DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2011/48

Low- and intermediate level radioactive waste from Risø, Denmark. Location studies for potential disposal areas. Report no. 8

Characterization and description of areas Østjylland

Peter Gravesen, Bertel Nilsson,
Stig A. Schack Pedersen
& Merete Binderup

GEOLOGICAL SURVEY OF DENMARK AND GREENLAND
MINISTRY OF CLIMATE AND ENERGY

GEUS

DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2011/48

Low- and intermediate level radioactive waste from Risø, Denmark. Location studies for potential disposal areas. Report no. 8

Characterization and description of areas Østjylland

Peter Gravesen, Bertel Nilsson,
Stig A. Schack Pedersen
& Merete Binderup

GEOLOGICAL SURVEY OF DENMARK AND GREENLAND
MINISTRY OF CLIMATE AND ENERGY

GEUS

1. Introduction

The low and intermediate level radioactive waste from Risø: the nuclear reactor buildings, different types of material from the research periods and waste from hospitals and research institutes have to be stored in a final disposal in Denmark for at least 300 years (Indenrigs- og Sundhedsministeriet, 2005, 2007). The task is to locate and recognize sediments or rocks with low permeability which can isolate the radioactive waste from the surrounding deposits, the groundwater resources, the recipients and from human activities. The sediments or rocks shall also act as a protection if the waste disposal leaks radioactive material to the surroundings. This goal can be reached by low water flow possibilities, high sorption capacity for many radionuclides and self-sealing properties.

The investigation of geological deposits as potential waste disposals for high radioactive waste from nuclear power plants has earlier focused on deep seated salt deposits and basement rocks. Nevertheless, the Tertiary clays were mapped as well (Atomenergikommissionen, 1976, Dinesen, Michelsen & Lieberkind, 1977). The salt diapirs and the salt deposits are not included in the present study.

The task is to find approximately 20 areas where a waste disposal potentially can be located. The 20 areas have to be reduced to 1-3 most potential locations where detailed field investigations of the geological, hydrogeological - hydrochemical and geotechnical conditions will be performed.

2. Background

In Denmark many different fine grained sediments and crystalline rocks occur from the earth surface down to 300 m depth. Therefore, the possible geological situations include sediments and rocks of different composition and age. These situations are also geographical distributed over large areas of Denmark. These sediments and rocks are shortly described based on existing information in Report no. 2, where five different types are included. 1: Crystalline granites and gneisses of Bornholm (because these rock types are host for waste disposals in many other countries). 2: Sandstones and shales from Bornholm (as these sediments are relatively homogenous although they have fracture permeability). 3: Chalk and limestone (because these sediments may act as low permeable seals, but in most areas act as groundwater reservoirs). 4: Fine-grained Tertiary clay deposits (as these sediments have a low permeability, are widely distributed, and can reach large thicknesses). 5: Fine-grained Quaternary clays from Elsterian, Saalian, Weichselian and Holocene. These sediments are distributed all over Denmark.

The geological formations most studied in Europe for disposal of radioactive waste are clay (in Belgium, France, Germany and Switzerland), crystalline rocks (Sweden, Finland and Switzerland) and salt (Germany).

All Danish sand and gravel deposits are excluded from the description owing to their potential as groundwater reservoirs, their high permeability, low sorption capacity and no-self-sealing properties for the waste. The sand and gravel deposits often occur below or above the low permeable and fractured deposits and sand layers may be intercalated in them.

3. Data and methods

A report from 2007 (Indenrigs- og Sundhedsministeriet, 2007) recommends the types of existing data needed for the preliminary selection of disposal sites. The recommendations are based on guidelines from the International Atomic Energy Agency (IAEA, 1994, 1999, 2005).

Gravesen et aI. (2010, Report no. 1) briefly describes the existing data collections including databases, maps and models, which have been used during the work of selections of approximately 20 potentially suitable areas. Most of the information is stored in GEUS databases: Borehole data and co-ordinates, groundwater and geochemical information, GIS based maps, geophysics and much more, but information is also collected from other institutions. The methods are described in more details and the description is the directly background for the selection of the sites.

4. Selection of areas and localities

Selection of potential areas on eastern Jylland has to fulfil the criteria and answer the questions described and put forwards in Gravesen et al., (2010, Report no. 1).

