dz6b	–865.72
Y	KLX13A	543.969	545.034	Chlorite	Clay Minerals	Calcite	**Goethite**	ZSMEW120A	–515.57

Table 4-3. Mapping information of goethite-bearing sealed network (from p_fract_sealed_nw in data delivery Sicada_08_062).

Sampled (Y/N)	IDCODE (Borehole)	Adj. SecUp	Adj. SecLow	MIN1	MIN2	MIN3	MIN4	Deformation zone	Elevation (Adj. SecUp)
N	KLX04	239.554	239.652	Red Feldspar	Quartz	**Goethite**		FSM_N	–214.24
N	KLX04	674.848	676.405	Calcite	**Goethite**	Chlorite	Pyrite	FSM_EW007	–647.55
N	KLX13A	576.768	576.897	Chlorite	Calcite	**Goethite**		ZSMEW120A	–548.12
Y	KLX13A	578.330	583.590	Chlorite	Prehnite	Calcite	Adularia*	ZSMEW120A	–549.67
N	KLX16A	406.600	407.100	Calcite	Hematite	Prehnite	**Goethite**	ZSMNE107A	–347.32

*Goethite listed as additional mineral in the Boremap comment file (bm_comment in data delivery Sicada_08_062).

Table 4-4. Mapping information of goethite alteration included in Boremap comment file (bm_comment in delivery Sicada_08_062)*

Sampled (Y/N)	IDCODE (Borehole)	Adj. SecUp	Adj. SecLow	Deformation zone	Elevation (Adj. SecUp)
N	KLX04	963.19	963.26	klx04_dz1c	–933.98

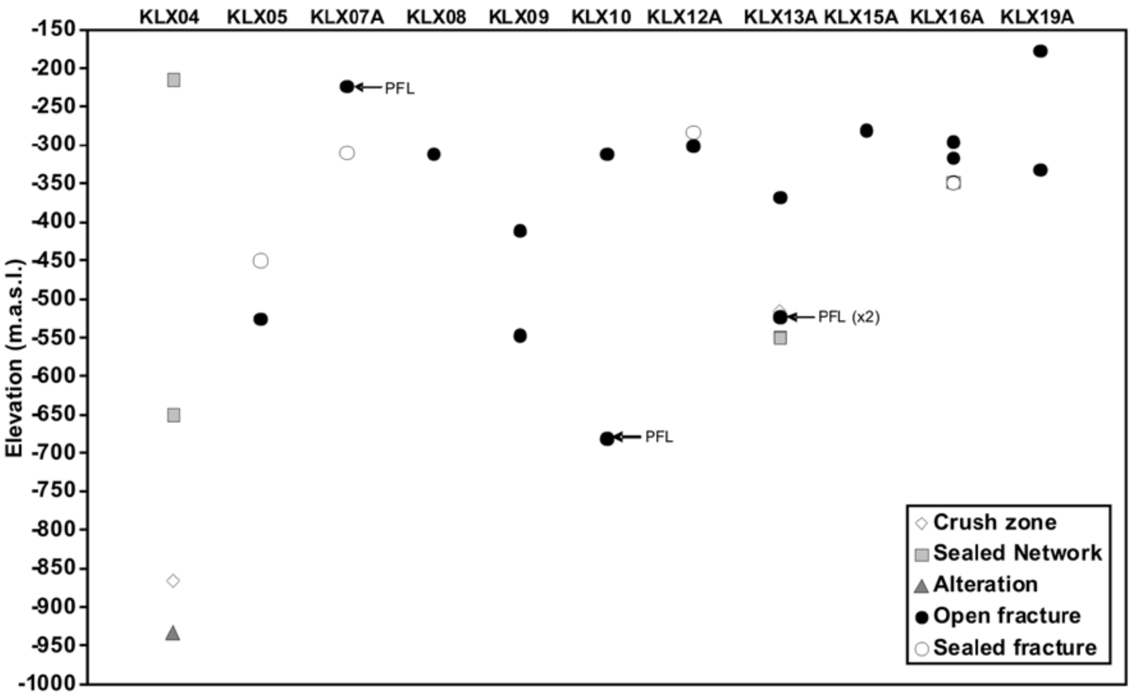

Figure 4-1. *Depth distribution of all mapped goethite occurrences from greater depth than –150 m above sea level (as listed in Table 4-1 to Table 4-4). "PFL" = Fracture is in water conductive section (PFL anomaly) but is not listed as best choice fracture in the Sicada data.*

4.2 SEM-EDS analyses

SEM-EDS analyzes were carried at the Department of Earth Sciences, University of Gothenburg. The acceleration voltage was 20 kV and the specimen current was about 1nA. X-ray spectrometric corrections were made by an on-line Oxford INCA software. Detection limit was 0.1 oxide % and Fe(II) and Fe(III) were not distinguished. Quantitative chemical analyzes were not achieved for fracture surface samples due to the uneven surface of the samples. Minerals from these samples were identified by visual inspection and interpretation of X-ray spectra or element ratios.

5 Results

5.1 Descriptions of samples

Explanations to the abbreviations in the tables are presented in Appendix 2.

5.1.1 Open fractures

Sample: KLX08: 388.30–388.35 m

Old mapping data		Suggested updated mapping data	
IDCODE	KLX08	**IDCODE**	KLX08
FRACT_MAPPED	Broken	**FRACT_MAPPED**	Broken
FRACT_INTERPRET	Open	**FRACT_INTERPRET**	Open
ADJUSTEDSECUP	388.349	**ADJUSTEDSECUP**	388.349
MIN1	Calcite	**MIN1**	Calcite
MIN2	Chlorite	**MIN2**	Chlorite
MIN3	Pyrite	**MIN3**	Pyrite
MIN4	Goethite	**MIN4**	Clay minerals

Description: The mapped goethite occurrence is found in an open fracture (Figure 5-1) as a fine-grained, brown powder on the fracture surface (Figure 5-2). The powder is made up of fine-grained, angular mineral fragments (Figure 5-3), which in turn are made up of common rock forming minerals such as quartz and feldspars but also of chlorite, clay minerals and Fe-oxides (which give the colouration). EDS analyzes indicate a significant amount of Zn, Mn, C and Cl on the surface of these minerals (especially related to Fe-oxides and Fe-rich chlorite/clay minerals). Zn, Mn, as well as C might originate from the drilling equipment and Cl may be a remnant from the mapping (i.e. HCl used for calcite identification). Individual fragments of native Zn or Zn-oxide are also observed. This fine-grained powder is only found in morphological depressions of the fracture surface, which indicates that it has been emplaced after the drilling (and not precipitated on the fracture surface). These observations indicate that the fine-grained powder mapped as goethite, is drilling induced and is therefore recommended to be removed from the mapping data. As described below for other samples, significant peaks for Zn, Cl, Mn and C in the spectra are typical for fine-grained, brown coloured powder, which is interpreted to be drilling induced. In contrast, most other fracture coating minerals identified in this and in other samples show no peaks for Cl, C, Mn and Zn.

Figure 5-1. *Photograph of fracture KLX08: 388.349 m.*

Figure 5-2. *Photograph of fracture KLX08: 388.349 m.*

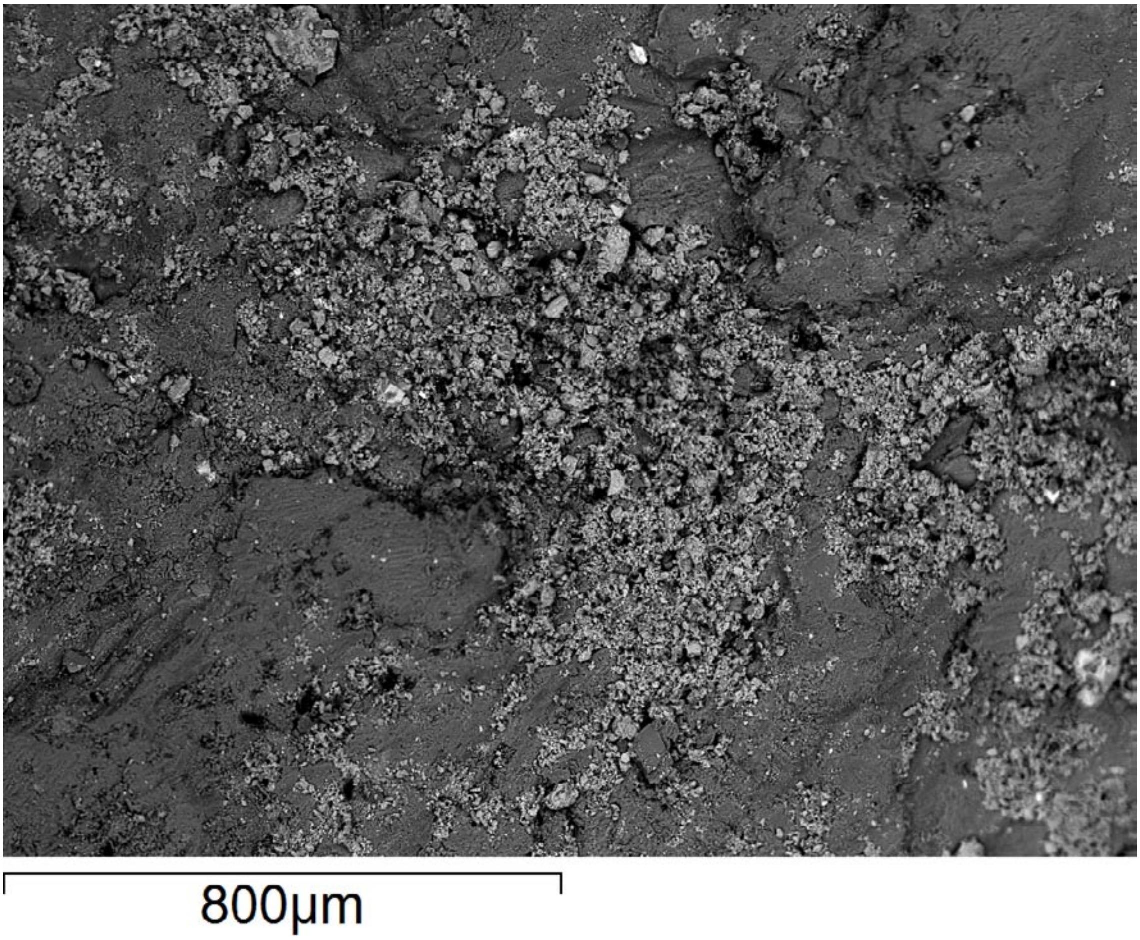

Figure 5-3. *Back-scattered SEM-image of fine-grained, brown-coloured powder on the smooth fracture surface of open fracture KLX08: 388.349 m.*

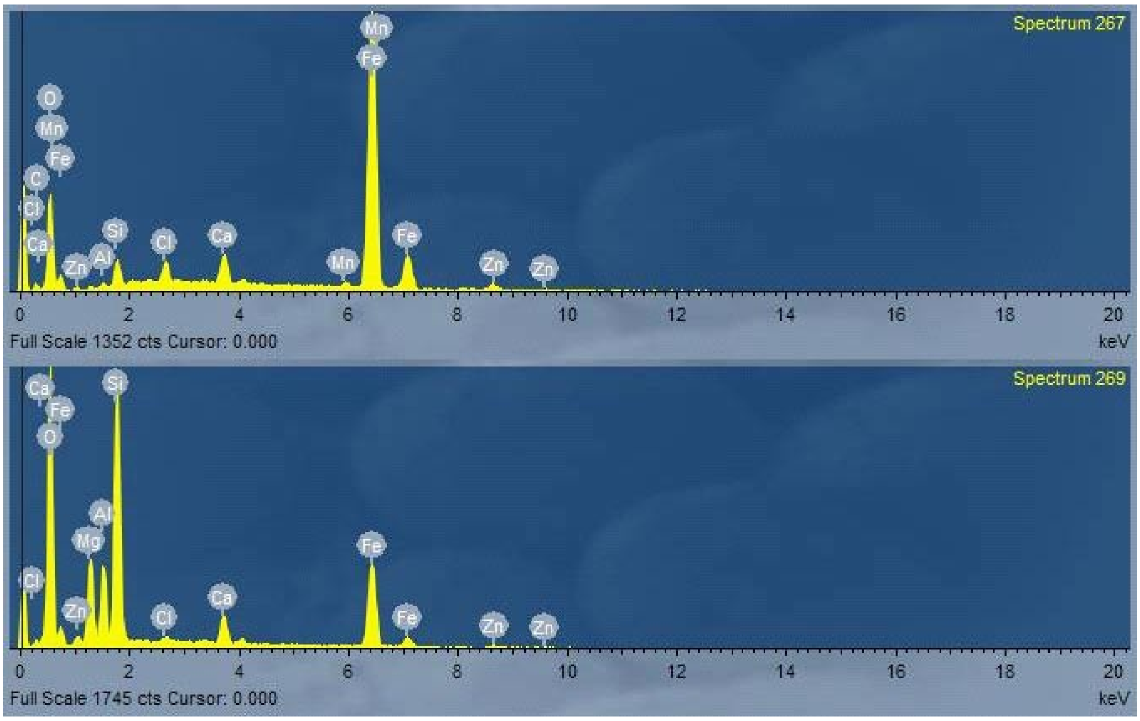

Figure 5-4. *EDS-spectra for Fe-oxide (Spectrum 267) and Fe-rich chlorite/clay mineral (Spectrum 269) from open fracture KLX08: 388.349 m. Note the peaks for C, Cl, Zn and Mn.*

Sample: KLX08: 388.53–388.61 m

Old mapping data		**Suggested updated mapping data**	
IDCODE	KLX08	**IDCODE**	KLX08
FRACT_MAPPED	Broken	**FRACT_MAPPED**	Broken
FRACT_INTERPRET	Open	**FRACT_INTERPRET**	Open
ADJUSTEDSECUP	388.561	**ADJUSTEDSECUP**	388.561
MIN1	Chlorite	**MIN1**	Chlorite
MIN2	Calcite	**MIN2**	Calcite
MIN3	Clay Minerals	**MIN3**	Clay Minerals
MIN4	Goethite	**MIN4**	Pyrite
		Comment	Chalcopyrite

Description: The mapped goethite occurrence is found in an open fracture as a fine-grained, brown powder on the fracture surface and on the fresh drill core surface (Figure 5-5). The powder is made up of fine-grained, angular mineral fragments of common rock forming minerals such as quartz and feldspars but also of chlorite, clay minerals and Fe-oxides (which give the colouration, Figure 5-6 and Figure 5-7). EDS analyzes indicate a significant amount of Zn, Mn, C, Si and Cl on the surface of these minerals (especially related to Fe-oxides and Fe-rich chlorite/clay minerals, Figure 5-8). Zn, Mn, as well as C and Si might originate from the drilling equipment and Cl may be a remnant from the mapping (HCl used for calcite identification). This fine-grained powder is only found in morphological depressions on the fracture surface, which indicate that it has been emplaced after the drilling (and have not been precipitated on the fracture surface). These observations indicate that the fine-grained powder mapped as goethite, is drilling induced and is recommended to be removed from the mapping data. Additional minerals to be included in the mapping file are pyrite and chalcopyrite.

***Figure 5-5.** Photographs of fracture KLX08: 388.561 m. Arrows show drilling induced mineral fragments on the side of the drill core.*

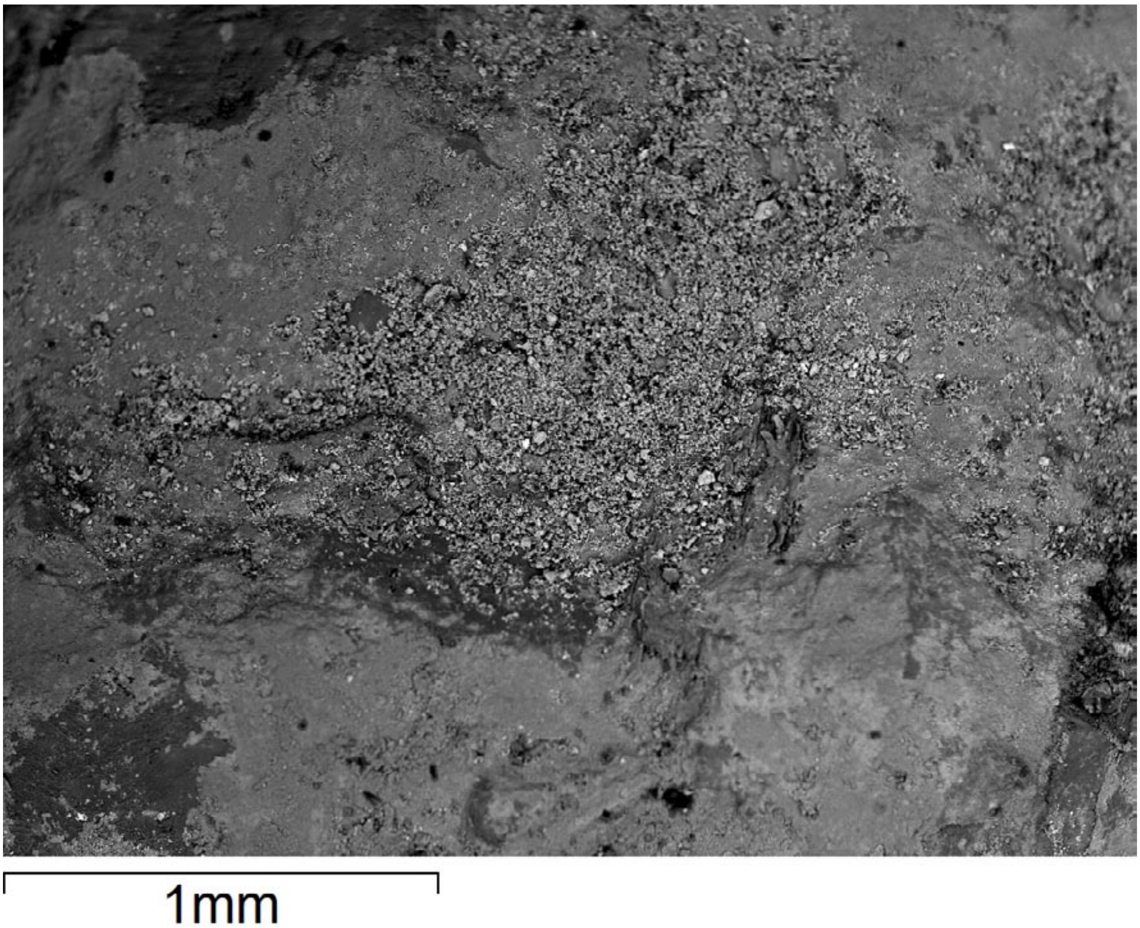

***Figure 5-6.** Back-scattered SEM-image of the fracture surface of open fracture KLX08: 388.561 m.*

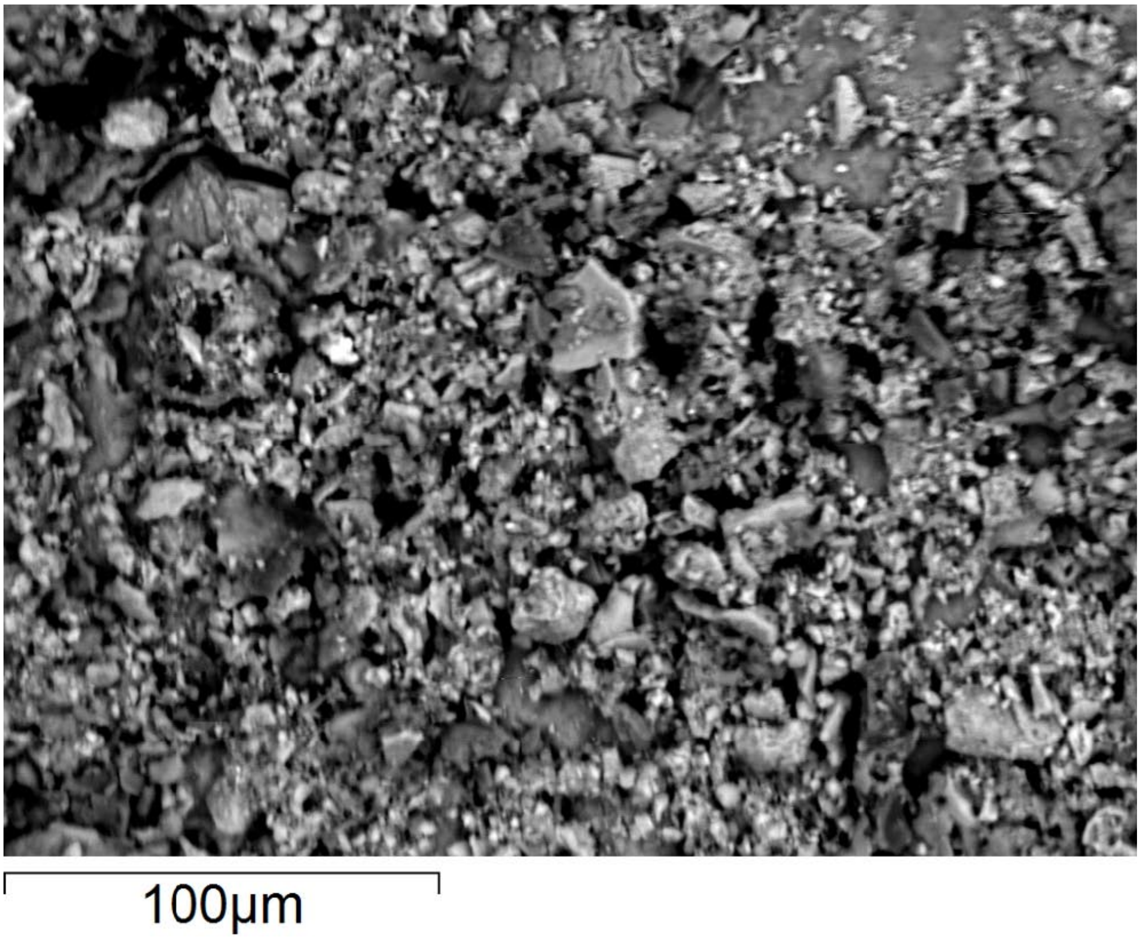

Figure 5-7. Back-scattered SEM-image of the fracture surface of open fracture KLX08: 388.561 m.

