DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2001/38

Image and SEM-analysis of Fractures in Granite

TRACe-Fracture
Toward an Improved Risk Assessment of the Contaminant Spreading in Fractured Underground Reservoirs
Progress report

A. Rosenbom, M. Hansen, K.E.S. Klint,
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Introduction

This report was written as part of the EU-project: Trace-Fracture. Based on the geological model and the fracture analysis performed in June 2000, a location in the Northern Spain was selected for In-situ impregnation and collection of representative samples of fractured granite. Annette Rosenbom, Knud Erik Klint, Niels Springer and Hans Jørgen Lorentzen from GEUS collected a number of samples during two weeks of fieldwork in August 2000. During the next 4-month a number of fractures were evaluated and prepared for Scanning Electron Microscope (SEM) analysis. The largest fractures exceeded the maximum size for SEM analysis and were photographed in normal incident light. The SEM images and the normal photos are forming the base for image analysis and measurement of geometrical properties in order to construct a fracture model for the fractured granite on the “Spanish site”.

This report includes thus a description of the sampling procedure and the sampled fractures. The images are shown in Appendix 1 and a CD-ROM with the images is included in the report.

This report is no. 4 of 4 annual progress reports containing the deliveries from GEUS in task 1-1, 1-2 and 1-3. The reports are:

1. Klint K.E.S., Francisco S., Gravesen P. and Molinelli L., 2001: Geological Settings and Fracture Distribution on a Granite site in Northern Spain. In: Trace-Fracture. Toward an Improved Risk Assessment of the Contaminant Spreading in Fractured Underground Reservoirs.

2. Klint K.E.S., Rosenbom A. and Gravesen P., 2001: Geological Setting and Fracture Distribution on a Clay Till site in Ringe, Denmark. In: Trace-Fracture. Toward an Improved Risk Assessment of the Contaminant Spreading in Fractured Underground Reservoirs.

3. Rosenbom A. and Klint K.E.S., 2001. Image and SEM-analysis of Fractures and Pore Structures in Clay Till. In: Trace-Fracture. Toward an Improved Risk Assessment of the Contaminant Spreading in Fractured Underground Reservoirs.

4. Rosenbom A., Hansen M., Klint K.E.S., Lorentzen H.J. and Springer N., 2001: Image and SEM-analysis of Fractures in Granite. In: Trace-Fracture. Toward an Improved Risk Assessment of the Contaminant Spreading in Fractured Underground Reservoirs.

Objectives

The goal of this task was to investigate a fractured granite site in Northern Spain and build a fracture network model, which should form the base for the construction of a model that could simulate transport and spreading of contaminants in fractured underground reservoirs.

A full investigation of fractures includes:

- Classification and characterisation of the fractures into fracture systems with characteristic properties.

- Calculation of quantitative fracture properties for each fracture system, primarily spacing of the individual fracture systems and measurement of the mechanical fracture aperture (opening diameter).

- Hydraulic tests of fractured core samples (laboratory measurement of porosity, relative and liquid/gas permeability.

This report focus exclusively on the selection and sampling of representative intact fractures for direct measurement of fracture geometry and hydraulic properties.

Site description

The investigated area is situated in the northern part of Spain near the Atlantic coast. Various types of fractured granitic rocks of Hercynican age (300-400 Ma) dominates the geology in the area. Several tectonic events have affected the formation of different types of fractures since the intrusion of the granite. In connection with the geological investigation of the area a detailed characterisation of the fractures was carried out (Klint et al 2001a). Nine localities in the area were selected for detailed analysis of the fractures. The result showed that the primary fractures could be overall classified into five categories:

1. Planar/undulating shear fractures with a general smooth surface.
2. Undulating/irregular extensional fractures, with a general rough surface, and in some cases with preferential growth of quartz crystals on the fracture surface.
3. Transform strike slip faults with a general small displacement (30-40 cm).
4. Normal faults with similar small displacements.
5. Zones of intensive fracturing/faulting with deeply weathered granite that formed an almost gravel like sediment.