The two areas chosen at Juelsminde peninsula, Klejs-Sønderby and Thyrsted-Glud are interesting regarding the Quaternary and Paleogene deposits along the eastern rim of the peninsula. Between Vissing and Haslund, Paleogene deposits are found in the high Lysnet plateau just west of the clay pit area at Ølst and Hinge. North of Randers Fjord, between Østrup and Støvring, thick sequences of very fine-grained Paleogene clays occurs.

Therefore, it is relevant to investigate and analyse these different geological situations in relation to potential disposal areas.

5. Area 12. Klejs – Sønderby, Juelsminde peninsula, East Jylland

5.1 The location of the area

The area is situated on the Juelsminde peninsula, eastern Jylland (Fig. 1). It includes the areas Klejs and Sønderby, both located close to the eastern or northern coast of the peninsula (Fig. 2).

Figure 1. Location of the area. The Juelsminde peninsula is located on the east coast of Jylland.

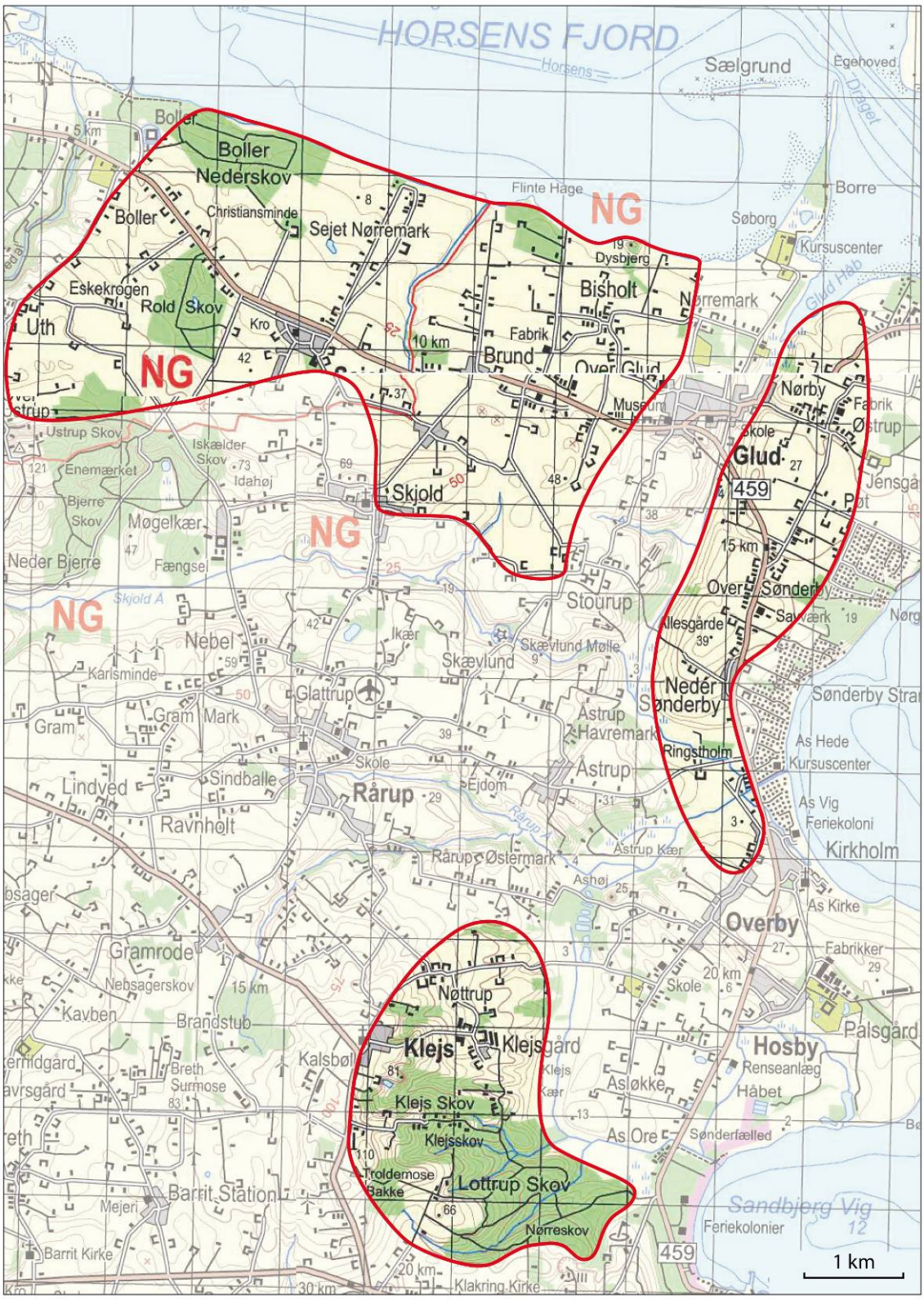


Figure 2. A detailed map of Area 12. The Area consists of two subareas. One area around Klejs and Klejs and Lottrup Skove and one area between Neder Sønderby and Nørby.

