DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2001/36

Geological Setting and Fracture Distribution on a Clay Till site in Ringe, Denmark

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

K.E.S. Klint, A. Rosenbom and P. Gravesen

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G E U S

Content

1. 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 is no. two of four progress reports with the data and results completed so far.

This report contains a description of the work accomplished so far, a detailed geological model and a macroscopic fracture model representative for the Ringe site.

The four report are as follows:

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.

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

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.

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.

2. Goals and Scopes

The goal of Task 1-1, 1-2 and 1-3 is 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 this site include:

- Construction of a geological/tectonic model.
- 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.
- Collection of additional intact samples of fractured sediment in for impregnation and measurement of the mechanical fracture aperture (opening diameter) on intact samples of fractured rocks.
- Construction of a conceptual macroscopic fracture network model.
- Hydraulic tests of fractures, either from wells or in core samples.

Collection and organisation of previous materials and information about the site.

3. 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 1.1

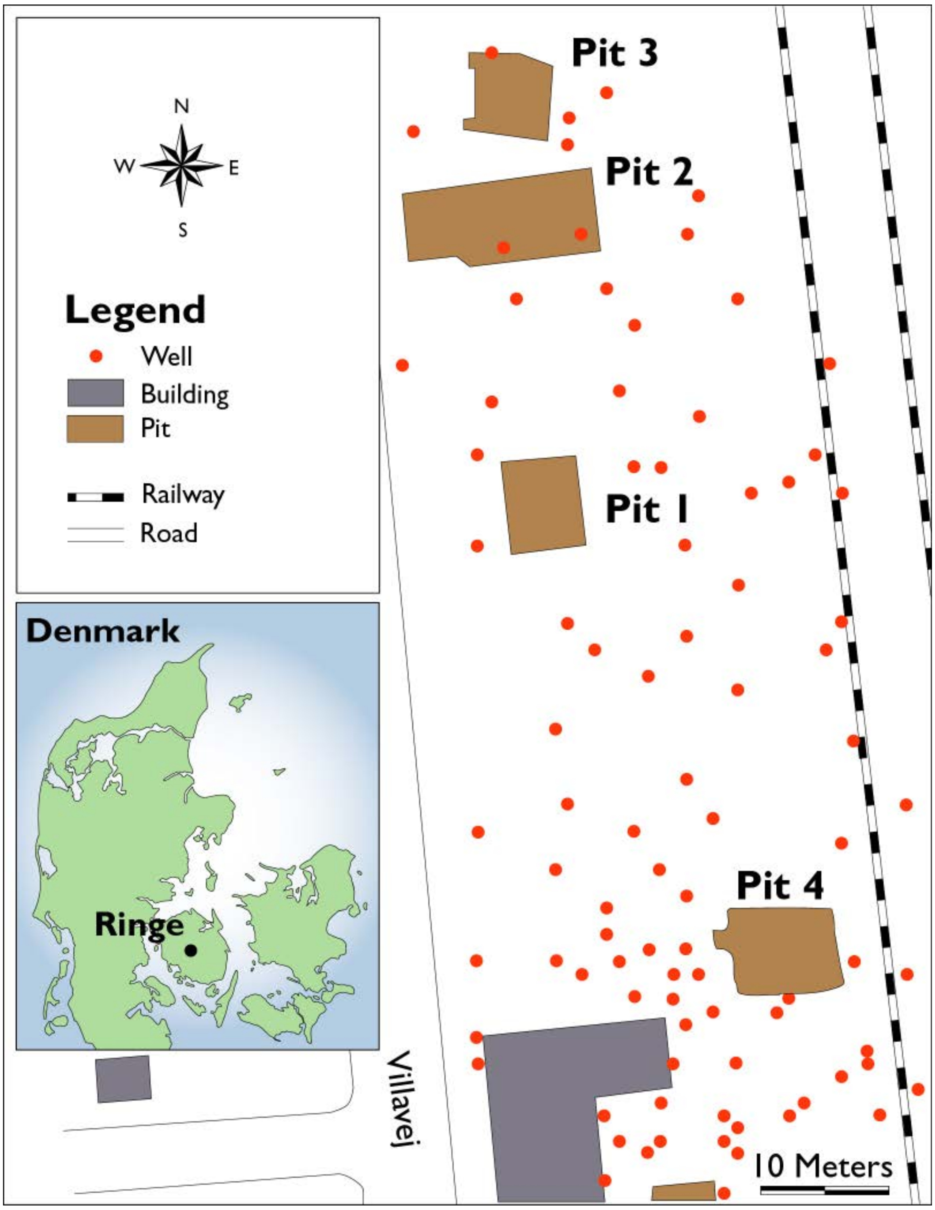


Figure **Fejl! Ukendt argument for parameter.**.1 Location of the Ringe site.

Historical description

The asphalt and creosote production at the Ringe site took place in 1929-1962. In this period tanks for storage of pollutants where placed all over the area. From 1962 to 1988 the factory was owned by a coal firm (1962-1968), Fiat (1968-1974) and the auto firm O.P.N. ApS. (1974-1988). In 1987 it was discovered that the clayey till on the site was strongly contaminated with creosotes. In July 1988 it was taken over by the Environmental Protection Agency with the purpose to clean it up. In 1988 the site remediation commenced (Kemp & Lauritzen, 1992a, 1992b). Old buildings and storage tanks were removed along with excavated contaminated soil, just leaving the office of the factory standing. Today “Dansk Metal” owns this building.

