P-05-183

Forsmark site investigation

Structural investigations of deformation zones (ductile shear zones and faults) at Forsmark – a pilot study

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Keywords: Forsmark, AP PF 400-05-046, Structural geology, Shear zone, Fault, Mylonite, Cataclasite, Fault breccia, Kinematics.

Abstract

A pilot study of predominantly brittle structures, i.e. faults and fractures, has been undertaken at Forsmark. The main aim of the work is to assess whether or not a more comprehensive investigation of faults may improve the understanding of their kinematic history.

Structural data were obtained from outcrops along the Eckardfjärden deformation zone (EDZ), and from selected sections of drill cores from five boreholes. Polished thin sections from samples collected both from outcrops and from the drill cores were studied using standard petrographic techniques, and in some cases also SEM (backscatter). Observations from thin sections combined with data from the field and from drill cores form the basis for the conclusions of the pilot study.

The investigated structures present in the area include; low-grade ductile shear zones, several generations of cataclasite, and breccias cemented by diagenetic minerals. The observations along the EDZ are consistent with a sequence of progressively more brittle faulting, following plastic deformation.

There are good exposures of ductile shear zones and fault rocks along the investigated part of the EDZ. The possibility of obtaining additional data on surface faults and fault populations, e.g. in road sections, has not been explored. Although the central parts of other major faults are not exposed, populations of minor structures that are related to nearby master faults may provide information of potential significance to a kinematic analysis. In the drill cores, abundant faults that show good slickensides were observed. Given that the orientation of a sufficient number of these structures can be determined, it would likely result in the identification of fault populations with specific properties that may be related to movement on master faults of regional significance. Combining data from surface outcrops with observations from logged drill cores would provide important input to a kinematic study.

As a general conclusion, it is considered that a more comprehensive structural study may lead to improved understanding of the kinematic pattern in the area of interest. This would require that relevant data can be obtained from a variety of faults and fault populations with different properties and orientations. Based on the conclusions from the pilot study, such data may be derived from in-depth studies of available cores that intersect variably oriented faults. The possibility of extending the data set using observations from detailed fieldwork on surface outcrops (e.g. along roads) may be further explored. Field and core studies should be supplemented by a general study of the petrography and the micro-structural history of the faults.

Sammanfattning

En pilotundersøkelse av forkastninger og sprekker er utført i Forsmark. Hensikten med arbeidet er å vurdere om en mer fullstendig undersøkelse av forkastninger kan gi økt forståelse for forkastningenes kinematiske historie.

Strukturdata ble innhentet fra blotninger langs Eckarfjärden deformation zone (EDZ), og fra utvalgte seksjoner av borekjerner fra fem borehull. Polerte tynnslip av prøver samlet på overflaten og fra borekjerner ble studert ved hjelp av standard petrografiske teknikker, og i noen tilfeller supplert med SEM (backscatter). Observasjoner fra tynnslip kombinert med data fra felt og fra borekjerner utgjør grunnlaget for konklusjonene fra pilotstudiet.

De undersøkte strukturene som finnes i området omfatter lav-grads, duktile skjærsoner, flere generasjoner med kataklasitt, og breksjer sementert av diagenetiske mineraler. Disse observasjonene er i samsvar med en rekke av hendelser med stadig mer sprø deformasjon som følger etter plastisk deformasjon.

Det finnes gode blotninger av skjærsoner og forkastninger langs det undersøkte segmentet av EDZ. Det er ikke avklart om undersøkelser på overflaten, for eksempel i vegskjæringer, kan gi mer data om forkastninger og forkastningspopulasjoner. Selv om den sentrale delen av store forkastninger ikke er blottet, kan populasjoner av strukturer som er relatert til store forkastninger gi informasjon som er betydning for en kinematisk analyse. Et betydelig antall forkastninger med gode slickensides ble observert i borekjerner. Dersom orienteringen av et stort nok antall av disse strukturene kan bestemmes, kan dette lede til identifikasjon av forkastningspopulasjoner, med bestemte egenskaper, som kan knyttes til store forkastninger av regional betydning. Ved å kombinere data fra overflaten med observasjoner fra kjerne-logger, kan dette gi viktige data til en kinematisk undersøkelse.

Som en generell konklusjon antas det at en mer omfattende strukturell undersøkelse i Forsmark kan gi en bedre forståelse av det kinematiske mønsteret i området som er av interesse. Dette vil kreve relevante data fra ulike forkastninger og forkastnings-populasjoner med forskjellige egenskaper og orientering. På grunnlag av konklusjonene fra pilotstudiet, kan en få slike data ved inngående undersøkelser av tilgjengelige borekjerner som krysser forkastninger med ulik orientering. Det bør avklares om det vil være mulig å bedre data-settet ved ytterligere undersøkelser på overflaten (for eksempel i vegskjæringer). Under-søkelser på overflaten og av borekjerner bør suppleres med en generell undersøkelse av forkastningsbergartenes petrografi og mikro-teksturelle utvikling.

Contents

1 Introduction

This document reports the results of a pilot study of the kinematics of a restricted number of deformation zones at the Forsmark site. This study forms one of the activities performed within the site investigation work at Forsmark (Figure 1-1). The work was carried out in accordance with activity plan AP PF 400-05-046. Controlling documents for performing this activity are listed in Table 1-1. 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
Name	AP PF 400-05-046	1.0
Method descriptions	**Number**	**Version**
/Braathen 1999/	Tectonophysics 302, 99–121	
/Braathen et al. 2002/	Norwegian Journal of Geology, 82, 225–241	
/Braathen et al. 2004/	Tectonics, 23, TC4010, doi:10.1029/2003TC001558	
/Nordgulen et al. 2002/	Norwegian Journal of Geology, 82, 299–316	
/Osmundsen et al. 2003/	Journal of the Geological Society, London 160, 1–14	
/Petit 1987/	Journal of Structural Geology 9, 597–608	