5.2 Terrain, topography and surface processes

Klejs

The Klejs area is located in the central, eastern part of the Juelsminde peninsula. The size of the area is c. 7.4 km^2. The western part of the area is situated very high above sea level. The top of the highest hill in the area, Troldemose Bakke is 110 m above sea level (m.a.s.). The landscape slopes from west toward east and the eastern delimitation of the area is found only c. 5 m.a.s. Superimposed on this highly sloping area is a marked undulation of the terrain with many indented valleys. No lakes are found in the area but the southern part of the area contains several streams that merge into two streams downhill.

Some c. 60 % of the area is covered by woods. The remaining part of the area is used for agriculture. The small village Klejs is situated in the western part of the area, and minor "villages"/clusters of houses are found at Nøttrup, Klejsgård and Klejsskov in the wood. Some smaller roads cross the northern and western part of the area and some other roads/paths are crossing the woods.

Owing to dense vegetation of the woods and cultivation of the open landscape, most of the surface processes (soil creep, frost – thaw processes, soil development etc.) proceed slowly and undramatic. The most active surface processes are expected to be found along the streams, although there are no signs of severe erosion in form of alluvial fanes or sediment accumulations without vegetation at the foot of the hills.

Examples of the terrain are seen in figs. 3 and 4.

Sønderby

The Sønderby area is located in the north-eastern part of the Juelsminde peninsula. The size of the area is c. 8.5 km^2. The central part of this N-S-oriented area is marked by a an elongated hill with a plateau on the top, situated between c. 25 and 35 meters above sea level (m.a.s.). The plateau slopes gently toward south and toward the western delimitation of the area, c. 5 m.a.s. The slopes toward east and north are even more gently. Most of the southern part of the area is low-lying and includes two relatively wide stream valleys situated c. 3 m.a.s. The northwestern delimitation of the area follows the coastline at Glud Håb. A narrow beach meadow is found here. In contrast to the Klejs area, the hills of this area are much less undulating and without streams. No lakes are present.

The predominating part of the area is used for agriculture. The main road between Glud and Neder Sønderby crosses the area. Several minor roads are also crossing the area. The small village Neder Sønderby is located in the south-eastern part of the area. A number of houses are located along the roads, especially along the main road. Woods make up less than 5 % of the area.

Owing to the relatively gentle relief and intensive cultivation, the surface processes (soil creep, frost – thaw processes, soil development etc.) proceed slowly and undramatic. The most active surface processes are expected to be found in and along the streams in the southern part of the area.

Figure 3. The Klejs area seen from the east.

Figure 4. The Klejs area towards the south.

5.3 Surface geology and profiles

The Quaternary sediments in the area of the Juelsminde peninsula mainly consist of glacial clayey till but several valley crossing the till deposits contain Holocene freshwater deposits, perhaps resting on meltwater sand and gravel (Fig. 5). Cliff sections occur along the coastline but the most illustrative section is the Albæk Hoved section just west of Juelsminde, outside the area.

