DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2001/34

TRACe-Fracture
Toward an Improved Risk Assessment of the Contaminant Spreading In Fractured Underground Reservoirs

Deliveries from GEUS Task 1.1, 1.2 and 1.3
Annual Progress report

GEOLOGICAL SURVEY OF DENMARK AND GREENLAND
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Annual Progress Report No. 34. March 2001

SUMMARY

Introduction

This report was written as part of the Annual GEUS Deliveries for the EU-project EVK1-CT1999-00013: TRACE-FRACTURE (Toward an Improved Risk Assessment of the Contaminant Spreading in Fractured Underground Reservoirs). The report contains a short summary of the work accomplished so far and four progress reports with the data and results:

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. GEUS Progress report no 35.

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. GEUS Progress report no 36

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. GEUS Progress report no 37.

Rosenbom A.E., Hansen M., Klint K.E.S.K., 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. GEUS Progress report no 38.

Goals and scopes

The goal of Task 1-1, 1-2 and 1-3 was to investigate two generic contaminated sites located on fractured rock and construct a geological model in combination with a fracture model. Combined with detailed analysis of possible contaminant transport in the fractured rock, this data should form the basis for the construction of a Risk Assessment model capable of simulating spreading of contaminants in fractured underground reservoirs.

The fracture investigations on the two sites included:

- Construction of a geological model for both sites.
- 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) on intact samples of fractured rocks.
- Hydraulic tests of fractures, either from wells or in core samples.

The Deliveries from GEUS were originally as follows:

TASK 1-1. CORE SAMPLING AND SEM ANALYSIS OF FRACTURES
Participants: GEUS, CH2M-Hill
A detailed geological investigation and fracture characterisation will be carried out on both sites. Existing geological and topographical maps as well as reports of earlier studies will be reviewed. The fractures will be classified according to their origin, and the spatial distribution of individual fracture-system will be measured. A representative number of fractured intact samples and core samples will be collected from both sites by GEUS and CH2M-Hill. GEUS will impregnate the samples in epoxy resin and prepare thick-section slices (50-200 μm thick) of selected fractures for SEM images analysis (Scanning Electron Microscope). The analysis will provide SEM-images of single fracture cross-sections, which allow the separation of macropores within the matrix. A number of serial sections (25-50) of the individual samples will form the basis of a 3-dimensional reconstruction of the fractures, and a database with SEM images will be formed for further analysis.

TASK 1-2. DEVELOPMENT OF A SINGLE FRACTURE MODEL AND DETERMINATION OF ITS STRUCTURAL PARAMETERS.
Participants: ICE/HT, GEUS
Based on the SEM images of Task 1-1, ICE/HT and GEUS will develop a network model for the representation of single fractures. GEUS will feed the data of SEM images to a commercial image analysis software for the determination of the geometrical characteristics of fractures such as the aperture size distributions and the mean shape factor. Furthermore, ICE/HT will develop a method for the determination of the connectivity of a single fracture in terms of network models (specific genus) from serial section SEM images. In addition, ICE/HT will use the fracture surface technique for the determination of the fractal dimension of the fracture-wall roughness from random SEM images. Then, the investigated fractures will be characterised in terms of the parameters of network models.

TASK 1-3. DEVELOPMENT OF A NEW FRACTURE NETWORK MODEL AND DETERMINATION OF ITS STRUCTURAL PARAMETERS
Participants: ICE/HT, GEUS
Based on the measured field data, a fracture/macropore network model will be established, and quantitative fracture properties will be calculated for the individual fracture systems (primarily spacing for systematic fractures and fracture trace-frequency for non-systematic fractures) Other features which could increase substantially the permeability of the subsurface, such as root holes and burrows will be described as well. The nature and origin of the individual fracture systems will be determined and form the basis for an evaluation of the general fracture distribution in the areas. The collection of cores and intact samples will be closely related to the network model, in order to collect the most representative samples.

Description of work

Site 1 "Spanish Site"

The fieldwork in Spain was delayed 3-4 month due to various problems:
During the 1st Plenary meeting in Santiago de Compostella the selected site was inspected by the participants in the project.