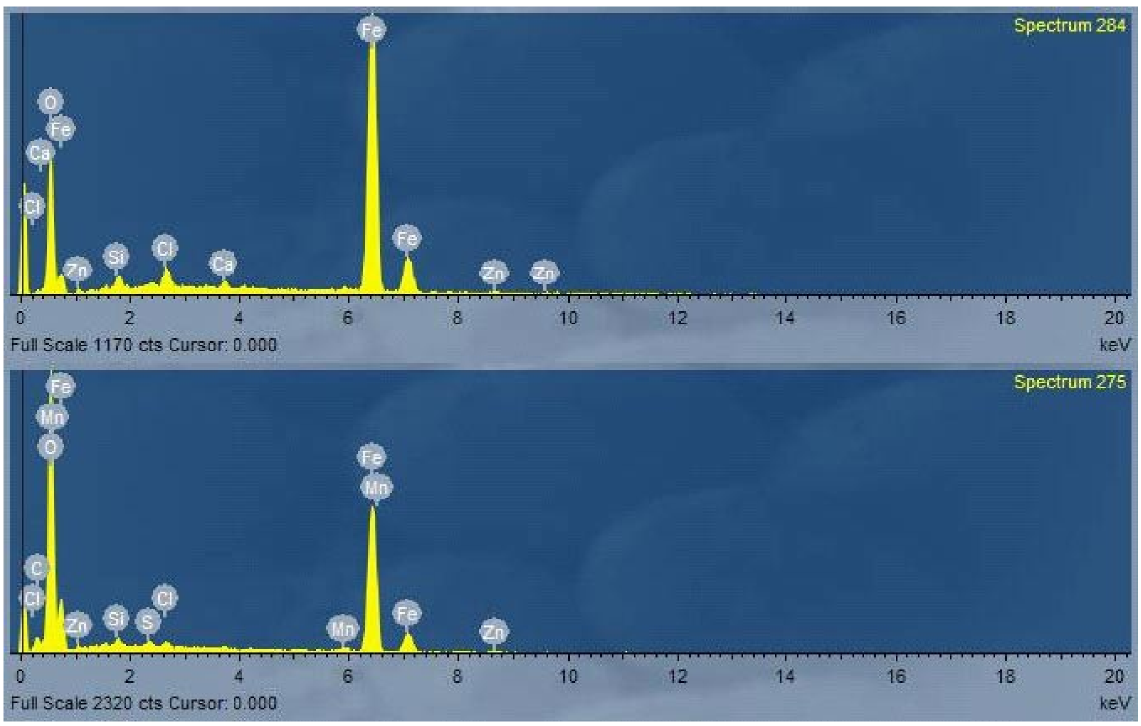

Figure 5-8. EDS-spectra for Fe-oxides (Spectrum 284 and Spectrum 275) from fracture KLX08: 388.561 m. Note the peaks for C, Cl, Zn and Mn.

Sample: KLX09: 437.22–437.27 m

Old mapping data		Suggested updated mapping data	
IDCODE	KLX09	**IDCODE**	KLX09
FRACT_MAPPED	Broken	**FRACT_MAPPED**	Broken
FRACT_INTERPRET	Open	**FRACT_INTERPRET**	Open
ADJUSTEDSECUP	437.210	**ADJUSTEDSECUP**	437.210
MIN1	Pyrite	**MIN1**	
MIN2	Goethite	**MIN2**	
MIN3		**MIN3**	
MIN4		**MIN4**	

Description: The mapped goethite occurrence is found in an open fracture (Figure 5-9) as fine-grained, scattered spots with metallic lustre (Figure 5-10). The spots are partly corroded. They are interpreted to be fragments from the drilling equipment because they resemble metallic fragments which have corroded (as shown in the SEM-images Figure 5-11, Figure 5-12). In addition, the EDS-analyses show that these fragments are made up of Fe mainly, but include some Si, Zn, Mn, S, Mo, C and Cl as well (Figure 5-13). This further supports an origin from the drilling equipment, which is Fe-dominated and have trace amounts of e.g. Mn, Mo and Si. Furthermore, metallic markings on the core, resulting from drill wear, adjacent to this fracture (Figure 5-9) indicate that the drilling has been experiencing some difficulties at this stage and it is therefore even more likely that fragments from the drilling equipment has been emplaced on the fracture surface. During the drill core mapping, these metallic spots were identified as pyrite crystals, which have been partly altered to goethite. SEM-investigations show that no pyrite is present. Instead, the spots are interpreted to be fragments from the drilling equipment and both pyrite and goethite should therefore preferably be removed from the mapping data.

Figure 5-9. *Photograph of fracture KLX09: 437.210 m.*

Figure 5-10. *Photograph of fracture surface from open fracture KLX09: 437.210 m.*

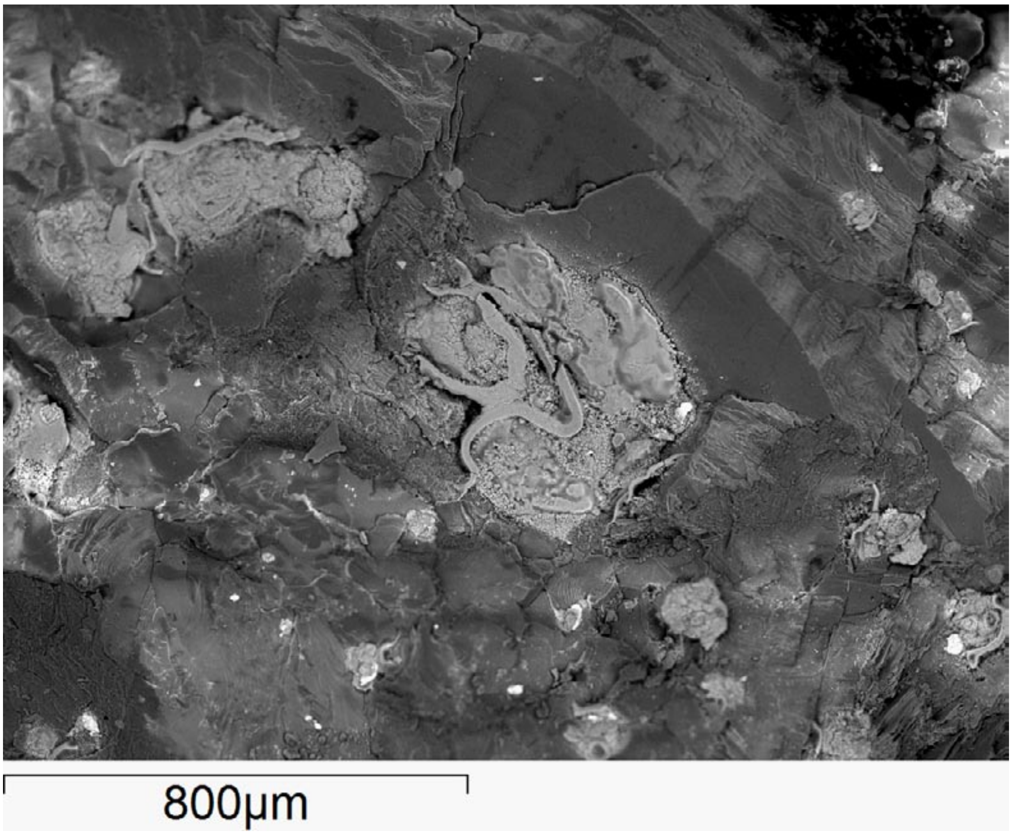

Figure 5-11. *Back-scattered SEM-image of metallic fragments on the surface of open fracture KLX09: 437.210 m.*

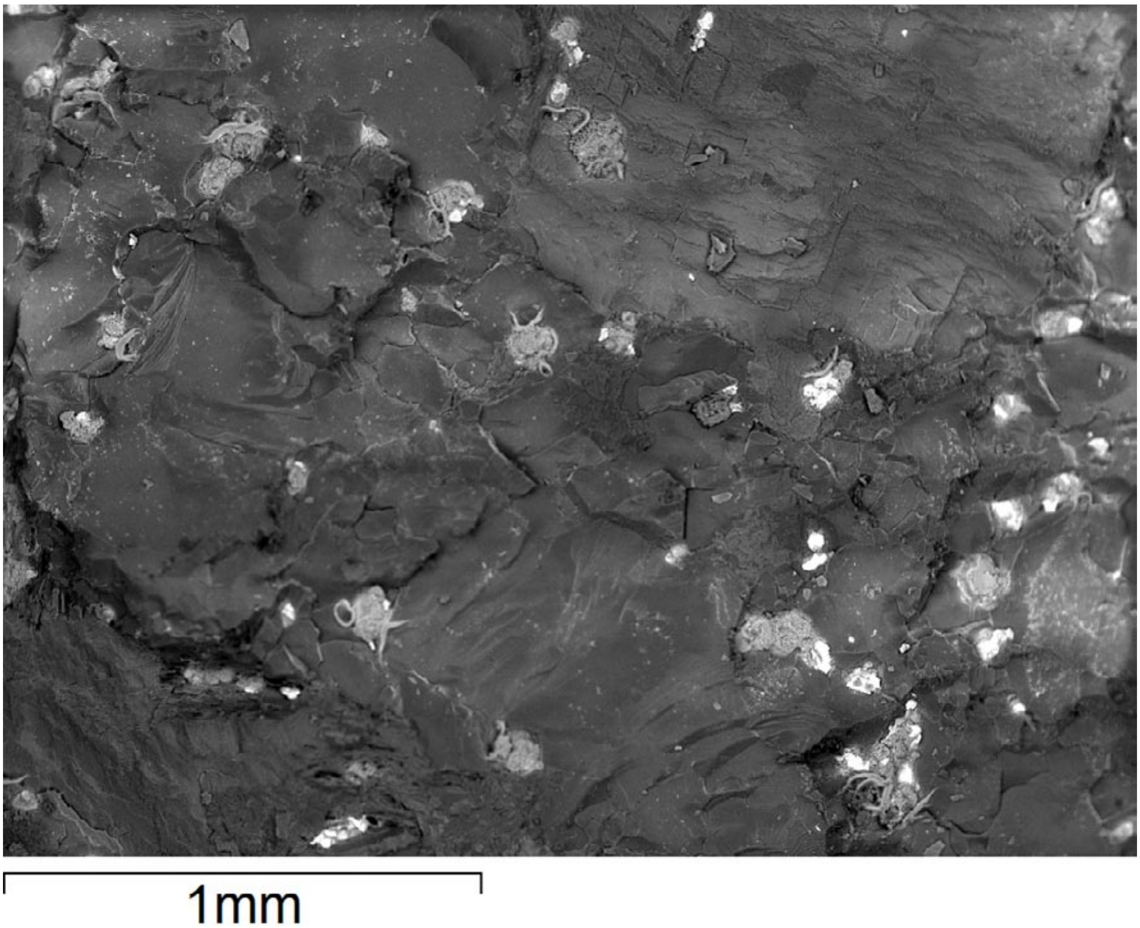

***Figure 5-12.** Back-scattered SEM-image of metallic fragments on the surface of open fracture KLX09: 437.210 m.*

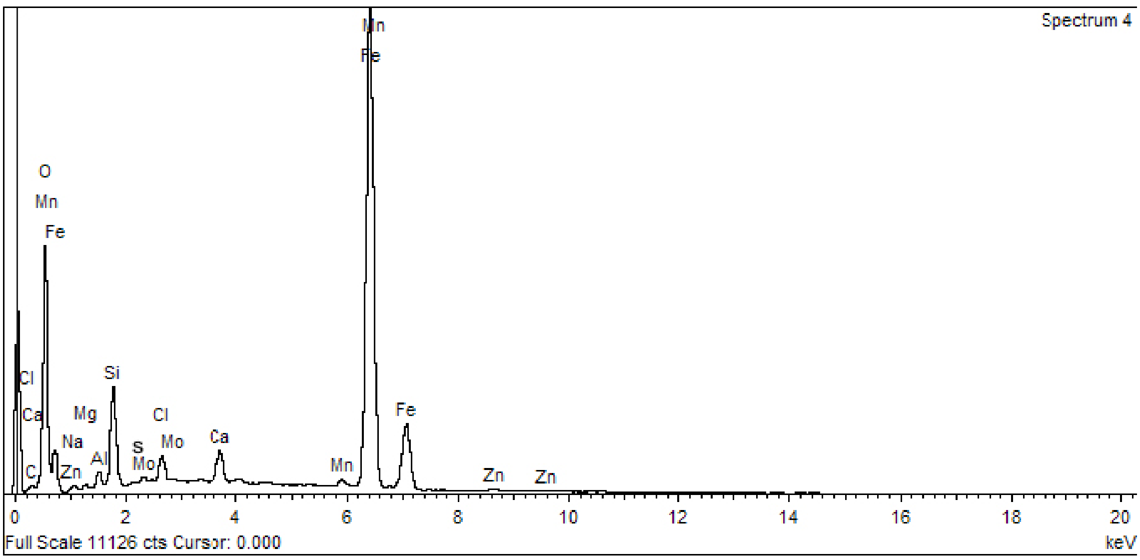

***Figure 5-13.** EDS-spectrum for metallic fragment on the surface of fracture KLX09: 437.210 m.*

Sample: KLX10: 331.97–332.02 m

This sample contains two fractures with mapped goethite occurrences (sample is shown in Figure 5-14).

Figure 5-14. *Photograph of sample KLX10: 331.97–332.02 m (the two pieces in the centre of the photograph).*

Old mapping data		Suggested updated mapping data	
IDCODE	KLX10	**IDCODE**	KLX10
FRACT_MAPPED	Broken	**FRACT_MAPPED**	Broken
FRACT_INTERPRET	Open	**FRACT_INTERPRET**	Open
ADJUSTEDSECUP	331.987	**ADJUSTEDSECUP**	331.987
MIN1	Calcite	**MIN1**	Calcite
MIN2	Chlorite	**MIN2**	Chlorite
MIN3	Quartz	**MIN3**	Quartz
MIN4	Goethite	**MIN4**	Hematite

Description: The mapped goethite occurrence is found in an open fracture as a fine-grained, brown powder on the fracture surface, especially around the drill core edges, which may indicate that it is drilling induced powder (Figure 5-15). The powder consists of fine-grained, angular mineral fragments (Figure 5-16 and Figure 5-17). These fragments are made up of common rock forming minerals such as quartz and feldspars but also of chlorite, clay minerals and Fe-oxides (which give the colouration). EDS analyzes indicate a significant amount of V, Ti, Ca, Cl on the surface of these minerals (especially related to Fe-oxides and Fe-rich chlorite/clay minerals, Figure 5-8). Some of these elements might originate from the drilling equipment. Some of the parts of the filling show typical hematite colour (cf. /Drake and Tullborg 2004, 2007/, and hematite is therefore suggested to replace goethite in the mapping data, because goethite is probably emplaced as a drilling induced powder on the fracture surface. This interpretation is based on the angular fragments of this coating and by the position of the powder on the fracture surface, i.e. mostly at the drill core rim, as well as partly by the chemistry of the powder, i.e. rich in elements which generally are rare in fracture coatings cf. /Drake and Tullborg 2008abc/).