Earlier projects.

A number of research projects has used the site for scientific experiments. A large amount of wells has been established, and three open pits has been excavated during these projects in the period from 1994 to 1998.

In 1995 two Large Undisturbed Columns (LUC-samples) of fractured till were carefully excavated from Pit 1 at two depth intervals (2-3.5 m b.g.s.).

The following types of experiments were performed by Kim Broholm (Broholm K., 1998):

- batch experiments (biodegradation and sorption)
- small column experiments (diffusion)
- large column experiments (transport and biodegradation)
- a field experiment (transport and biodegradation)
- detailed measurements of organic compounds in the groundwater.

Peter Jørgensen (1998) performed hydraulic tests on the two LUC samples (Large Undisturbed Columns) and measured hydraulic conductivity and calculated hydraulic fracture apertures from these experiments. Intact samples of fractures from the LUC were successfully captured in Kubiena boxes after the hydraulic tests had been accomplished, and one sample has been analysed in the SEM (Scanning Electron Microscope).

Four types of full field-scale tests were employed In Pit 2to determine the hydrologic properties of the rather complex, coupled till – sand lens - sandy aquifer system. Hydraulic conductivity was calculated from break through curves of tracers. Based on the fracture spacing measured in Pit 1 and 2 the hydraulic apertures of the fractures were calculated at three different depth intervals. (2.5-4 and 5.5 m b.g.s.) (Sidle et al., 1998). Additional investigations and analysis of these data were performed by Nillsson et al 2001.

Pit 3 was excavated in 1998 in connection with the EU-project Pore-to-Core. One of the purposes of this project was to investigate the transport and natural attenuation of organic pollutants in the fractures. In order to do that the fracture distribution were investigated and intact samples from selected fractures were collected in a certain depth interval in order to study the fracture geometry and construct a 2D model for single fractures (Klint & Fredericia, 1998).

The fractures were impregnated and the mechanical aperture of single fractures were measured using Scanning Electron Microscope (SEM) analysis. The fracture geometry was described using analysis of the SEM-images from binary thick sections (Klint and Tsakiroglou, 2000). The result showed that the flow in fractures takes place in a channel network and not along the entire fracture surface.

4. Geological settings

Denmark is strongly influenced by glacial deposits as the area has been overridden by glaciers several times during the last 2 mill. years.

Regional geology.

The Ringe area is strongly dominated by clay till in the uppermost 5 meter of the surface (see figure 4.1). The contaminated site is situated on an elongated hill approximately 80 meters above sea level.

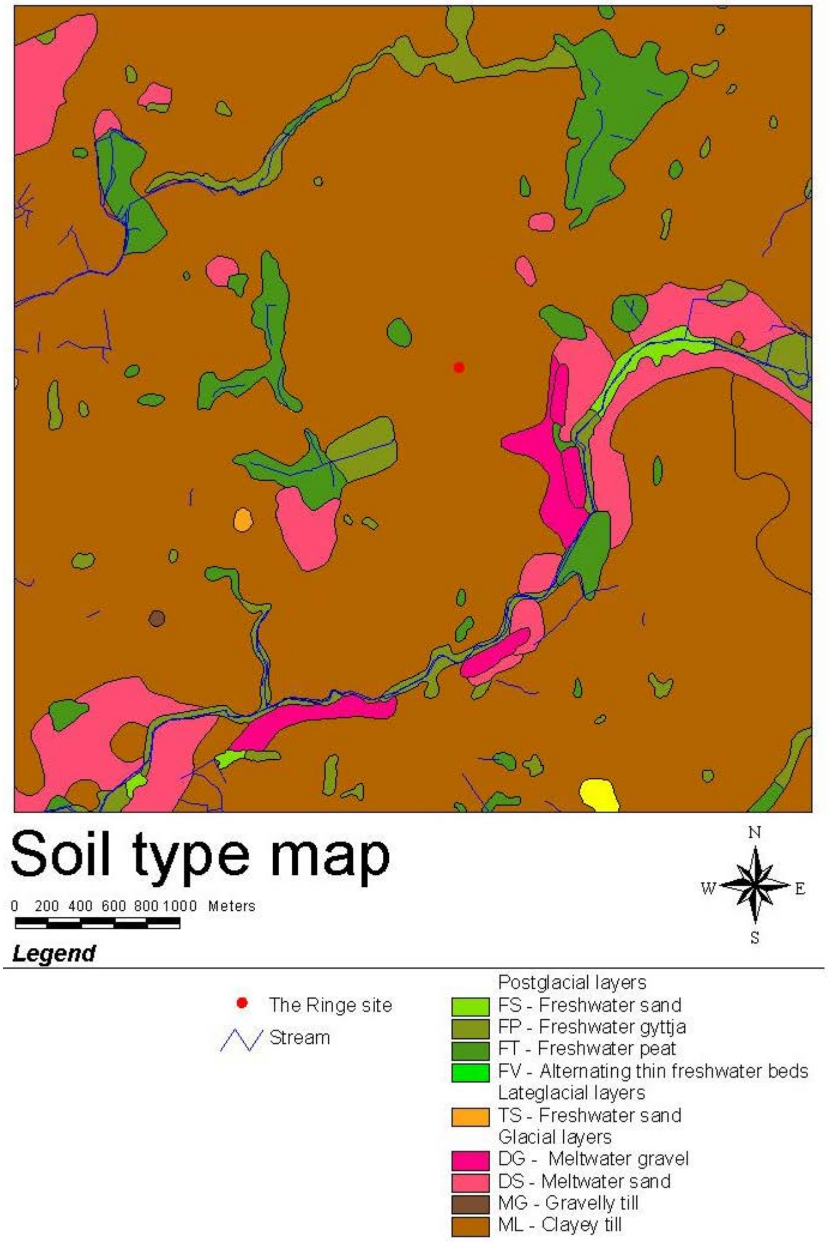


Figure. 4.1 Soil map that shows the distribution of sediment types in one meter depth.