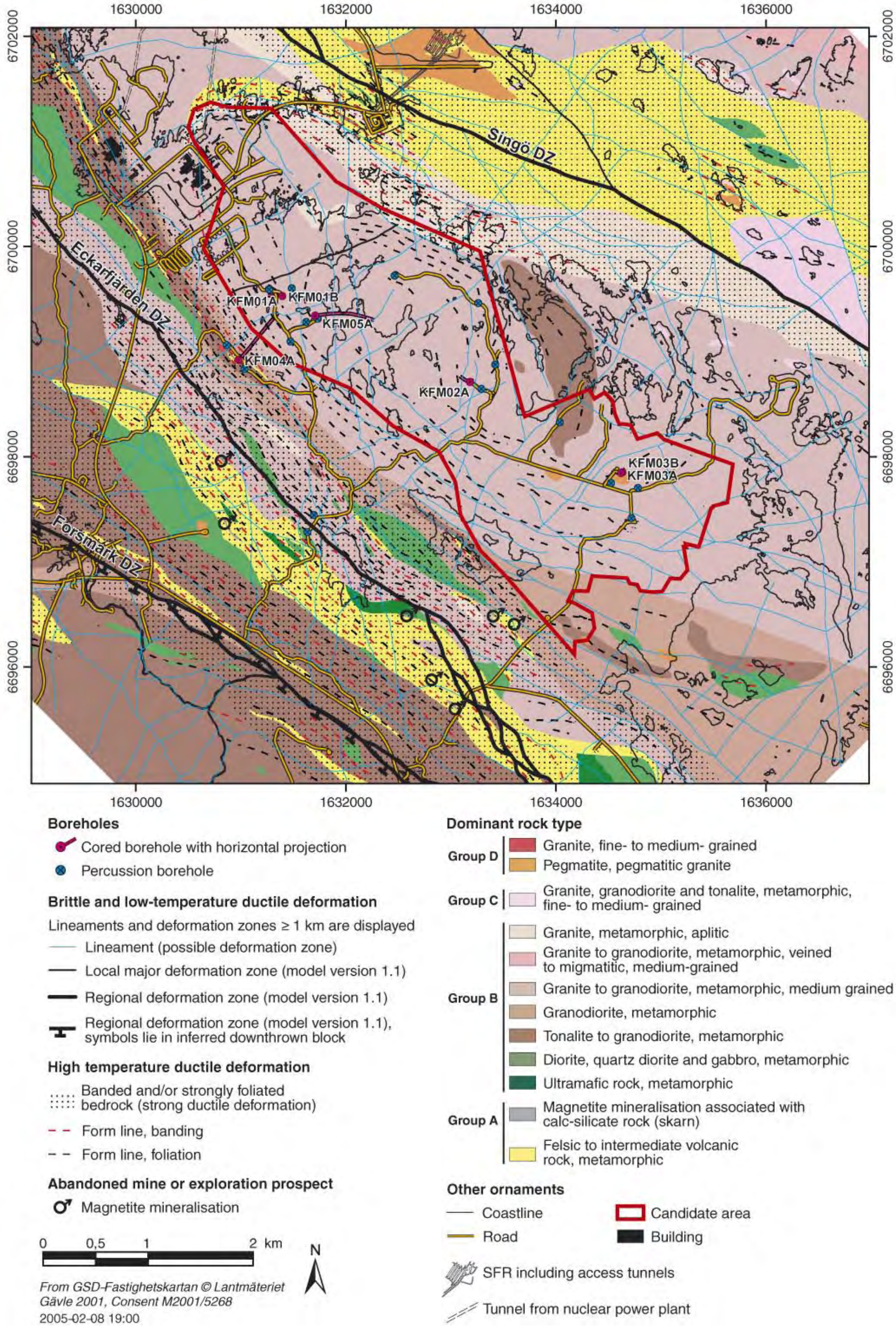

Figure 1-1. *General overview of the Forsmark site investigation area.*

2 Objective and scope

The objective of this pilot study is to assess what possibilities exist at the Forsmark site to obtain an improved understanding of the kinematics of particularly the brittle deformation zones in the area. The project has not involved detailed and systematic work, but has involved an investigation of some selected localities along one regional deformation zone in the field and a few deformation zone intersections in boreholes. Observations from thin sections combined with data from the field and from drill cores form the basis for the conclusions of the pilot study.

Given the initial nature of the work, and its limited scope, only preliminary conclusions can be drawn regarding the general pattern and specific properties of faults and fractures. However, the study allows us to address the explicit aim of the project in an adequate manner.

3 Equipment

3.1 Description of equipment

During field work and core inspection, the standard equipment for structural investigations was used, including hammer, compass, hand lens, diluted HCl, digital camera, and GPS (Garmin etrex) for locating observation points according to SKB standards (Swedish Grid). Samples collected in the field and from drill cores were cut in the core laboratory, and selected chips were correctly marked (felt pen) and sent for preparation of polished thin sections. The thin sections were petrographically analysed and some selected sections were analysed using SEM in backscatter mode.

4 Execution

4.1 General

The project was carried out in conformity with the accepted activity plan AP PF 400-05-046. Literature studies preceded the field investigations that were carried out at Forsmark on May 2–3, 2005.

The first day was devoted to field work along a section of the Eckarfjärden deformation zone (EDZ), which is a major NW-SE-oriented ductile shear and fault zone with a clear geophysical signature /SKB 2004/. The second day involved a brief inspection of selected sections from several drill cores, with a specific aim to study deformation zones with abundant faults and fractures. The following drill holes and intervals were inspected: KFM01A (635–690 m), KFM02A (155–190 m), KFM02A (410–520 m), KFM04A (410–465 m), KFM05A (890–952 m) and KFM07A (830–900 m). Samples for thin section preparation were collected both in the field and from the drill cores. A total of 17 polished sections were studied at the Geological Survey of Norway (Trondheim) using standard petrographic techniques, and in some cases also SEM (backscatter).

4.2 Data handling and processing

At the Geological Survey of Norway (NGU) in Trondheim, structural data were analysed and plotted using standard techniques. The thin sections were analysed in several steps:

1) Scanning at high resolution of the entire section using a standard slide scanner.
2) Printing of the scanned jpg-images as A4 colour prints that greatly aid in establishing general relationships and locating critical features for detailed study.
3) Petrographic analysis and documentation of textural and micro-structural relations using a digital camera attached to the microscope (Leitz).
4) Detailed studies of specific mineralogical and textural details using SEM in backscatter mode.

4.3 Analysis and interpretation

The methods employed from fieldwork through structural data analysis and petrographic work are based on those described in /Braathen 1999, Braathen et al. 2002, Nordgulen et al. 2002/ and /Osmundsen et al. 2003/. In this report, definition of fault rocks is according to the classification in /Braathen et al. 2004/. Criteria for identifying the slip-direction on slickenside surfaces is presented in /Petit 1987/.

4.4 Nonconformities

No nonconformities have been noted.