The original site was a landfill near the city of Ourense in Galicia. It was situated on fractured granite and it basically met the requirements for the project. But the conditions for the site had changed and the waste was covered with 3-4 meters of sediment. The available information regarding the position and composition of the contamination was not adequate within the framework of this project. It would have required large resources in respect of identifying the source of contamination by excavating through the sediment-cover, and subsequent installation of a number of wells for monitoring and sampling the fractured granite.
Two other possible sites were inspected during the meeting and both were rejected as both sites rested on thick unconsolidated sedimentary covers of sand and gravel with no fractures.

CH2M-Hill was given the task to locate a new site and the choice finally fell on a facility in Northern Spain with a production that occasionally causes spill of different oil products into the subsurface.

The facility is placed in two small valleys that merge into one valley, which ends in a small beach towards the Atlantic coast. The valleys are separated by three hills that are 130-240 m high. The hills consists primarily of fractured coarse grained granodiorite, that have been intruded by a more fine-grained leucogranite. The valleys has a thin cover of sediments. The facility is partly constructed on steps that are cut out of the hill side and thus offers exposures of the rock. There are furthermore a large number of road-cuts and quarries in the surrounding hills, and the coastline offers excellent exposures of the different rock-types and fractures. A large number of wells inside the facility have been monitored for a number of years and information's about the groundwater quality and measurement of the groundwater level are available. This site was accordingly very well suited for the project.

The project was unfortunately delayed due to the negotiations with the owner of the facility, but the conditions were finally agreed on in mid June. One of the conditions was to keep the company name and exact location confidential. The site will therefore be referred to as "the Spanish site" and the name of the company as well as the exact type of company will not be mentioned either. For the same reason all names of cities as well as geographical co-ordination points on maps will be removed. Geological information and topographical information will be the only data shown on maps.

Field work

In June, Knud Erik Klint from GEUS and Francisco Sanchez From CHM2-Hill conducted a full scale fracture investigation and geological mapping in the area. Fresh outcrops along roads, quarries and coastal sections were investigated, and nine localities were selected for detailed fracture analysis. More than 500 fractures were carefully described and measured. From these investigations a preliminary fracture model has been constructed, and a number of representative locations were selected for sampling of intact fractures. Based on the preliminary fracture analysis sampling of cores with representative intact fractures were planned.

In August, Niels Springer, Hans Jørgen Lorentzen, Knud Erik Klint and Annette Rosenbom from GEUS were sampling intact fractured samples of granite for a period of two weeks. Susanne Arquero from CHM2-Hill assisted with the logistics for the first three days. A large number of samples were collected by using a new methodology introducing in situ impregnation of fractures, thus maintaining original fracture apertures. Samples and large blocks with open fractures were also collected for hydraulic experiments in the laboratory. Attempts to conduct in situ hydraulic tests on natural fractures failed due to the complexity of the fractures. The samples were send to GEUS for further analysis in the laboratory.

Data analysis

A geological model as well as a fracture model has been constructed for the area, by GEUS in co-operation with CH2M-Hill. GEUS has constructed a fracture model that includes analysis of the regional fracture distribution in the area, as well as classification of different fracture systems related to different tectonic events that created them. The fractures are closely related to fault systems and intrusive dykes in the area, and these structures and features have naturally been incorporated in the geological model. A report describing the geological settings and the distribution of fractures has been prepared. (Klint et al. 2001a.)

The samples of impregnated fractures that were collected in August, were analysed during the fall and winter, and a report with the results has been prepared (Rosenbom et al., 2001b). The report contains a large number of fracture Images, which have been stored on CD-ROM and prepared for image analysis in Scan-pro 5.

Site 2 “The Ringe Site”

The Ringe 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. From the earlier projects a general geological model has been established for the Ringe site. The investigations showed that the site is dominated by glacigene sediments (till) deposited by a glacier during the Weichselian glacial period. The Ringe site has been thoroughly investigated during a number of previous projects. A large number of well data as well as geological data from three large excavations were available for the project. The local County of Funen has currently initiated a project for the construction of a more regional hydraulic model. A number

of new wells are being installed during the spring 2001. A new and improved hydraulic model are accordingly under construction.