The hill is part of an undulating till plain that is truncated by a meltwater valley with a small stream that are running from east towards west-south west just south of the site (~1 km) (figure 4.2). The surface falls in general to a level of 60 meter above sea level towards west. Several small hills and depressions indicate that the area have been deposited from a stagnating glacier (dead-ice relief), which may have been overridden during a later ice advance.

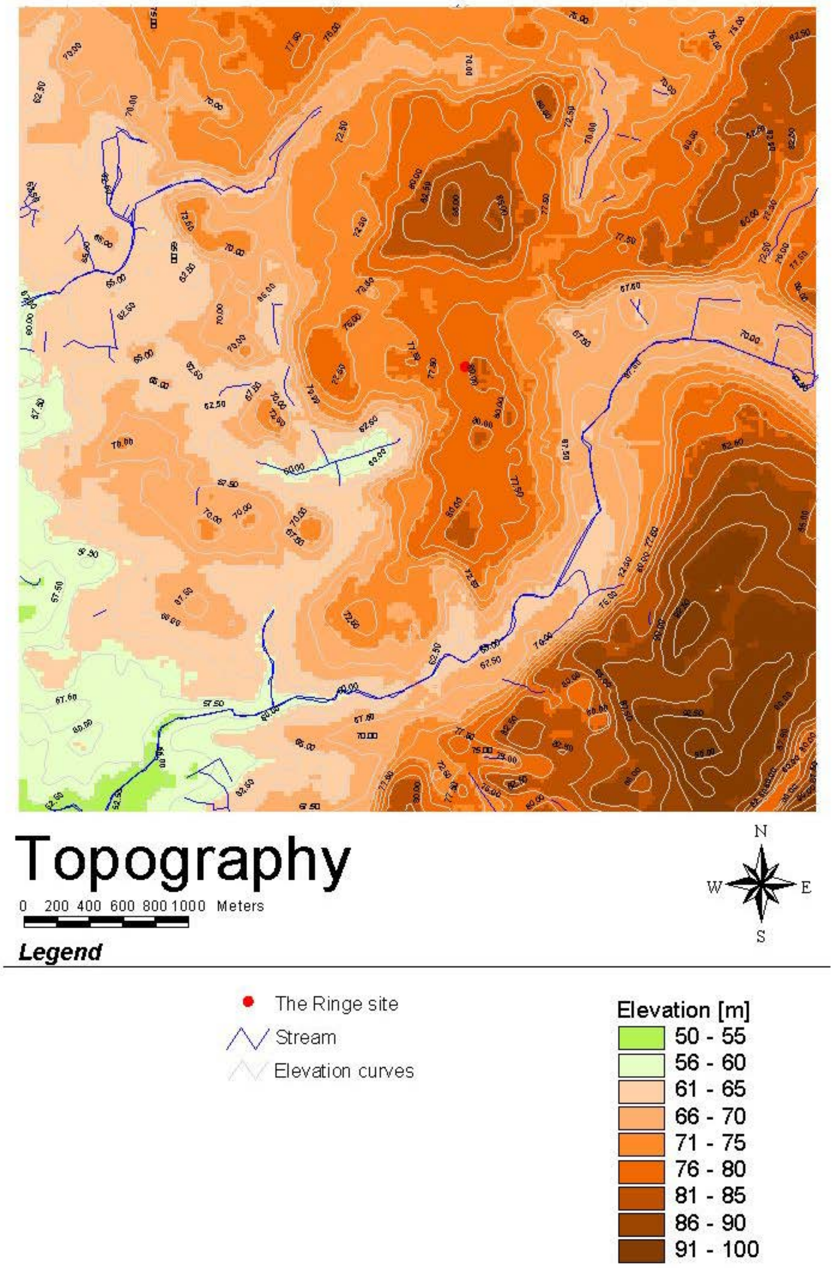


Figure 4.2. Topographical map with the Ringe site placed on an elongated hill (red dot).

The small depression just south-west of the area may have been formed as a result of dead-ice melting slowly and leaving a “hole” in the landscape. The river valley south of the area is a typical meltwater river that has truncated the surrounding till. This river valley is composed of meltwater gravel and sand (figure 4.1), and such overridden and buried melt-water valleys constitutes important groundwater reservoirs throughout Denmark.