5 Results

5.1 Field investigations

Field studies were carried out solely along the Eckardfjärden deformation zone (EDZ). Several stations were studied over a distance along strike of approximately 1 km (Figure 1-1). The EDZ is one of the most prominent regional deformation zones at the Forsmark site. In the study area, the host rock metagranite is transformed along the zone into steeply southwest-dipping, planar protomylonites and mylonites with a pronounced, generally gently plunging lineation.

The mylonitic fabrics of the EDZ are overprinted and cut by a number of different fractures and small faults hosting a wide variety of minerals, e.g. epidote, quartz, chlorite and calcite. Kinematic indicators are sparse. However, on most outcrops, there are steeply dipping fault strands oriented parallel or sub-parallel to the mylonite fabric (Figure 5-1). Exposed fault planes with epidote and/or chlorite exhibit slickenlines that have gentle plunges, in some cases similar in orientation to the lineation in the mylonitic fabrics (Figure 5-1). The sense of shear cannot be determined although in some cases the relative displacement on individual faults is seen to be sinistral.

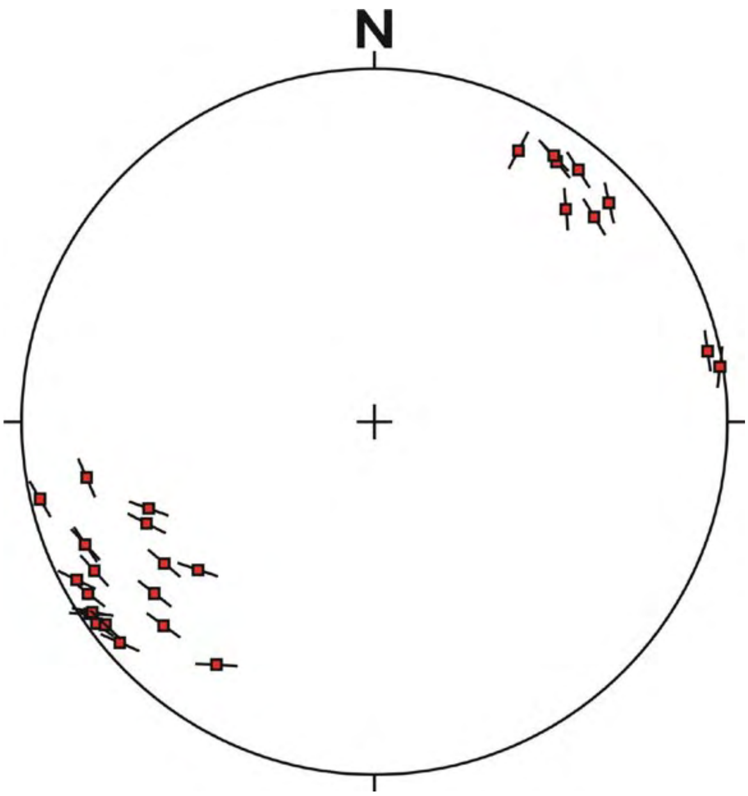

Figure 5-1. *Forsmark field data. Slip-linear plot of mesocopic faults (N=28) based on data obtained from several outcrops (see locality list with coordinates in Appendix 1). Lower hemisphere, equal area projection (Schmidt net). The plot shows that the observed faults are oriented approximately NW-SE with steep dips. The linear features are generally consistent with a predominant strong strike-slip component, however, the sense of slip could not be determined.*

The mylonitic fabric is observed in several localities. At locality PFM006165, a zone of proto- to ultramylonite is several metres wide across strike (Figure 5-2). The mylonites are generally low grade and consist of plagioclase, K-feldspar, quartz, epidote, chlorite and white mica. Epidote-rich semi-ductile shear zones cut through and are sub-parallel to the mylonitic fabric. Cataclasites are also present in many localities and are developed along the zones of high ductile strain.

Younger than the mylonites and cataclasites are calcite- and/or quartz-filled breccias and a series of micro-faults and -fractures hosting variable mineral assemblages. Calcite-filled breccias spatially associated with mylonites are present at PFM006166, whereas excellent examples of quartz-filled breccia are present at PFM006168 (Figure 5-3). Evidence of later generations of thin veinlets cutting the previously formed ductile shear zones and fault rocks are present at several localities, e.g. PFM006170, where quartz veins are offset by mainly NE-SW-oriented small faults filled with epidote (Figure 5-4).

Figure 5-2. *Mylonite along the EDZ (PFM006165). The rock consists of plagioclase, K-feldspar, quartz, epidote, chlorite and white mica (cf Figure 5-8). Note pale green epidote-rich zones. Yellow pen for scale is 12 cm long.*

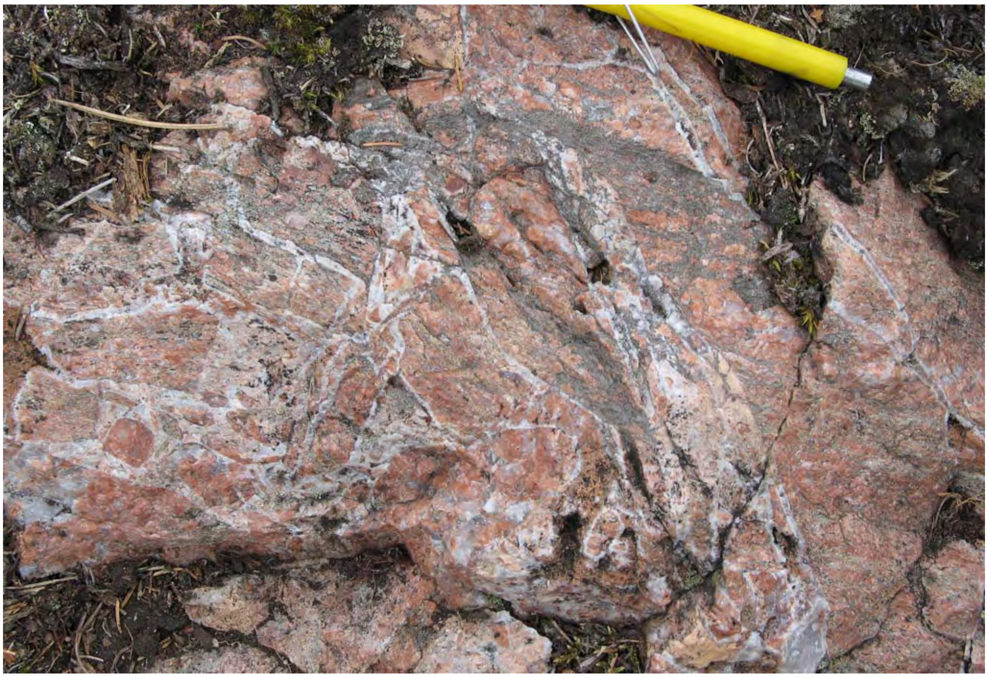

Figure 5-3. *Quartz-filled breccia with angular fragments of a fine-grained, reddish pink granitoid present within the EDZ (PFM006168). At this locality, there are NW-SE-trending faults with gently SE-plunging slickensides. Yellow pen for scale.*