Figure 5-15. *Photograph of open fracture KLX10: 331.987 m.*

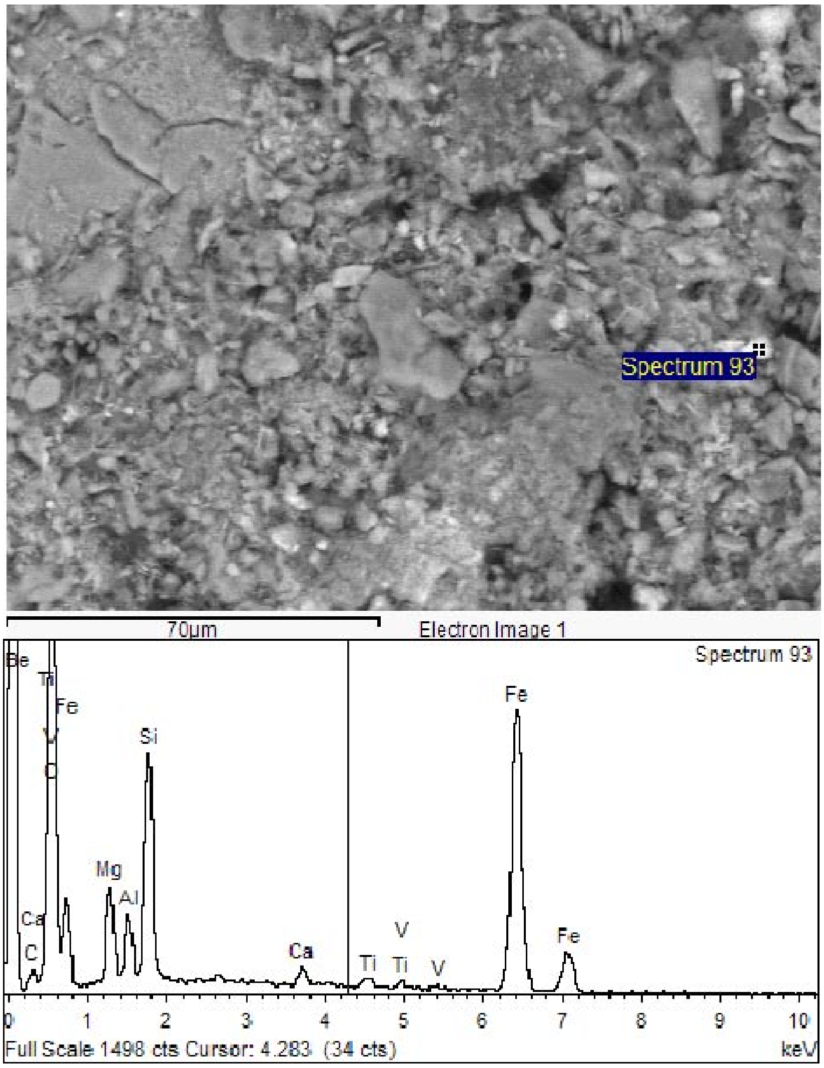

Figure 5-16. *Back-scattered SEM-image and related EDS-spectrum for Fe-rich clay mineral (or chlorite) (Spectrum 93) in powder of fine-grained angular mineral fragments from open fracture KLX10: 331.987 m.*

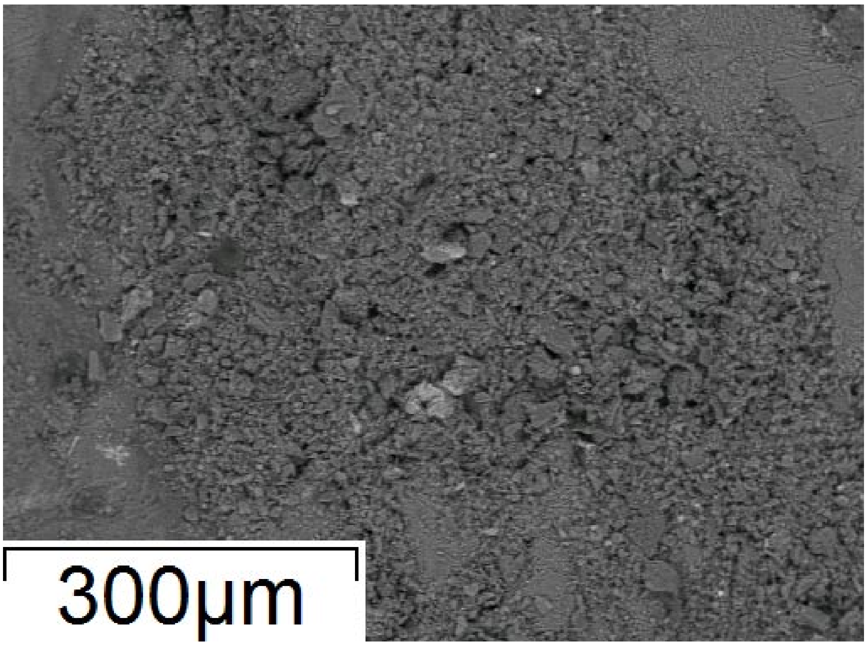

Figure 5-17. Back-scattered SEM-image of powder of fine-grained angular mineral fragments from open fracture KLX10: 331.987 m.

Old mapping data		Suggested updated mapping data	
IDCODE	KLX10	**IDCODE**	KLX10
FRACT_MAPPED	Broken	**FRACT_MAPPED**	Broken
FRACT_INTERPRET	Open	**FRACT_INTERPRET**	Open
ADJUSTEDSECUP	332.012	**ADJUSTEDSECUP**	332.012
MIN1	Calcite	**MIN1**	Calcite
MIN2	Chlorite	**MIN2**	Chlorite
MIN3	Hematite	**MIN3**	Hematite
MIN4	Goethite	**MIN4**	Clay minerals

Pyrite should be added to the comment file (bm_comment).

Description: The mapped goethite occurrence is found in an open fracture as a fine-grained, brown powder on the fracture surface especially around the drill core edges, which may indicate that it is drilling induced powder (Figure 5-18). The powder consists of fine-grained, angular mineral fragments (Figure 5-19 and Figure 5-20). These fragments are made up of quartz and feldspars but also of chlorite, clay minerals and Fe-oxides (which give the colouration). EDS analyzes indicate a significant amount of Mn, Ti, Ca, Cl on the surface of these minerals (especially related to Fe-oxides and Fe-rich chlorite/clay minerals, Figure 5-8). Some of these elements (e.g. Mn) may originate from the drilling equipment. Parts of the filling show typical hematite colour (cf. /Drake and Tullborg 2004, 2007/. Goethite is interpreted to have been emplaced as a drilling induced powder on the fracture surface (as indicated by the angular fragments of this coating and by the position of the powder on the fracture surface, i.e. at the drill core rims and where originally present minerals have been damaged and removed during drilling, as well as partly by the chemistry of the powder, i.e. rich in elements which are rare in fracture coatings otherwise, cf. /Drake and Tullborg 2008abc/). Furthermore, fresh unaltered pyrite is present on the fracture surface, indicating prevailing reducing conditions in the fracture. These observations indicate that the fine-grained powder mapped as goethite, is drilling induced and is therefore recommended to be removed from the mapping data. Clay minerals and pyrite should be included in the mapping data.

Figure 5-18. *Photograph of open fracture KLX10: 332.012 m.*

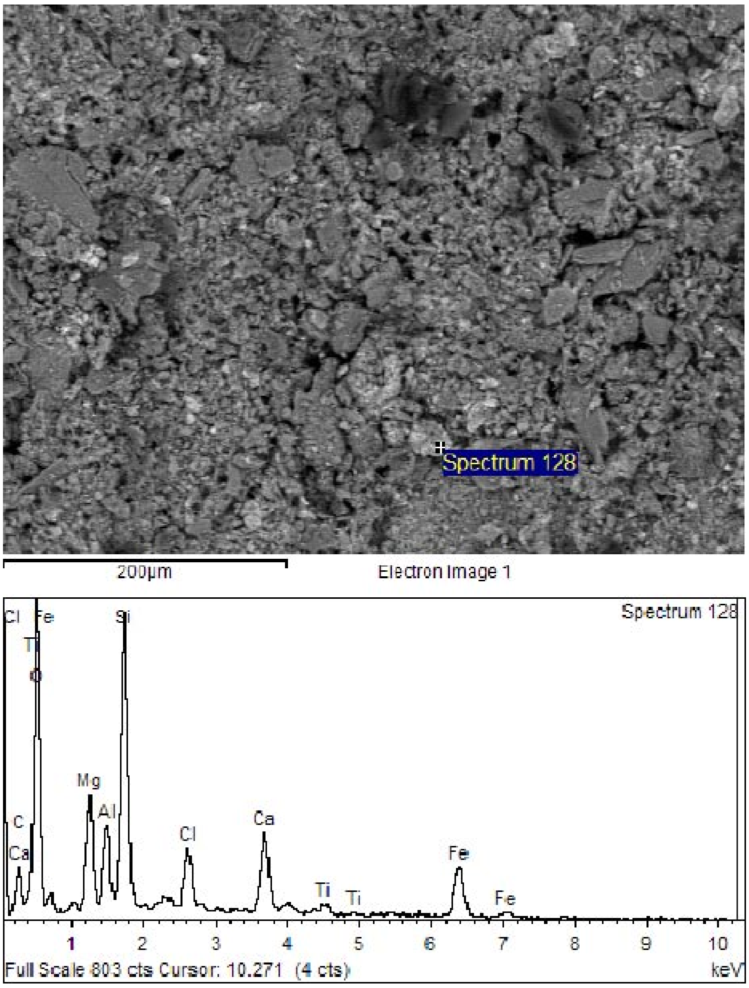

Figure 5-19. *Back-scattered SEM-image and related EDS-spectrum for Fe-rich and Ca-rich clay mineral (Spectrum 128) in powder of fine-grained angular mineral fragments from open fracture KLX10: 332.012 m.*

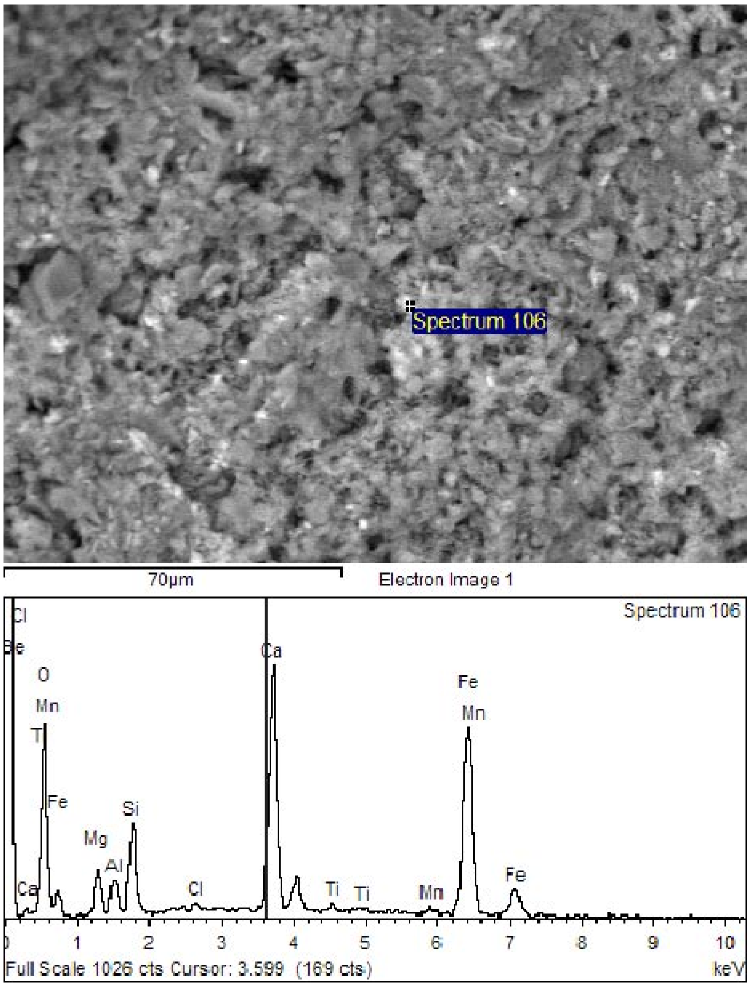

Figure 5-20. *Back-scattered SEM-image and related EDS-spectrum for a mixture of Fe-rich clay mineral and calcite (Spectrum 106) in powder of fine-grained angular mineral fragments from open fracture KLX10: 332.012 m.*

Sample: KLX10: 704.32–704.44 m

Old mapping data		**Suggested updated mapping data**	
IDCODE	KLX10	**IDCODE**	KLX10
FRACT_MAPPED	Broken	**FRACT_MAPPED**	Broken
FRACT_INTERPRET	Open	**FRACT_INTERPRET**	Open
ADJUSTEDSECUP	704.339	**ADJUSTEDSECUP**	704.339
MIN1	Calcite	**MIN1**	Calcite
MIN2	Clay Minerals	**MIN2**	Clay Minerals
MIN3	Goethite	**MIN3**	Adularia
MIN4		**MIN4**	Pyrite

Description: The mapped goethite occurrence is found in an open fracture as a fine-grained, brown powder on the surface of an older fracture mineral coating (Figure 5-21). Detailed SEM-EDS investigations reveal that no Fe-rich minerals (except fresh pyrite) are present in the coating. Most of the coating is made up of calcite, illite and adularia (possibly hematite-stained, but no hematite was identified) with minor amount of pyrite (Figure 5-22). Therefore it is suggested that goethite is removed from the mapping data.

Figure 5-21. *Photograph of sample KLX10: 704.32–704.44 m with fracture surface of open fracture KLX10: 704.339 m shown.*

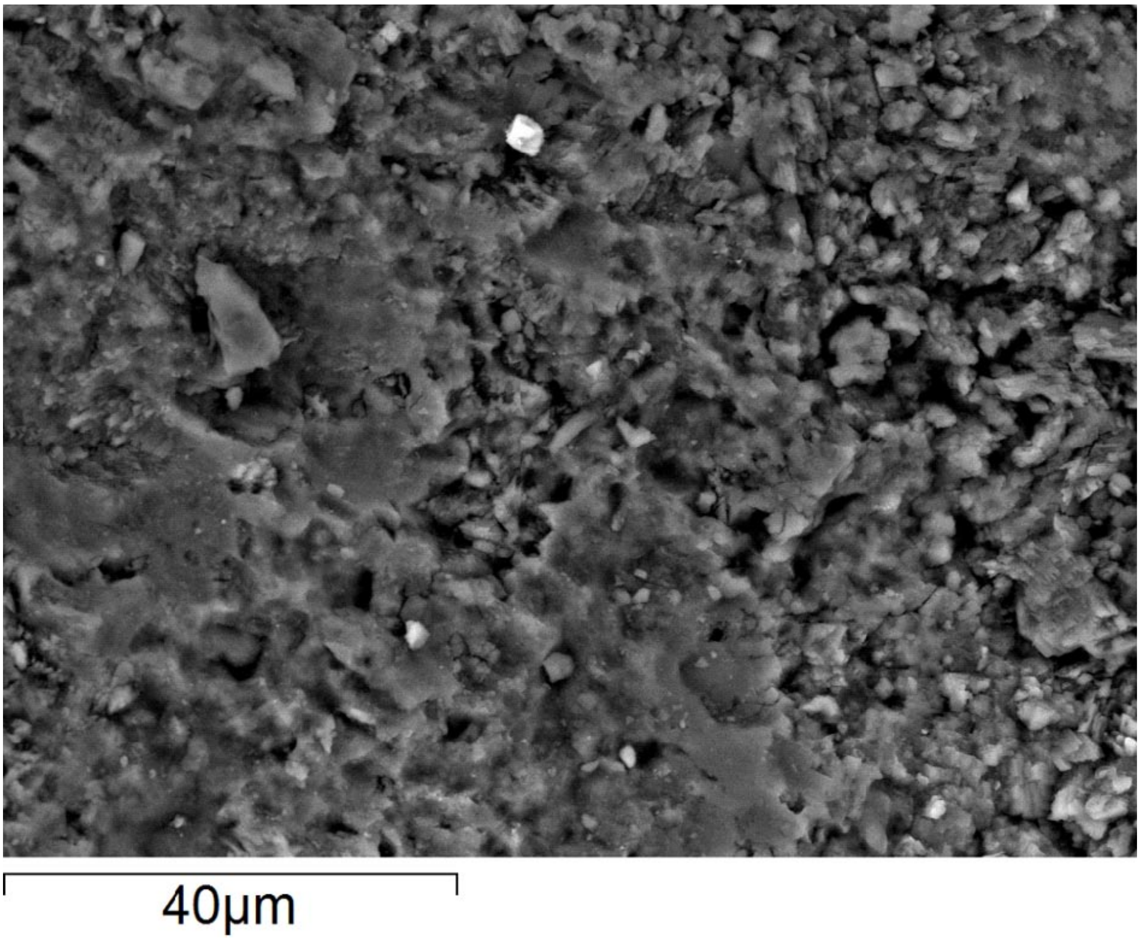

Figure 5-22. *Back-scattered SEM-image of illite and adularia coating (dark) with a bright pyrite crystal on the fracture surface of open fracture KLX10: 704.339 m.*

Sample: KLX12A: 332.17–332.25 m

Old mapping data		Suggested updated mapping data	
IDCODE	KLX12A	**IDCODE**	KLX12A
FRACT_MAPPED	Broken	**FRACT_MAPPED**	Broken
FRACT_INTERPRET	Open	**FRACT_INTERPRET**	Open
ADJUSTEDSECUP	332.221	**ADJUSTEDSECUP**	332.221
MIN1	Calcite	**MIN1**	Calcite
MIN2	Chlorite	**MIN2**	Chlorite
MIN3	Goethite	**MIN3**	Pyrite
MIN4		**MIN4**	

Description: The mapped goethite occurrence is found in an open fracture as a fine-grained, brown powder on the fracture surface, as well as on the side of drill core and at the fracture-drill core edges, which may indicate that it is drilling induced powder (Figure 5-23 and Figure 5-24). The powder consists of fine-grained, angular mineral fragments (Figure 5-25 and Figure 5-26). These fragments are made up of common rock forming minerals such as quartz and feldspars but also of chlorite, clay minerals and Fe-oxides (which give the colouration). EDS-analyses indicate a significant amount of e.g. Mn, Ca, Si on the surface of these minerals (especially related to Fe-oxides and Fe-rich chlorite/clay minerals). Goethite is interpreted to have been emplaced as a drilling induced powder on the fracture surface (as indicated by the angular fragments of this coating and by the position of the powder on the fracture surface, i.e. at the fracture-drill core rims and at the drill core side). Furthermore, fresh pyrite is present on the fracture surface indicating prevailing reducing conditions in the fracture. These observations indicate that the fine-grained powder mapped as goethite, is drilling induced and is recommended to be removed from the mapping data and that pyrite should be included instead.

Figure 5-23. *Photograph of drill core sample KLX12A: 332.17–332.25 m. Arrows indicate oxidized metallic markings on the core, resulting from drill wear (consisting of a fine-grained powder similar to that on the fracture surface).*

Figure 5-24. *Photograph of the fracture surface of open fracture KLX12A: 332.221 m.*

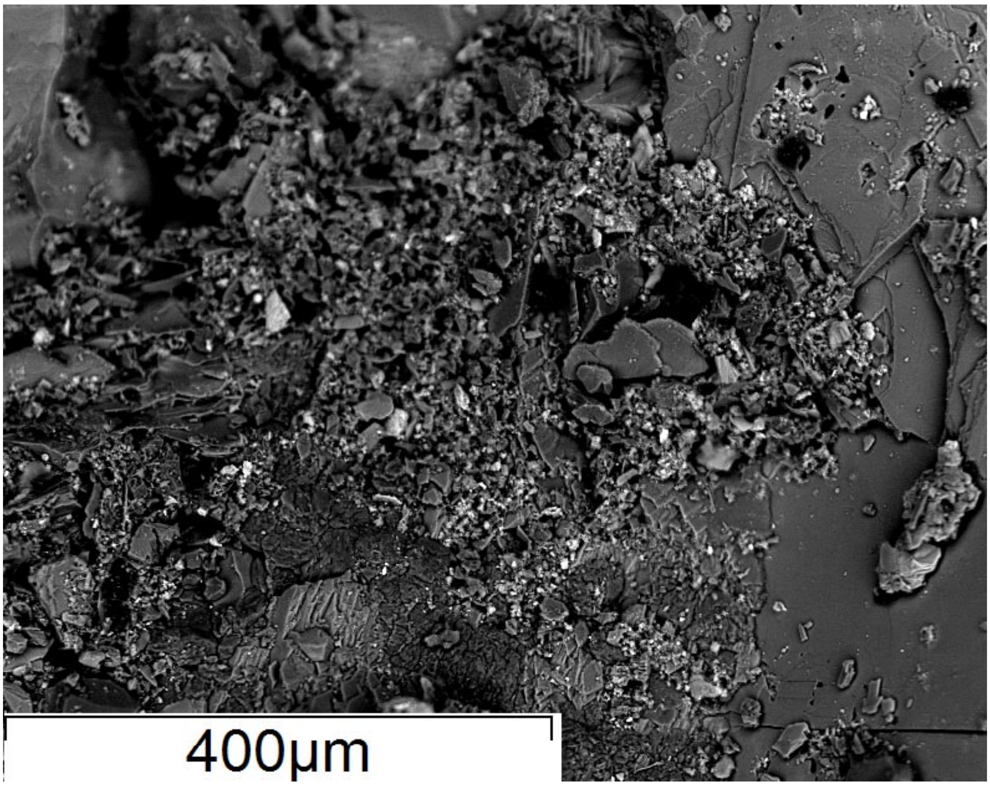

Figure 5-25. *Back-scattered SEM-image of fine-grained powder consisting of angular mineral fragments on the rather smooth fracture surface of open fracture KLX12A: 332.221 m.*

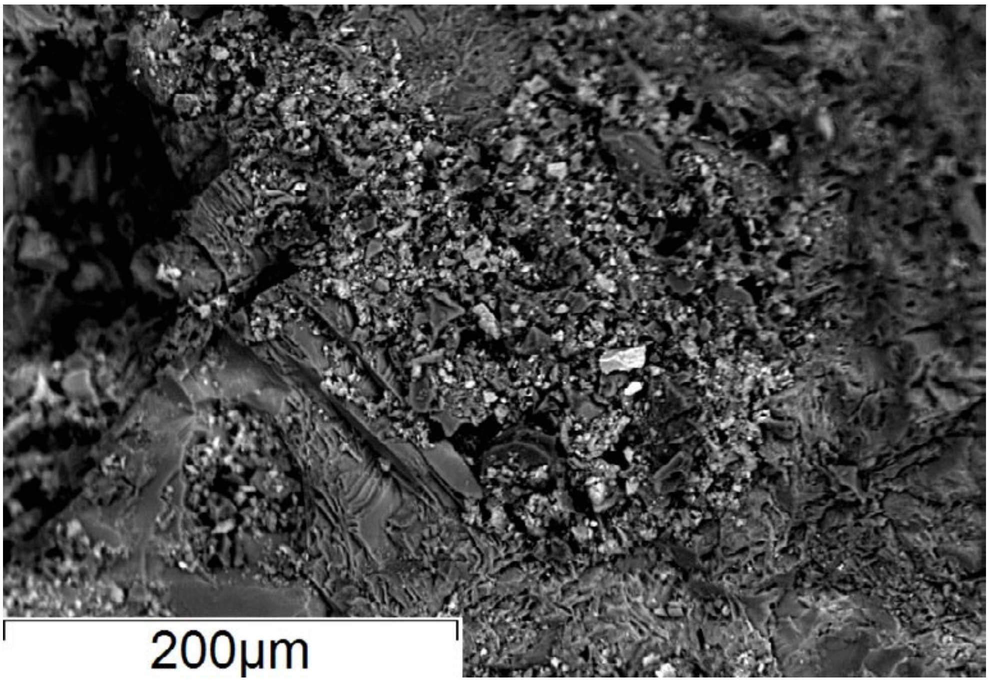

Figure 5-26. *Back-scattered SEM-image of fine-grained powder consisting of angular mineral fragments on the rather smooth fracture surface of open fracture KLX12A: 332.221 m.*

Sample: KLX13A: 550.74–550.75 m

This sample contains two fractures with mapped goethite occurrences (sample is shown in Figure 5-27).