Local geological setting

From the earlier projects a local geological model has been established for the Ringe site. The investigations showed that the site is dominated by sediments deposited during the Weischelian glacial period (the last 100.000 years). A very detailed slice diagram that shows the distribution of sand and clay till in one meter intervals to a depth of 22 meter below the ground surface, was constructed during a previous project Klint and Fredericia (1998). This diagram is included in appendix 1. The following three different glacigene units can be derived from the geological investigations:

Upper clayey till unit.
The upper 5-6 meter is dominated by a continuous clayey till, which cover the total area. Occasional minor sand-lenses are imbedded in this till. The till has been investigated in great details (Klint & Fredericia, 1998), and the results shows that this till may be classified as a lodgement-till deposited below a glacier transgressing the area from east-south east during the Young Baltic Ice-advance (Houmark-Nielsen, 1987) - approximately 14.000 BP. One major sand lens 4-5 meter below the surface, in the northern part of the Ringe site below pit 2 and 3, had a good hydraulic contact to the primary aquifer, while other lenses in the central area further south seemed to be isolated from the primary Aquifer.

Central glacigene complex.
Below the upper unit appears, from 5-16 meter below the surface, a complex of glacio-fluvial silty/sandy/gravely deposits inter-bedded with clayey and sandy diamict sediments. The sediments are partly deformed, and isolated sand-lenses appears especially in the central part of the site. Most of the sand-lenses in the central part of the area forms a secondary aquifer, with a groundwater table approximately 8-9 m b.g.s.. Some sand-lenses appears dry and must have a hydraulic contact to the primary aquifer. Approximately 12 m b.g.s. a more general widespread 3-4 meter thick clayey till covers most of the area, though locally penetrated by sandy bodies. A widespread sand-layer between 16-17 meter depth covers most of the area, thus creating a good hydraulic contact to a major sandy aquifer dominating the western and southern part of the site. This complex may very well consist of “dead-ice” deposits, which will explain the heterogeneity of the sediments

Lower sandy aquifer/till complex.
The primary sandy aquifer in the area consist of a more than 16 meter thick and more than 60 meter wide elongated body consisting of glacio-fluvial sand and gravel. This body is crossing the whole area from north-east towards south-west and is probably outlining a buried glacial river valley, which may by related to the Main Glacial North East Advance (Houmark-Nielsen, 1987) - transgressed the area approximately 20.000-16.000 BP. This river valley cut down into an older clayey till or maybe two clayey till units separated by a 4-5 meter thick sandy layer 26-30 meter below the surface. This buried river valley may be an equivalent to the present river valley situated approximately 1 km south of the area (figure 4.1)

The primary water table is situated approximately 20-22 meter below the surface in the primary aquifer.

Fracture distribution

The upper 5 meter of till may be separated into three zones with characteristic distribution of fractures and other macropores:

An *upper zone* dominated by bio-pores, desiccation fractures and high porous matrix.
A *central zone* dominated by well connected desiccation and glaciotectonic shear-fractures.
A *lower zone* dominated by glaciotectonic shear-fractures.

Three distinct fracture systems are recognised plus a number of random oriented fractures in the upper two meters (Figure 4.3):

System 1 fractures.
They 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.
They 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.
They 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 shows that, even though fractures has a clear hydraulic connection to each other, different chemical conditions prevails in the fractures. This is regarded to reflect different hydraulic conductivity, 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 has 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.