Figure 5-4. *Quartz veins in reddish pink metagranite cut by epidote-filled fractures and approximately NE-SW-oriented micro-faults. At this locality, there are probably two generations of quartz veins and epidote fractures (PFM006170). Yellow pen for scale is 12 cm long.*

5.2 Drill core investigations

Selected sections from five drill holes were inspected with the aim of investigating the style of deformation in the previously defined deformation zones (Table 5-1). Based on this investigation, samples for petrographic analysis were collected from characteristic fault rocks (Appendix 1).

Drill core KFM01A is sub-vertical and intersects a medium-grained metagranite in the analysed section at 639−684 m that corresponds to DZ3 in /Carlsten et al. 2004a/. In this section, the rock is cut by fractures, faults and breccia zones with different minerals including chlorite, laumontite and calcite. Several fractures with a steep attitude have lineations defined mainly by slickensides on chlorite-coated fault surfaces. Observed slickensides are fairly steep and slightly oblique to the dip of the fault. Spectacular laumontite fill in highly fractured and partly brecciated metagranite occurs at ca 663 m and 673.4 m. A laumontite-filled fracture at 652.9 m (Figure 5-5) was sampled for thin section study (see Figure 5-15).

Drill core KFM02A is sub-vertical and intersects different types of metagranitoids and amphibolite in the analysed section 160−184 m and predominantly medium-grained metagranite in the analysed section 415−520 m. These sections correspond to DZ3 and DZ6 in /Carlsten et al. 2004b/. In general, there are subordinate fractures filled with epidote + quartz; fractures with chlorite that in some cases carry pyrite and/or quartz; laumontite-filled fractures that may carry calcite; and chlorite-coated fractures with some quartz. The chlorite-filled fractures display well-defined slickensides with commonly oblique to steeply oblique orientation. Some surfaces with black, polished fault planes were observed. A strongly altered zone with hematite, laumontite, chlorite and white mica, possibly resulting from dissolution of quartz combined with albitisation(?), occurs at ca 171.8 m. This corresponds to the altered vuggy rocks that have been described in /Möller et al. 2003, Petersson et al. 2003/.

Drill core KFM04A is oriented 60° towards the northeast and is inferred to approximately follow a NE-SW-oriented fault zone /SKB 2005/. The rock type in the investigated section at 412−464 m consists of different types of metagranitoid and amphibolite. In the inspected interval, which corresponds to DZ4 in /Carlsten et al. 2004c/, several types of mineral-filled faults and fractures are present. A hematite-altered rock at 413–414 m is cut by a fault carrying laumontite and minor calcite(?). A strong lineation is present on the fault surface (Figure 5-6), which is cut by a minor fault filled by quartz. Parallel to the borehole at 418–419 m, a zone of strong cataclasis and brecciation with epidote + hematite + laumontite is cut by calcite-filled fractures. At ca 441 m, a fault along the borehole is filled by laumontite and platy calcite. Furthermore, laumontite breccia occurs at 460.4 m. In general, there are several chlorite-covered small faults with quite well-developed slickensides.

Table 5-1. Overview of drill cores inspected in the project.

Drill core	Length, direction	Deformation zone section	Deformation zone identification
KFM01A	1,001 m, 318/85	639–684 m	DZ3 /Carlsten et al. 2004a/
KFM02A	1,002 m, 276/85	160–184 m	DZ3 /Carlsten et al. 2004b/
		415–520 m	DZ6 /Carlsten et al. 2004b/
KFM04A	1,001 m, 045/60	412–462 m	DZ4 /Carlsten et al. 2004c/
KFM05A	1,003 m, 081/60	892–916 m	DZ4 /Carlsten et al. 2004d/
		936–950 m	DZ5 /Carlsten et al. 2004d/
KFM07A	1,001.5 m, 260/60	803–1,001.5 m	DZ4 /Carlsten et al. 2005/

Figure 5-5. *KFM01A: Laumontite-filled fractures at 652.9 m. Note laumontite alteration in the wall rock immediately adjoining the laumontite vein.*

Figure 5-6. *KFM04A: Fault sub-parallel to the borehole at ca 414 m. Laumontite-filled fault with minor carbonate(?) and well-developed slickensides is cut at a high angle by a quartz-filled fault.*

Drill core KFM05A is oriented 60° towards the east and was inspected in two intervals at 892−916 and 936−950 m that correspond to DZ4 and DZ5 in /Carlsten et al. 2004d/. The rock type along these two sections is dominated by medium-grained metagranite. In DZ4, hematite-alteration occurs along small faults and fractures that may carry laumontite, quartz and calcite (Figure 5-7). Some chlorite may be associated with laumontite. In DZ5, fractures and faults are filled predominantly by laumontite, with less calcite and chlorite. Slickenlines occur sporadically in both deformation zones, but judging from the inspected core sections, they appear to be less common than in other studied drill cores.

Drill core KFM07A is oriented 60° towards the west and was inspected within the interval 803–901 m that corresponds to DZ4 /Carlsten et al. 2005/. The rock type along this section is dominated by foliated fine- to medium-grained metagranite. In this drill core, the main faults and fractures and local pockets of breccia contain laumontite; in places there is also calcite and/or epidote and/or chlorite. In the deeper part of the studied section, there are numerous chlorite-covered faults with good slickensides.

Figure 5-7. *Drill core KFM05A, DZ4 at 894 m. Note grain size reduction along the fault which is filled with reddish laumontite and white calcite.*

5.3 Thin section studies/microtextures

A complete list of the high-quality, polished thin section prepared from samples collected in the field (10 samples) and from drill cores (7 samples) is presented in Appendix 1. Prior to petrographic analysis, the thin sections were scanned at high resolution, providing a useful image that greatly aids in establishing general relationships and locating critical features for detailed study. Following initial examination of the thin sections, a set of six representative sections, as stated in the contract, were selected for more detailed study and presented in this report. Samples of mylonites and associated cataclasites were mainly collected in the field, whereas core samples provide examples of small-scale faults and fractures as well as associated mineral growth.