Field work

Samples of intact fractured till captured in steel-boxes were available from uncontaminated areas. In the light of this project it was decided to perform one large excavation in a highly contaminated area, in order to collect samples of contamination and to study the distribution of contamination in the fractured till. Field work was carried out in week 13, 2000, by the following participants: Annette Rosenbom (GEUS), Knud Erik Klint (GEUS) and Pierre Le Thiez (IFP). A number of intact samples of fractured clay till were collected as well as samples of contamination. Fracture surfaces with a “channel like” distribution of NAPL were photographed for later analysis.

Data analysis.

Impregnation and SEM analysis of uncontaminated samples of fractured clay till have been finished. 7 samples were selected for detailed analysis of the fracture geometry. Special focus has been put to a detailed study of the pore-structures in the matrix close to the fractures. A data report with the results and images stored on CD-ROM has been prepared (Rosenbom et al., 2001a).

Results

The four annual progress reports contains the Deliveries from GEUS in task 1-1, 1-2, 1-3 and 6-1.

Summary report 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. GEUS Progress report no 35.

The geological history of the Spanish site includes a long history of geological events. Nine different tectonic events has thus affected the area since the granite was intruded some 400 mill. years ago. These events may be related to regional plate tectonic events that resulted in systematic faults, intrusions and fractures. Local uplift and cooling events created non-systematic fracture systems, and subsequent weathering created zones of deeply weathered granite, primarily in fracture/fault zones. The granite is a non-stratabound overall homogenous rock. The fractures are quite heterogeneous and is thus expected to contain very different hydraulic conditions in different regions.

The fracture data collected from Spanish site has been analysed. The degree of fracturing is highly heterogeneous with areas of low fracturing, intersected by zones of highly fractured granite with potentially high hydraulic conductivity. The different types of fractures, dykes and faults have been classified according to the origin of the fractures.

Quantitative values of fracture density in various areas have facilitated an estimation of typical fracture density in fresh granite and in fracture zones. The weathered granite consists of loose unconsolidated “gravel like” rock with a potential high hydraulic conductivity, and the valley floors are covered with sandy deposits.

The area consist thus of four characteristic potential hydraulic homogenous areas: Fresh granite, fracture/fault-zones, weathered granite and sedimentary cover in the valleys.

The heterogeneity of the area prevent the construction of a very accurate hydraulic model, since areas covered with vegetation offers little information about the geological conditions, but there seems to be a connection between the geomorphology and the distribution of fracture zones and weathered granite. A detailed geomorphological analysis of aerial photos, combined with additional hydraulic well-tests in the valley, will be the best way to estimate the distribution of these zones. And these investigations will be carried out during the Spring 2001.

Summary report 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. GEUS Progress report no 36:

The clay till at the Ringe site represents a very different fractured environment compared to the Granite site in Spain. The geological history of the area is thus restricted to maximum 100.000 years and accordingly more simple. The great number of data from previous projects combined with the latest investigation form the background for one of the most detailed geological models ever constructed in clay till.

The report presents the latest geological model of the area. A 3D model of the distribution of clay till and sandy deposits has been constructed in one meter intervals form the surface to the primary groundwater aquifer 22 m below ground level. Detailed investigations of fractures in the upper five meter of till show, that the fractures were formed as a combination of loading from glaciers and subsequent freeze/thaw and desiccation processes. Compared to earlier models, this new model involves the latest hydraulic data for different fractures. New well-data and regional geomorphological data are included for the construction of a better regional hydraulic model in the area.

Three characteristic zones with different distributions of fractures have been identified in the upper five meters of till, and a conceptual fracture model has been constructed. This model forms the basis for the selection of representative fractures, and thus for the sampling of intact samples of fractured till.

The variability of the fracture density throughout the area are regarded to be closely connected to the sub-glacial drainage conditions under the glacier during the deformation of the till. The till is thus partly overlaying a sand lense, which is regarded to have provided good local drainage, resulting in the occurrence of larger and more well-developed fractures, than in the surrounding areas with a thick till cover.

Summary report 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. GEUS Progress report no 37.

Based on the geological investigations a number of contaminated samples of clay till, containing representative dominating fractures, have been collected for further investigation.