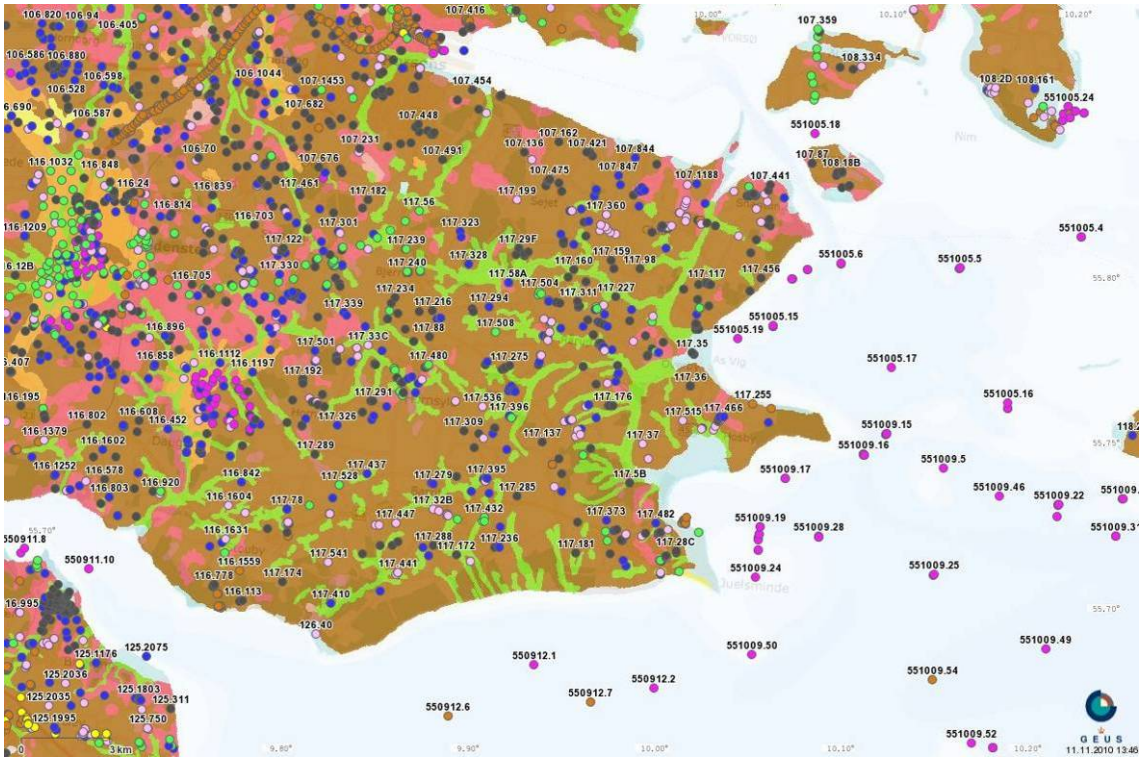


Figure 5. Map of the surface geology with boreholes from the Jupiter Database at GEUS. Originally in 1:200.000. Legend: Brown: Clayey till Red: Meltwater sand and gravel; Orange: Meltwater clay; Green: Holocene freshwater deposits. (From GEUS's Homepage after Pedersen, 1989). Legend for the Boreholes: See fig.6.

5.4 Boreholes

Several boreholes in the area reach Paleogene clays and glacial clayey tills. Most of the samples from the boreholes are characterised lithological and are related to formal units but only few samples have been dated by microfossils.

The locations of the boreholes for the entire Juelsminde peninsula are seen in fig. 6. Subarea Klejs is seen in fig. 7 and Sønderby in fig. 8.