Mylonites

Mylonitic rocks were observed along the EDZ (see field description). In general, the thin sections show that proto-mylonites and mylonites consist of strongly recrystallized quartz, saussurititic plagioclase, K-feldspar, chlorite, epidote, fine-grained white mica and opaques (Figures 5-8 and 5-9). The mineralogy and the general lack of plastic deformation in the plagioclase show that the fabrics were formed under low-grade metamorphic (greenschist-facies) conditions. Locally, shear bands oblique to the main fabric are present in thin sections (Figure 5-8). The mylonites are cut at high angles by a network of brittle fractures and small faults (Figures 5-9, 5-10 and 5-11).

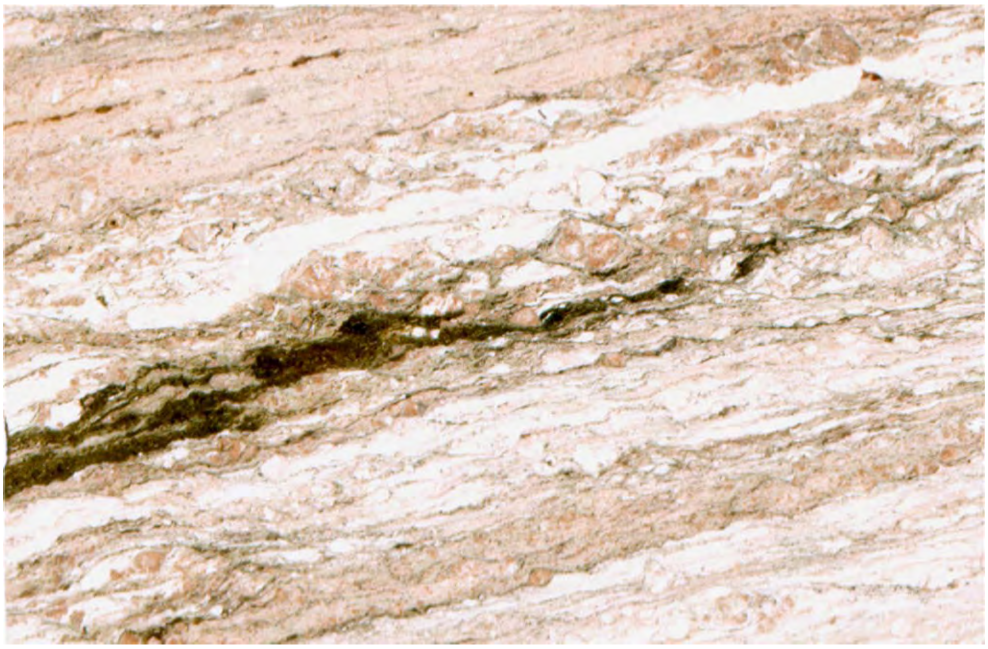

Figure 5-8. *Mylonitic fabric developed from granitic host rock along the EDZ (sample PFM006165_B). Tiny flakes of white mica are oriented parallel to the high-strain fabric. Note shear bands oblique to the main fabric. The thin section is not oriented.*

Figure 5-9. *Finely laminated quartz-rich mylonite to ultramylonite from the EDZ (sample PFM006169_C; parallel light). Tiny flakes of white mica (not seen) are oriented parallel to the high-strain ductile fabric. The mylonite fabric is cut at high angles by a network of brittle fractures and micro-faults with local pockets of brecciation (cf Figure 5-10). Note that chlorite+ epidote-minerals(?) are present as mineral fill in the fractured rock. Younger than these features are two generations of hairline micro-fractures (not seen) filled with quartz and unidentified mineral(s). The field of view is 30 mm wide.*

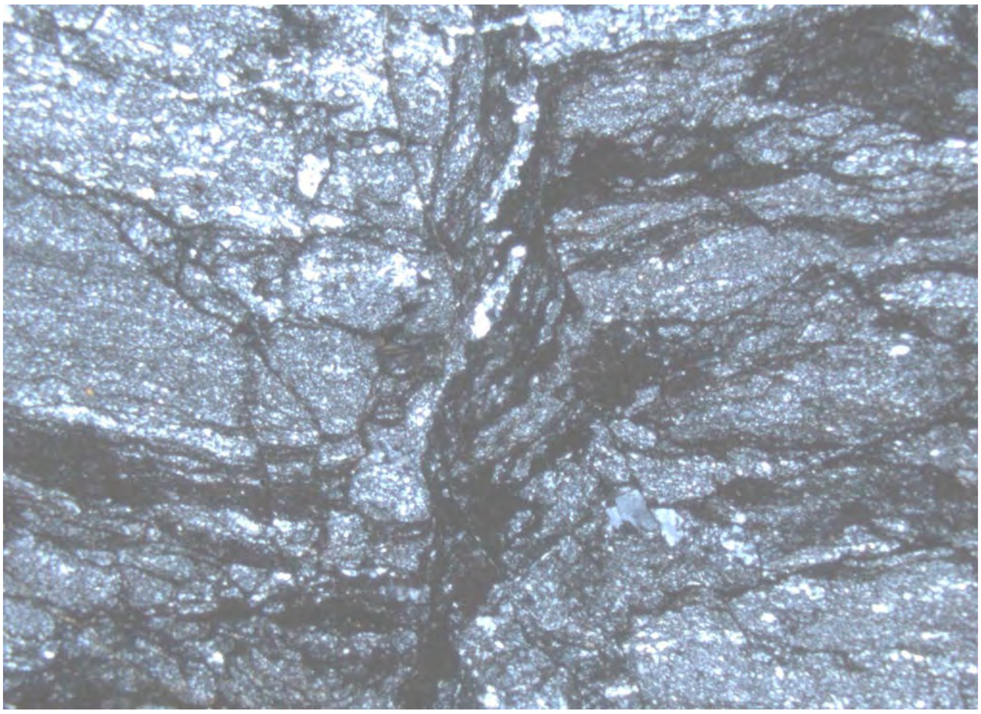

Figure 5-10. *Detail from Figure 5-9, showing fracturing and local brecciation along micro-faults in finely laminated quartz-rich mylonite (crossed polars). Tiny flakes of white mica (not seen) are oriented parallel to the high-strain ductile fabric. The field of view is ca 5 mm wide.*

Figure 5-11. *Detail from sample 169A (locality PFM006169). Fracturing and brecciation along micro-faults in finely laminated quartz-rich mylonite is cut by 2–3 generations of thin veinlets, some of which are filled with quartz, and finally by another generation of micro-faults (upper left). The field of view is ca 5 mm wide.*

Cataclasites

In several outcrops, cataclasites are observed, commonly in close association with low-grade mylonites and commonly oriented sub-parallel to the mylonite fabric. An example of a layered cataclasite is shown in Figure 5-12. Clasts in the cataclasites are angular to sub-rounded and consist mainly of quartz and feldspar in a fine-grained sub-microscopic matrix. In cases, the cataclasites have been brecciated (see below), and they are cut by thin fractures and micro-faults.

