DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2001/37

Image and SEM-analysis of Fractures in Clay Till

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 GEUS deliveries to the EU-project EVK1-CT1999-00013: TRACE-FRACTURE (Toward an Improved Risk Assessment of the Contaminant Spreading in Fractured Underground Reservoirs).
During the last year a number of fractures in clay till were collected, analysed, evaluated, and prepared for Scanning Electron Microscope (SEM) analysis and earlier investigations has been revised and included in the report as well.

This report includes thus a description of the sampling procedure and the sampled fractures. A CD-ROM with the results of the image and Scanning Electron Microscope (SEM) analysis is included in the report.

This report is no. 3 of 4 annual progress reports containing the deliveries from GEUS in task 1-1, 1-2, 1-3 and 6-1. The reports are:

1. Klint K.E.S., Sanchez F., 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. Geological Survey of Denmark and Greenland. Progress report 2001/35.

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. Geological Survey of Denmark and Greenland. Progress report 2001/36.

3. Rosenbom A., Hansen M. 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. Geological Survey of Denmark and Greenland. Progress report 2001/37.

4. Rosenbom A.E., 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. Geological Survey of Denmark and Greenland. Progress report 2001/38.

Objective

The objective was to investigate the distribution and nature of fractures in clay till at a contaminated site in the town of Ringe in Denmark, and to:

1. collect representative intact samples of the fractured till in order to analyse the mechanical fracture aperture and construct a conceptual fracture network model for the area.
2. revise existing data from pervious investigations in the area.

A full investigation of fractures includes:

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

- Calculations 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 and direct measurement of fracture geometry using analysis of images captured by a Scanning Electron Microscope (SEM).

Site description

The pilot site is located at an abandoned asphalt and creosote factory in Ringe, about 20 km south of the city Odense, on the isle of Funen, Denmark (Figure 1).

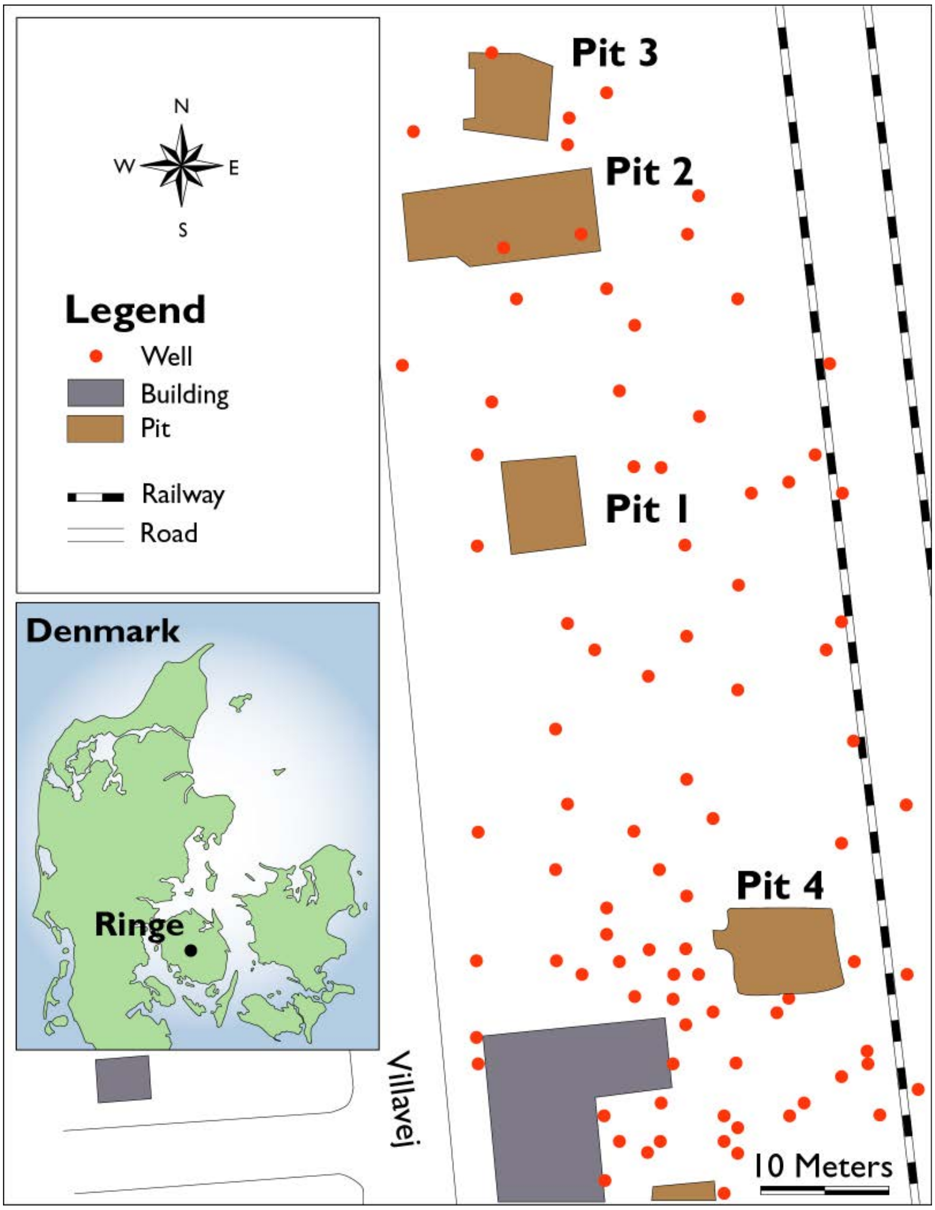

Figure 1. Location of the Ringe site with position of the excavations where samples have been collected within the framework of TRACe-Fracture.

Geological settings

From the earlier projects a general geological model has been established for the Ringe site. The investigations showed that glacigene sediments deposited during the Weichselian glacial period (the last 100.000 years) dominate the site. Three major glacigene units have been described in the uppermost 22 m of sediment (Klint et al., 2001b). 5-8 m of clay till cover the uppermost part of the area. Below the till approximately 8-10 m of deformed glacigene sediments appear overlaying a large sandy aquifer to the west and another till unit towards southeast. The upper till was classified as a basal till deposited below a glacier transgressing the Ringe area from southeast approximately 15.000 years ago. The till is accordingly consolidated and deformed by the glacier.

Distribution of fractures and other macropores in the upper till

The upper 5 m of till may be separated into three zones with characteristic distribution of pores:

An *upper zone* from 0.5-2.5 m below ground surface, which is dominated by bio-pores, desiccation fractures and high porous matrix.

A *central zone* from 2.5 to 4 m below ground surface, which is dominated by well-connected desiccation and glaciotectonic fractures.

A *lower zone* below 4 m, that is dominated by primarily fractures.

Three distinct fracture systems were recognised plus a number of random oriented fractures in the upper five meters (Figure 2):

- System 1 fractures are interpreted as being formed due to contraction, either as a result of either freeze/thaw processes, or desiccation processes or most likely a combination of both. During the contraction the tectonic system 2 fractures were reactivated, and they partly controlled the development of an orthogonal fracture pattern, as the system 1 fractures were formed perpendicular to the system 2 fractures.

- System 2 fractures are vertical/sub-vertical glaciotectonic fractures formed as a result of an almost vertical pressure from the loading of a transgressing glacier.

- System 3 fractures which are horizontal/sub-horizontal fractures classified as tectonic shear-fractures, formed as a result of horizontal shear movement along the sole of the same transgressing glacier, and horizontal fractures formed during the subsequent pressure release after the glacier has melted away.

The fracture precipitation and the presence of roots on some of the fracture surfaces show that, even though fractures have a clear hydraulic connection to each other, different chemical conditions prevails in the fractures. This is regarded to reflect different hydraulic conductivities and the presence of roots or root patterns are reflecting the highest hydraulic conductivity, in this case practically all the fractures with root-patterns belong to system 2 fractures. The fractures have accordingly different hydraulic properties and the bulk hydraulic conductivity of the whole system is primary controlled by the system 2 fractures below 2.5 m.