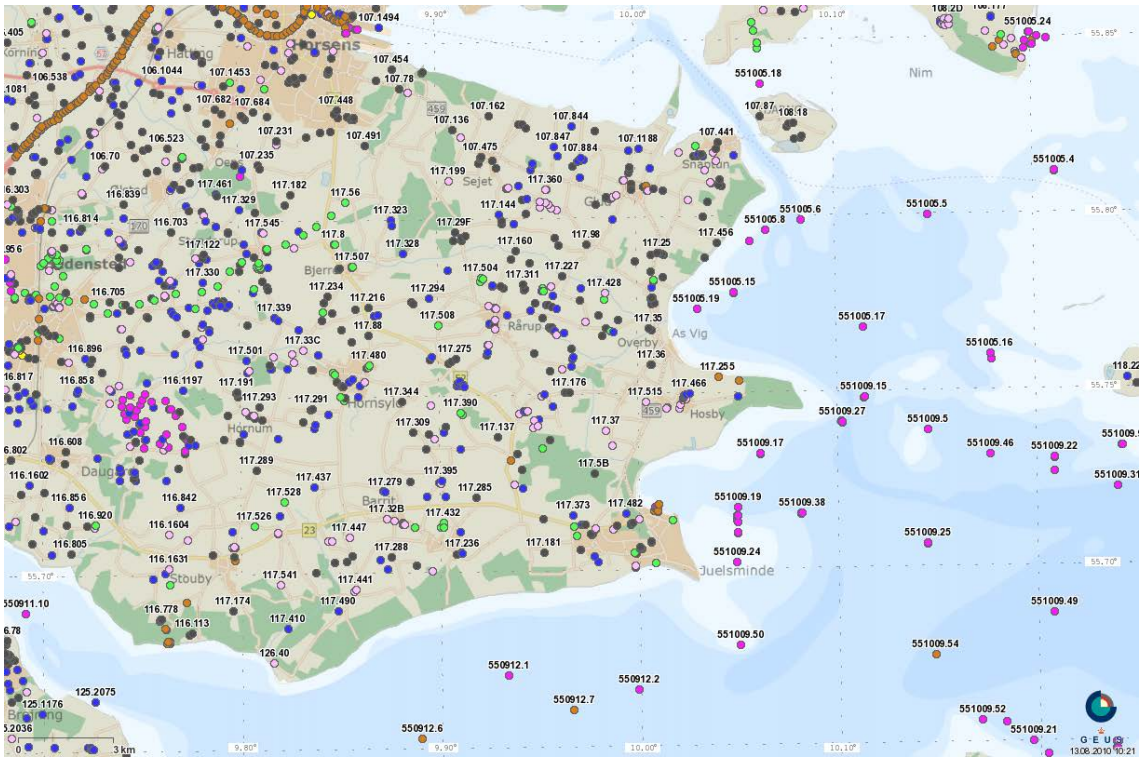


Figure 6. Map of the locations of boreholes on the Juelsminde Peninsula from the Jupiter Database at GEUS. Legend: 117. 362: DGU No., Blue dot: Water supply well, Red dot: Geotechnical borehole, Pink dot: Raw material borehole, Green dot: Other borehole, Light red dot: Abandoned borehole, Black dot: Unknown purpose.

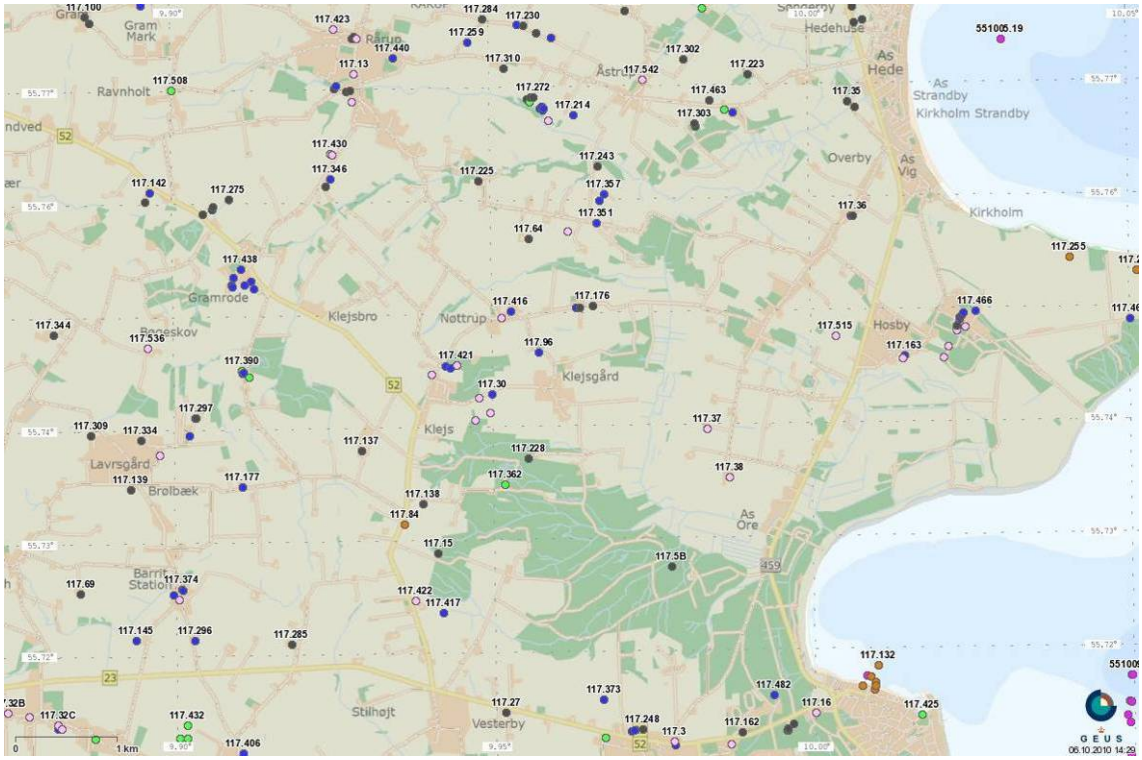


Figure 7. Boreholes in the Klejs subarea. Legend: see fig 6.