Location 6 were selected for sampling of representative fractures from each group except type 5 (The deeply weathered fracture zones). This location was selected for a number of reasons. The site was the only one that contained all the fracture types. It was easily assessable, as it consisted of a more than 200 m long road-cut. It was furthermore close to location 2 and 9, and could thus be correlated to a relatively large area. The granite was relatively fresh and finally, we were allowed to collect samples from the granite rocks. On Figure 1 the location is marked, and the detail plan on Figure 2 shows the position of the sampling points.

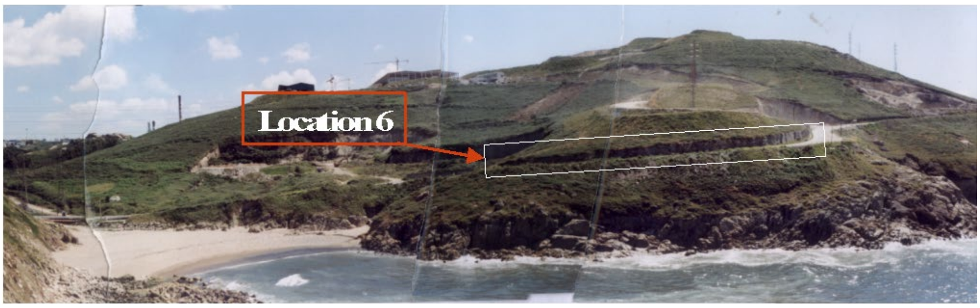

Figure 1. Photo of the sampling site area (outlined with a white frame).

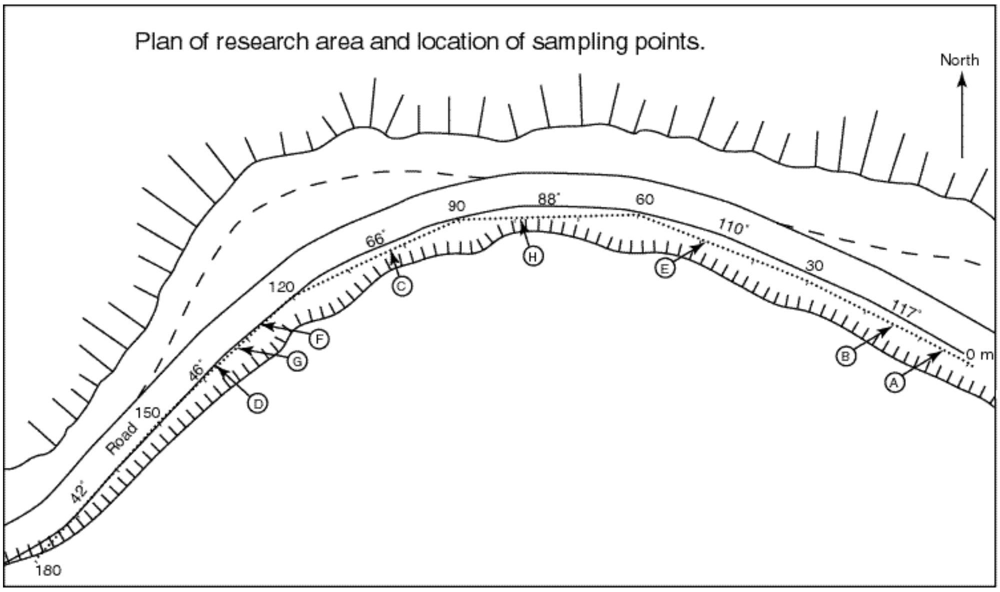

Figure 2. Plan of research area and location of sampling points (Site A-G).

Sampling procedure

Six sites (A.B.C.D.E.G) were selected for sampling and impregnation of fractures (Figure 2).

For each site the fractures were classified and the position, orientation, size and surface characteristics were measured according to the methodology described by Klint et al. (2001a). Besides each sample as well as the sampling point were photographed.

For description of:

1. flow characteristic (porosity, relative and liquid/gas permeability)
2. geometry

of the different fracture categories present in the granite exposure different types of approximately intact granite samples were collected.