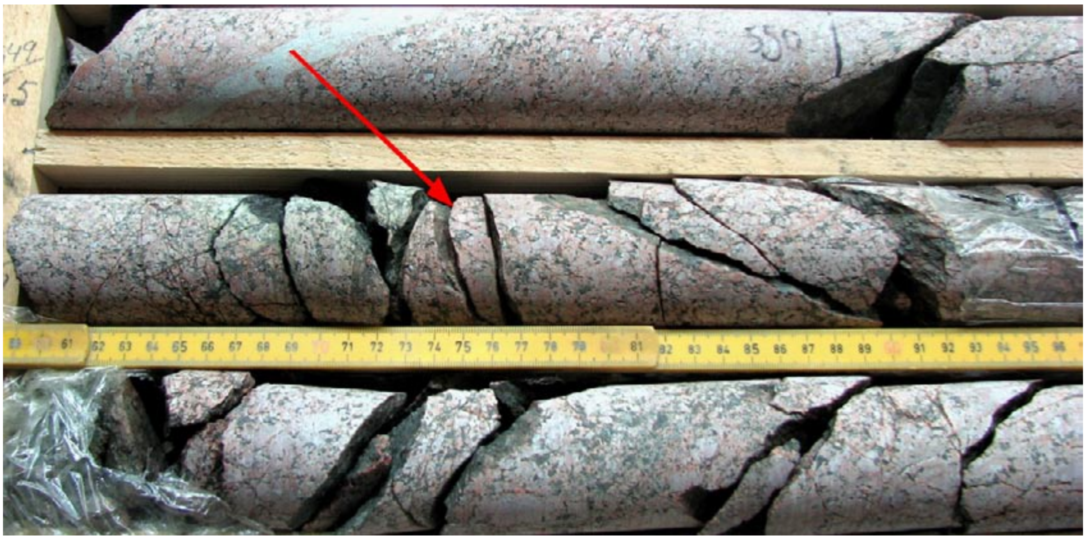

Figure 5-27. *Photograph of drill core sample KLX13A: 550.74–550.75 m (arrow).*

Old mapping data		Suggested updated mapping data	
IDCODE	KLX13A	**IDCODE**	KLX13A
FRACT_MAPPED	Broken	**FRACT_MAPPED**	Broken
FRACT_INTERPRET	Open	**FRACT_INTERPRET**	Open
ADJUSTEDSECUP	550.762	**ADJUSTEDSECUP**	550.762
MIN1	Goethite	**MIN1**	Chlorite
MIN2	Chlorite	**MIN2**	Clay Minerals
MIN3	Clay Minerals	**MIN3**	Hematite
MIN4		**MIN4**	Pyrite

Description: Open fracture with a fracture coating consisting of chlorite, clay minerals, hematite and pyrite (Figure 5-28). The red-staining of the fracture is due to hematite-staining of feldspars and chlorite, as shown by the typical colour (cf. /Drake and Tullborg 2004, 2005, 2006, 2007, 2008abc/), which is darker than the colour of goethite (cf. /Drake and Tullborg 2008d/). Furthermore, fresh pyrite is present on the fracture surface (younger than hematite) indicating prevailing reducing conditions in the fracture. Chlorite dominates the coating and is quite Mg-rich (Figure 5-29). It is therefore recommended that goethite is changed to hematite in the mapping data and that pyrite is included as well.

***Figure 5-28.** Photograph of the fracture surface of open fracture KLX13A: 550.762 m.*

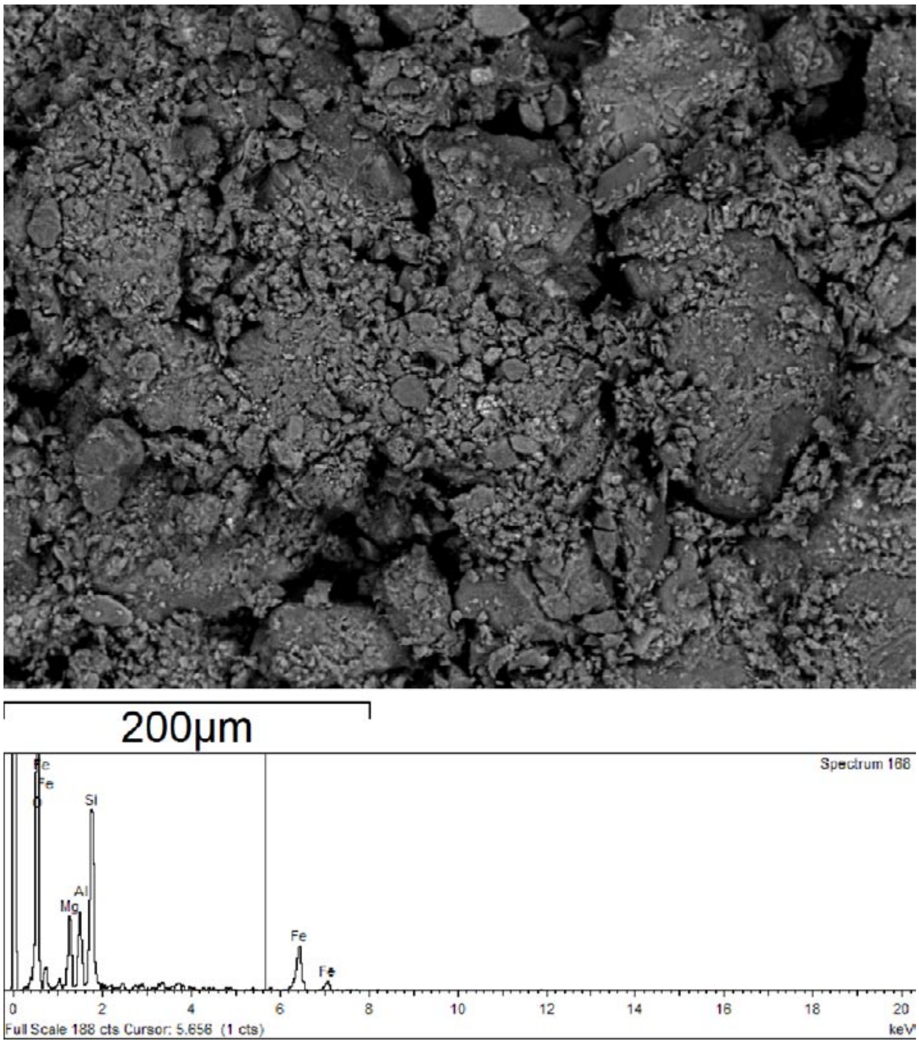

Figure 5-29. *Back-scattered SEM-image with related EDS-spectrum of a chlorite-dominated part of the fracture coating of open fracture KLX13A: 550.762 m.*

Old mapping data		**Suggested updated mapping data**	
IDCODE	KLX13A	**IDCODE**	KLX13A
FRACT_MAPPED	Broken	**FRACT_MAPPED**	Broken
FRACT_INTERPRET	Open	**FRACT_INTERPRET**	Open
ADJUSTEDSECUP	550.766	**ADJUSTEDSECUP**	550.766
MIN1	Goethite	**MIN1**	Chlorite
MIN2	Chlorite	**MIN2**	Clay Minerals
MIN3	Clay Minerals	**MIN3**	Calcite
MIN4		**MIN4**	Hematite

Description: Open fracture with a fracture coating consisting of chlorite, clay minerals, hematite and pyrite (Figure 5-30). The red-staining of the fracture is due to hematite-staining of feldspars and chlorite, as shown by the typical colour (cf. /Drake and Tullborg 2004, 2005, 2006, 2007, 2008abc/), which is darker than the colour of goethite (cf. /Drake and Tullborg 2008d/). Just as in fracture KLX13A: 550.762 m, chlorite dominates the coating and is quite Mg-rich. The most common clay mineral is illite. It is recommended that goethite is changed to hematite in the mapping data and that calcite is included as well.

Figure 5-30. Photograph of the fracture surface of open fracture KLX13A: 550.766 m.

Sample: KLX13A: 551.30–551.41 m

Old mapping data		Suggested updated mapping data	
IDCODE	KLX13A	**IDCODE**	KLX13A
FRACT_MAPPED	Broken	**FRACT_MAPPED**	Broken
FRACT_INTERPRET	Open	**FRACT_INTERPRET**	Open
ADJUSTEDSECUP	551.406	**ADJUSTEDSECUP**	551.406
MIN1	Clay Minerals	**MIN1**	Clay Minerals
MIN2	Chlorite	**MIN2**	Chlorite
MIN3	Goethite	**MIN3**	Calcite
MIN4		**MIN4**	Hematite

Pyrite and barite should be added to the comment file (bm_comment) in Sicada.

Description: This open fracture is located in a highly fractured section in KLX13A (Figure 5-31). The coating is dominated by clay minerals and chlorite, with their characteristic dark green to green colour. Some parts of the filling are more brownish, similar to hematite-stained fracture coatings described in other samples above and from earlier studies in the area (cf. /Drake and Tullborg 2004, 2005, 2006, 2007, 2008abc/). This colouration is darker than the colour of goethite, and is mainly due to hematite-staining/pigmentation of fracture chlorite (cf. /Drake and Tullborg 2008d/). Therefore it is suggested that hematite, should replace goethite in the mapping file. The amount of hematite is very small, even in the brown coloured parts of the coating. Figure 5-32 shows an SEM-image on a related EDS-spectrum of Mg-rich chlorite in a brown coloured part of the filling. Very few, if any, Fe-rich spots (hematite) are visible. Other minerals to be included in the mapping data are calcite, pyrite and barite.

__Figure 5-31.__ Photograph of drill core sample KLX13A: 551.30–551.41 m.

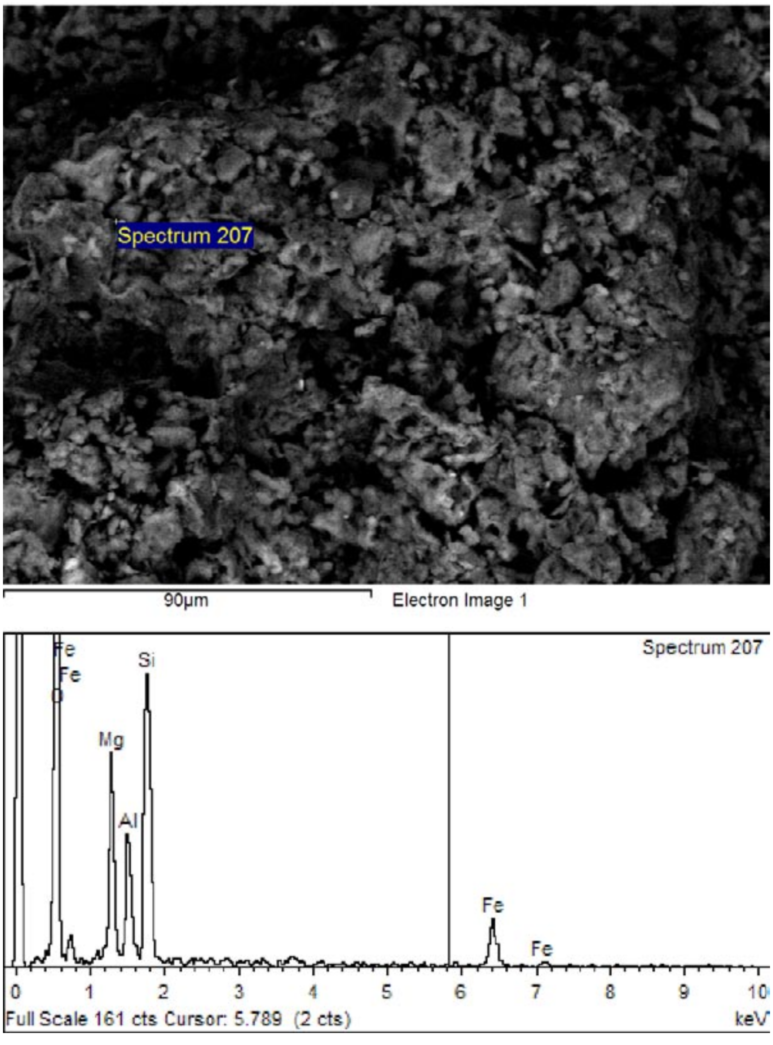

__Figure 5-32.__ Back-scattered SEM-image and related EDS-spectrum for brown coloured fracture coating dominated by chlorite (Mg-rich). No Fe-oxides are visible. Sample KLX13A: 551.30–551.41 m.

Sample: KLX15A: 379.39–379.63 m

Old mapping data		**Suggested updated mapping data**	
IDCODE	KLX15A	**IDCODE**	KLX15A
FRACT_MAPPED	Broken	**FRACT_MAPPED**	Broken
FRACT_INTERPRET	Open	**FRACT_INTERPRET**	Open
ADJUSTEDSECUP	379.524	**ADJUSTEDSECUP**	379.524
MIN1	Chlorite	**MIN1**	Chlorite
MIN2	Calcite	**MIN2**	Calcite
MIN3	Goethite	**MIN3**	Goethite
MIN4	Hematite	**MIN4**	Hematite

Clay minerals and barite should be added to the comment file.

Description: The fracture coating in this open fracture is made up of soft dark green (chlorite and clay minerals) and brown minerals (dark, brick red hematite and bright brown goethite, as well as clay minerals), as well as some whitish calcite (Figure 5-33 and Figure 5-34). As seen in Figure 5-33, a brown coloured powder, similar to the fracture coating is also visible on the side of the drill core. In contrast to the metallic markings on the core, resulting from drill wear, described for other samples above, the powder on the drill core side in this sample is probably originating from the fracture coating, especially since the fracture coating is made up of minerals that have clearly grown from the fracture surface (and is not emplaced as a loose powder) (Figure 5-35 and Figure 5-36). The brown coloured parts of the filling are made up of Fe-oxides/oxyhydroxides ("1" in Figure 5-35 and the bright parts of Figure 5-36) and spherulitical aggregates of corrensite ("2" in Figure 5-35, which has been reported earlier from this area, cf. /Drake and Tullborg 2007/). The Fe-oxides/oxyhydroxides are both pure Fe-oxide (hematite) and Fe-oxyhydroxides containing some Si and Al as well (see EDS-spectrum in Figure 5-35), which resembles to EDS-analyses of goethite from earlier studies in the Laxemar subarea (/Drake and Tullborg 2008d/).