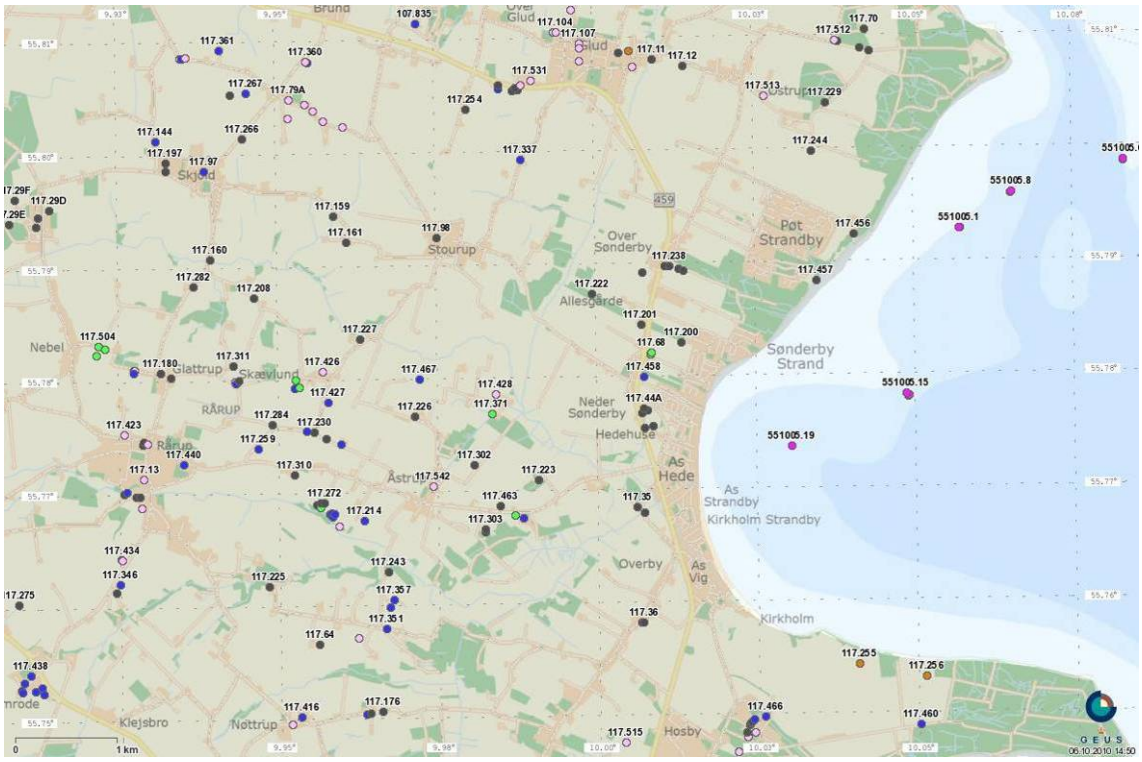


Figure 8 . Boreholes in the Sønderby subarea. Legend: see fig. 6.

Examples of the boreholes are shown in fig. 9 from Klejs (DGU no. 117.362) and fig. 10 from Sønderby (DGU no.117.456). Both boreholes reach the Eocene clays.

No geophysical surveys are known from the area.

De Nationale Geologiske Undersøgelser for Danmark og Grønland

Udskrevet 12/4 2011 Side 1

BORERAPPORT

DGU arkivnr: 117. 333

Borested : JUELSMINDE NØTTRUPVEJ 8
7130 Juelsminde

Kommune : Hedensted
Region : Midtjylland

Boringsdato : 16/2 1976 **Boringsdybde** : 62 meter **Terrænkote** : 25 meter o. DNN

Brøndborer :
MOB-nr :
BB-journr :
BB-bornr :

Prøver
- modtaget :
- beskrevet : **af** : G
- antal gemt :