The following types of granite samples with fractures were collected (if possible) at each site:

I. intact cylindrical samples with at diameter of 1" (2,5 cm) or 5,4 cm (for 1, 2)
II. intact impregnated cylindrical samples with a diameter of 1" (2,5 cm) (for 2)
III. intact impregnated cylindrical samples with a diameter of 5,4 cm (for 2)
IV. intact large block of granite including a fracture (for 1)

Type I sample will be analysed for the flow characteristic and hereafter impregnated. Type II and III samples were required in the analysis of fracture geometry since some of the fractures tends to open during the sampling procedure. It was therefore necessary to fix the fractures with epoxy resin before sampling them. Type IV samples will if possible be used for 3D-flow-test of a fracture. This is especially interesting in relation to slickensides on the fracture surface.

The sampling procedure at each site was:

- Collect type I sample if possible. Problems in drilling an oriented sample in relative to the orientation of a fracture may appear. This could make it impossible to get an intact sample of the fracture.
- Type IV sample was collected at places where other minor fractures maked it possible to take out an intact block.
- Plug holes for injection of epoxy was selected. All the holes, which contained a sample of type I, was normally used. By taking out an impregnated sample type III around the injection-hole it is possible to get the exact geometry of the fracture and the sedimentation in it, and then afterwards compare it with the type I sample, which had been exposed to different flow tests in the laboratory before impregnation.

  Water was injected into the plug hole to see how permeable the fracture was and a suitable epoxy resin viscosity was here after prepared. The epoxy resin, which was used, was:

  Component A: Vn 3082 1HL, Biphenol –A- Epichlortrydénhartz, VN 2735.

Component B: Polyalkylamin.

The epoxy has approximately the same viscosity as water. For impregnating fractures with a large aperture and/or high permeability, quartsflower was added to the epoxy.

- The epoxy solution was injected into the selected plug-hole. If the hole was horizontal a rubber-plug was used to seal the hole, to keep the epoxy from running out of the hole. The epoxy had finish hardening two days after injection.
- Samples of type II and III was collected. Samples with the large diameter was primary taken around the injection point.

The samples were all drilled with a special constructed drilling machine (Husqvarna).

Sample preparation

After the collection of the impregnated, partly impregnated (sample type II and III) and not impregnated (type IV and I) granite samples, the samples were send to GEUS.

GEUS´ laboratory impregnated the samples of type II and III a second time with the same epoxy but added a colour tracer. Adding a colour tracer to the epoxy would in the following analysis show which areas of the fracture that were not impregnated under natural field conditions. After the second impregnation the samples were send to Dansk Beton Teknik A/S to be cut into thick-slices of 0.5 cm. Before looking at the samples in the Scan Electronic Microscope (SEM), normal photos of the samples were taken and the fracture aperture was measured. If the aperture was too large (>0.5 cm) there was no need to conduct SEM-analysis. The digital picture could be used in the picture-analysis.

Flow experiments will be conducted on the samples of type IV and I. This has not been performed yet.

Results

This chapter contains a description of the sampling at each of the six sites separately. The description includes details concerning the fractures that were sampled, photographs of the sampling site with an indication of the sampling points and a table with some information concerning each sample.

Site A

Site A (Profile 6A, at 5 meter on baseline, Figure 2) represent:

Plane 1 Fracture system 1: 1´st order shear fracture.
Fracture orientation: 98/82 S.
Surface characteristics: Planar, smooth.
Remarks: Weak striation. Cutting normal fault.

Plane 2 Fracture system 4: Normal fault.
Fault orientation: 25/80 SE.
Surface characteristics: Undulating, smooth.
Remarks: Weak striation. Do not crosscut the 1´st order fracture.

Plane 1 and 2 is shown on the photo in Figure 3.