Figure 5-33. *Photograph of sample KLX15A: 379.39–379.63 m.*

Figure 5-34. *Photograph of the two fracture surfaces of open fracture KLX15A: 379.524 m (sample KLX15A: 379.39–379.63 m).*

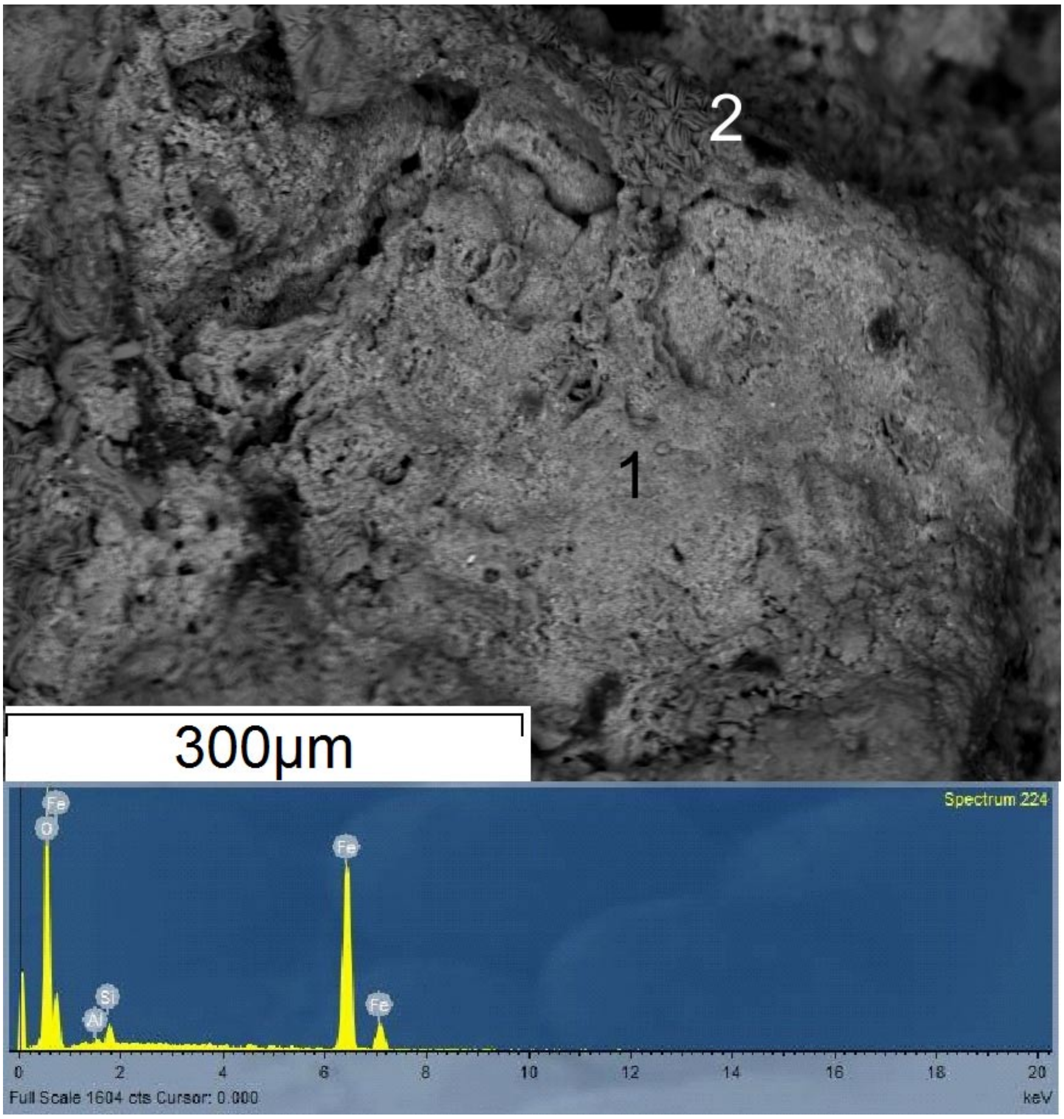

Figure 5-35. *Back-scattered SEM-image and related EDS-spectrum of brown-coloured minerals: Fe-oxides/-oxyhydroxides ("1", with related EDS-spectrum: "Spectrum 224") and corrensite ("2"). From open fracture KLX15A: 379.524 m (sample KLX15A: 379.39–379.63 m).*

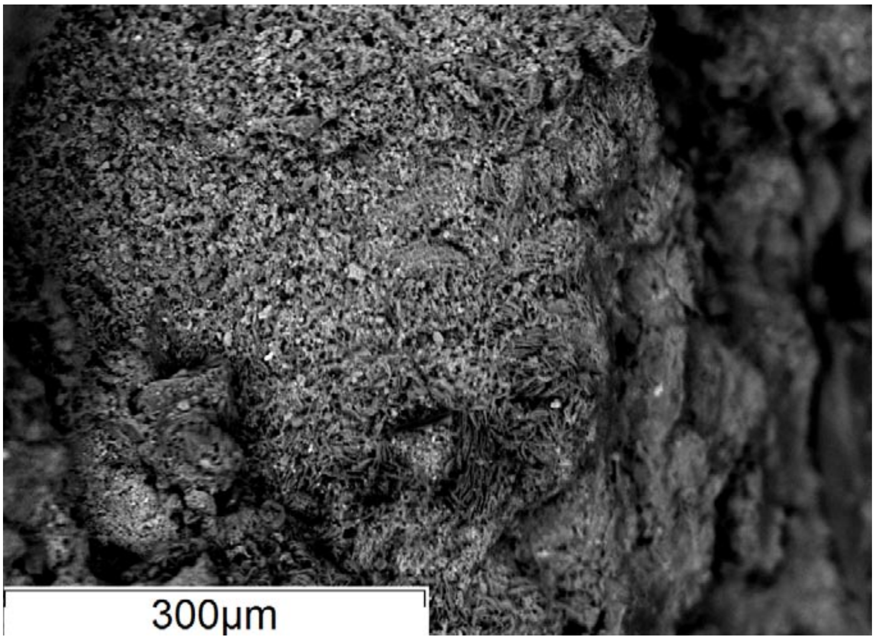

Figure 5-36. *Back-scattered SEM-image brown-coloured minerals: Fe-oxides/-oxyhydroxides (bright parts) and corrensite (darker parts). From open fracture KLX15A: 379.524 m (sample KLX15A: 379.39–379.63 m).*

Sample: KLX16A: 348.01–348.14 m

This sample contains two fractures with mapped goethite occurrences (sample is shown in Figure 5-37).

Figure 5-37. *Photograph of drill core sample KLX16A: 348.01–348.14 m (X), 1) fracture 348.067 m, 2) 348.173, 3 and 4) oxidized metallic markings on the core, resulting from drill wear.*

Old mapping data		Suggested updated mapping data	
IDCODE	KLX16A	**IDCODE**	KLX16A
FRACT_MAPPED	Broken	**FRACT_MAPPED**	Broken
FRACT_INTERPRET	Open	**FRACT_INTERPRET**	Open
ADJUSTEDSECUP	348.067	**ADJUSTEDSECUP**	348.067
MIN1	Calcite	**MIN1**	Calcite
MIN2	Epidote	**MIN2**	Epidote
MIN3	Hematite	**MIN3**	Hematite
MIN4	Goethite	**MIN4**	Clay minerals

Prehnite should be added to the comment file.

Description: Open fracture with a coating of calcite, epidote, hematite, clay minerals and prehnite (Figure 5-48). Minor yellow coloured areas of the coating have been mapped as goethite. However, SEM-investigations show that these areas are made up of calcite and illite and not by goethite. A plausible explanation is that the yellow discolouration is due to staining from acid used during the mapping to identify calcite. It is therefore suggested that goethite should be removed from the mapping data. Clay minerals and prehnite should be added in the mapping data.

Figure 5-38. *Photograph of the fracture surface of open fracture KLX16A: 348.067 m from drill core sample KLX16A: 348.01–348.14 m.*

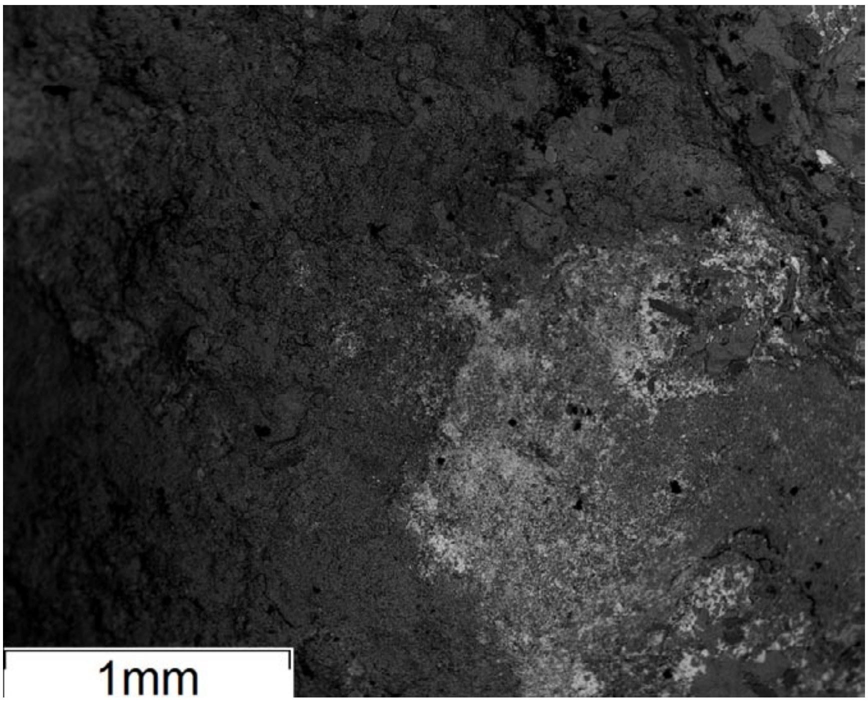

Figure 5-39. *Back-scattered SEM-image of hematite-stained part (bright area) on the fracture surface of open fracture KLX16A: 348.067 m, from drill core sample KLX16A: 348.01–348.14 m. The dark area to the upper left, surrounding the hematite-stained part is the yellow-coloured area in Figure 5-39. This area is mainly consists of calcite and illite.*

Old mapping data		Suggested updated mapping data	
IDCODE	KLX16A	**IDCODE**	KLX16A
FRACT_MAPPED	Broken	**FRACT_MAPPED**	Broken
FRACT_INTERPRET	Open	**FRACT_INTERPRET**	Open
ADJUSTEDSECUP	348.173	**ADJUSTEDSECUP**	348.173
MIN1	Calcite	**MIN1**	Calcite
MIN2	Hematite	**MIN2**	Hematite
MIN3	Goethite	**MIN3**	Goethite
MIN4		**MIN4**	Clay minerals

Description: Open fracture with a coating of calcite, hematite, goethite and clay minerals (suggested to be added to the mapping data) (Figure 5-40). Two noteworthy features indicating signs of oxidizing conditions sometime in the history of the fracture are present on the fracture surface: 1) typical hematite-stained, brownish red parts and 2) bright yellow to brown parts. SEM-investigations show that 1) is made up of Fe-oxides (probably hematite) and Fe-rich chlorite and clay minerals (probably due to staining of this minerals by small hematite crystals); 2) is made up of Fe-rich clay minerals, calcite and Fe-oxide/oxyhydroxide (Figure 5-41), which might be both hematite and goethite. Both pure Fe-oxide (probably hematite) and Fe-oxide with a significant amount of Si (a common feature of goethite /Deer et al. 1992/), are identified, which further indicates that hematite and goethite are present together in this sample. More investigations are needed to make a proper identification of potential origin.

Figure 5-40. *Photograph of the fracture surface of fracture KLX16A: 348.173 m from drill core sample KLX16A: 348.01–348.14 m.*

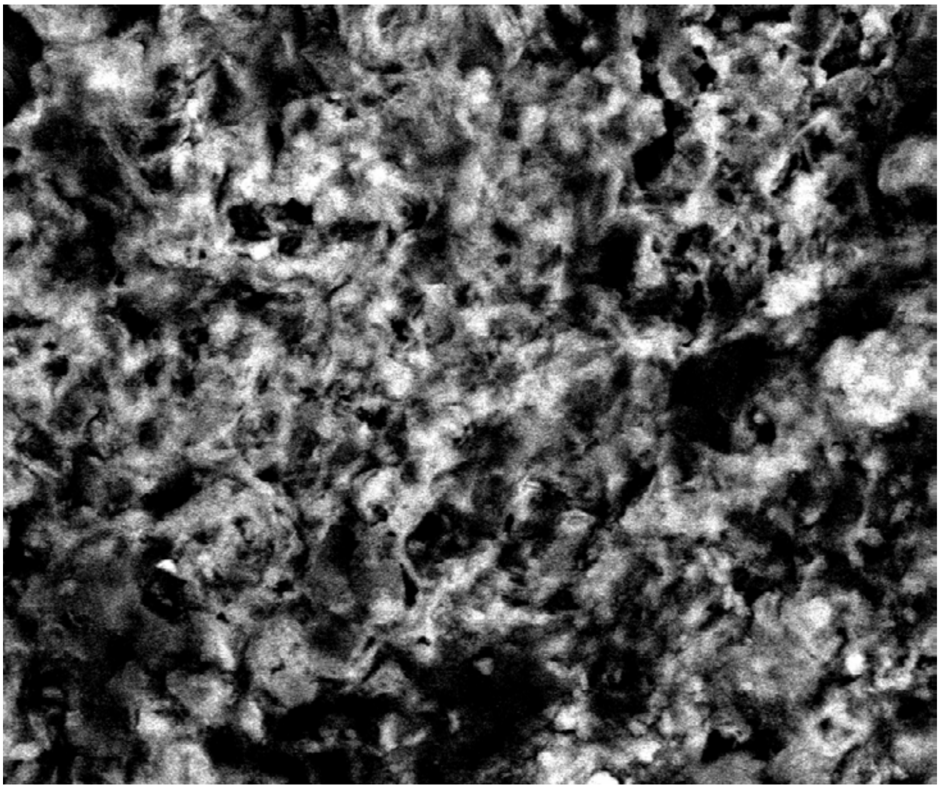

Figure 5-41. *Back-scattered SEM-image of Fe-oxide-stained part (bright area) on the fracture surface of open fracture KLX16A: 348.173 m (drill core sample KLX16A: 348.01–348.14 m). Width of image is ~70 µm.*

Sample: KLX16A: 371.85–371.93 m

Old mapping data		Suggested updated mapping data	
IDCODE	KLX16A	**IDCODE**	KLX16A
FRACT_MAPPED	Broken	**FRACT_MAPPED**	Broken
FRACT_INTERPRET	Open	**FRACT_INTERPRET**	Open
ADJUSTEDSECUP	371.851	**ADJUSTEDSECUP**	371.851
MIN1	Calcite	**MIN1**	Calcite
MIN2	Goethite	**MIN2**	Goethite
MIN3	Hematite	**MIN3**	Hematite
MIN4		**MIN4**	Clay minerals

Adularia, quartz, albite and barite should be added as additional minerals in the Boremap comment file.

Description: Open fracture with a thin fracture coating (Figure 5-42), which is dominated by white to grey coloured calcite, brick red hematite-stained adularia and a bright brown to yellow coating (mapped as goethite). SEM-investigations show that the latter part of the coating is made up of Fe-oxide-stained adularia, and clay minerals. The Fe-oxide crystals are occasionally quite large (Figure 5-43, Figure 5-44 and Figure 5-45). EDS-analyses of these crystals show significant amounts of e.g. Si (Figure 5-43, Figure 5-44 and Figure 5-45), indicates the presence of goethite on the fracture coating, as goethite may incorporate significant amount of e.g. Si in the crystal structure /Deer et al. 1992/. Additional minerals to be added to the mapping data are clay minerals, adularia, quartz, albite and barite.

Figure 5-42. *Photographs of drill core sample KLX16A: 371.85–371.93 m (left) and of the fracture surface of open fracture KLX16A: 371.851 m (right).*

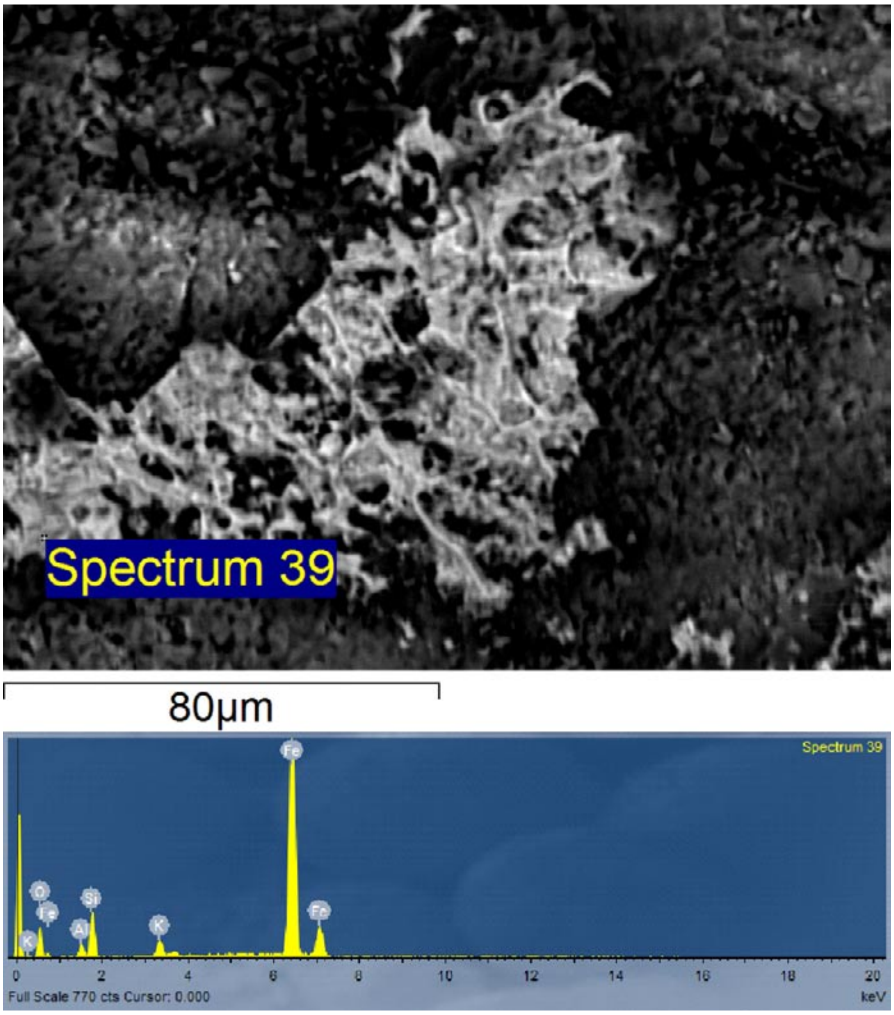

Figure 5-43. *Back-scattered SEM-image and EDS spectrum (of a Fe-rich mineral) on the fracture surface of open fracture KLX16A: 371.851.*

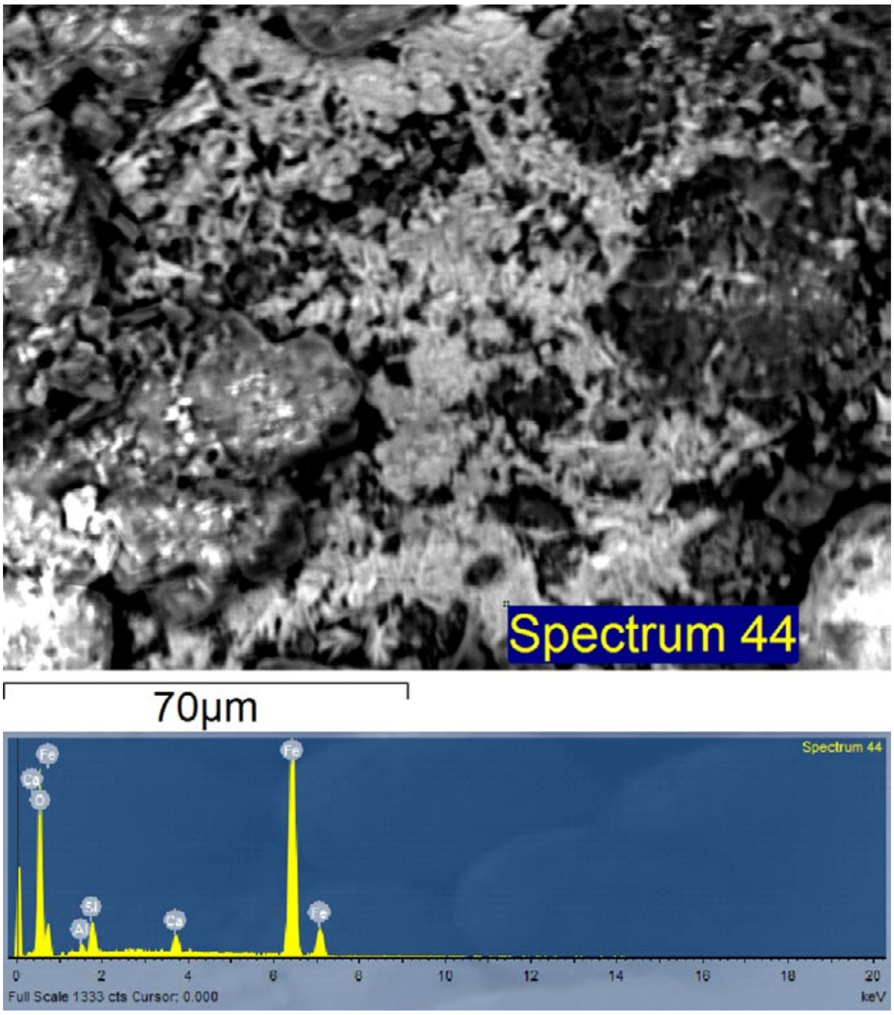

Figure 5-44. *Back-scattered SEM-image and EDS spectrum (of a Fe-rich mineral) from the fracture surface of open fracture KLX16A: 371.851 m.*