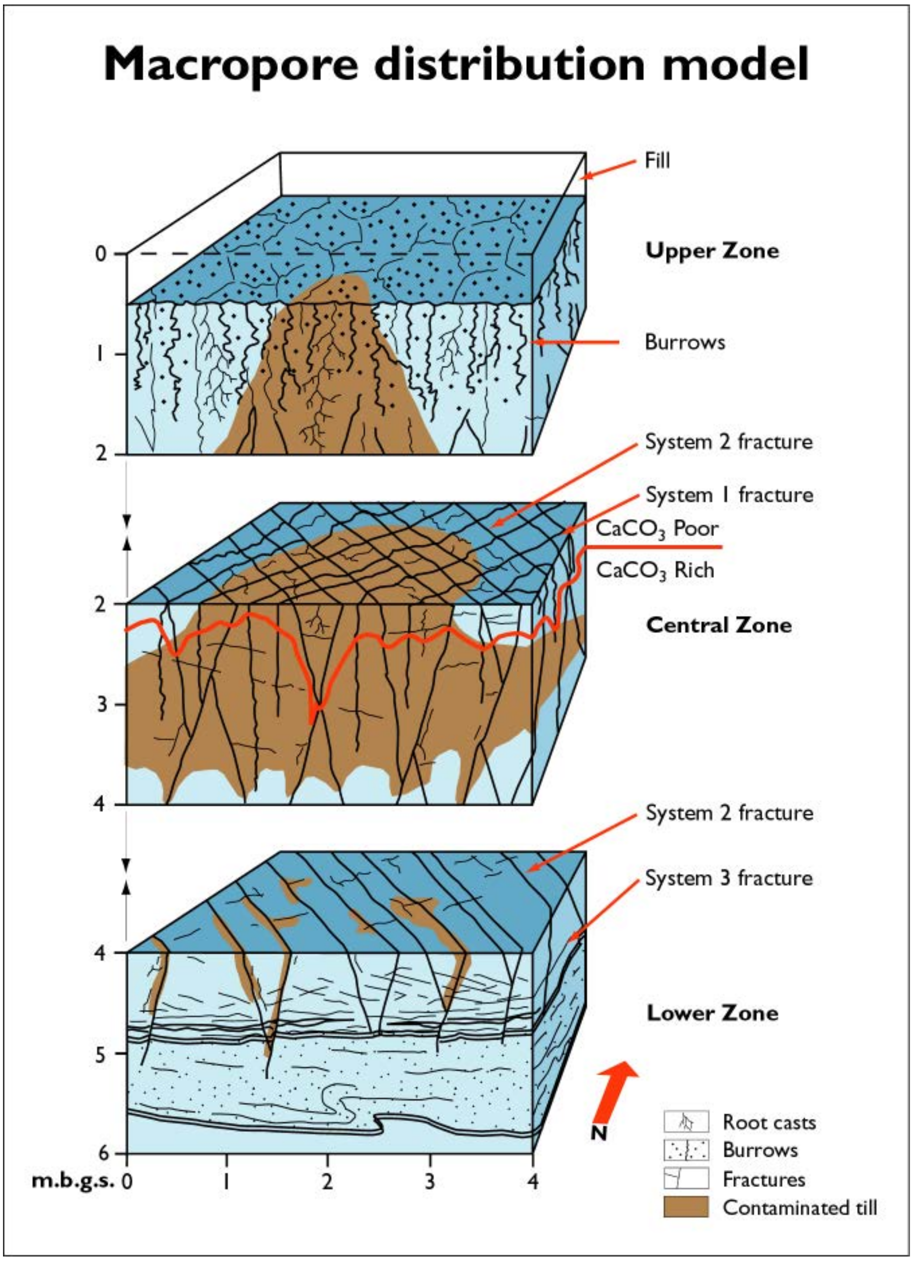

Figure 2. Macropore distribution model near Pit 2 and 3. The distribution of LNAPL is marked and since the system 2 fractures seems to be the dominating fractures most of the intact samples were collected from this fracture system.

Collection of intact samples

A number of intact samples were collected for impregnation and image analysis of micro-morphological features. The samples represent examples of dominant fractures at different depths, thus representing the variation of pores in the Ringe till. Some samples, which were collected during previous projects (Klint and Tsakiroglou, 1998), were also included in order to improve the fracture model for the area. A total of 10 samples were impregnated (Table 1), but after evaluation of the sample quality only 7 samples were selected for the SEM analysis. Two sections from sample seven were selected, which gives a total of 8 analysed samples.

Sample no.	Position	Depth	Orientation	Precipitation	System	Order	Remarks
No 2 12-95 010694 E10	Pit 2 profile E	2.76 m b.g.s.	100/90	1	1	First order	Sample 2-4 is taken from the same fracture
No 3 166-94 290694 H5	Pit 2 profile H	3.60 m b.g.s.	123/80NE	1 – 4 Roots	2	First order	
No 4 161-94 220694 E11	Pit 2 profile E	3.10 m b.g.s.	100/90	1 Roots	2	First order	Fracture close to Transition between weathered and un-weathered till
No 5 164-94 220694 H3	Pit 2 profile H	2.63 m b.g.s.	127/70NE	4 Roots	2	First order	
No 7.1	Pit 2	2.68 m b.g.s.	121/85NE	1 – 4 Roots	2	First order	
No 7.2	Pit 2	2.68 m b.g.s.	121/85NE	1 – 4 Roots	2	First order	
No 8	Pit 2	3.25 m b.g.s.	141/90	1 – 4 Roots	2	First order	
No 10	Pit 1	3 m b.g.s	118/90	4 Few roots	2	First order	Captures from LUC (Large undisturbed column)

Table 1. List of samples with position referring to profiles in Pit 2, depth below natural ground surface, orientation of fracture, fracture system, and fracture order, and precipitation on the fracture surface (1: light greyish surface cover probably reduced iron, 2: Clay-coating, 3: no cover, 4: iron/manganese-oxide).

Sampling procedure

A smooth face perpendicular to the fracture was cleaned and stainless steel box (Kubiena box, 15x8x5 cm) with a removable top and bottom lid was placed perpendicular to the fracture. While very carefully removing the sediment along the outer side of the box, the box was gently pushed further into the matrix, until a small monolith containing a fracture was excavated. Minor stones were removed and the holes filled with till, finally the monolith was scraped with a knife until the surface matched the outer rim of the box. The top lit was attached to the box and the block was carefully removed from the wall.

Finally the sediment was scraped off the bottom side of the box and the bottom lid was attached.
A sketch of the macrostructure's in the sample was drawn, and the orientation and position of the box and fractures were measured (Table 1). Finally the box was sealed airtight with plastic-bags and tape and placed in a refrigerator at 5 C^0.

Laboratory work

Sample impregnation

One of the key problems during the impregnation of the sample is the removal of the water without drying the sample and creating additional desiccation fractures or changing the aperture of the existing fractures. This can be done by replacing the water with a solvent prior to its impregnation with a resin. The preparation of samples for image-analysis includes thus three basic operations:

- Removing the water from the sample:

The lids were removed. The Kubiena-box was placed in a plastic-box and the sample was covered with acetone for a week. Then the acetone was carefully poured from the box and the procedure was repeated at least 8 times. Adding a few drops of liquid paraffin checked the retention of water.

- Impregnating the samples:

A polyester resin was mixed with acetone and a dye was added. The mixture was poured over the sample and refilled periodically for the next 10 minutes. The impregnation box was then placed in a vacuum desiccator. More resin was added if necessary, and the sample was left in vacuum for 3-4 days. The sample was then cured for at least 6 weeks and heated to max. 60 ^{0}C for 2-3 days. After the solidification of the resin had been completed, the sample was removed from the steel box.

- Cutting and grinding the samples:

The sample was carefully cut and then thoroughly inspected. A fracture was selected for further investigation and then a smaller sample of approximately 4x6x1.5 cm was cut perpendicular to the selected fracture. The sample was then re-impregnated in vacuum, and glued to a glass-plate. It was grinded and polished until a silk-smooth surface with no rip-off's was obtained.

Fracture description and evaluation

Fractures appear clear on the SEM-images, but all fractures are not original and hence the description of fractures includes an evaluation of their "origin". All original fractures measured in the field are more or less influenced by chemical processes. This is a basic field criterion that distinguishes fractures created during sampling from original fractures.

Criteria of fracture evaluation of SEM images

Weathering characteristics: (a) *Dissolution of $CaCO_3$ skeletons within the fracture-zone*. The existence of large differences between dissolution of $CaCO_3$ skeletons within a fracture and within the matrix is an indication of a true fracture. The weathering of fracture walls is also considered a sign of authentication. (b) *Clay coating and precipitates on the fracture-walls*. In general, a fracture consists of a large number of interconnected cavities or channels, and over time these voids may be coated by clay or precipitates such as $CaCO_3$, iron or manganese oxides, while young fractures lack of these characteristics. SEM-analysis of the material filling in the fracture are performed in order to identify these precipitates and distinguish between resin and original fill.

Bridges: Fracture-walls always have some contact regions across their walls. These "Bridges" are a clear sign of original pore space. If the fracture has been disturbed during sampling and resin impregnation, some of these bridges may break. If the bridges are broken, the fracture aperture is very large and unreliable, although in some cases a rough estimate of the original aperture can be obtained by accounting for the distance between broken bridges

Jigsaw-puzzle-pattern: Some fractures resemble with bricks arranged in a jigsaw puzzle with a very sharp jagged transition. This is a clear indication of very young and possibly not original fractures, and all fractures with such features were excluded.

SEM-analysis

Before the initiation of the SEM analysis, each sample was photographed in visible incident and UV light for identifying fractures and characteristic clasts, which allow the recognition of specific regions on the sample surface. From each section, overlapping SEM images of the same fracture were captured at various magnifications (25x – 1.600x). Then the sample surface was grinded and polished and the procedure repeated on some of the samples in order to collect multiple serial sections. The mean distance between serial sections was properly adjusted and ranged from 50 to 250 μm. The images were stored for further processing. Other samples were carefully analysed at different magnifications in order to perform detailed analysis of pore structures inside the fractures and in the matrix next to the fracture.