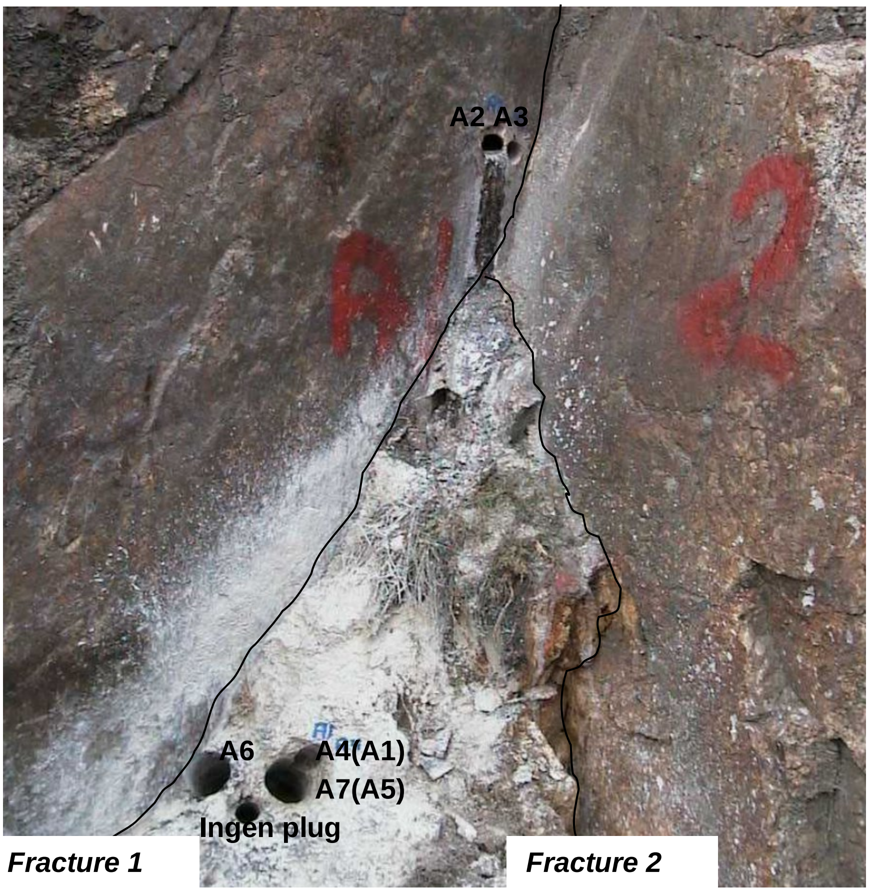

Figure 3. The sampling points are indicated. Fractures are marked with a black line.

Figure 4. Sample A3, A4 and A5. In sample A5 the partly impregnated fracture plan 1 (marked with black lines) is represented. The aperture is measured to be app. 0.5-1 cm.

Figure 5. Sample A6 and A7. Impregnated fracture marked with a black line.

Sample	Type	Note
A1		Drilled to the fracture-plane – sample is hereby cut of -> no sample with intact fracture. Impossible to get a type I sample of fracture plane 1 because of the fracture orientation. Plug hole will be used as injection point for epoxy.
A2		Wanted to crosscut plan 2 - no fracture-plane was found – in the drilling process the sample could have been cut off at the plan -> no sample with intact fracture
A3		To check for the fracture plan 2, water was add to plug hole A2 and no flow was registered. Epoxy was added to plug hole A2 and after two days A3 was drilled -> a minor fracture was found in the A3 plug, but not the fracture plan 2.
A4		Checking, if the fracture is impregnated, by drilling into the injection hole A1. Plane 1 is impregnated at the injection point.
A5	II	Sample with impregnated fracture with an aperture of 0.5-1 cm.
A6	III	Sample with impregnated fracture
A7	III	Sample with impregnated fracture

Table 1. List of samples of fracture 1 and 2 collected at site A.

Site B

Site B (Profile 6B, at 15 meter on baseline, Figure 2) represent:

Fracture system 3: Dextral strike slip transform fault
Fault orientation: 80/72 SE
Surface characteristics: Planar with slickenside. The fault is situated in a contact between a dyke and the granodiorite. The fault is photographed, Figure 6.

Figur 6. Site B. Sampling points are marked.

Figure 7. Samples from site B.