Formål : Vandforsyningsboring
Anvendelse :
Boremetode : Rotaryboring

Kortblad : 1313 IVNV
UTM-zone : 32
UTM-koord. : 560547, 6178927

Datum : ED50
Koordinatkilde :
Koordinatmetode : Dig. på koor.bord

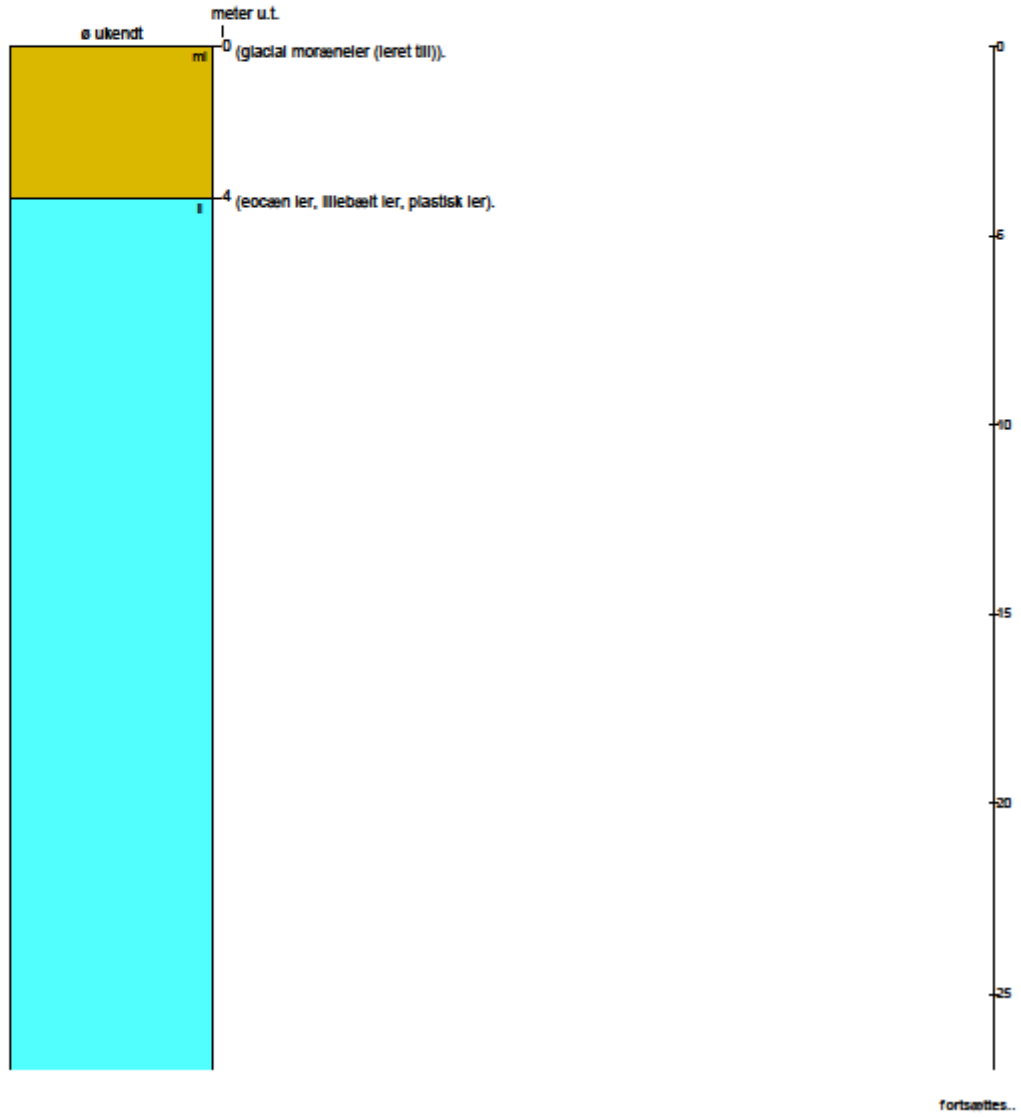


Figure 9. Geological log from the Klejs subarea of the Borehole DGU no. 117.333. The Upper 27 m of the 62 m deep borehole. Legend: ml: Clayey till, L: Eocene clay.

De Nationale Geologiske Undersøgelser for Danmark og Grønland

Udskrevet 6/10 2010 Side 1

BORERAPPORT

DGU arkivnr: 117. 456

Borested : Østrup By, Glud
8700 Horsens
Pøt Strand nr.1

Kommune : Hedensted
Region : Midtjylland

Boringsdato :

Boringsdybde : 22 meter

Terrænkote : 22,04 meter o. DNN

Brøndborer : Vejle Amtskommune
MOB-nr : 5727
BB-journr :
BB-bornr :