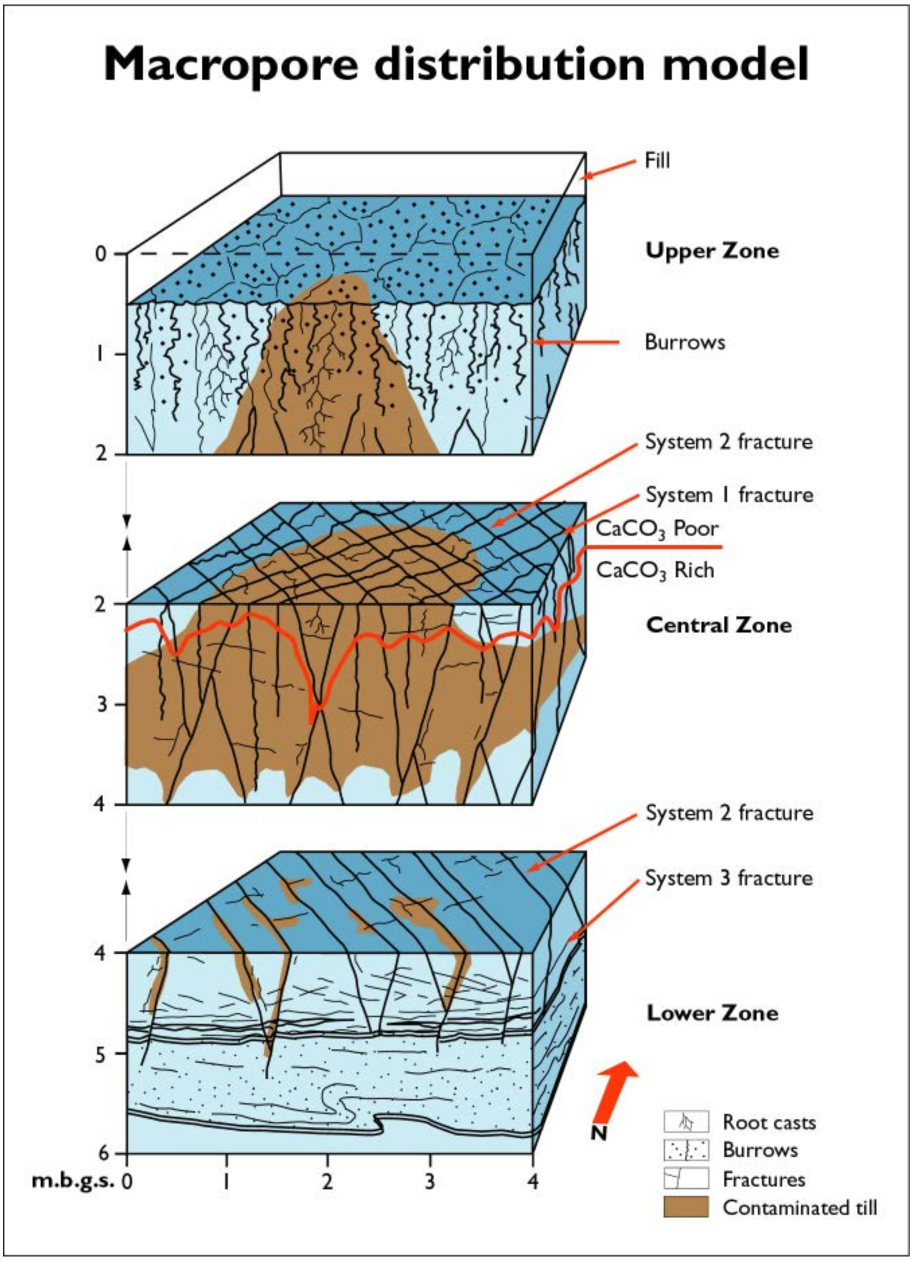


Figure 4.3. Macropore distribution model. near pit 2 and 3. The distribution of LNAPL is marked.

5. Fieldwork

Samples of intact fractured till captured in steel-boxes were available from areas. 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.

A pit 7 x 7 meter large and 3.5 meter deep were excavated by a backhoe (Figure 5.1).
The surface of the freshly excavated pit-face was cleaned from smeared material. The cleaned face were then "chipped" off with knifes trowels and wherever a fracture made the till "break" along a natural fracture plane, the fractures was carefully cleaned and described along vertical and horizontal profiles according to the terminology and methods described by Klint and Fredericia (1998). Fractures with contamination on the surface was photographed (Figure 5.2) and the contaminated areas registered.


Figure 5.1 Pit no. 4. All matrix was saturated with dissolved phase contamination.

Description of the lithology.

From the surface to app.1.5 meter below ground surface:
Fill from earlier excavations. The fill consist of remnants from buildings, concrete, asphalt, mixed with soil. In the southern part of the pit a concrete foundation marks the transition towards and old basement.

1.5 – 2.5 meter below ground surface:
Clayey till, silty, sandy with few stones. The matrix is soft and $CaCO_3$-poor. The colour is dark olive grey due to contamination. There is a strong smell of oil and free phase NAPL flows out of minor cavities and down the surfaces of fractures as they are exposed. Some water flows into the pit from the eastern side.
Fractures forms a clear network of polygonal vertical desiccation-fractures. A clear network on the fracture surfaces shows that the contaminant flows in a channel like network on the fracture surface (Figure 5), but root-holes and burrows are also filled with the NAPL's.

2.5-3.5 meter below ground surface:
Clayey till, strongly silty, sandy with few stones, many limestone-clasts. The matrix is firm and $CaCO_3$-rich. The colour is olive grey. Still a strong smell of oil. The fracture distribution change from the randomly oriented desiccation fractures towards systematic oriented oblique and conjugating fractures striking NE-SW. Horizontal/sub-horizontal shear-fractures are well-distributed below 3 meters depth. The network-pattern on the fractures changes gradually from the well-defined network down to approximately 3 meters, where the contamination is more even distributed over the entire fracture surface. Most of the fractures contains NAPL and water.

Collection of intact samples.

5 contaminated 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. A smooth face perpendicular to the fracture was cleaned and a stainless steel box (Kubiena box, 15 x 8 x 5 cm), with a removable top and bottom lid, were placed perpendicular to the fracture, and while very carefully removing the sediment along the outer side of the box, the box were 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 were 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 were attached.
A sketch of the macrostructure's in the sample was drawn, and the orientation and position of the box and fracture were measured (Table 1). Finally the box was sealed air-tight with plastic-bags and tape and placed in a refrigerator at 5 C^0.

Three samples of contaminated fracture surfaces were collected in Kubiena-boxes in order to describe the distribution of contamination.

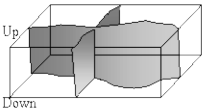
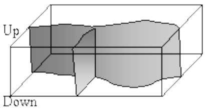
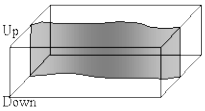
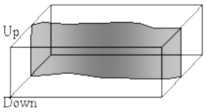
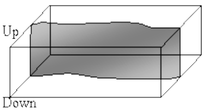
LOCATION: Ringe pit 4			PROFILE: 1 and 2				Date: April 29 2000	
Kubienabox: 1-5			**Fracture ('s)**				**Sketch**	
Sample no	Depth	Orientation	System	Order	Surface-precipitates	Orientation	Description of sample/structures	
2000-01	1.6 m b.s	horisontal	1	1	Roots 2 Contami-nation	94/90 and 35/90		Dessiccation fractures highly contaminated
2000-02	2.6 m b.s	horisontal	1	1	Roots 1 Contami-nation	162/78E		Dessiccation fractures highly contaminated
2000-03	2.0 m b.s	horisontal	1	1	Roots 2 Contami-nation	90/90		Dessiccation fractures highly contaminated
2000-04	2.2 m b.s	horisontal	1	1	Roots 2 Contami-nation	90/90		Dessiccation fractures highly contaminated Same fracture as 2000-03
2000-05	2.0 m b.s	horisontal	1	1	Roots 2 Contami-nation	170/68E		Dessiccation fractures highly contaminated

Table 1. Description of Kubiena samples.