Sample	Type	Notes
B1		Type I sample – not intact
B2		Type I sample – not intact
B3		Type I sample – not intact
B4		Type I sample – not intact
B5		Type I sample – not intact
B6		Type I sample – not intact
B7.1	I	Sample is not impregnated -> flow measurements.
B7.2	I	Sample is taken to check if the epoxy has entered the deeper parts
B8	I	Sample is not impregnated -> flow measurements.
B9	III	Impregnated sample
B10	I	Sample is not impregnated -> flow measurements.
B11	III	Sample insufficiently impregnated both parts of it can be used
B12	I	Sample is not impregnated -> flow measurements. Nice fracture sample
B13	III	Minor fracture totally filled with epoxy
B14	I	Sample is not impregnated -> flow measurements.
B15	III	Partly impregnated sample

Table 2. List of samples collected at site B.

Site C

Site C (Profile 6C, at 103 meter on baseline, Figure 2) represent:

> Fracture system 3: Dextral strike slip transform fault
> Fracture orientation: 67/85 NW
> Surface characteristics: Planar with slickenside

The fractures are photographed, Figure 8.

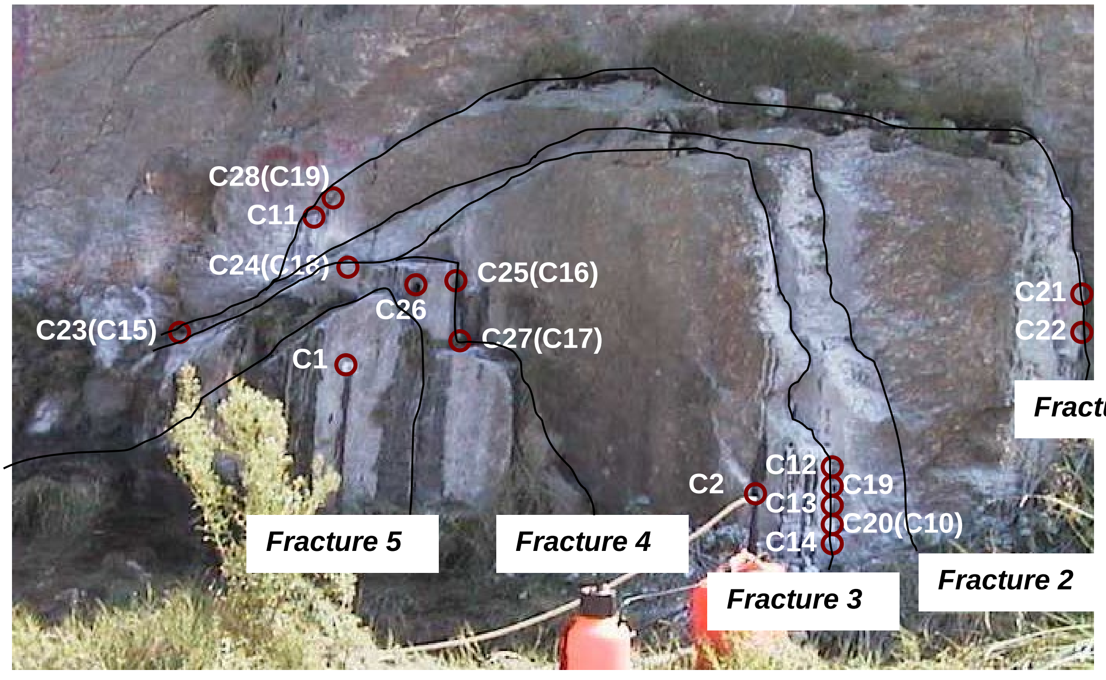

Figure 8. Site C. The sampling points is indicated with a red circle and the fracture planes are marked with a black line.

Figure 9. Samples of type I from Site C.

Figure 10. Impregnated samples of type III from Site C.

Figure 11. Impregnated samples of type III from Site C.