Intact samples of fractures that have been hydraulic tested in large undisturbed columns during earlier projects, have been impregnated and prepared for detailed analysis of mechanical fracture aperture in a Scanning Electron Microscope (SEM).

Detailed analysis of the matrix surrounding the fractures and especially the pore distribution close to the fracture has also been analysed in the SEM at magnifications up to 1.600 times. A large amount of SEM images of single fractures were finally captured on seven new samples in order to analyse a larger number of fractures and thus expand our knowledge of the variability of fracture apertures in clay till. Binary images of the fractures were furthermore constructed and all the images were stored on a CD-ROM for Scan-Pro 5 analysis.

Summary report 4.

Rosenbom A.E., Hansen M., Klint K.E.S.K., 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. GEUS Progress report no 38.

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 out of the outcrop as monoliths, but most of the samples were collected as core-samples containing impregnated fractures. The samples were taken to the laboratory at GEUS and prepared for SEM analysis or flow experiments.

SEM-Images of fractures with an aperture typically smaller than 2 mm were successfully captured. Fractures with larger apertures than 3mm were photographed in normal incident light, and the aperture may be estimated from these images. The images have been stored on a CD-ROM for further analysis of the geometrical properties.

Most of the fractures contained a filling consisting of organic matter and fine sediment that have deposited inside the fracture. This is regarded to be a general feature in the near surface fractures. Some fractures have openings that seem to be dilated and may have opened recently. This may have happen during the construction of the road. The individual fractures must therefore be carefully evaluated before realistic fracture apertures are measured. Strongly weathered granodiorite could not be sampled too, as it was falling apart.

The fractures have in general very large apertures, and since the maximum size of an image is 5.000 μm, fractures with an aperture larger than 5.000 μm were analysed on normal images captured in incident light and UV-light. The granite fractures are generally very different from the clay-till fractures. The variation of apertures (up to 15.000 μm) in granite are much larger than the maximum fracture apertures in clay till (up to ~1.000 μm).

General Summary

A detailed geological investigation has been carried out on two contaminated fractured sites: a contaminated site in Northern Spain characterised by fractured granite rocks and a contaminated site in Fractured clay till in Denmark.

The fractures in the crystalline rocks at the “Spanish site” vary in many respects from the fractures in the clay till. While the clay till allows formation of biogene channels within the fracture, the fractures in the crystalline rocks are entirely depending on the type of deformations. Some fractures have a very irregular or undulating shape face with a rough surface, while other have a planar shape with a smooth surface (Figure 1). Slickensides are abundant on many fracture surfaces as well as growth of quartz crystals on some fractures. Aperture varies at a much larger scale than in the clay fractures. The size of the fractures and the shape of the fracture network are very different from the clay fractures. So a new approach must be considered in this model.

Previous studies of fractures in crystalline rocks show that especially the “surface roughness” of the fractures are important for allowing fluids to migrate through the fractures. The area of contact between the two opposite sites of the fracture create boundaries, while connected areas of “no contact” creates channels, in which the fluids flow. Smooth fractures may thus have a larger contact surface, while rough fractures may have a smaller contact surface.

The characterisation of the surface roughness and the classification of fractures into regional systems with characteristic surfaces are therefore essential. Representative samples of the primary fracture types have therefore been collected and a special attention has been given to the study of contact area across fractures in 2-dimensions.

The fracture data collected from the Spanish site have been analysed. The degree of fracturing is highly heterogeneous with areas of low fracturing, intersected by zones of highly fractured granite with potentially high hydraulic conductivity. The different types of fractures, dykes and faults have been classified according to the origin of the fractures. Nine different tectonic events have affected the area since the granite was intruded some 400 mill. years ago. These events may be related to regional plate tectonic events creating systematic faults, intrusions and fractures. Local uplift and cooling events created non-systematic fracture systems, and subsequent weathering created zones of deeply weathered granite, primarily in fracture/fault zones, thus causing very different hydraulic properties in different regions.