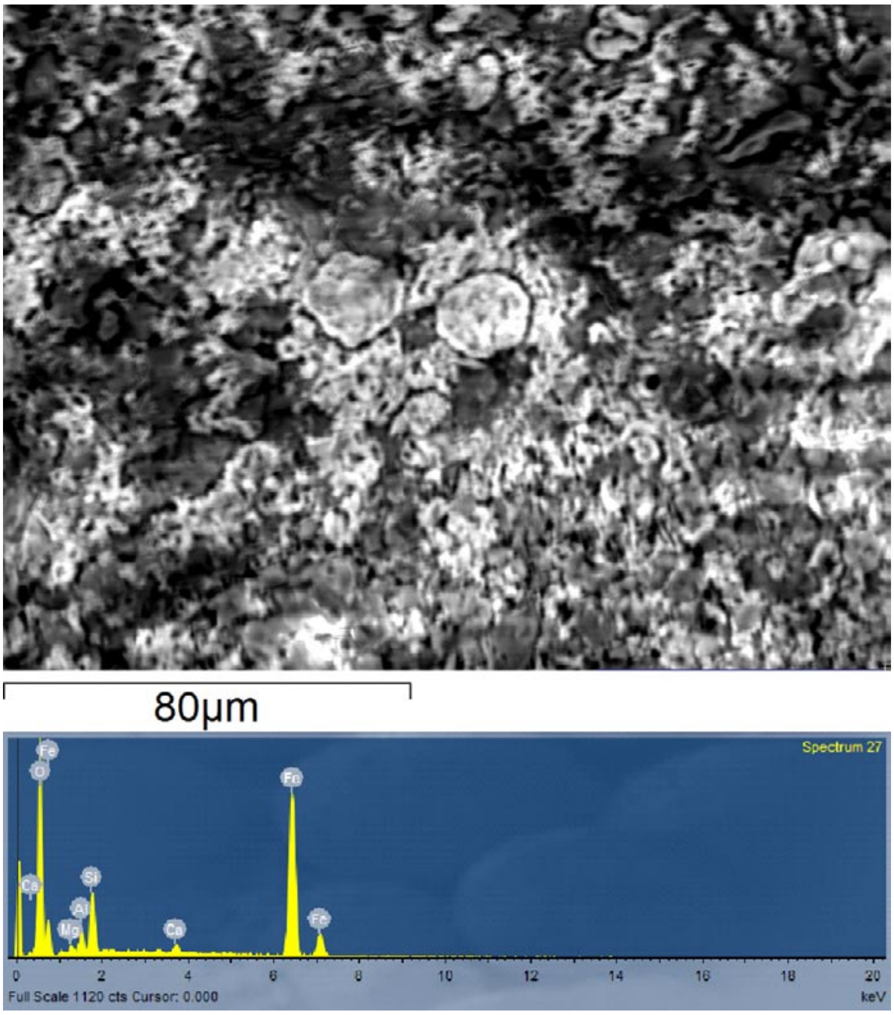

Figure 5-45. *Back-scattered SEM-image and EDS spectrum (of a Fe-rich mineral) of the fracture surface of open fracture KLX16A: 371.851 m, from sample KLX16A: 371.85–371.93 m.*

Sample: KLX19A: 229.44–229.51 m

Old mapping data		**Suggested updated mapping data**	
IDCODE	KLX19A	**IDCODE**	KLX19A
FRACT_MAPPED	Broken	**FRACT_MAPPED**	Broken
FRACT_INTERPRET	Open	**FRACT_INTERPRET**	Open
ADJUSTEDSECUP	229.510	**ADJUSTEDSECUP**	229.510
MIN1	Chlorite	**MIN1**	Chlorite
MIN2	Calcite	**MIN2**	Calcite
MIN3	Goethite	**MIN3**	Clay minerals
MIN4		**MIN4**	Pyrite

Adularia is added to comment file.

Description: No goethite is present on the fracture surface (shown in Figure 5-486). Minerals in addition to calcite and chlorite are clay minerals (Figure 5-47), pyrite, and adularia. Therefore, it is suggested that the mapping data is updated by removing goethite and adding clay minerals, pyrite and adularia.

Figure 5-46. *Photographs of sample: KLX19A: 229.44–229.51 m (left) and the fracture surface of open fracture KLX19A: 229.510 m (right).*

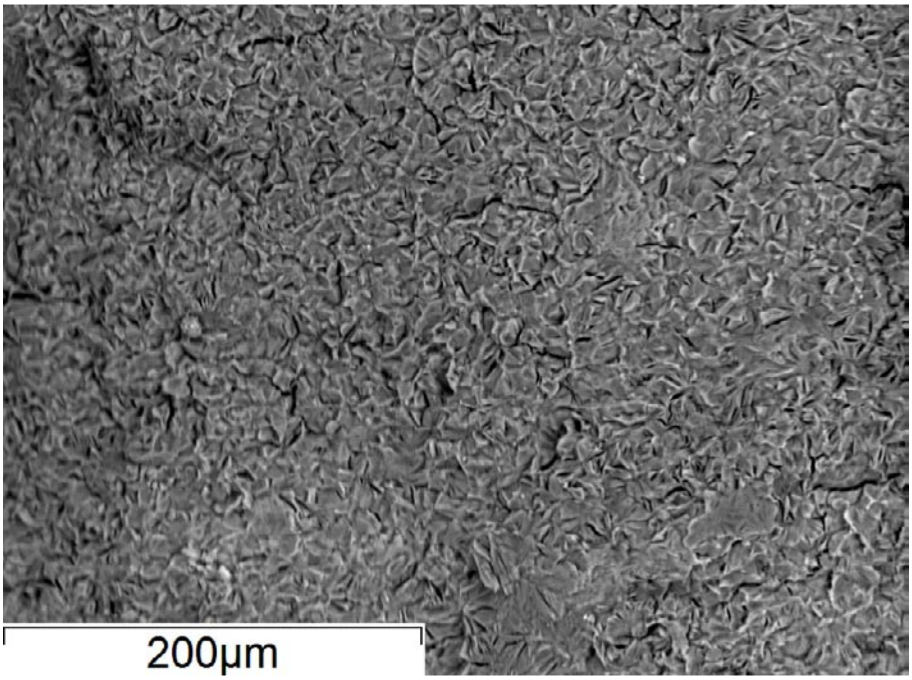

Figure 5-47. *Back-scattered SEM-image of Mg-rich chlorite/clay minerals coating open fracture KLX19A: 229.510 m.*

Sample: KLX19A: 414.48–414.55 m

Old mapping data		Suggested updated mapping data	
IDCODE	KLX19A	**IDCODE**	KLX19A
FRACT_MAPPED	Broken	**FRACT_MAPPED**	Broken
FRACT_INTERPRET	Open	**FRACT_INTERPRET**	Open
ADJUSTEDSECUP	414.363	**ADJUSTEDSECUP**	414.363
MIN1	Calcite	**MIN1**	Calcite
MIN2	Chlorite	**MIN2**	Chlorite
MIN3	Goethite	**MIN3**	Laumontite
MIN4		**MIN4**	Adularia

Epidote, hematite, clay minerals, quartz, galena and pyrite should be added in the comment file (bm_comment).

Description: No goethite is present on the fracture surface (fracture and fracture surface is shown in Figure 5-48). Minerals in addition to calcite and chlorite are laumontite, adularia, epidote, hematite, clay minerals, quartz, galena and pyrite. Therefore, it is suggested that the mapping data is updated by removing goethite and adding laumontite, adularia, epidote, hematite, clay minerals, quartz, galena and pyrite.

Figure 5-48. Photograph of drill core sample KLX19A: 414.48–414.55 m (left) with the fracture surface of open fracture KLX19A: 414.363 m (right).

5.1.2 Sealed fractures

Sample: KLX07A: 432.15–432.27 m

Old mapping data		Suggested updated mapping data	
IDCODE	KLX07A	**IDCODE**	KLX07A
FRACT_MAPPED	Broken	**FRACT_MAPPED**	Broken
FRACT_INTERPRET	Sealed	**FRACT_INTERPRET**	Sealed
ADJUSTEDSECUP	432.144	**ADJUSTEDSECUP**	432.144
MIN1	Calcite	**MIN1**	Calcite
MIN2	Chlorite	**MIN2**	Chlorite
MIN3	Goethite	**MIN3**	Clay minerals
MIN4		**MIN4**	

Description: Small areas of fine-grained powder on the fracture surface (Figure 5-49) and on the drill core (perpendicular to the drill core length axis, Figure 5-50). This powder is made up of angular mineral fragments (Figure 5-51). The fragments are common rock forming minerals quartz and feldspars but barite, illite, Fe-rich chlorite and Fe-stained chlorite are also present. The powder is interpreted to be drilling induced because 1) similar powder is found on the side of the fresh drill core as typical drilling induced marks, 2) because of the characteristics and position of the powder (angular fragments in morphological depressions of the fracture surface) and 3) the fracture is interpreted to be sealed and therefore the powder has most probably been emplaced after the fracture was broken during the drilling. Clay minerals are added to the mapping data because it is interpreted to belong to an earlier generation of fracture minerals (along with calcite and chlorite) present in the fracture.

Figure 5-49. Photograph of drill core sample KLX07A: 432.15–432.27 m with open fracture KLX07A: 432.144 m. Arrows indicate powder mapped as goethite.

Figure 5-50. Photograph of drill core sample KLX07A: 432.15–432.27 m. Arrow indicates powder on the side of the drill core (same as the powder on the fracture coating in Figure 5-49.

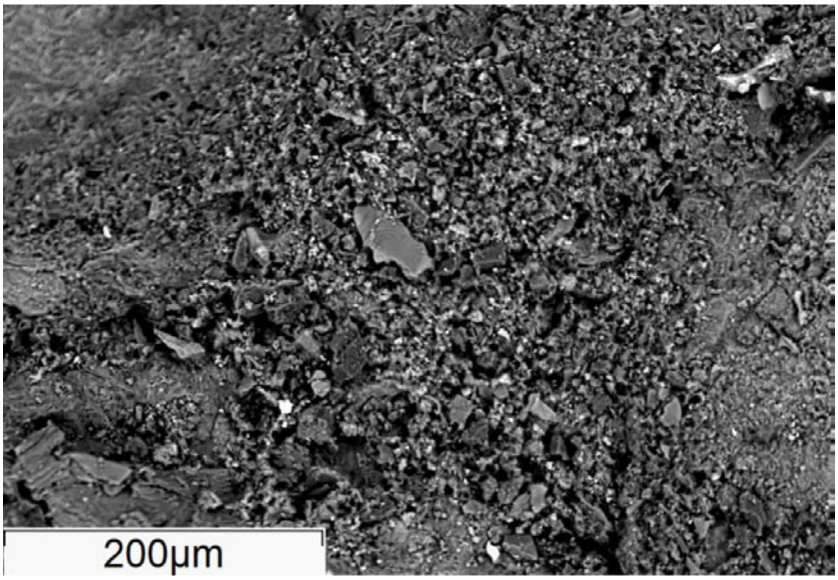

Figure 5-51. Back-scattered SEM-image of fine-grained brown filling from the fracture surface of open fracture KLX07A: 432.144 m.

Sample: KLX16A: 408.23–408.27 m

Sample including two sealed fractures (Figure 5-53), each including mapped fracture-filling goethite. The adjacent drill core section has several markings on the core, resulting from drill wear, perpendicular to the length axis of the drill core.

Figure 5-52. Photograph of drill core sample KLX16A: 408.23–408.27 m (lower drill core, centre drill core piece).

Old mapping data		Suggested updated mapping data	
IDCODE	KLX16A	**IDCODE**	KLX16A
FRACT_MAPPED	Unbroken	**FRACT_MAPPED**	Unbroken
FRACT_INTERPRET	Sealed	**FRACT_INTERPRET**	Sealed
ADJUSTEDSECUP	408.237	**ADJUSTEDSECUP**	408.237
MIN1	Hematite	**MIN1**	Hematite
MIN2	Goethite	**MIN2**	
MIN3		**MIN3**	
MIN4		**MIN4**	

Interpretation: No fracture-filling goethite. Goethite is recommended to be removed from the mapping data.

Figure 5-53. *Photographs of drill core sample KLX16A: 408.23–408.27 m, showing fracture KLX16A: 408.237 m (upper fracture in photo to the left, right fracture in the photo to the right) and KLX16A: 408.241 m (lower fracture in photo to the left, left fracture in the photo to the right).*

Old mapping data		Suggested updated mapping data	
IDCODE	KLX16A	**IDCODE**	KLX16A
FRACT_MAPPED	Broken	**FRACT_MAPPED**	Broken
FRACT_INTERPRET	Sealed	**FRACT_INTERPRET**	Sealed
ADJUSTEDSECUP	408.241	**ADJUSTEDSECUP**	408.241
MIN1	Hematite	**MIN1**	Hematite
MIN2	Goethite	**MIN2**	Clay minerals
MIN3		**MIN3**	Calcite
MIN4		**MIN4**	

Description: Sealed fracture (presently partly open, Figure 5-55). The mapping only identified hematite (dark brownish red) and goethite (bright brown). SEM-investigations show that clay minerals and calcite are present. The bright brown parts are made up of Fe-rich clay minerals, calcite and Fe-oxide (Figure 5-54), with a plate-like shape, typical for hematite, of relatively pure Fe-oxide composition (i.e. hematite). Goethite is suggested to be removed from the mapping data. Furthermore, since the fracture is mapped as “sealed” it is not probable that the Fe-oxides have been formed recently. There are markings on the core, resulting from drill wear at this fracture (Figure 5-52).

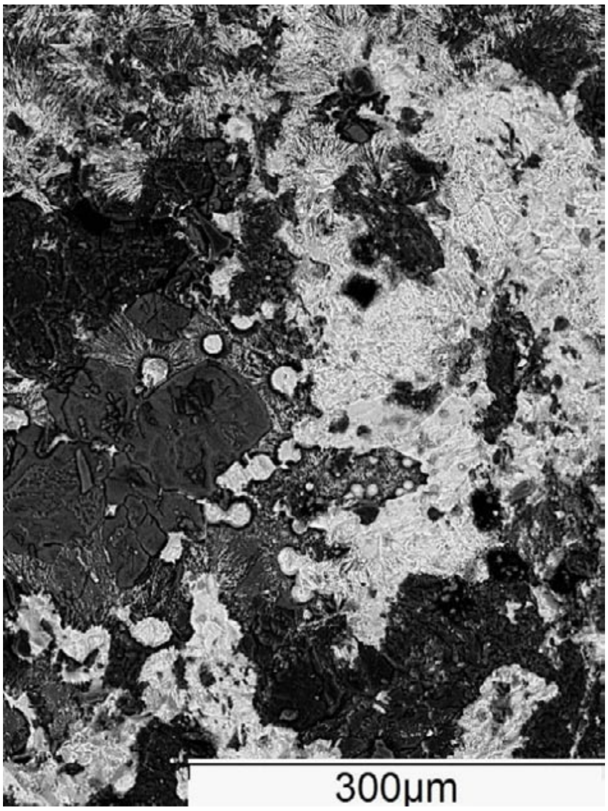

Figure 5-54. *Back-scattered SEM-images of hematite (bright, plate-like minerals) from fracture KLX16A: 408.241 m, from drill core sample KLX16A: 408.23–408.27 m.*

5.1.3 Crush zones

Sample: KLX13A: 544.44–544.7 m

Old mapping data		**Suggested updated mapping data**	
IDCODE	KLX13A	**IDCODE**	KLX13A
VARCODE	Crush zone	**VARCODE**	Crush zone
ADJUSTEDSECUP	543.969	**ADJUSTEDSECUP**	543.969
ADJUSTEDSECLOW	545.034	**ADJUSTEDSECLOW**	545.034
MIN1	Chlorite	**MIN1**	Chlorite
MIN2	Clay minerals	**MIN2**	Clay minerals
MIN3	Calcite	**MIN3**	Calcite
MIN4	Goethite	**MIN4**	Adularia

Description: This drill core section has been highly oxidized during drilling as shown by the discolouration of the whole drill core pieces in the interval (Figure 5-55 and Figure 5-56). The brown coloured part of the fracture coating (mapped as goethite) has a significant amount of Fe but also e.g. Zn and C (Figure 5-57), which is a further indication that this colouration is related to the drilling activity. Therefore, it is suggested that goethite is removed from the mapping data. Adularia should be added to the mapping data.

***Figure 5-55.** Photograph of drill core sample KLX13A: 544.44–544.7 m.*

***Figure 5-56.** Photograph of drill core sample KLX13A: 544.44–544.7 m*

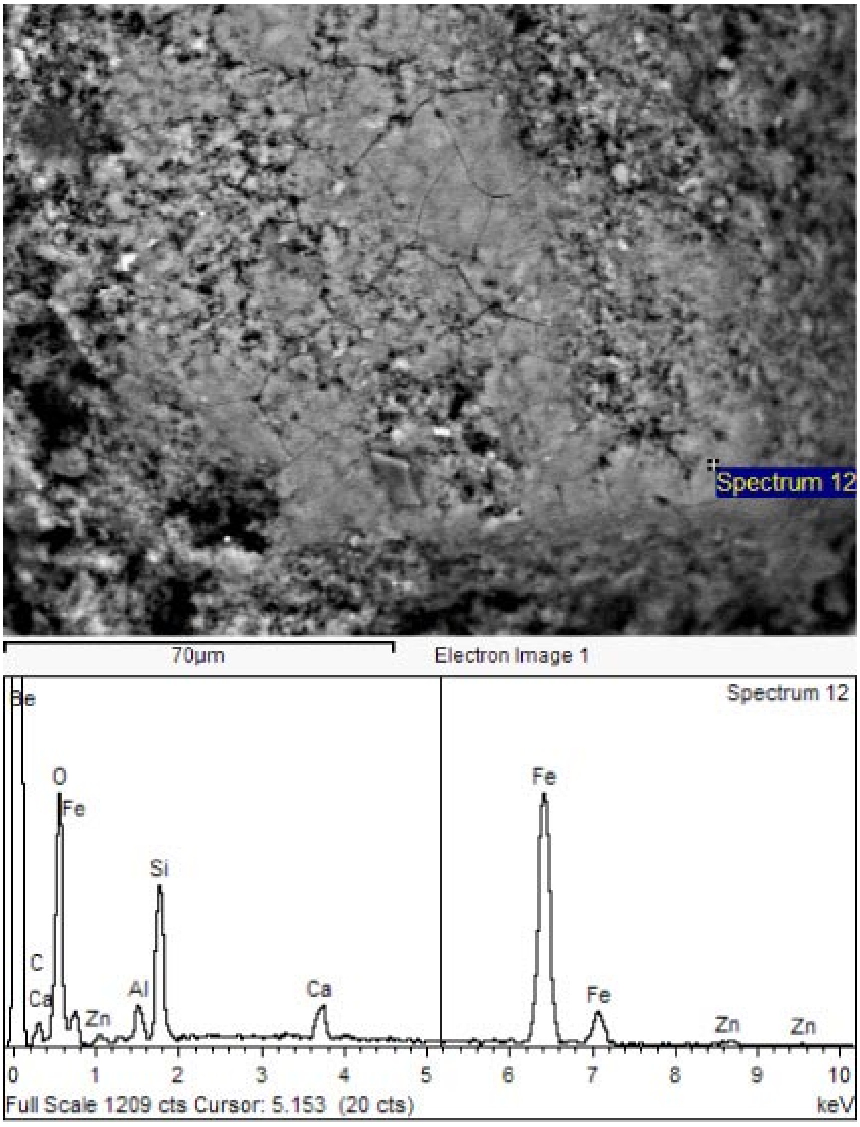

Figure 5-57. Back-scattered SEM-image and related EDS-spectrum for a mixture of Fe-rich coating on top of the fracture minerals (Spectrum 12) from fracture KLX13A: 543.969 m. Note the peaks for Zn and C.