Sample	Type	Representing fracture	Fracture orientation - Notes
C1			Injection hole for impregnation of fractures 3 and 4
C2			Injection hole for impregnation of fractures 2
C10	I	3	102/82S. Intact sample
C11			No intact plug
C12		3	88/88S. No intact sample
C13		3	79/90S. No intact sample
C14		3	97/82S. No intact sample
C15	I	1,2	94/84N. Intact sample - Injection point for epoxy
C16	I	4	92/88N. Intact sample
C17	I	4	83/86N. Intact sample
C18	I	3,4	96/77N. Intact sample
C19	III	1	78/86N. Small plug C19 not intact -> large partly impregnated sample is taken instead
C20	III	3	80/82N. Impregnated – drilled around C10
C21	III	1	86/84N. Impregnated – fracture with a lot of root-material.
C22	III	1	86/84N. Impregnated – fracture with a lot of root-material.
C23	III	1,2	97/88N. Impregnated – drilled around C15
C24	III	3,4	104/82N. Impregnated – drilled around C18
C25	III	4	90/89N. Partly impregnated – large fracture -drilled around C16
C26	III	4	96/89N. Impregnated
C27	III	4	84/86N. Impregnated – drilled around C17
C28	III	1	75/86N. Impregnated – drilled around C19

Table 3. Samples collected at site C.

Site D

Site D (Profile 6D, at 137 meter on baseline, Figure 2) represent:

Fracture system 2: 2´nd order fracture
Fracture orientation: 79/90
Surface characteristics: Irregular rough
Remarks: Extensional fracture

The fracture is photographed, Figure 12.