Description of methods

Images were captured with the Back-scattered Electron detector (BSE) utilising a Phillips XL-40 Scanning Electron Microscope (SEM). Using the BSE detector it is possible to distinguish between the lighter and the heavier elements, thus separate components of differing chemical affinity.

Two types of SEM images were collected. One type was captured using the Phillips XL-40 microscope, which were used to present an overview of the fractures. Another type was captured using the Noran Vantage image acquisition system, Image Display provided with the Electron Dispersive Scanning system (EDS) attached to the SEM apparatus. These images were used for the mathematical characterisation of the fractures. All images were captured at 15 kV and with a spot-size of 5. The samples have been investigated using the following magnifications as listed in Table 2. There are a few minor differences between the two image types just described. The images obtained using the Phillips XL-40 microscope have a rectangular shape while those obtained using the Vantage Image Display have a cubic shape. The height of the images is the same, but the latter ones are shorter than the other type. Another thing is that the latter type has a better resolution than the images from the Phillips XL-40 microscope, although this is a matter of choice.

The Noran Vantage application Feature Sizing is a Unix based program. Its main purpose is to measure parameters of particles in binary or grey-level images, obtained by SEM analysis, in conjunction with quantitative chemical analysis (EDS). By treating the pore-spaces in the samples as “particles” the range of applications of the Feature Sizing program has become accessible.

At first a SEM image was recorded using the Noran Vantage image aqusition system Image Display. Apart from containing a number of filters Image Display enables the image to be converted into a binary form. In creating a binary image from a grey-level image, the grey-levels are split up into segments. These segments can be changed as needed. This enable the worker to regulate possible differences in the intensity of the image caused by fluctuations during capturing. Using a cursor the appropriate grey-level segment is pinned out, and the binary image will then be based on this. It can though be difficult to pin out the grey-level of the resin filled pore spaces without bringing some grains of the matrix into the result. As the grey-levels are a result of the SEM image the problems just described set certain limitations regarding the standard of the SEM images.

To be able to pick out the relevant “particles” and to calculate the chosen parameters, some filters had to be applied to the images. Until this stage two different approaches has been followed. Not so much because of differences in the samples, but more as an investigation of possibilities. Please note that only the filters used will be described.

The first approach included the two filters Binary Holefill and Erode used in that order. Binary Holefill is a filter that turns on pixels that are surrounded by other on pixels (pixels that are on are active ones (white dots), pixels that are off are inactive ones (black)); in other words holes or inclusions are being filled out. The filter Erode turns those pixels off that do not have on pixels as their four nearest neighbours. This can be done in steps but only one step was applied here.

The second approach comprised in addition to the above described the filter Template-separate. The order being Erode, Template-separate and finally Holefill. The Template-separate filter is normally used after an erode filter to restore the remaining particles to their original shape while preserving separations between grains that exists in the source image. Table 3 is a list of the distribution between the two approaches among the samples.
A matter of precaution is recommended though in working with filters - the end result will not end up too far from the original image.

The manipulated binary images were then run through the Vantage application Feature Sizing. A list of the parameters calculated by Feature Sizing is attached Figure 3. In Feature Sizing the on pixels of the binary image that corresponds to real features as seen in the grey-level image, are picked out using a cursor. At this stage it is important to be able to distinguish between true and false structures in the images, i.e. original and secondary fractures respectively. The greatest disadvantage working with Feature Sizing is that every image has to be modelled separately. The system cannot accept more than one frame at a time, which arises from the construction of the system.

Sample No.	***x25***	***x200***	***x800***	***x1600***
2 D	X			
3	X			
4 T	X	X	X	X
5	X			
7.1 A	X			
7.2 A	X	X	X	X
8.1 A	X			
8.2 A	X			
10.0 A	X	X		X

Table 2. Analyses at the showed magnification scales were conducted on the following samples.

Sample X Magnification	***1. Approach***	***2. Approach***
2 D x25	X	
4 T x25	X	
4 T x200	X	
4 T x800	X	
4 T x1600	X	
7.1 A x25		X
7.2 A x25		X
7.2 A x200	X	
7.2 A x800	X	
7.2 A x1600	X	
8.1 A x25		X
8.1 A x25		X
10 A x25		X
10 A x200	X	
10 A x1600	X	

Table 3. Approaches used on the following samples.

The following is a key to the parameters calculated using the Vantage Feature Sizing package and listed in the Data directory (Figure 4). Some of the parameters are visualised in Figure 3.

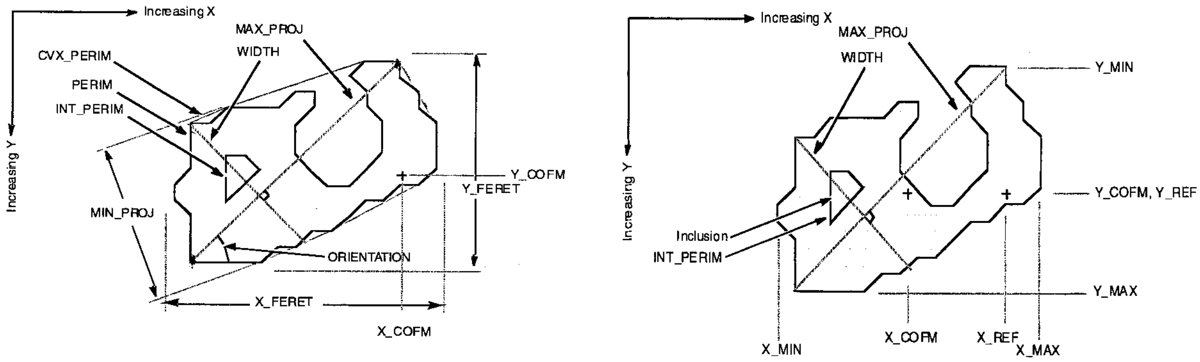

Figure 3. Visualisation of: (a) Basic particle parameters and (b) Basic frame parameters.

<u>*Basic particle parameters (Figure 3(a)):*</u>

AREA	Particle area – The number of pixels in the particle times PIXEL_AREA, in current measurement units squared.
ASPECT_RATIO	The aspect ratio is MAX_PROJ/WIDTH, which is without unit.
CIRC	Circularity equals $PERIM^2/(4 \cdot \Pi \cdot AREA)$, which is without unit.
X_COFM	X centre of mass – The average value of particle pixel X co-ordinates.
Y_COFM	Y centre of mass – The average value of particle pixel Y co-ordinates.
X_FERET	X Feret dimension – Projection of the particle on the X-axis, in current measurement units.
Y_FERET	Y Feret dimension – Projection of the particle on the Y-axis, in current measurement units.
LENGTH	Length – Derived length of particle, after it is straightened into a rectangle of equal area and perimeter, in current measurement units. $LENGTH = 0.25 \cdot (PERIM + \sqrt{PERIM^2 - 16 \cdot AREA})$.
ORIENTATION	Orientation – The angle between the positive X-axis and the maximum particle projection, in degrees. Clockwise rotation from the X axis is a positive orientation angle.
PARTICLE	Particle number – The number assigned to every particle.
PERIM	Perimeter – The sum of the distances between centres of adjacent pixels on the particle perimeter, times PIXEL_WIDTH, in current measurement units.
INT_PERIM	Internal perimeter – The sum of the distances between centres of adjacent pixels on the perimeters of particle inclusions, times PIXEL_WIDTH, in current measurement units.
MAX_PROJ	Maximum particle projection (maximum calliper dimension) – Largest separation between points on the particle convex perimeter, in current measurement units.
MEAN_PROJ	Mean particle projection – An average of all triangle altitudes drawn between pixels on the convex perimeter, in current measurement units.

MIN_PROJ	Minimum particle projection (minimum calliper dimension) – The shortest altitude of all triangles drawn between pixels on the convex perimeter, in current measurement units. Triangle bases are defined by adjacent pixels and peaks by pixels on the opposite side of the particle.
WIDTH	Width – Particle projection perpendicular to the maximum projection, in current measurement units.

<u>*Basic frame parameters (Figure 3(b)):*</u>

FRAME	The number assigned to the frame.
FRAME_LENGTH	Frame length is measured by the number of y-axis pixels, times the PIXEL_WIDTH, in current measurement units.
FRAME_WIDTH	Frame width is measured by the number of x-axis pixels, times the PIXEL_WIDTH, in current measurement units.
PARTICLES	The number of particles evaluated after passing the sieve and guard region operations.
PIXEL_WIDTH	Pixel width – The width of one pixel in current measurement units.
TOTAL_PARTICLES	Total particles – The total number of particles in the sizing file.