Figure 5.2 fracture surface with contamination distributed in channels.

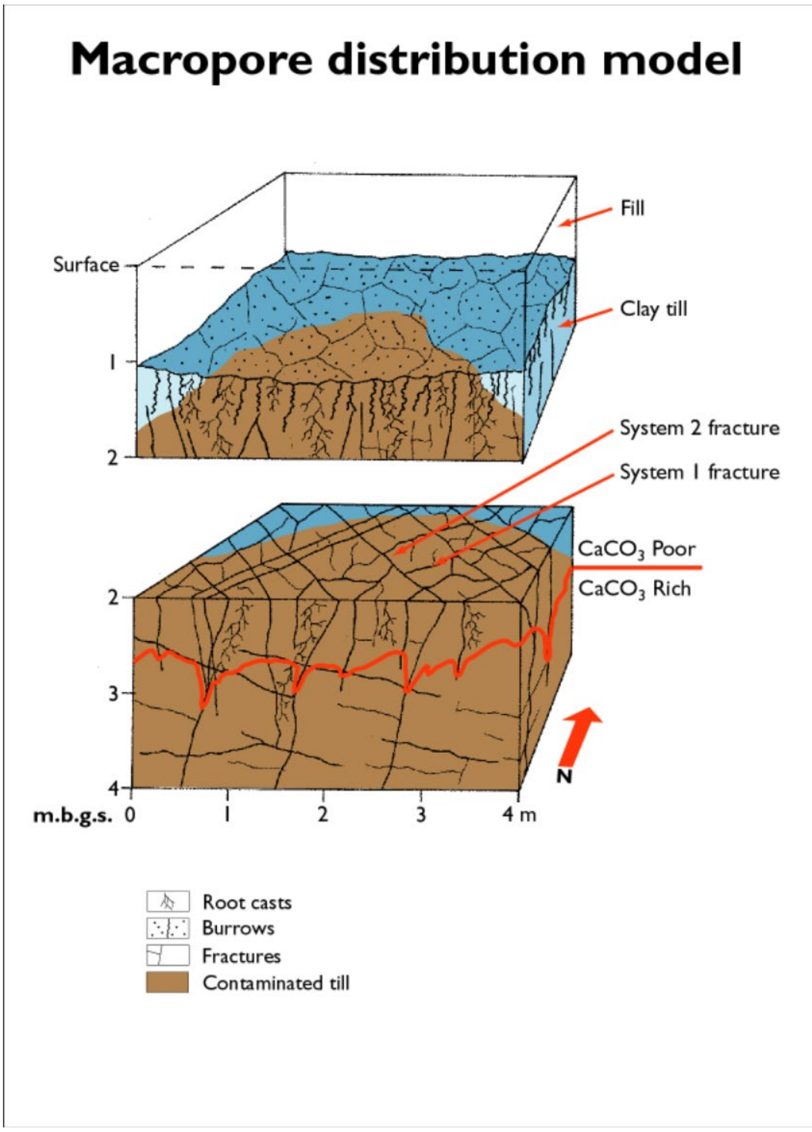


Figure 5.3 Macropore distribution model for Pit 4 at the Ringe site. This model shows the average distribution of the fracture systems and the distribution of the DNAPL-plume.

6. Main findings

Fracture properties.

The uppermost part of the Ringe till were dominated by numerous burrows. A total of 4-500 worm holes with a diameter of 2-4 mm were counted 80 cm below groundsurface. Earlier tracer tests with a blue dye in similar till indicates that 8-12 % of the worm holes are hydraulic active.

Fracture intensity/spacing were measured and calculated in Pit 2. The result is illustrated in table 2. These values forms the basis for the conceptual fracture model figure 6.3

Fracture system	**Fracture order**	**Spacing in different depth intervals m b.g.s.**			
		0.4-2.0 m	1.2-2.7 m	2.4-3.6 m	3.3-4.7 m
System 1 Vertical desiccation fractures	1'st order	54 cm	40	100	200
	2'nd order	137	50	50	20
	total	39	22	33	18
System 2 Conjugating shear fractures	1'st order	82	43	33	36
	2'nd order	73	16	26	31
	total	39	12	15	17
System 3 Sub-horizontal shear fractures	1'st order	0	0	0	38
	2'nd order	0	56	200	70
	total	0	56	200	23

Table 2 Fracture spacings in four depth intervals measured in Pit 2 at the Ringe site.

Hydraulic properties.

A large number of hydraulic tests has been conducted at the Ringe site over the years. Figure 6.2 shows the results from Peter Jørgensen's (1998) hydraulic tests on the two LUC samples (Large Undisturbed Columns).
Four types of full field-scale tests were employed in order to determine the hydrologic properties of the complex, coupled till – sand lens - sandy aquifer system (Nillsson et al 2001). Hydraulic conductivity was also calculated from break through curves of tracers. Based on the fracture spacing measured in Pit 1 and 2 the hydraulic apertures of the fractures were calculated at three different depth intervals. (2.5-4 and 5.5 m b.g.s.) (Sidle et al., 1998).