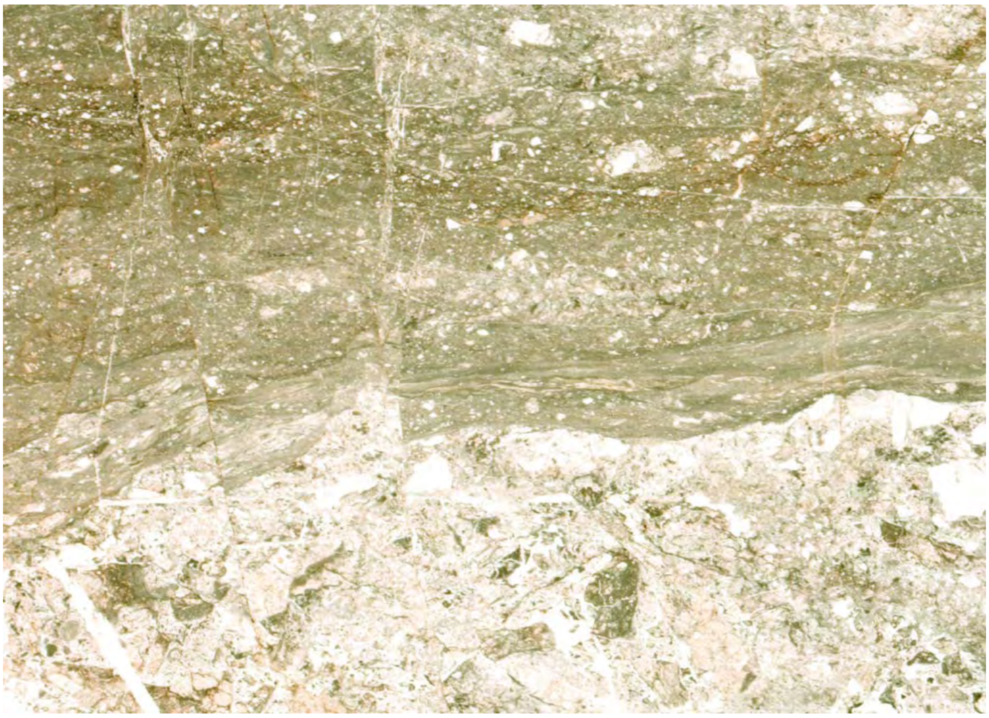

Figure 5-12. *Scanned thin section showing cataclasite collected from flinty dark grey fault rock (sample PFM006169_B). The figure shows cataclasite (lower part) in which there are identifiable clasts with quartz-mylonitic and cataclastic fabrics; finely laminated ultra-cataclasite with lenses of microcrystalline quartz (central part;) and cataclasite to ultra-cataclasite (upper part). The cataclasites are cut by fractures and micro-faults with local brecciation, the most prominent of which are oriented at a high angle to the layering in the cataclasite. These belong to a set of NNE-SSW to NE-SW faults with small offset. Note also several quartz-filled hairline fractures cutting the cataclasite with different orientations. The field of view is 30 mm wide.*

Breccias, faults and fractures

Prominent breccias have been observed in different localities along the EDZ as well as in drill cores. At PFM006166, fine-grained cataclastic fault rocks contain planar crystals of euhedral calcite up to ca 1 cm in length (Figures 5-13 and 5-14). A different type of breccia occurs at PFM006168, where a red-pink, fine-grained metagranite with coarse pegmatite veins appears to have been subjected to hydraulic(?) fracturing and deposition of white, fine-grained quartz filling the space between angular clasts of the host rock. The brecciation post-dates formation of cataclasite and faulting parallel to the EDZ.

In the drill cores, laumontite-filled faults and breccias are commonly observed. In KFM01A, the fault shown in Figure 5-15 is filled by laumontite, and along the walls of the fracture some laumontite alteration has occurred in the wall-rock. A detailed examination of the laumontite reveals a network of micro-fractures along grain boundaries and the cleavage (Figure 5-16). Extremely fine-grained breccias and cataclasites also occur as cross-cutting, thin veins in the metagranitoids in KFM04A (Figures 5-17 and 5-18).

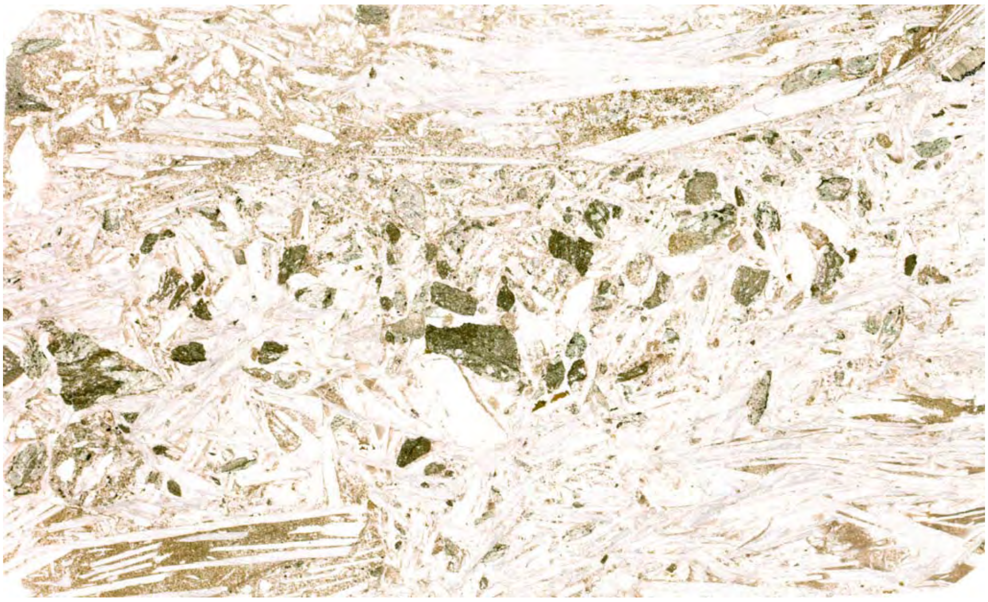

Figure 5-13. *Carbonate breccia with euhedral crystals of calcite filling the interstices between angular fragments of fine-grained, greenish cataclasite (sample 166; PFM006166). The field of view is ca 35 mm wide.*