Quantitative values of fracture density in various areas have facilitated an estimation of typical fracture density in fresh granite and in fracture zones. The weathered granite consists of loose unconsolidated “gravel like” rock with a potential high hydraulic conductivity, and the valley floors are covered with sandy deposits. The area may accordingly be separated into: Fresh granite, fracture/fault-zones, weathered granite and sedimentary cover in the valleys. The heterogeneity of the area prevents the construction of a very accu-

rate hydraulic model, since areas covered with vegetation offers little information about the geological conditions, but there seems to be a connection between the geomorphology and the distribution of fracture zones and weathered granite. A detailed geomorphological analysis of aerial photos, combined with additional hydraulic well-tests in the valley, will be the best way to estimate the distribution of these zones. The investigations will be carried out during the Spring 2001.

Construction of a preliminary macroscopic fracture network model for the upper five meters of till at the Ringe site has been completed. Additional well-data for the construction of a regional geological model are being collected and an improved hydrological model is under construction.

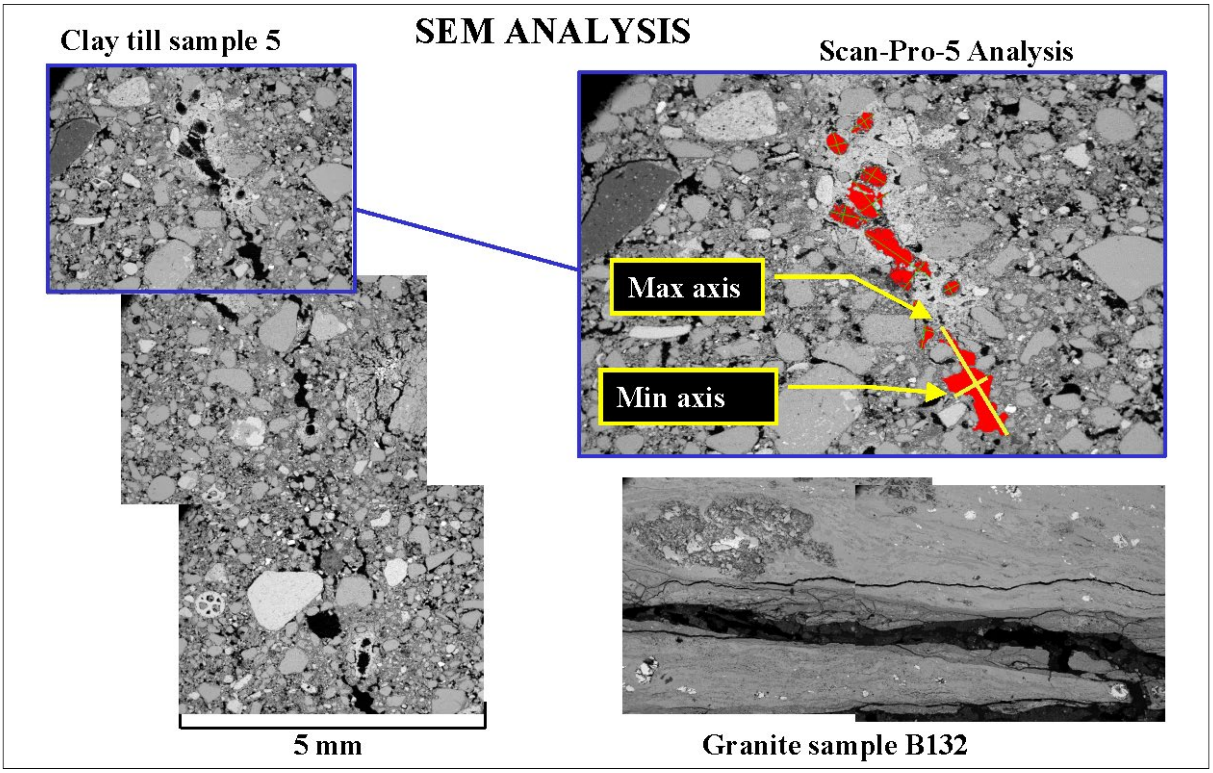

Figure 1. Example of fractures in Granite and in Clay till. With Scan-Pro 5 analysis of the pore size on one image. The scale is the same on both samples. Note how the till fracture consists of a number of channels while the granite fracture is relatively smooth with a continuos opening.