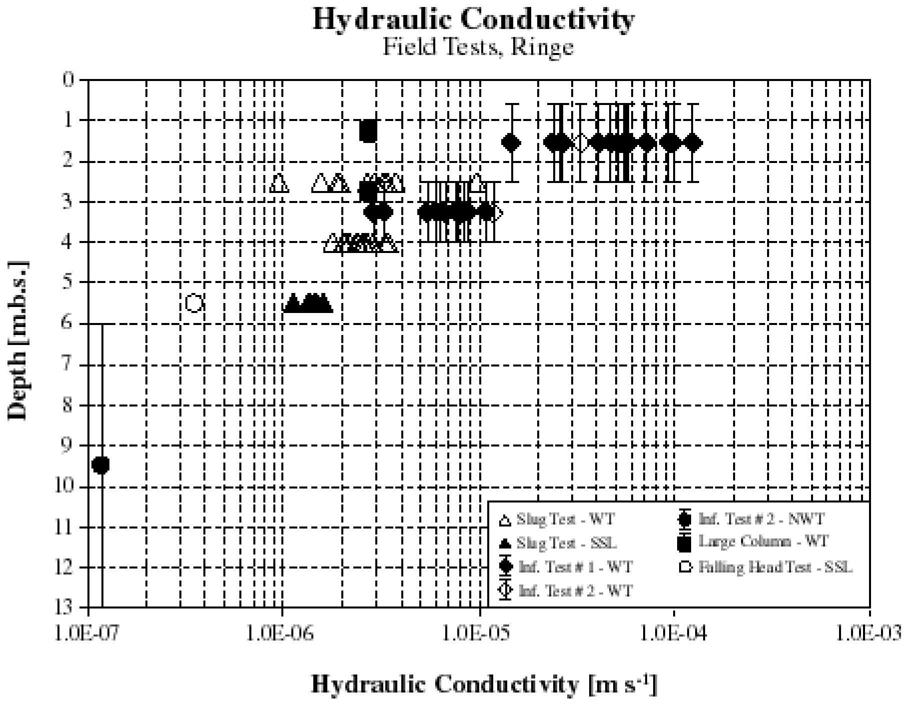


Figure 6.1 Hydraulic properties of the fractured till at the Ringe site.

Conceptual macropore distribution model.

A conceptual macropore distributions model has been constructed in order to simulate a hydraulic model representative for the upper 5-6 meter of the Ringe site Figure 6.2.

The model consists of three macroporezones:

An *upper zone* dominated by bio-pores, desiccation fractures and high porous matrix. It may be simulated as a bundle of tubes representing the wormholes This zone is representing the upper approximately 1,5 meter of till
A *central zone* dominated by well connected desiccation and glaciotectonic shear-fractures. This zone are defined by the transition between oxidised till (brown) and reduced till (olive grey), which is typically situated between 3,5 and 5 meter below ground surface, and the depth where the worm holes stops (~1,5 m b.g.s).
A *lower zone* dominated by glaciotectonic shear-fractures. This zone reach down to the transition to the Glacigene complex that is situated from 5-8 meter below ground surface. Only one system of fractures (system 2) are penetrating this level. And each of these fractures may be simulated as a pore-network of connected channels, where the size of the channels will be defined by the SEM analysis of the intact samples.

The matrix zones consists of:
Weathered matrix in the upper ~2,5 meter. The limestone content in this zone has been dissolved thus leaving a highly porous matrix typical with a porosity between 30-45%.

Unweathered matrix consist of firm consolidated clay till with a lime stone content close to 25-30%. The porosity is typically between 25-30%.

Below some of the area appears sandlenses with a naturally higher permeability. The depth changes from 3,5 meter to almost 15 meter below ground surface.