The data collected by SEM analysis and modelled using the Noran Vantage system is collected on a CD-ROM for further use. The following directories are to be found (Figure 4):

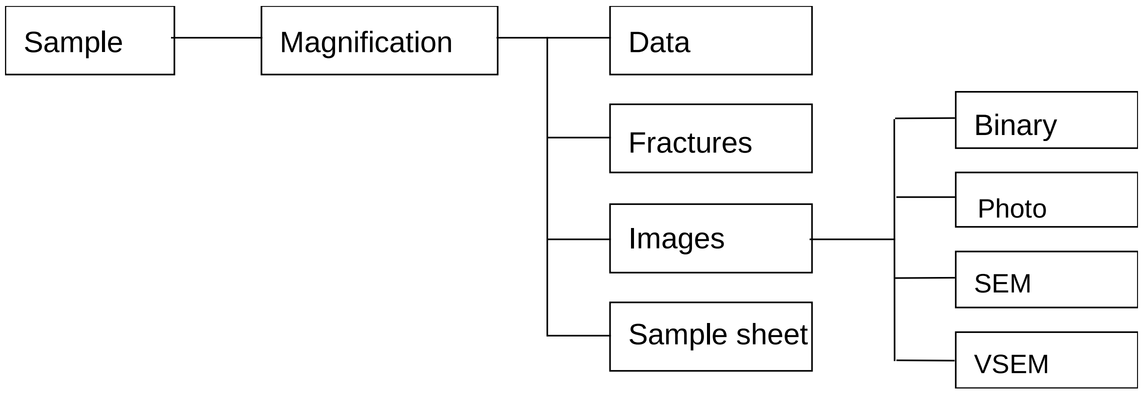

Figure 4. Diagram over directories on the CD-ROM attached to this report.

<u>The directories contains the following files:</u>

- <u>Data</u>: The calculated parameters are in XLS format with the SEM image obtained using the Vantage application as well as the final binary image.
- <u>Fractures</u>: The SEM images acquired using the Phillips XL-40 microscope are presented in the PowerPoint format, as connected to each other, so that they represent image-series covering the investigated fractures.

- Images: Images recorded using the Phillips XL-40 microscope are filed as [SEM]. Images acquired using the Noran Vantage system are filed as [VSEM], and finally the binary images used in the modelling are filed as [Binary]. Photographs of the samples in normal and UV-light are filed under [Photo]. All images are in the TIFF format.
- Sample sheets: The co-ordinates as well as other related information for the SEM images acquired using the Phillips XL-40 microscope are included in the sample sheets. These files which are in the PowerPoint format also contains UV and normal photos of the samples. The normal photos with locations of the SEM images are added as well.

Results

Photo-mosaic of single fractures

Connected SEM images of the fractures in sample 2D, 4T, 7.1A, 8.1A, 8.2A, and 10A are stored in PowerPoint files on the attached CD-ROM, as demonstrated on Figure 5. Sample 3 and 5 has been delivered separately earlier in this project.

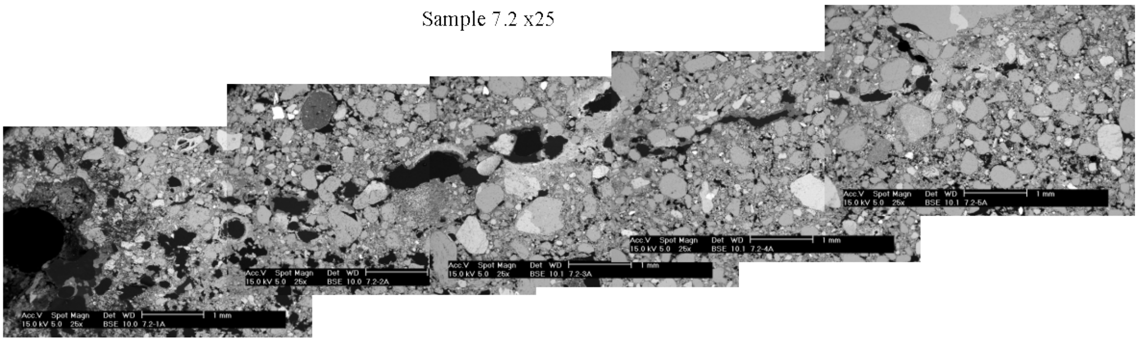

Figure 5. SEM-images of fracture in sample 7.2A.

Photo-mosaic of zone across fractures

In the following chapter photographs of sample with positions of SEM images, Vantage SEM images and Binary images of some selected fractures presenting sample 4T, 7.2A and 10A are presented. Similar information concerning sample 2D, 7.1A, 8.1A and 8.2A is to be found on the CD attached to this report.

Sample 4T

Sample 4T represent a system 2 fracture, which is outlined on Figure 6 by a black line. The SEM-images are taken across “the fracture zone” as illustrated with white boxes on Figure 6. Box no. 0 marks the centre of “the fracture zone” in all the magnifications (200x, 800x and 1600x). The binary images (Figure 9, 12 and 15) clearly illustrate the higher amount of pore-area (the white spots) in the fractured zone and at the same time mark that the fracture is not a plane, but a lot of smaller pores connected to each other.

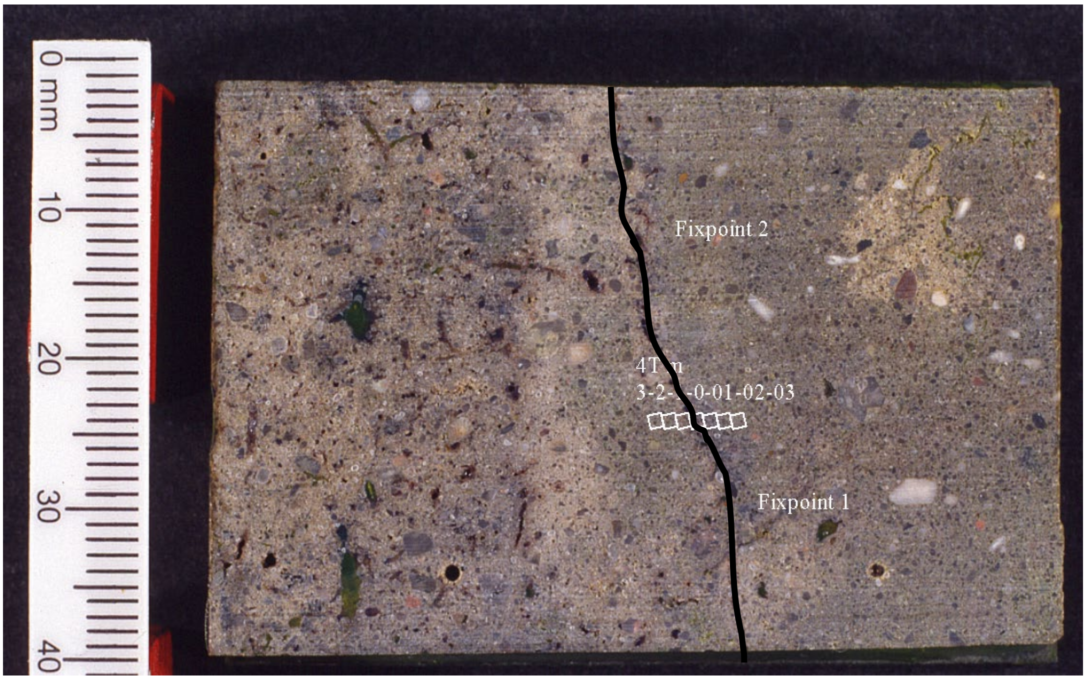

Figure 6. Photography of sample 4T.

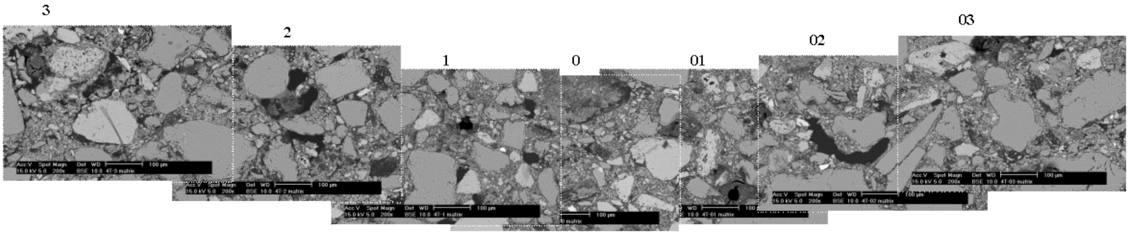

Figure 7. SEM-images (200x) of “the fracture zone” in sample 4T.

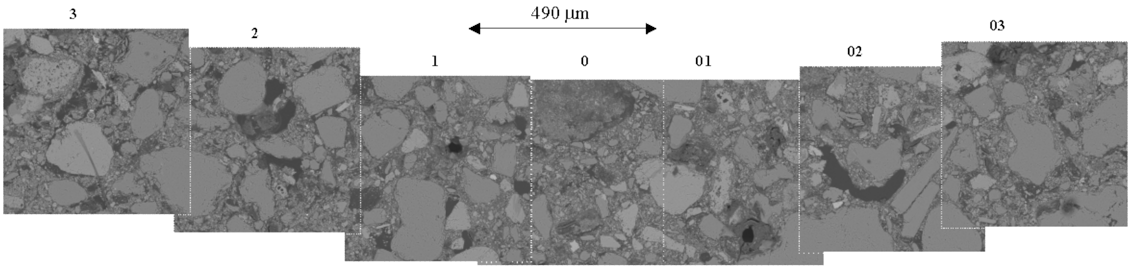

Figure 8. Vantage SEM-images (200x) of “the fracture zone” in sample 4T.