5.1.4 Sealed network

Sample: KLX13A: 579.62–579.69 m

Old mapping data		Suggested updated mapping data	
IDCODE	KLX13A	**IDCODE**	KLX13A
VARCODE	Sealed Network	**VARCODE**	Sealed Network
ADJUSTEDSECUP	578.330	**ADJUSTEDSECUP**	578.330
ADJUSTEDSECLOW	583.590	**ADJUSTEDSECLOW**	583.590
MIN1	Chlorite	**MIN1**	Chlorite
MIN2	Prehnite	**MIN2**	Prehnite
MIN3	Calcite	**MIN3**	Calcite
MIN4	Adularia*	**MIN4**	Adularia**

*Goethite listed as additional mineral in the Boremap comment file (bm_comment in data delivery Sicada_08_062).
**Goethite suggested to be removed from the Boremap comment file (bm_comment in data delivery Sicada_08_062), other minerals remain.

Interpretation: No goethite present. Goethite should be removed from Boremap comment file (bm_comment).

Figure 5-58. Photograph of sealed network section KLX13A: 578.330–583.590 m.

5.2 Compilation of the results and updates of the drill core mapping files

Suggested updates of earlier mapped goethite occurrences are shown in Table 5-1 for open and sealed fractures, in Table 5-2 for crush zones, in Table 5-3 for sealed network and in Table 5-4 for rock alteration. A total number of 31 of the 34 originally mapped occurrences of goethite have been removed in the mapping data, because it was evident that they were either resulting from drill wear (drilling induced; often as a fine-grained powder on the fracture coating and/or at the side of the drill core) or incorrectly identified. In the former case, the whole drill core section (5–10 m) around the mapped goethite occurrence, commonly showed signs of drill wear (parallel markings on the drill core side or sheared drill core pieces).

Table 5-1. Suggested updated mapping information of open and sealed fractures.

IDCODE (Borehole)	FRACT_ MAPPED	FRACT_ INTERPRET	Adj. SecUp	MIN1	MIN2	MIN3	MIN4	Strike	Dip	Deformation zone	Elevation
KLX05	Broken	Sealed	518.300	Hematite	Chlorite						–449.44
KLX05	Broken	Open	602.397	Hematite	Calcite	Epidote	Titanite	297.1	3.6		–525.47
KLX07A#	Broken	Open	311.414	Chlorite	Adularia	Hematite	Laumontite			Possible DZ	–222.98
KLX07A	Broken	Sealed	432.144	Calcite	Chlorite	Clay minerals		140.7	75.2		–309.57
KLX08	Broken	Open	388.349	Calcite	Chlorite	Pyrite	Clay minerals	194.7	48.3		–311.36
KLX08	Broken	Open	388.561	Chlorite	Calcite	Clay Minerals	Pyrite[1]	232.4	29.5		–311.54
KLX09	Broken	Open	437.210					356.1	7.0		–410.62
KLX09	Broken	Open	574.242	Chlorite	Adularia	Hematite		74.4	11.3		–546.66
KLX10	Broken	Open	331.987	Calcite	Chlorite	Quartz	Hematite	358.0	32.1	ZSMNE942A	–311.10
KLX10	Broken	Open	332.012	Calcite	Chlorite	Hematite	Clay minerals[2]	316.5	21.5	ZSMNE942A	–311.13
KLX10#	Broken	Open	704.339	Calcite	Clay Minerals	Adularia	Pyrite	92.4	9.9	ZSMEW946A	–680.99
KLX12A	Unbroken	Sealed	313.853	Epidote	Pyrite	Calcite		335.4	78.9		–282.47
KLX12A	Broken	Open	332.221	Calcite	Chlorite	Pyrite		280.7	13.4		–300.17
KLX13A	Broken	Open	394.712	Chlorite	Pyrite			321.8	7.2		–367.46
KLX13A#	Broken	Open	550.762	Chlorite	Clay Minerals	Hematite	Pyrite	10.3	38.7	ZSMEW120A	–522.31
KLX13A#	Broken	Open	550.766	Chlorite	Clay Minerals	Calcite	Hematite	327.4	20.1	ZSMEW120A	–522.32
KLX13A	Broken	Open	551.406	Clay Minerals	Chlorite	Calcite	Hematite[3]	358.2	69.7	ZSMEW120A	–522.95
KLX15A	Broken	Open	379.524	Chlorite	Calcite	Goethite	Hematite[4]	193.9	25.4	Possible DZ	–279.44
KLX16A	Broken	Open	348.067	Calcite	Epidote	Hematite	Clay minerals[5]	44.5	34.9	ZSMNE107A	–294.91
KLX16A	Broken	Open	348.173	Calcite	Hematite	Goethite	Clay minerals	290.3	37.0	ZSMNE107A	–295.00
KLX16A	Broken	Open	371.851	Calcite	Goethite	Hematite	Clay minerals[6]	18.1	61.7	ZSMNE107A	–316.20
KLX16A	Broken	Open	406.842	Calcite	Hematite			269.5	56.0	ZSMNE107A	–347.53
KLX16A	Unbroken	Sealed	408.237	Hematite				45.7	23.3	ZSMNE107A	–348.78
KLX16A	Unbroken	Sealed	408.241	Hematite	Clay minerals	Calcite		320.2	47.3	ZSMNE107A	–348.79
KLX19A	Broken	Open	229.510	Chlorite	Calcite	Clay minerals	Pyrite[7]	286.4	32.9		–176.68
KLX19A	Broken	Open	414.363	Calcite	Chlorite	Laumontite	Adularia[8]	93.9	14.0	Possible DZ	–331.53

[1] Chalcopyrite included in the comment file.
[2] Pyrite added in the comment file.
[3] Pyrite and barite added in the comment file.
[4] Clay minerals and barite added in the comment file.
[5] Prehnite added in the comment file.
[6] Adularia, quartz, albite and barite added in the comment file.
[7] Adularia added in the comment file.
[8] Epidote, hematite, clay minerals, quartz, galena and pyrite added in the comment file.

Table 5-2. Mapping information of goethite-bearing crush zones, from the p_fract_crush file in data delivery Sicada_08_062.

IDCODE (Borehole)	Adj. SecUp	Adj. SecLow	MIN1	MIN2	MIN3	MIN4	Deformation zone	Elevation (Adj. SecUp)
KLX04	894.446	895.104	Calcite	Chlorite	Clay Minerals		klx04_dz6b	–865.72
KLX13A	543.969	545.034	Chlorite	Clay Minerals	Calcite	Adularia	ZSMEW120A	–515.57

Table 5-3. Mapping information of goethite-bearing sealed network, from the p_fract_sealed_nw file in data delivery Sicada_08_062.

IDCODE (Borehole)	Adj. SecUp	Adj. SecLow	MIN1	MIN2	MIN3	MIN4	Deformation zone	Elevation (Adj. SecUp)
KLX04	239.554	239.652	Red Feldspar	Quartz			FSM_N	–214.24
KLX04	674.848	676.405	Calcite	Chlorite	Pyrite		FSM_EW007	–647.55
KLX13A	576.768	576.897	Chlorite	Calcite			ZSMEW120A	–548.12
KLX13A	578.330	583.590	Chlorite	Prehnite	Calcite	Adularia*	ZSMEW120A	–549.67
KLX16A	406.600	407.100	Calcite	Hematite	Prehnite		ZSMNE107A	–347.32

*Goethite removed as additional mineral in the Boremap comment file.

Table 5-4. Mapping information of goethite alteration included in the Boremap comment file (bm_comment in delivery Sicada_08_062)*

IDCODE (Borehole)	Adj. SecUp	Adj. SecLow	Deformation zone	Elevation (Adj. SecUp)
KLX04	963.19	963.26	klx04_dz1c	–933.98

Goethite removed from the Boremap comment file.

The three goethite occurrences that remain in the mapping file after these updates are listed in Table 5-5 and shown versus elevation in Figure 5-59. The occurrences are either from a deformation zone (ZSMNE107A in KLX16A) or from a possible deformation zone (in KLX15A), but not in any water-conducting sections (“PFL”-anomalies). The deepest occurrence is from –316.20 m above sea level (KLX16A).

These occurrences comprise quite large-grained goethite (up to some tens µm). This grain-size is much larger, and the crystallinity much more developed, compared with the youngest, and probably recently precipitated X-ray amorphous cryptocrystalline goethite in the area, described by /Dideriksen et al. 2007, Dideriksen et al. submitted/. Such potentially recent goethite has only been identified in near-surface drill core samples (/Dideriksen et al. submitted/). Therefore, it is indicated that the goethite occurrences identified in the present study have not been formed recently. Interestingly, all three occurrences show presence of both hematite and goethite in the same fracture coating.

Table 5-5. Goethite-bearing fractures remaining in the mapping data after SEM-investigations.

IDCODE (Borehole)	FRACT_ INTERPRET	Adj. SecUp	MIN1	MIN2	MIN3	MIN4	Deformation zone	Elevation
KLX15A	Open	379.524	Chlorite	Calcite	Goethite	Hematite	Possible DZ	–279.44
KLX16A	Open	348.173	Calcite	Hematite	Goethite	Clay minerals	ZSMNE107A	–295.00
KLX16A	Open	371.851	Calcite	Goethite	Hematite	Clay minerals	ZSMNE107A	–316.20

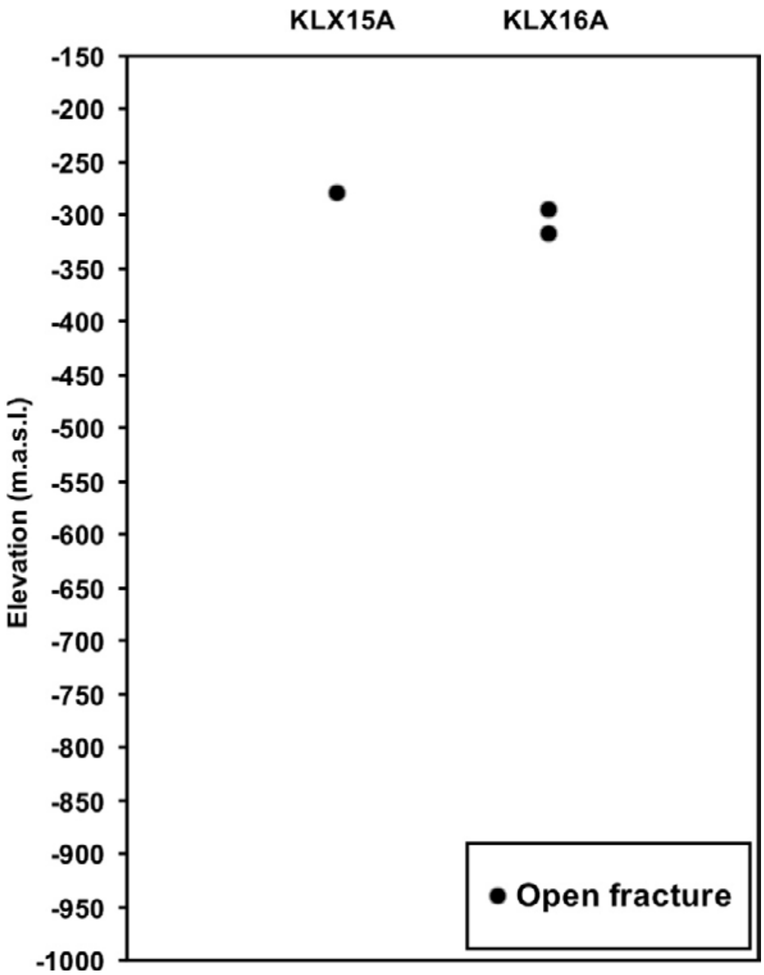

Figure 5-59. *Depth distribution of goethite occurrences from greater depth than –150 m above sea level (as listed in Table 5-1 to Table 5-4).*

5.3 Suggestion for further studies

Further studies are suggested to achieve more detailed characterisation of the three plausible goethite occurrences described in the present study. Further characterisation of these occurrences aids to the understanding of the significance of these occurrence, especially regarding timing.

Measurements of radionuclides in the U-series decay chain (^{238}U-^{234}U-^{230}Th), can be used to derive time constraints for oxidizing conditions in the bedrock fractures, as shown in near-surface fractures in Laxemar /Drake and Tullborg 2008d/, at the adjacent Äspö site /Tullborg et al. 2003/, but also in other areas /e.g. Smellie et al. 1986, Gascoyne and Cramer 1987, MacKenzie et al. 1992, Suksi and Rasilainen 2002, Min et al. 2005/. Disequilibria in the decay chain ^{238}U -^{234}U-^{230}Th indicate redistribution (removal or deposition) of uranium within the last 1 Ma and after such perturbation, the system will gradually return towards a state of secular equilibrium /Osmond and Ivanovich 1992, Gascoyne et al. 2002/. In the Laxemar area, radioactive disequilibrium in the fracture coatings requires that fracture fillings have experienced open system conditions in the last million years, even though most fractures have probably formed much earlier. Both ^{238}U and ^{234}U are leached by oxidative fluids and are much more mobile than Th, recent removal of U (oxidizing conditions) results in $^{234}U/^{238}U$ AR ~1 and $^{230}Th/^{234}U$ AR > 1 in the solid phase.

However, because U is only found in trace amounts in the fracture coatings, U-series measurements require relatively large sample volumes (1–5 g is preferred). These requirements are only met by one of the goethite samples from this study (KLX15A: 379.542 m). It should be noted that this sample has experienced oxidizing conditions during at least one year of storage after the core was drilled and that the fracture surface has been flushed with water during sawing of the sample. Therefore, there is a risk that the post-drilling handling of the drill core sample may influence the results of U-series measurements.

The two open fractures from KLX16A: 348.173 m and 371.851 m, contain too small amounts of fracture coating for U-series measurements. Instead, the methodology presented by /Dideriksen et al. 2007, Dideriksen et al. submitted/ may be applicable on these fracture coatings (requires about 20 mg or slightly more). This methodology includes detailed analyzes of Fe(III)/Fe(II) (Mössbauer spectroscopy), Fe isotopes ($\delta^{56}Fe$), X-ray diffraction and detailed SEM on fracture coating Fe-oxides. Using these methods /Dideriksen et al. 2007, Dideriksen et al. submitted/ distinguished goethite formed recently (with e.g. low degree of crystallinity) from older, low-temperature goethite and Fe-oxides and from very much older, hydrothermal hematite. This methodology requires about 20 mg for all analyses, however, if only investigating with X-ray diffraction (broad peaks), Fe isotopes and with SEM, only about 0.5 mg is needed.

6 Summary

A total number of 34 goethite occurrences from depths greater than –150 m above sea level have been mapped during the drill core mapping performed during the site investigations in Laxemar subarea. These occurrences are from greater depths than (~20 m) where the redox transition zone (change from oxidizing to reducing conditions) is normally observed in the Laxemar subarea /Drake and Tullborg 2008d/. They include occurrences in open fracture, sealed fractures, crush zones, sealed networks and as rock alteration.

Microscope investigations (mainly SEM-EDS) show that only three of these mapped occurrences may potentially be fracture coating goethite present in the fracture prior to drilling. The other mapped occurrences are recommended to be removed from the mapping data as it is indicated that they are either drilling induced (often as a fine-grained powder on the fracture coating and/or at the side of the drill core) or incorrectly identified. In the former case, the whole drill core section (5–10 m) around the mapped goethite occurrence commonly show signs of drill wear (parallel markings on the drill core side or sheared drill core pieces). There are also indications that some of the goethite-like coatings are actually stains of HCl used during the mapping procedure.

The three potential goethite occurrences are from open fractures, either from a deformation zone (ZSMNE107A in KLX16A) or from a possible deformation zone (in KLX15A), but not in any water-conducting sections (“PFL”-anomalies). The deepest occurrence is from –316.20 m above sea level (KLX16A).

These occurrences comprise quite large-grained goethite (up to some tens µm). This grain-size is much larger, and the crystallinity much more developed, compared with the youngest, and probably recently precipitated X-ray amorphous cryptocrystalline goethite in the area, described by /Dideriksen et al. 2007, Dideriksen et al. submitted/. The latter has only been identified in near-surface drill core samples (/Dideriksen et al. submitted/). Therefore, it is indicated that the goethite occurrences identified in the present study have not been formed recently.

Further studies are suggested to obtain a more detailed characterisation of the three remaining goethite occurrences from open fractures. U-series disequilibrium analyses and Fe-oxide analyses following the methodology of /Dideriksen et al. 2007; Dideriksen et al. submitted/ are proposed, although the amount of fracture material needed is a critical issue, as well as the post-drilling handling of the samples.

7 References

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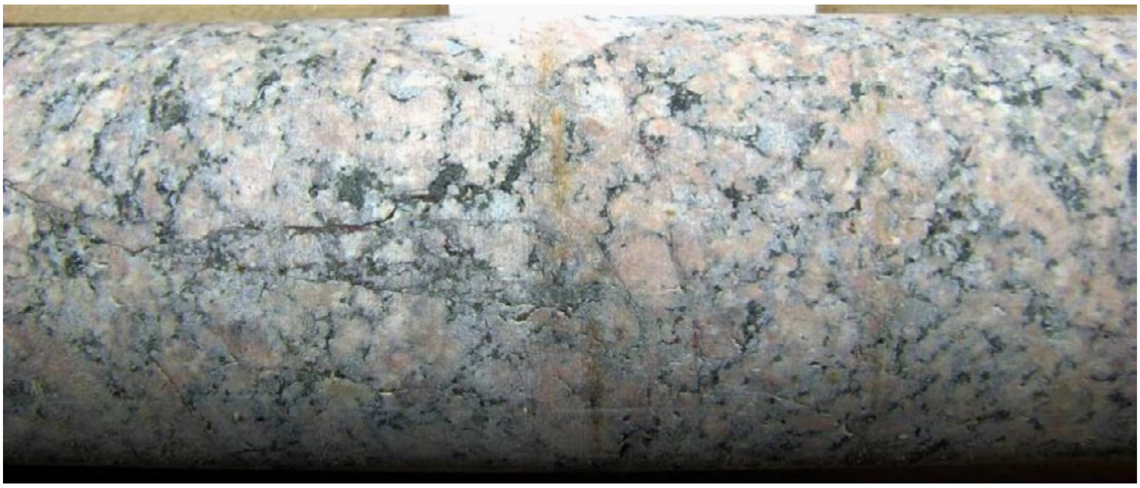
Sample descriptions

Old mapping data		Suggested updated mapping data	
IDCODE	KLX04	**IDCODE**	KLX04
VARCODE	Sealed Network	**VARCODE**	Sealed Network
ADJUSTEDSECUP	239.554	**ADJUSTEDSECUP**	239.554
ADJUSTEDSECLOW	239.652	**ADJUSTEDSECLOW**	239.652
MIN1	Red Feldspar	**MIN1**	Red Feldspar
MIN2	Quartz	**MIN2**	Quartz
MIN3	Goethite	**MIN3**	
MIN4		**MIN4**	

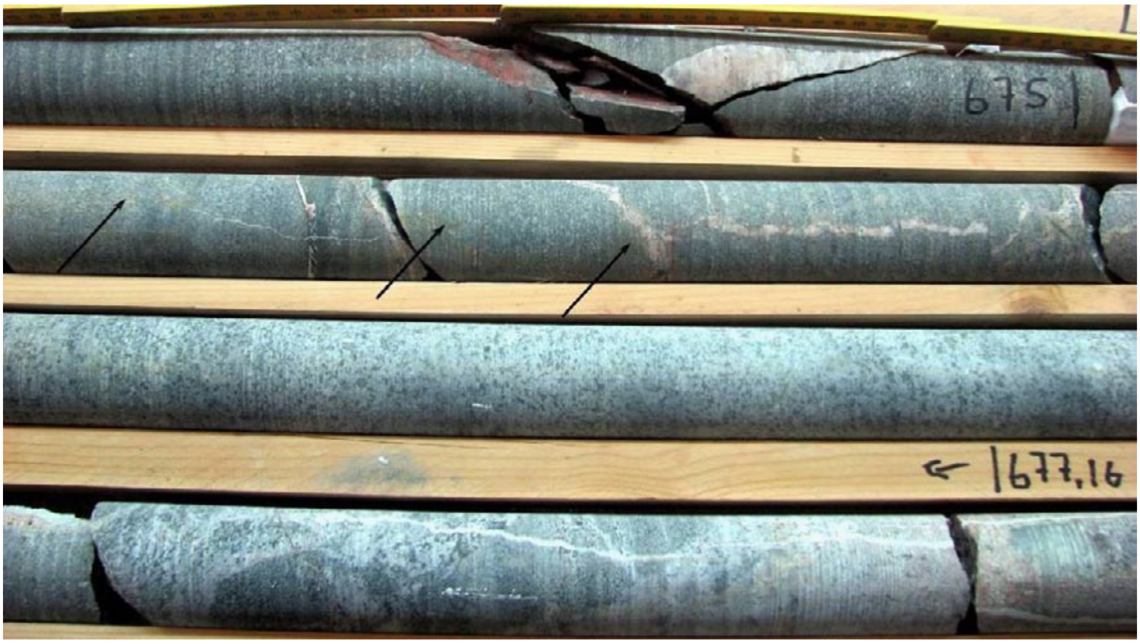
Interpretation: Section of corroded, metallic markings on the core, perpendicular to the drill core length axis, resulting from drill wear. These marks have nothing to do with the sealed network and therefore goethite should be excluded in the mapping file.