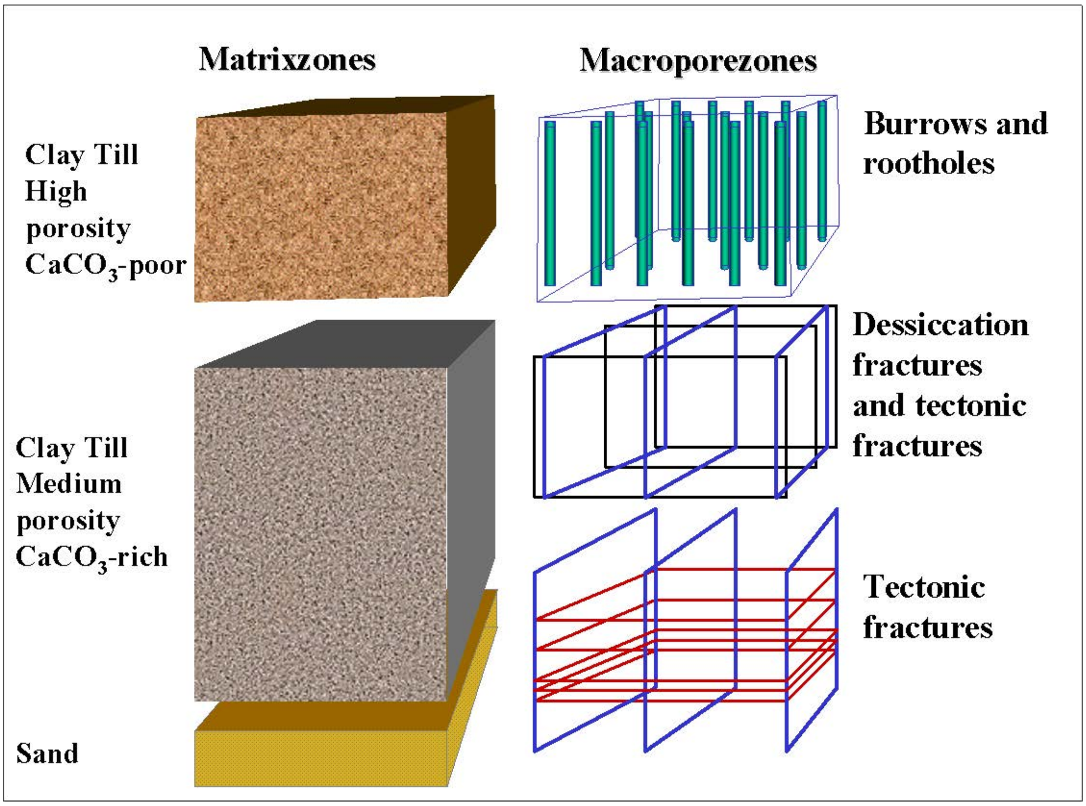


Figure 6.2 Conceptual fracture distribution model

7. Summary

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 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.

This 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 geo-morphological 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 lens, 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.

8. References

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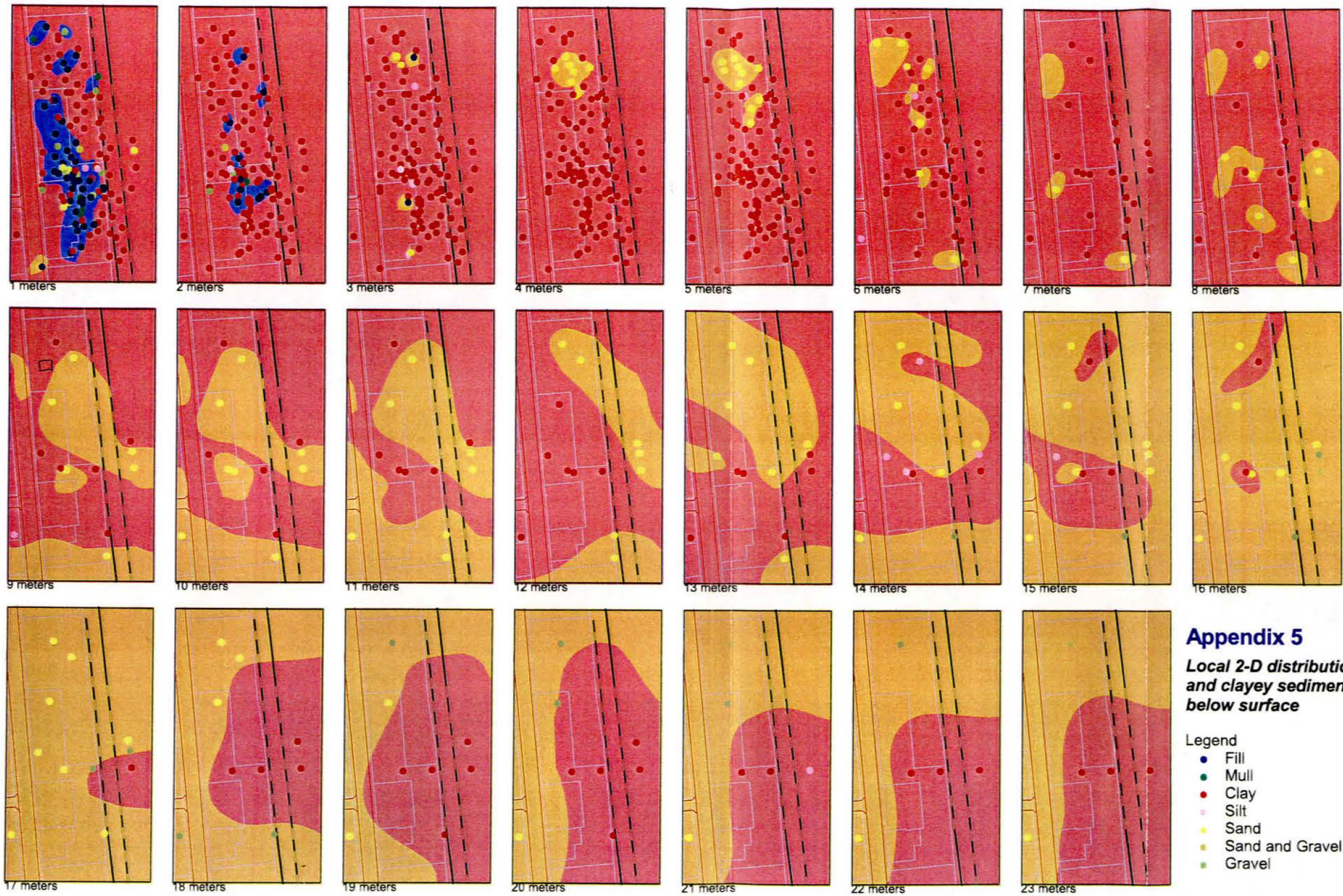
Appendix 1

Slice diagram with the distribution of sand and clay till in one meter slices to 22 meter below groundsurface.



Appendix 5

Local 2-D distribution of sandy and clayey sediments pr meter below surface

Legend
- Fill
- Mull
- Clay
- Silt
- Sand
- Sand and Gravel
- Gravel