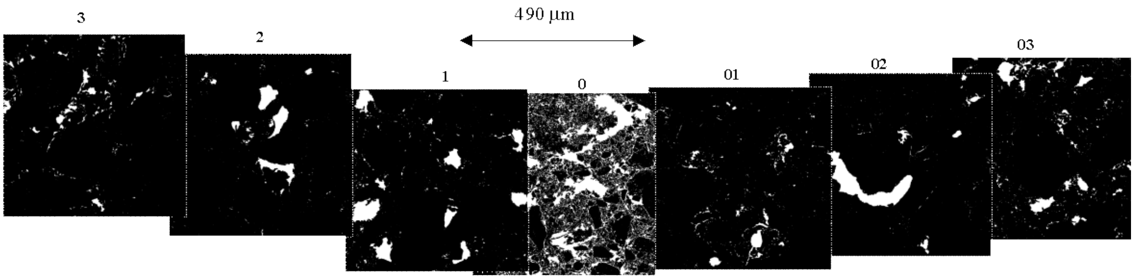

Figure 9. Binary images (200x) of “the fracture zone” in sample 4T.

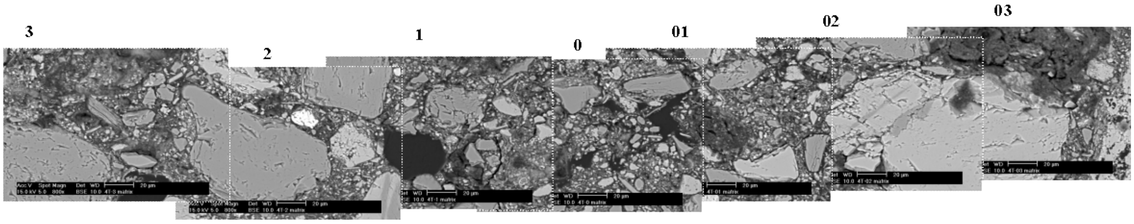

Figure 10. SEM-images (800x) of “the fracture zone” in sample 4T.

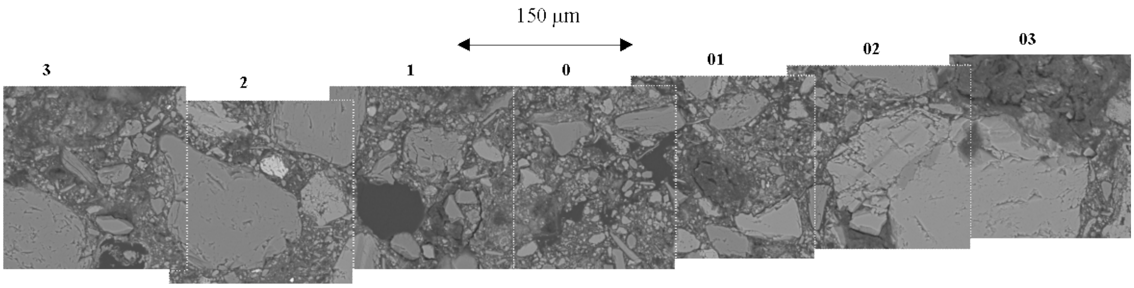

Figure 11. Vantage SEM-images (800x) of “the fracture zone” in sample 4T.

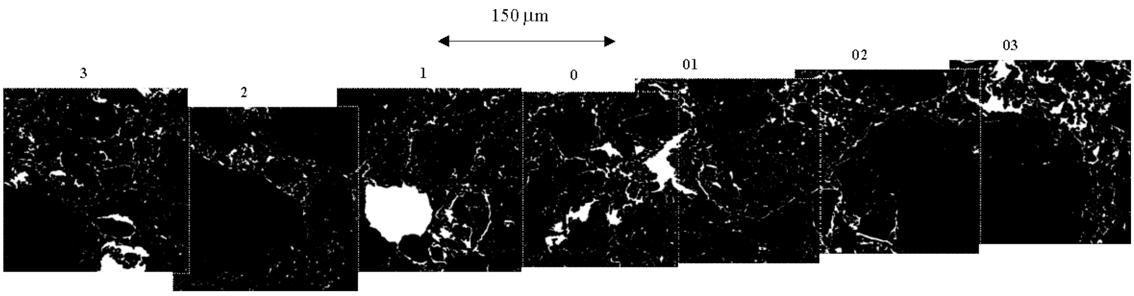

Figure 12. Binary images (800x) of “the fracture zone” in sample 4T.

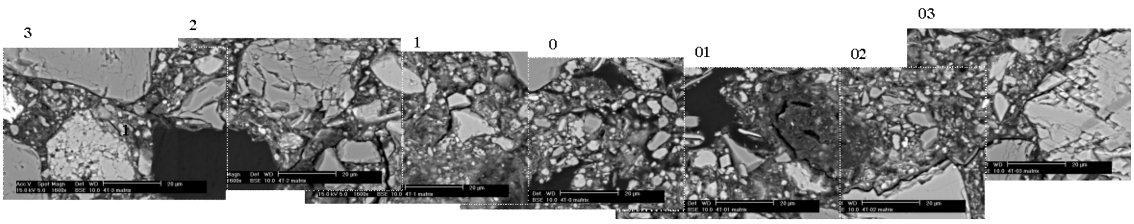

Figure 13. SEM-images (1600x) of “the fracture zone” in sample 4T.

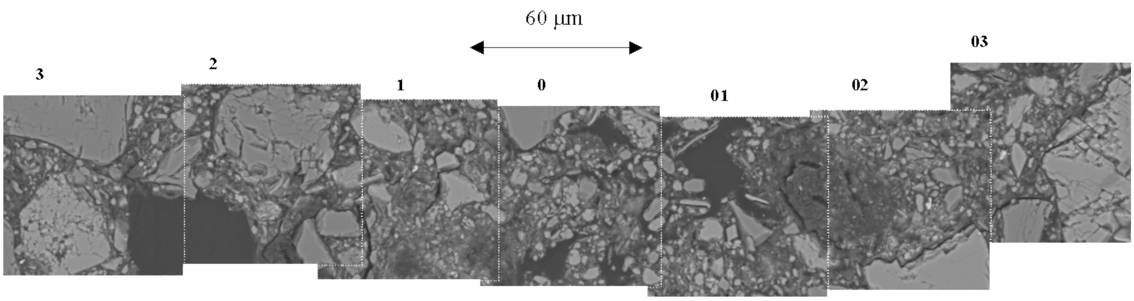

Figure 14. Vantage SEM-images (1600x) of “the fracture zone” in sample 4T.

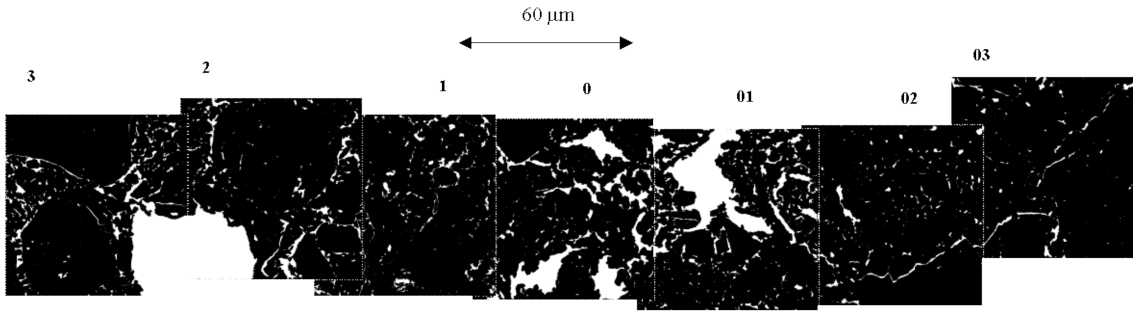

Figure 15. Binary images (1600x) of "the fracture zone" in sample 4T.

Sample 7.2A

The sample 7.2A also represents a system 2 fracture, which is outlined with a black line on Figure 16. The binary images with the magnification 200x (Figure 17) are taken across "the fracture zone" as illustrated with the white boxes on Figure 16. In the binary image no. 0 the fracture is one large connected pore (the white spots), which, however, do not either take form of a plane. The next figures of sample 7.2A contain images of magnifications 800x and 1600x concentrating on one side of the fracture and focusing on how the pore-area vary from the fracture and out into the matrix (Figure 17-23). These images show that the wall of the fracture is coated with finer material (clay minerals), which has hardly any pore area (Figure 23). The coating can result in disconnection of the pore space in the fracture with the porosity in the matrix and a minimisation of the diffusion between the fracture and the matrix. The images with the magnification 200x and 800x show large pore space in the matrix - pores, which can have a dominating effect on the transport and natural attenuation of pollution.