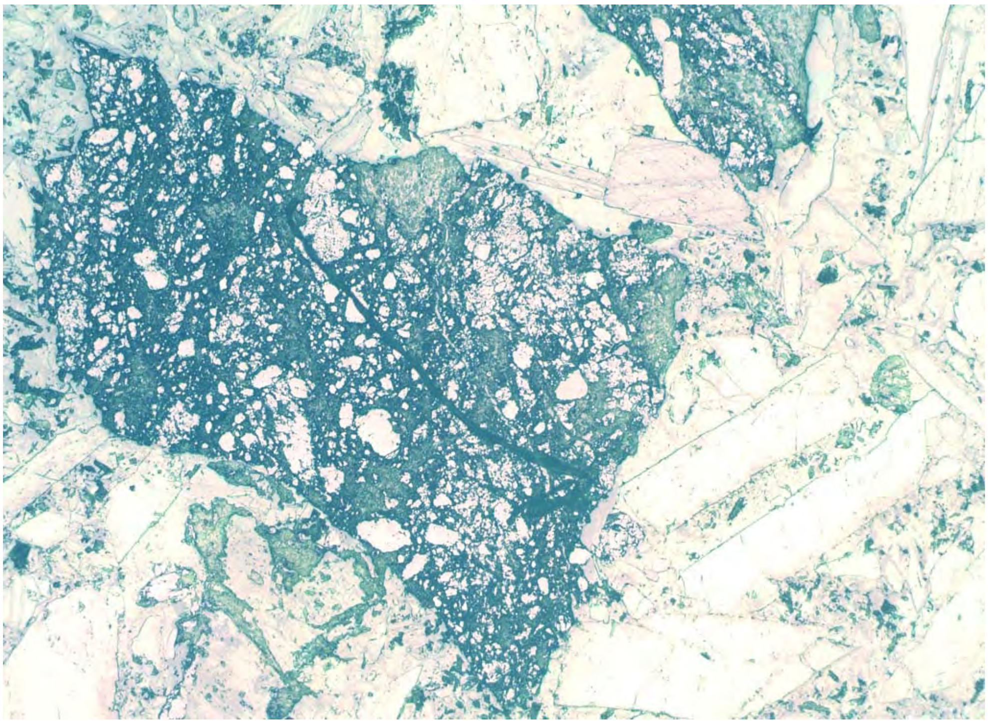

Figure 5-14. *Detailed texture in carbonate breccia (parallel light) showing randomly oriented, euhedral crystals of calcite filling the interstices between clasts of greenish cataclasite composed mainly of epidote, clinozoisite, chlorite, feldspar and quartz (sample 166; PFM006166). The field of view is ca 3 mm wide.*

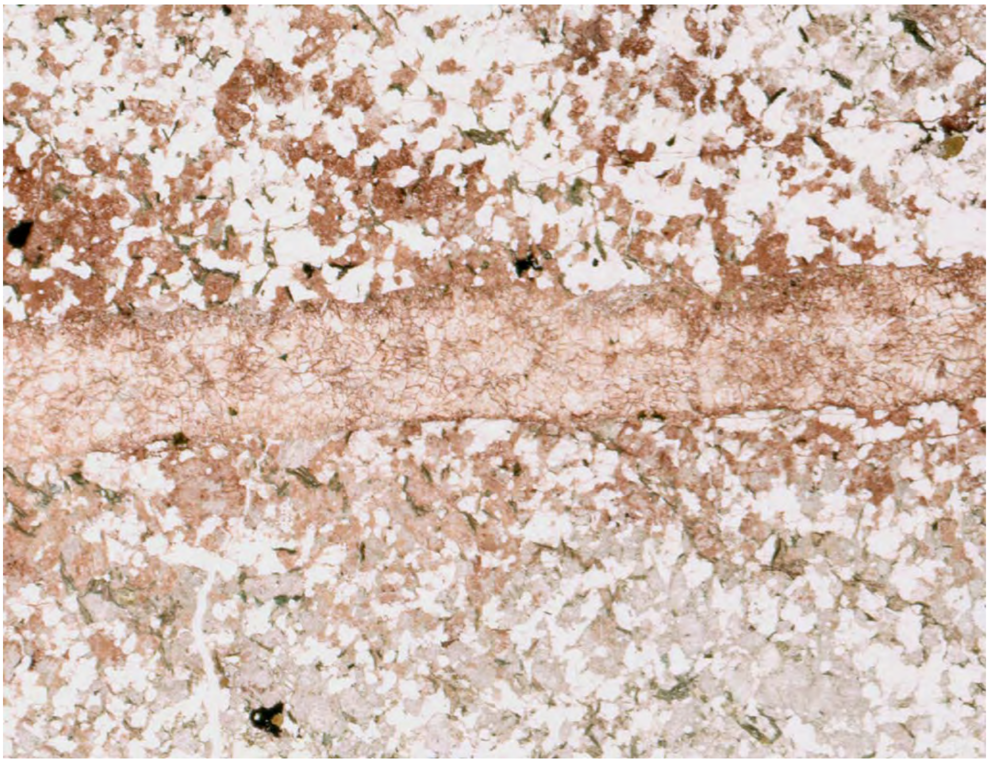

***Figure 5-15.** Scanned thin section showing laumontite-filled fault from sample KFM01A_652.9 m (cf Figure 5-5). The host rock consists of anhedral intergrowths of saussuritzed plagioclase and quartz with some chlorite. Laumontite is also present some distance into the host. The field of view is ca 20 mm wide.*