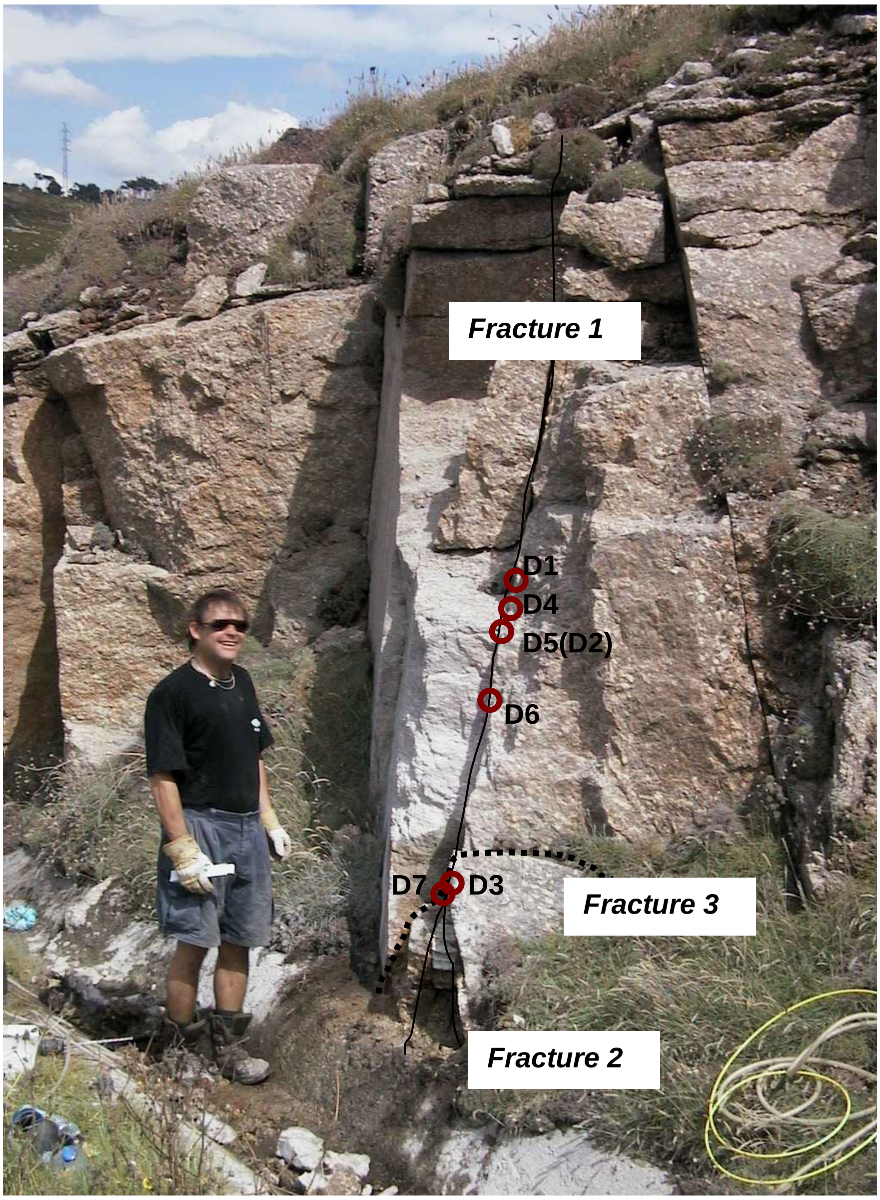

Figure 12. Site D. The sampling points are indicated with red circles and the three fractures are marked with black lines.

Figure 13. Samples of type I collected at site D.

Figure 14. A block of granite containing fracture 1 is collected at site D.

Sample	Type	Fracture orientation - Notes
D1		77/82N. No intact sample
D2		85/80N. No intact sample – epoxy injection point.
D3	II	79/84N.
D4	III	85/80N.
D5	III	85/80N. Sample containing the hole after the D2 plug.
D6	III	80/79N. Partly impregnated – can be used for flow tests.
D7	III	79/90. Partly impregnated – can be used for flow tests.
D8	IV	72/86N. Intact block sample of fracture 1.

Table 4. Samples of fracture 1 (Figure 12) at site D.

Site E

Site E (Profile 6E, at 44 meter on baseline, Figure 2) represent:

> Fracture system: Dextral strike slip transform fault
> Fracture orientation: 64/80 NW
> Surface characteristics: Planar with slickenside
> Remarks: Contact to dyke. Granodiorite on one side of the fracture and Leucogranite on the other side.

The fracture is photographed, Figure 15. Only two samples were collected at this site: One intact partly impregnated core samples (E2) and one block sample (E3) type IV. The fracture in plug E1 was not intact.

Figure 15. The fracture is marked with a black line. One intact partly impregnated core samples (E2) and one block sample (E3) type IV were collected at site E.

Figure 16. Only intact partly impregnated core sample (type III) from sites E.

Site G

Site G (Profile 6G, at 133 meter on baseline, Figure 2) represent:

Fracture system: 1´st order fracture
Fracture orientation: 127/90
Surface characteristics: Planar, smooth

The fracture is photographed, Figure 17.

Figure 17. Red circles indicate the sampling points at site G.

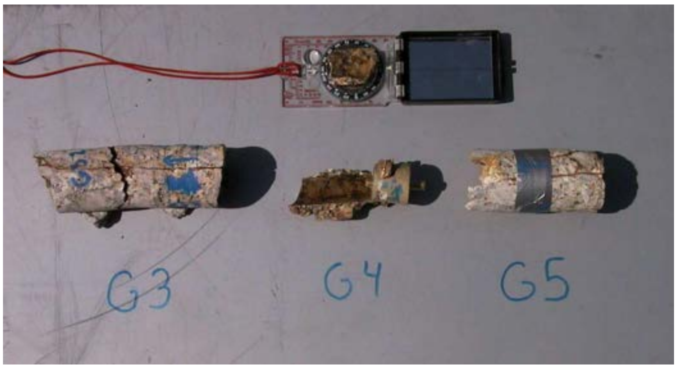

Figure 18. Samples from Site G.

Sample	**Type**	**Notes**
G1		148/86W. No intact sample of the fracture – impregnation hole.
G2		144/88W. No intact sample of the fracture – impregnation hole.
G3	III	146/84W. Two parts.
G4		144/88W. Not intact sample.
G5	III (II)	148/86W. Part of the sample can be used for flow tests.

Table 5. Samples collected at site G.

Pictures and SEM-images

Pictures and Scanning Electron Microscope (SEM)-images were taken of the fractures in the following thick-slices, Table 6.