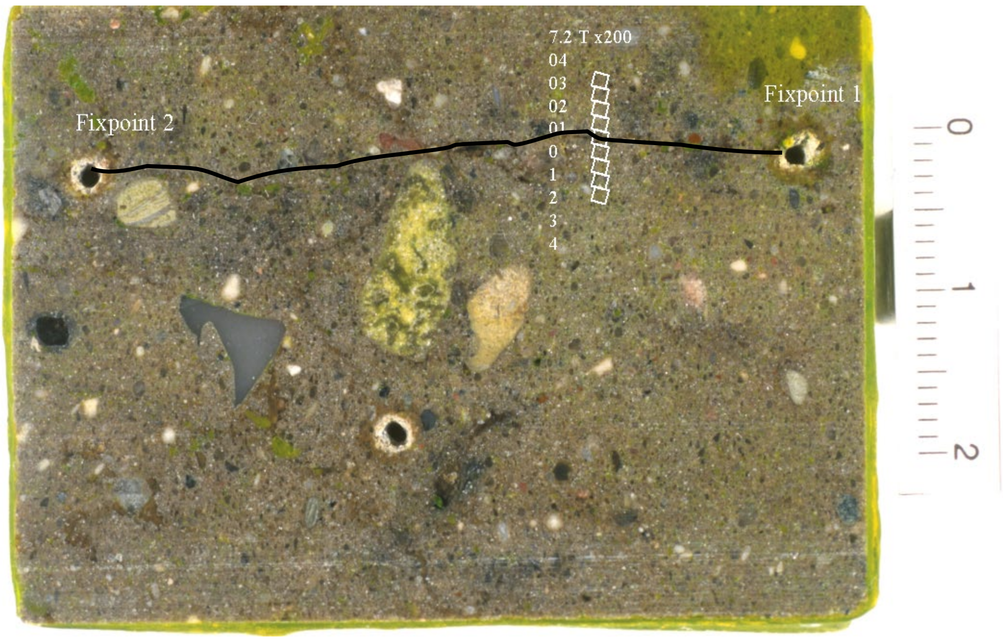

Figure 16. Photo of samples 7.2.

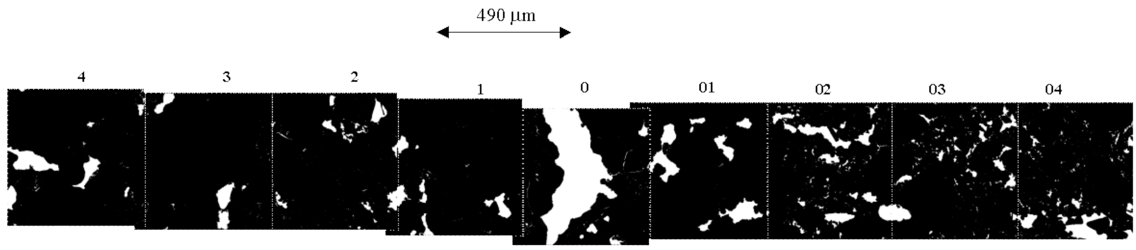

Figure 17. Binary images (200x) of "the fracture zone" in sample 7.2A.

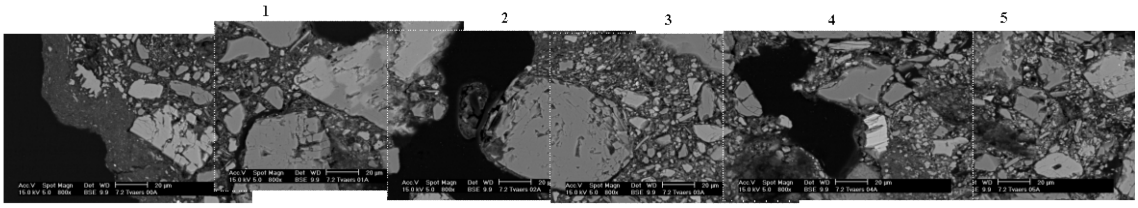

Figure 18. SEM-images (800x) of "the fracture zone" in sample 7.2A.

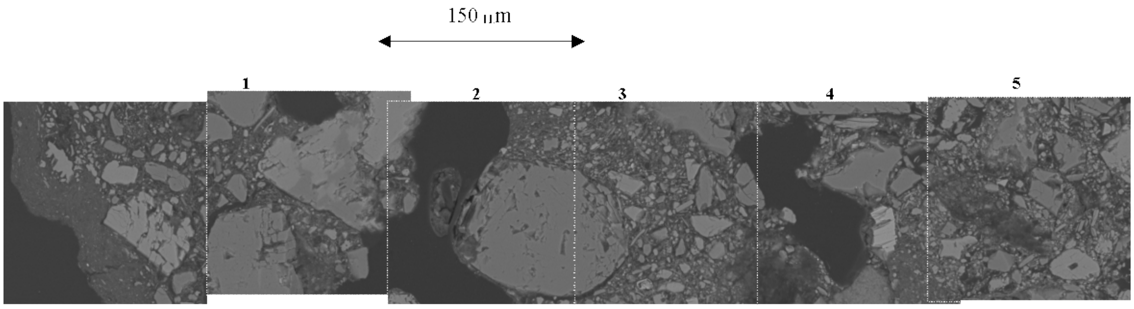

Figure 19. Vantage SEM-images (800x) of " the fracture zone" in sample 7.2A.

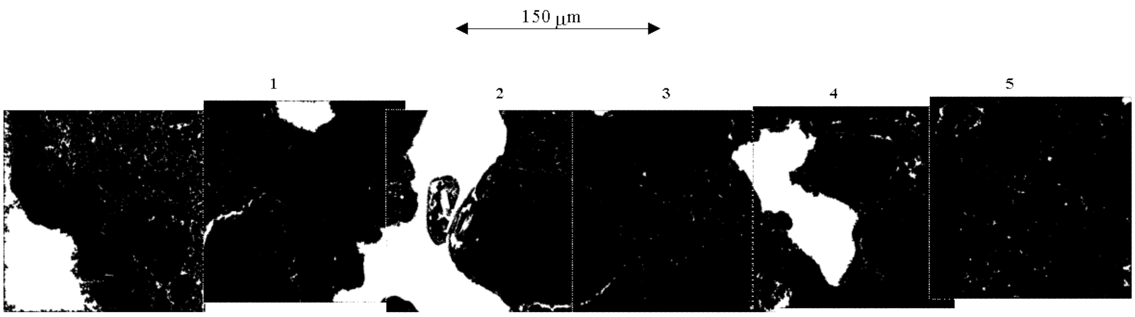

Figure 20. Binary images (800x) of "the fracture zone" in sample 7.2A.

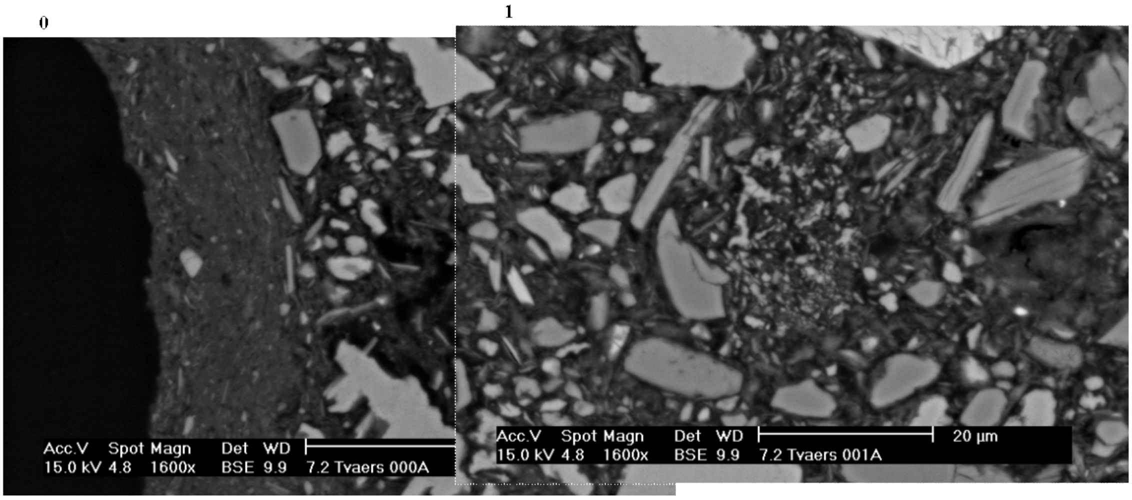

Figure 21. SEM-images (1600x) of “the fracture zone” in sample 7.2A.