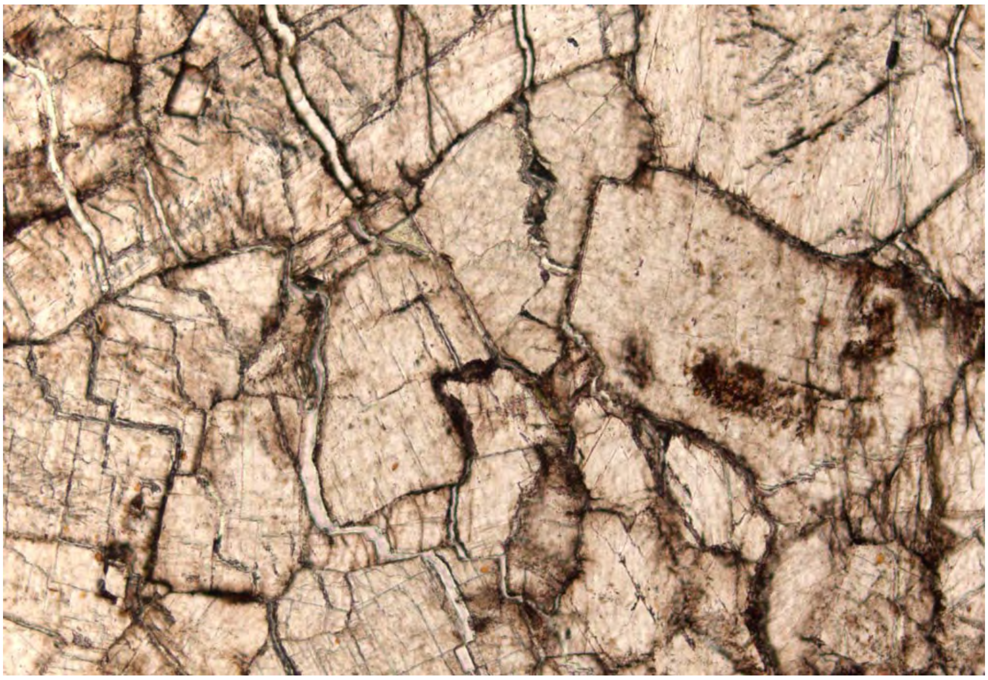

***Figure 5-16.** Photomicrograph of laumontite vein shown in Figure 5-15 (KFM01A_652.9 m). Note the numerous micro-fractures filled by a pale unidentified mineral. The field of view is 2.0 mm wide.*

Figure 5-17. *Scanned thin section (KFM04A_415.0 m) showing a foliated metagranitoid cut by a dense array of micro-faults and cataclasites (lower part and lower right). Thin veins (grey) cut across the section (upper part) consist of fine-grained cataclasite (see Figure 5-18). The white 'veins' do not contain any minerals. The field of view is 30 mm wide.*

Figure 5-18. *Photomicrograph of cataclasite vein shown in Figure 5-17 (KFM04A_415.0 m). The cataclasite consists of extremely fine-grained greyish-red zeolite matrix and fractured grains of quartz and feldspar. The field of view is 3.0 mm wide.*

6 Summary and conclusion

The purpose of the investigation is to carry out a pilot study of primarily the brittle structures at Forsmark, and to assess the potential for more extensive kinematic studies. The report should also recommend further investigations in order to achieve an improved understanding of the kinematic pattern of faults in the area of interest. The summary and conclusions are therefore related to possible studies that can be conducted in the area, seen in the light of the brief results presented above.

The main conclusions are:

1. Low-grade mylonites were mainly observed and studied in the field along the Eckardfjärden deformation zone (EDZ). Stretching lineations are present but shear sense indicators are relatively scarce. However, extensional shear bands were observed in thin section, and studies of oriented samples may yield relevant data.

2. Low-grade mylonites show transitions towards cataclasites in that the competing processes of plastic and frictional flow varies. In general, this depends on strain rate, mineral behaviour and metamorphic reactions following breakdown of feldspar.

3. The sequence of fault rocks observed in this study is compatible with deformation events occurring at gradually decreasing crustal depth, i.e. they follow an expected unroofing succession. Progressively more brittle faulting, ending in breccias cemented by diagenetic minerals, followed dominant plastic deformation under low-grade metamorphic conditions (see also /SKB 2005/).

4. There are good exposures of ductile shear zones and fault rocks along the investigated part of the EDZ. The possibility of obtaining additional data on surface faults and fault populations, e.g. in road sections, has not been explored. However, investigation of such sections, if present, may potentially be very useful in a kinematic analysis.

5. The nature of fault rocks and their patterns of cross-cutting relationships are important in structural analysis. Based on their overall geometry and matrix mineralogy, brittle fault rocks can in many cases be separated into categories that most likely formed during separate events. Petrographic studies conducted in this project show that a series of deformational events can be identified. In the drill cores, abundant faults that show good slickensides were observed. Given that the orientation of a sufficient number of these structures can be determined, it would likely result in the identification of fault populations with specific properties that may be related to movement on master faults of regional significance.

6. As a general conclusion, it is considered that a more comprehensive structural study may lead to improved understanding of the kinematic pattern in the area of interest. This would require that relevant data can be obtained from a variety of faults and fault populations with different properties and orientations. Based on the conclusions from the pilot study, such data may be derived from in-depth studies of available cores that intersect variably oriented faults. The possibility of extending the data set using observations from detailed fieldwork on surface outcrops (e.g. along roads) may be further explored. Field and core studies should be supplemented by a general study of the petrography and the micro-structural history of the faults.

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Appendix 1

List of localities and samples

Locality_ID	East	North	Samples
Forsmark field localities			
PFM006162	6697336	1631586	No samples
PFM006163	6697979	1631017	No samples
PFM006164	6697340	1631585	164A Ep-Chl mylonite/cataclasite
			164B Q-vein cut by q-fracture and ep-fracture
PFM006165	6697398	1631527	165A Ultramyl-mylonite transition
			165B Ultramyl-mylonite transition
PFM006166	6697535	1631410	166 Fault rock with secondary calcite
PFM006167	6697860	1631160	167 Hem+ep+qtz cataclas cut by cc breccia
PFM006168	6698000	1631037	168 Qtz-cemented breccia
PFM006169	6698162	1630943	169A Small fault in catacl with black laminae
			169B Multi-generation foliated cataclasite
			169C Mylonite with microfaults
PFM006170	6679975	1631078	No samples

Drill cores	Depth	Def zone	
KFM01A	652.9	DZ3	Laumontite-cemented breccia
KFM02A	161.9	DZ3	Fracture with white mineral
	168.0	DZ3	Fracture with albite, zoned
	439.8	DZ6	Chlorite fracture
KFM04A	415.0	DZ4	Laumontite fracture cut by qtz-fracture
	460.4	DZ4	Laumontite breccia with fabric
KFM05A	894.1	DZ4	Laumontite fracture with platy calcite
		DZ5	No samples
KFM07A		DZ4	No samples