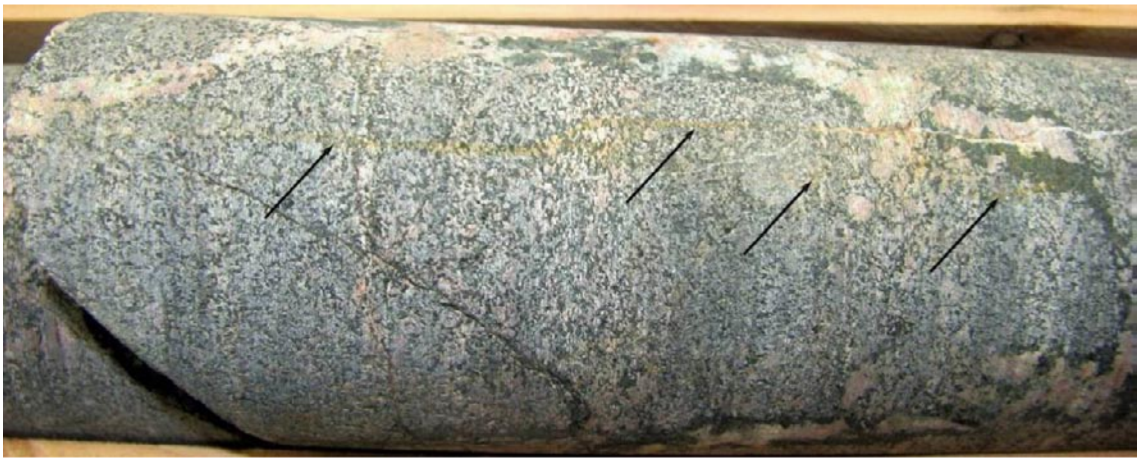
Photograph of sealed network section KLX04: 239.554–239.652 m.

Old mapping data		Suggested updated mapping data	
IDCODE	KLX04	**IDCODE**	KLX04
VARCODE	Sealed Network	**VARCODE**	Sealed Network
ADJUSTEDSECUP	674.848	**ADJUSTEDSECUP**	674.848
ADJUSTEDSECLOW	676.405	**ADJUSTEDSECLOW**	676.405
MIN1	Calcite	**MIN1**	Calcite
MIN2	Goethite	**MIN2**	Chlorite
MIN3	Chlorite	**MIN3**	Pyrite
MIN4	Pyrite	**MIN4**	

Interpretation: Section of corroded, metallic markings on the core, parallel with the drill core length axis, resulting from drill wear. These marks have nothing to do with the sealed network and therefore goethite should be excluded in the mapping file.



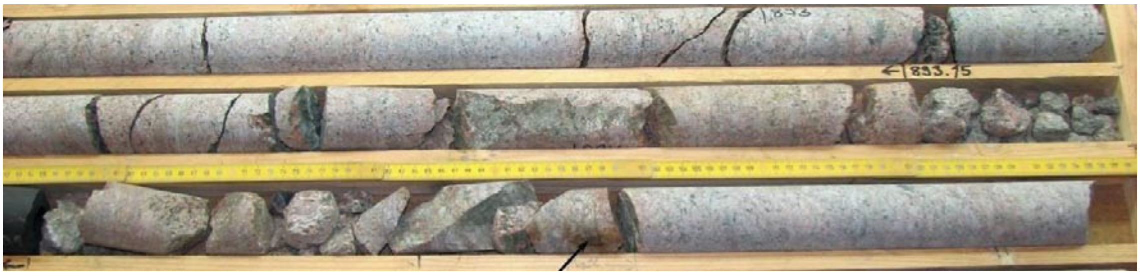
Photograph of sealed network section KLX04: 674.848–676.405 m.



Photograph of sealed network section KLX04: 674.848–676.405 m.

Old mapping data		Suggested updated mapping data	
IDCODE	KLX04	**IDCODE**	KLX04
VARCODE	Crush Zone	**VARCODE**	Crush Zone
ADJUSTEDSECUP	894.446	**ADJUSTEDSECUP**	894.446
ADJUSTEDSECLOW	895.104	**ADJUSTEDSECLOW**	895.104
MIN1	Calcite	**MIN1**	Calcite
MIN2	Chlorite	**MIN2**	Chlorite
MIN3	Clay Minerals	**MIN3**	Clay Minerals
MIN4	Goethite	**MIN4**	

Interpretation: Drill core section with an iron-rich film covering most of the drill core pieces, resulting from drill wear, or other drilling or post-drilling activity. Therefore goethite should be excluded in the mapping file. Furthermore, hematite and adularia should be added to the mapping file.



Photograph of crush zone section KLX04: 894.446–895.104 m.

IDCODE	KLX04
VARCODE	Alteration
ADJUSTEDSECUP	963.19
SECUP	963.26

Goethite is added as an additional alteration mineral in the comment file (bm_comment).

Interpretation: Drill core section with an iron-rich film covering a large part of the side of the drill core, as result of drill wear. Therefore, goethite should be excluded from the mapping data.

Photograph of section KLX04: 963.19–963.26 m for which goethite is included in the comment file for the alteration features.

Old mapping data		**Suggested updated mapping data**	
IDCODE	**KLX05**	**IDCODE**	**KLX05**
FRACT_MAPPED	Broken	**FRACT_MAPPED**	Broken
FRACT_INTERPRET	Sealed	**FRACT_INTERPRET**	Sealed
ADJUSTEDSECUP	518.300	**ADJUSTEDSECUP**	518.300
MIN1	Hematite	**MIN1**	Hematite
MIN2	Goethite	**MIN2**	Chlorite
MIN3	Chlorite	**MIN3**	
MIN4		**MIN4**	

Interpretation: No goethite on the fracture surface.

Photograph of open fracture KLX05: 518.300 m.

Old mapping data		**Suggested updated mapping data**	
IDCODE	**KLX05**	**IDCODE**	**KLX05**
FRACT_MAPPED	Broken	**FRACT_MAPPED**	Broken
FRACT_INTERPRET	Open	**FRACT_INTERPRET**	Open
ADJUSTEDSECUP	602.397	**ADJUSTEDSECUP**	602.397
MIN1	Hematite	**MIN1**	Hematite
MIN2	Goethite	**MIN2**	Calcite
MIN3	Calcite	**MIN3**	Epidote
MIN4		**MIN4**	Titanite

Interpretation: No goethite on the fracture surface. Minerals to be added to the mapping data: epidote and titanite.

Photograph of open fracture KLX05: 602.397 m.

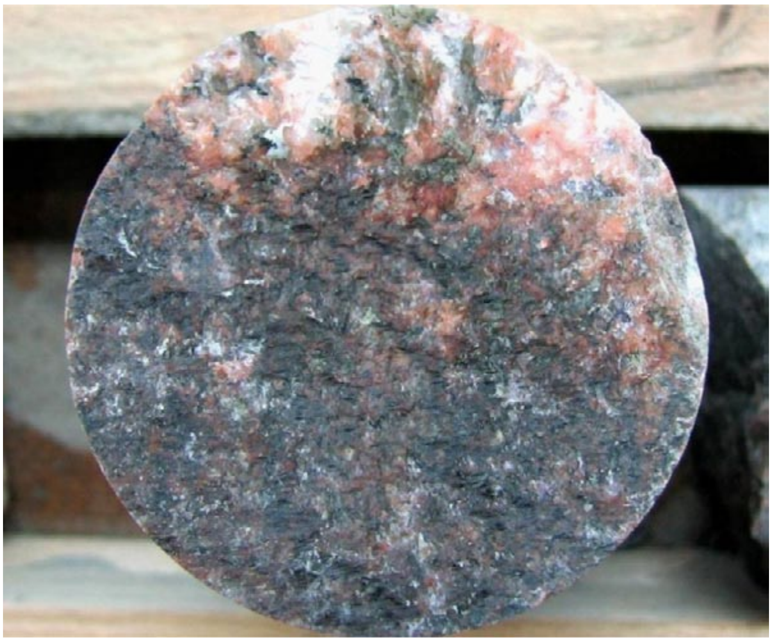
Old mapping data		**Suggested updated mapping data**	
IDCODE	**KLX07A**	**IDCODE**	**KLX07A**
FRACT_MAPPED	Broken	**FRACT_MAPPED**	Broken
FRACT_INTERPRET	Open	**FRACT_INTERPRET**	Open
ADJUSTEDSECUP	311.414	**ADJUSTEDSECUP**	311.414
MIN1	Goethite	**MIN1**	Chlorite
MIN2	Chlorite	**MIN2**	Adularia
MIN3		**MIN3**	Hematite
MIN4		**MIN4**	Laumontite

Interpretation: No goethite on the fracture surface. Minerals to be added to the mapping data: hematite, adularia and laumontite.

Photograph of open fracture KLX07A: 311.414 m.

Old mapping data		Suggested updated mapping data	
IDCODE	**KLX09**	**IDCODE**	**KLX09**
FRACT_MAPPED	Broken	**FRACT_MAPPED**	Broken
FRACT_INTERPRET	Open	**FRACT_INTERPRET**	Open
ADJUSTEDSECUP	574.242	**ADJUSTEDSECUP**	574.242
MIN1	Chlorite	**MIN1**	Chlorite
MIN2	Goethite	**MIN2**	Adularia
MIN3		**MIN3**	Hematite
MIN4		**MIN4**	

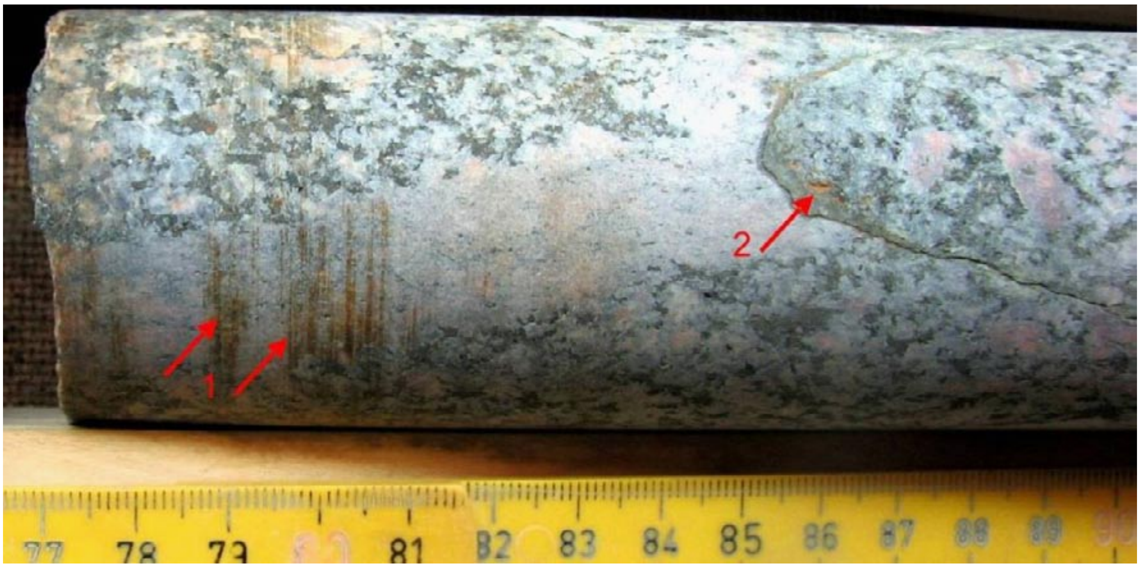
Interpretation: No goethite on the fracture surface. Minerals to be added to the mapping data: hematite and adularia.



Photograph of open fracture KLX09: 574.242 m.

Old mapping data		Suggested updated mapping data	
IDCODE	**KLX12A**	**IDCODE**	**KLX12A**
FRACT_MAPPED	Unbroken	**FRACT_MAPPED**	Unbroken
FRACT_INTERPRET	Sealed	**FRACT_INTERPRET**	Sealed
ADJUSTEDSECUP	313.853	**ADJUSTEDSECUP**	313.853
MIN1	Epidote	**MIN1**	Epidote
MIN2	Pyrite	**MIN2**	Pyrite
MIN3	Goethite	**MIN3**	Calcite
MIN4	Calcite	**MIN4**	

Interpretation: The core has several, oxidized metallic markings perpendicular to the drill core length axis, consisting of a fine-grained Fe-rich powder ("1" in the photograph), as a result of drill wear. The same kind of powder (mapped as goethite) is found in porous parts of the sealed fracture (KLX12A: 313.853 m, see "2" in the photograph). Goethite does therefore not belong to the original fracture filling and should be removed in the mapping data. This fracture is situated in a drill core section (about 5 m in length) which features repeated metallic marking (resulting from drill wear).



Photograph of sealed fracture KLX12A: 313.853 m ("2") and adjacent metallic markings on the core, resulting from drill wear ("1").

Old mapping data		**Suggested updated mapping data**	
IDCODE	KLX13A	**IDCODE**	KLX13A
FRACT_MAPPED	Broken	**FRACT_MAPPED**	Broken
FRACT_INTERPRET	Open	**FRACT_INTERPRET**	Open
ADJUSTEDSECUP	394.712	**ADJUSTEDSECUP**	394.712
MIN1	Chlorite	**MIN1**	Chlorite
MIN2	Goethite	**MIN2**	Pyrite
MIN3	Pyrite	**MIN3**	
MIN4		**MIN4**	

Interpretation: No goethite on the fracture surface.

Photograph of open fracture KLX13A: 394.712 m.

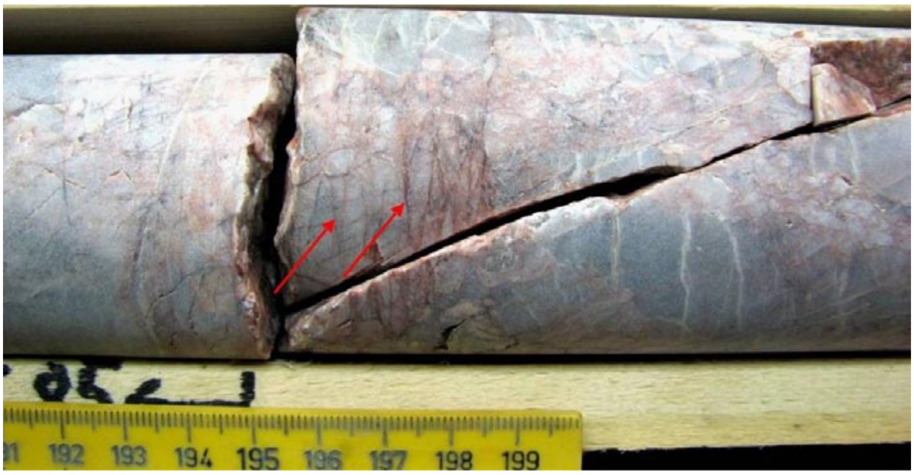
Old mapping data		Suggested updated mapping data	
IDCODE	KLX13A	**IDCODE**	KLX13A
VARCODE	Sealed Network	**VARCODE**	Sealed Network
ADJUSTEDSECUP	576.768	**ADJUSTEDSECUP**	576.768
ADJUSTEDSECLOW	576.897	**ADJUSTEDSECLOW**	576.897
MIN1	Chlorite	**MIN1**	Chlorite
MIN2	Calcite	**MIN2**	Calcite
MIN3	Goethite	**MIN3**	
MIN4		**MIN4**	

Interpretation: The core has several oxidized metallic markings perpendicular to the drill core length axis, consisting of a fine-grained Fe-rich powder resulting from drill wear (see arrows in the photograph). These have incorrectly been mapped as goethite, but do not belong to the sealed network and shall be removed from the mapping file.

Photograph of sealed network section KLX13A: 576.768–576.897 m. Arrows indicate metallic markings on the core, resulting from drill wear.

Old mapping data		Suggested updated mapping data	
IDCODE	KLX16A	**IDCODE**	KLX16A
VARCODE	Sealed Network	**VARCODE**	Sealed Network
ADJUSTEDSECUP	406.600	**ADJUSTEDSECUP**	406.600
ADJUSTEDSECLOW	407.100	**ADJUSTEDSECLOW**	407.100
MIN1	Calcite	**MIN1**	Calcite
MIN2	Hematite	**MIN2**	Hematite
MIN3	Prehnite	**MIN3**	Prehnite
MIN4	Goethite	**MIN4**	

Interpretation: No goethite in the sealed network. The red colour of the filling is typical for hematite, as shown in earlier studies in the area.



Photograph of sealed network section KLX16A: 406.600–407.100 m.

Old mapping data		Suggested updated mapping data	
IDCODE	KLX13A	**IDCODE**	KLX13A
FRACT_MAPPED	Broken	**FRACT_MAPPED**	Broken
FRACT_INTERPRET	Open	**FRACT_INTERPRET**	Open
ADJUSTEDSECUP	406.842	**ADJUSTEDSECUP**	406.842
MIN1	Calcite	**MIN1**	Calcite
MIN2	Hematite	**MIN2**	Hematite
MIN3	Goethite	**MIN3**	
MIN4		**MIN4**	

Interpretation: No goethite on the fracture surface. The red colour of the filling is typical for hematite, as shown in earlier studies in the area.

Photograph of open fracture KLX16A: 406.842 m.

Appendix 2

Abbreviations

Below is a list of Sicada abbreviations/codes, their meaning and examples.

Sicada code	Meaning	Example
IDCODE	Borehole name	KLX08
VARCODE	Feature such as alteration, sealed network or crush zone.	Sealed Network
FRACT_MAPPED	If the fracture is broken or sealed when mapped	Broken
FRACT_INTERPRET	If the fracture is interpreted as open, sealed or partly sealed prior to drilling.	Open
ADJUSTEDSECUP	Upper intercept in the borehole (in borehole length)	110.987
ADJUSTEDSECLOW	Lower intercept in the borehole (in borehole length)	110.987
MIN1	Most abundant fracture mineral	Epidote
MIN2	Second most abundant fracture mineral	Epidote
MIN3	Third most abundant fracture mineral	Epidote
MIN4	Fourth most abundant fracture mineral	Epidote
ELEVATION	Intercept in the borehole (in meters above sea level)	–100.201