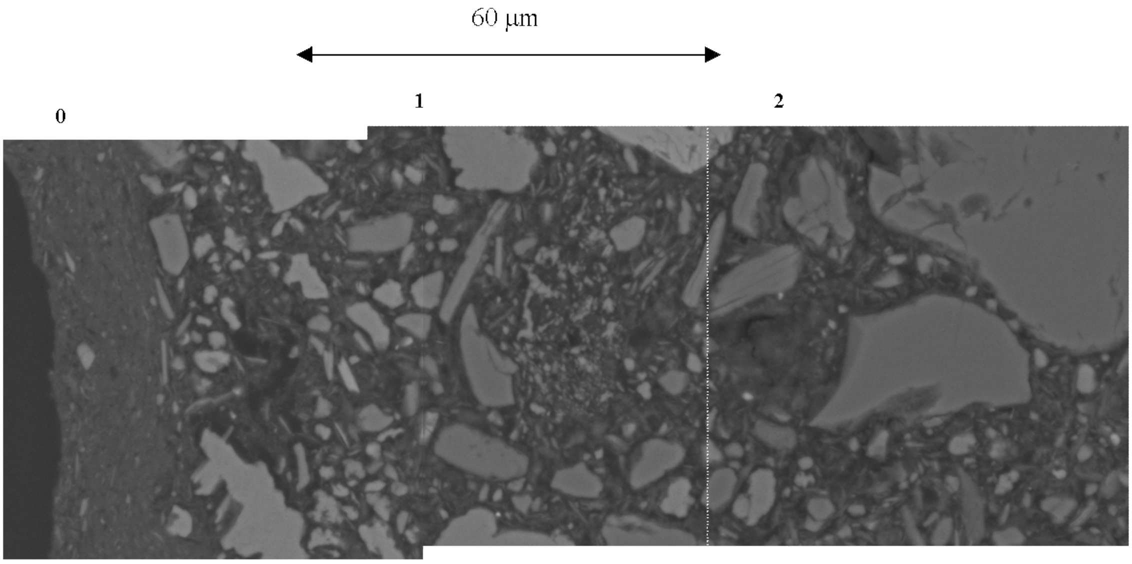

Figure 22. Vantage SEM-images (1600x) of “the fracture zone” in sample 7.2.

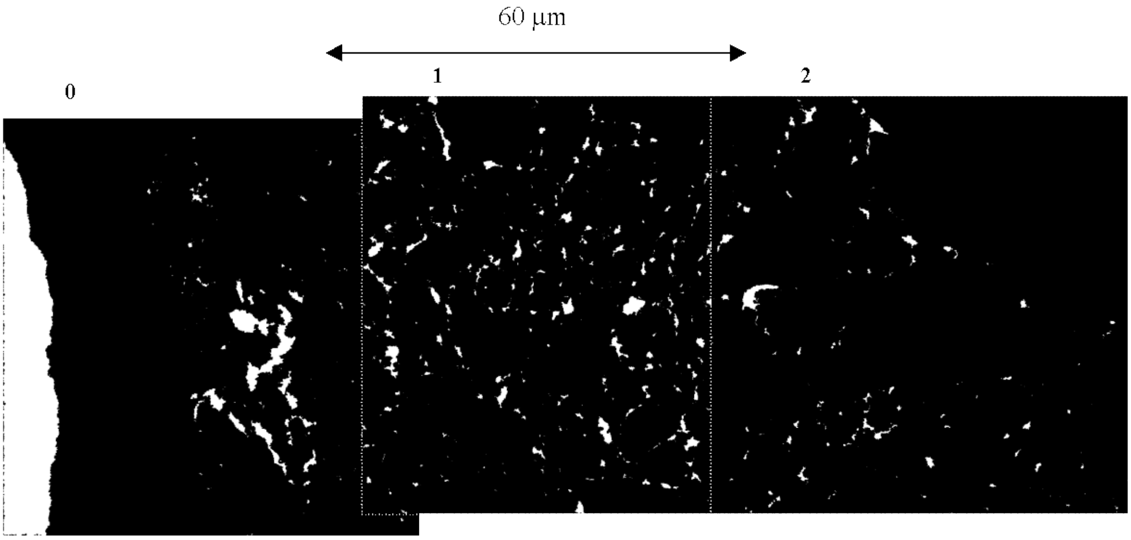

Figure 23. Binary images (1600x) of “the fracture zone” in sample 7.2A.

Sample 10A

Sample 10A represent a system 2 fracture, which is outlined on Figure 24 by a black line. SEM-images are taken from “the fracture zone” and out in the matrix as illustrated with white boxes on Figure 24. Box no. 1 contain the centre of “the fracture zone” in all the magnifications (200x and 1600x). As in sample 7.2A, the images show coating on the walls of the fracture and that the coating varies in thickness. By zooming in on the coating, longitudinal pore areas appear more or less parallel to the fracture plane. These openings in the coating can be a result of the impregnation process. In the clayey till from Ringe there is a high content of smectite in the clay fraction. These minerals can, while impregnating the sample, shrink. Since the coating contain a lot of finer material including clay minerals this shrinking process could be the reason for the longitudinale openings in the coating. By neglecting these openings, there is hardly any natural porearea in the coating, but as in sample 7.2A larger pores emerge further in the matrix. In Figure 30 the natural pore area of each image is add (ref. the excel-file) emphasising, that the coating (image no. 1) has only a pore-area on 4μm^2.

Figure 24. Photography of sample 10A.

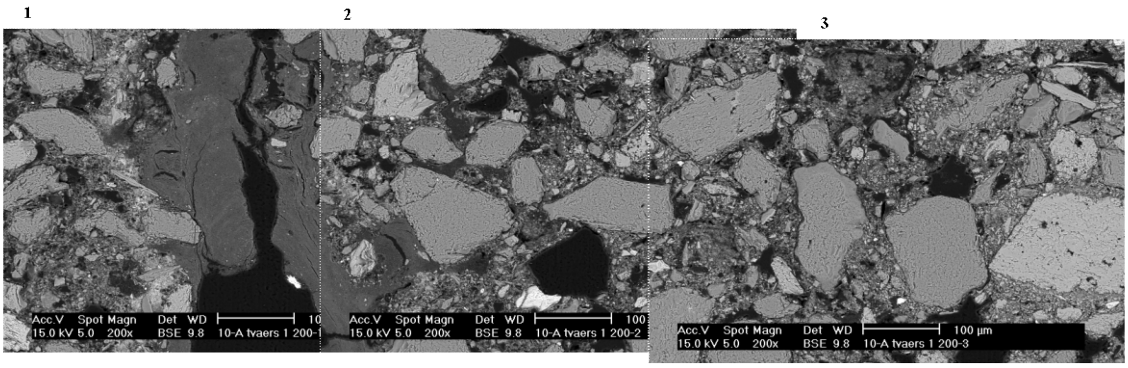

Figure 25. SEM-images (200x) of “the fracture zone” in sample 10A.

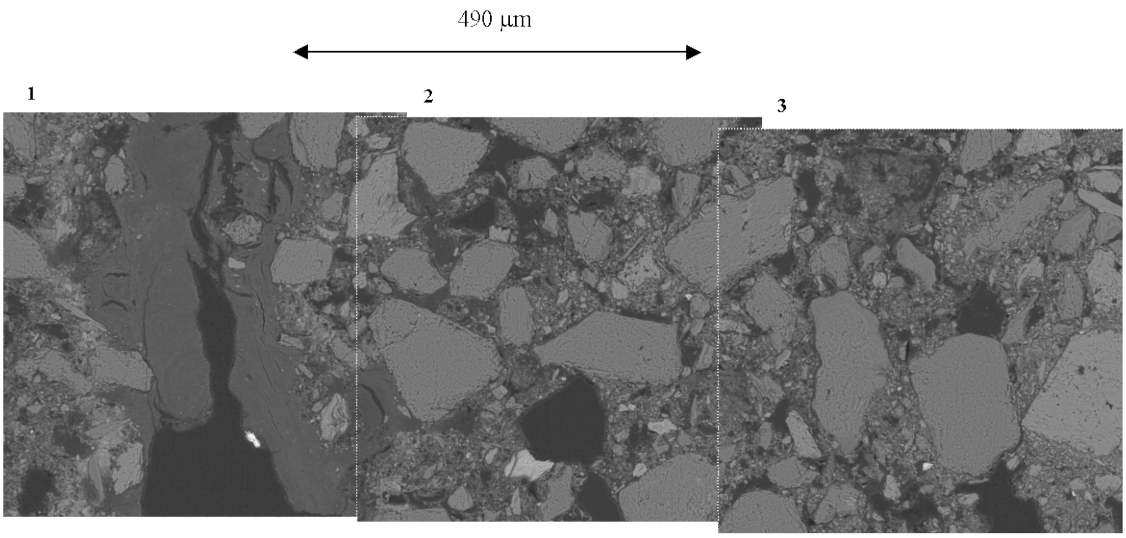

Figure 26. Vantage SEM-images (200x) of “the fracture zone” in sample 10A.