Site	Sample	Thick-slices	Notes
A	A5	A5.1	Fracture 1. Aperture too big for SEM-analysis.
		A5.2	Fracture 1. Aperture too big for SEM-analysis.
	A6	A6.2	Fracture 1.
B	B9	B9.1	Main vertical fault zone + one minor horizontal fracture.
		B9.2	Main vertical fault zone + one minor horizontal fracture.
		B9.3	Main vertical fault zone.
		B9.4	Minor horizontals fracture - can be opened a bit while drilling.
	B11	B11.2	Main vertical fault zone.
	B13	B13.0	Main vertical fault zone.
		B13.1	Main vertical fault zone.
		B13.2	Main vertical fault zone.
C	C21	C21	Only picture of Fracture 1.
	C22	C22.1	Picture of Fracture 1 – only SEM-images of minor fractures in connection to it. Aperture too big.
	C22	C22.2	Only picture of Fracture 1.
	C23	C23.1	Fracture 1 and 2 – one minor fracture.
	C24	C24.0	Fracture 3 and 4 – two minor fractures.
		C24.1	Fracture 3 and 4.
	C25	C25.1	Fracture 4. No fill.
	C26	C26.1	Picture of Fracture 4 only SEM-images of one minor fracture. Some fill.
		C26.2	Minor fracture represented in C26.1 and C26.3.
		C26.3	Picture of Fracture 4 only SEM-images of one minor fracture. Some fill.
	C28	C28	Only picture of Fracture 1. Sample with quartz filling in fracture.
E	E2	E2.22	Main fracture and three minor fractures. A lot of fill.
G	G3	G3	Only picture of fracture.

Table 6. List of thick-slices used in photography and SEM-image analysis.

The SEM-images were captured with the Back-scattered Electron detector (BSE) utilising a Phillips XL-40 Scanning Electron Microscope. Using the BSE detector it is possible to distinguish between the lighter and the heavier elements, thus separate components of differing chemical affinity. The epoxy used was therefore represented by a black colour on the SEM-images. During mounting of thick-sections on the sample-holder in the SEM a certain method was use for having a certain co-ordinate system of the section. Each SEM-image is set-up on this co-ordinate system, which is in μm.

The attached Appendix 1 contains photos and SEM-images of the fractures. All the photos and SEM-images are kept on a digital form and stored on the CD-ROM attached the report. On the CD and in the Appendix 1 each thick-slice has its own directory containing:

- An UV-picture of the thick-slice.
- Tables with the data concerning the SEM-images (B/BN = Brightness, C= Contrast).
- SEM-pictures of the fractures.

Main findings

Four major types of fractures/faults were identified in the area. A number of samples from each type were selected from 6 sites and a number of fractures were impregnated in situ with a epoxy resin.

Some fractures were fixed with bolts and cut directly from the outcrop as monoliths.

A number of core-samples with the impregnated fractures were collected and prepared for SEM analysis in the laboratory.

SEM-images of fractures with an aperture typically smaller than 2 mm were successfully captured and the images has been stored on a CD-ROM for further analysis of the geometrical properties.

Fractures with larger apertures than 3 mm were photographed in normal incident light, and the aperture may be estimated from these images.

Hydraulic experiments on fractures are still in progress.

Problems concerning the reliability of the collected data and lack of data.

Most of the fractures contain a filling consisting of organic matter and fine sediment that have deposited inside the fracture. This is regarded to be a general natural feature in the near surface fractures and will be included in the flow measurements performed on the granite samples. The degree of filling in the deeper fractures is unclear, only conducting hydraulic test in wells can test the bulk hydraulic conductivity.

Strongly weathered granite could not be sampled, as it was falling apart. Zones of strongly weathered rock should however be hydraulic tested and bulk hydraulic properties may be extracted from well tests.

Some fractures have apertures that seem to be dilated and may have opened recently. This may have happened during the construction of the road. The individual fractures must therefore be carefully evaluated before realistic fracture apertures are measured.

References

Klint K.E.S., Francisco S., Gravesen P. and Molinelli L., 2001: Geological Settings and Fracture Distribution on a Granite site in Northern Spain. In: Trace-Fracture. Toward an Improved Risk Assessment of the Contaminant Spreading in Fractured Underground Reservoirs. Progress report no. Pp:

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APPENDIX 1

Images of fractured samples