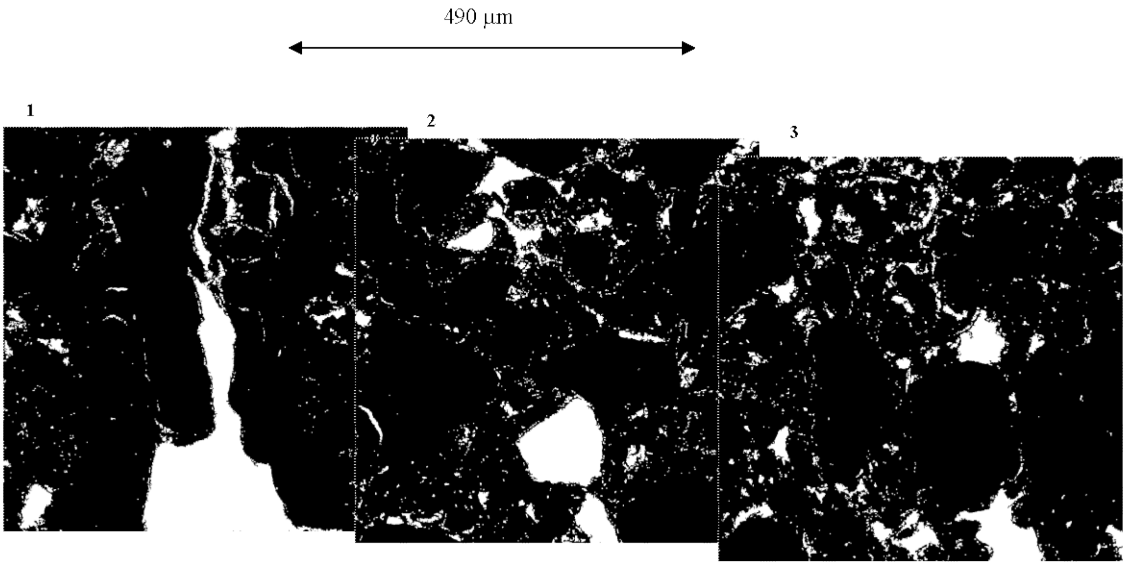

Figure 27. Binary-images (200x) of “the fracture zone” in sample 10A.

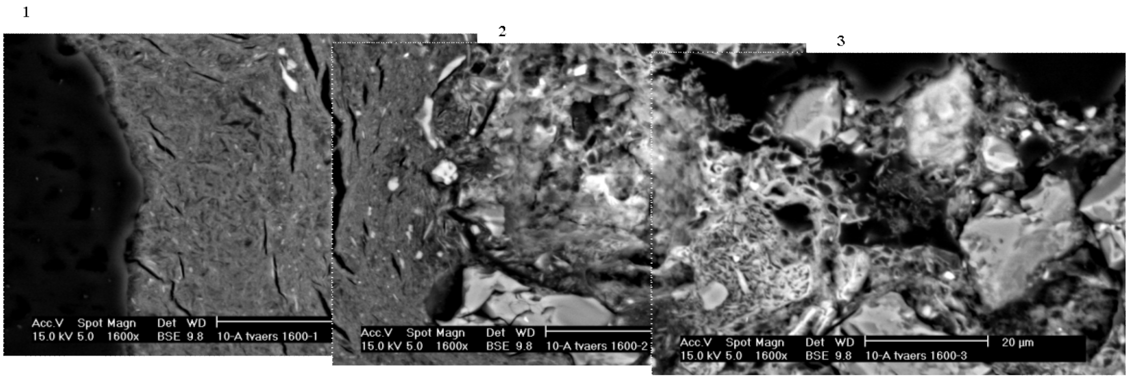

Figure 28. SEM-images (1600x) of “the fracture zone” in sample 10A.

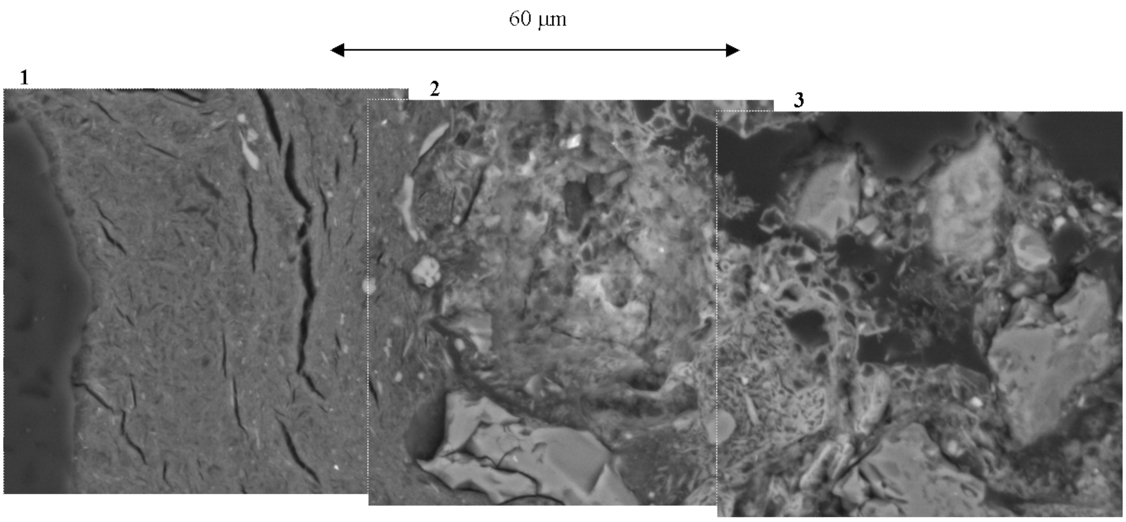

Figure 29. Vantage SEM-images (1600x) of “the fracture zone” in sample 10A.

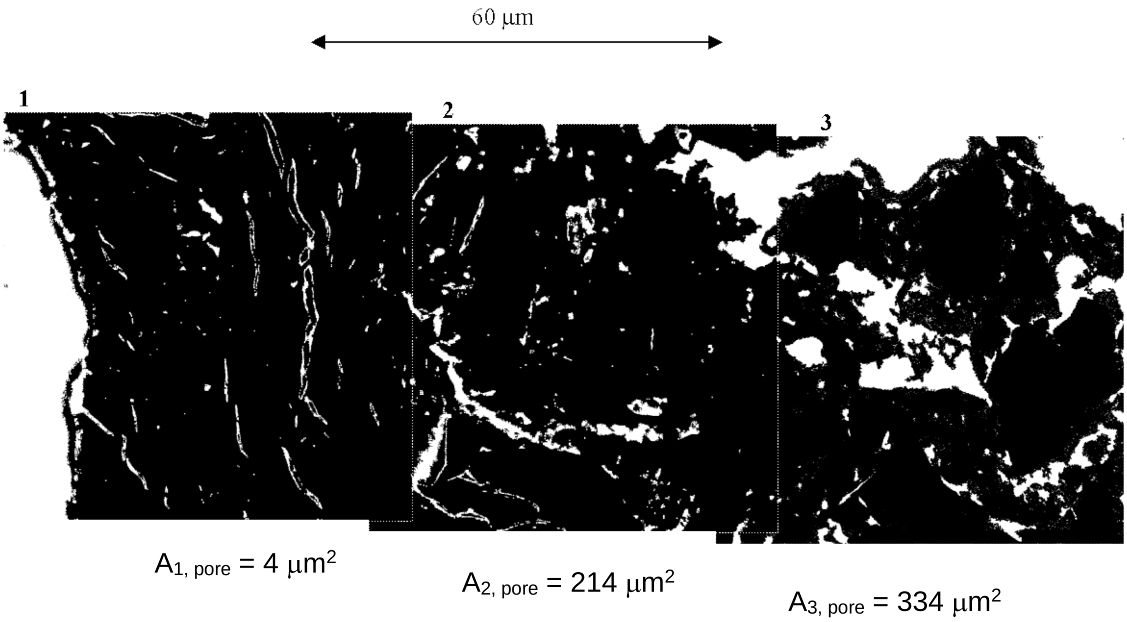

Figure 30. Binary images (1600x) of "the fracture zone" in sample 10A. Below the images the natural pore area A of each images are noted.

Summary

From the intact till samples collected at the Ringe site, additional samples have been selected for impregnation and grinding.

These samples have been photographed and analysed in the Scanning Electron Microscope (SEM) at different magnifications (25x-1600x). Two types of SEM-images were collected: one presenting an overview of the fracture in the sample (SEM-images) and one used in the mathematical characterisation of the fractures (Vantage SEM-image). The images have been collected across “the fracture zone” and from the fracture and into the matrix. From the Vantage SEM-images:

- Binary images have been prepared for the visualisation of the pore area distribution in “the fracture zone” and fracture geometry.
- Mathematical parameters describing the pores have been estimated with Vantage Feature Sizing package.

The parameter estimates and SEM-, Vantage SEM- and binary-images are given in the CD-ROM attached to this report.

The images show:

- that the fractures are not planes, but consist of channel shaped pores.
- that most of the fractures are coated with finer material, which has hardly no pore area.
- that the thickness of the coating vary in the fracture.
- that the fracture can be partly coated.
- that there is larger pores perhaps isolated in the matrix-zone.
- that the coating may contain smectite, which change mineral-size with the humidity in the media - so the thickness of the coating can vary with the humidity.

References

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