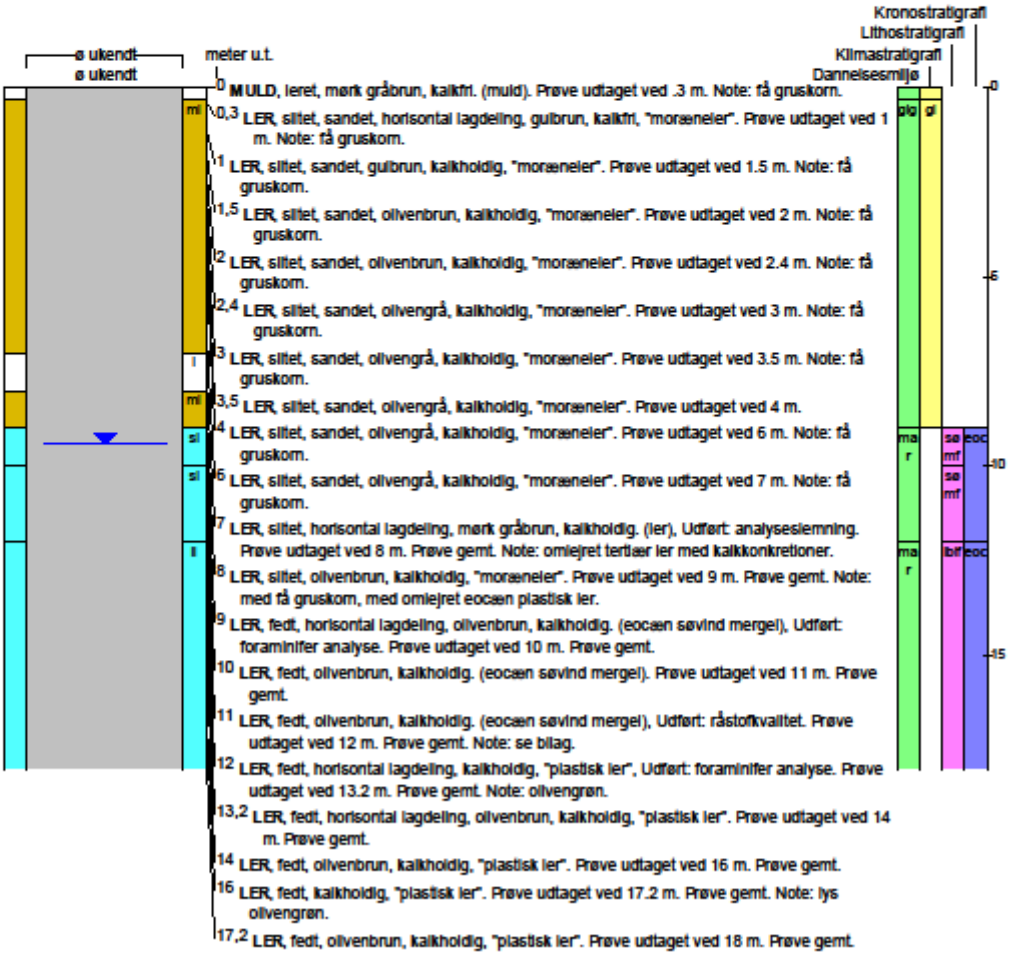
Prøver
- modtaget : 11/9 1989 **antal** : 24
- beskrevet : 27/7 1995 **af** : TC/PJ
- antal gemt : 14

Formål :
Anvendelse :
Boremetode : Tørboring/slagboring

Kortblad : 1313 IVNV
UTM-zone : 32
UTM-koord. : 565337, 6183660

Datum : ED50
Koordinatkilde :
Koordinatmetode : Dig. på koor.bord

	Ro-vandstand	Pejledato	Ydelse	Sænkning	Pumpetid
Indtag 1 (seneste)	9,4 meter u.t.				



fortsættes..

Figure 10. Borehole log from the Sønderby subarea DGU no. 117.456. The upper part of the 22 m deep borehole. Legend: ML. Clayey till, SL: Søvind Marl Formation. Eocene, L: Eocene clays.

5.5 Sediment and rock characteristics, mineralogy and chemistry

5.5.1 Pre-Quaternary deposits

The clay deposits in the area can be seen in the Albæk Hoved Cliff just west of Juelsminde where a series of Paleogene deposits occur in a low cliff section pushed up and disturbed by Quaternary glaciers. Some of the formations can be seen in fig. 11, including the following: Late Paleocene red brown plastic clay from the Holmehus Formation, Early Eocene green grey sandy clay with volcanic ash layers from the Ølst Formation, red brown plastic clay from the Røsnæs Clay Formation and Early to Mid Eocene Green plastic clay from the Lillebælt clay Formation. The Late Eocene Søvind Marl Formation was earlier exposed in the cliff.

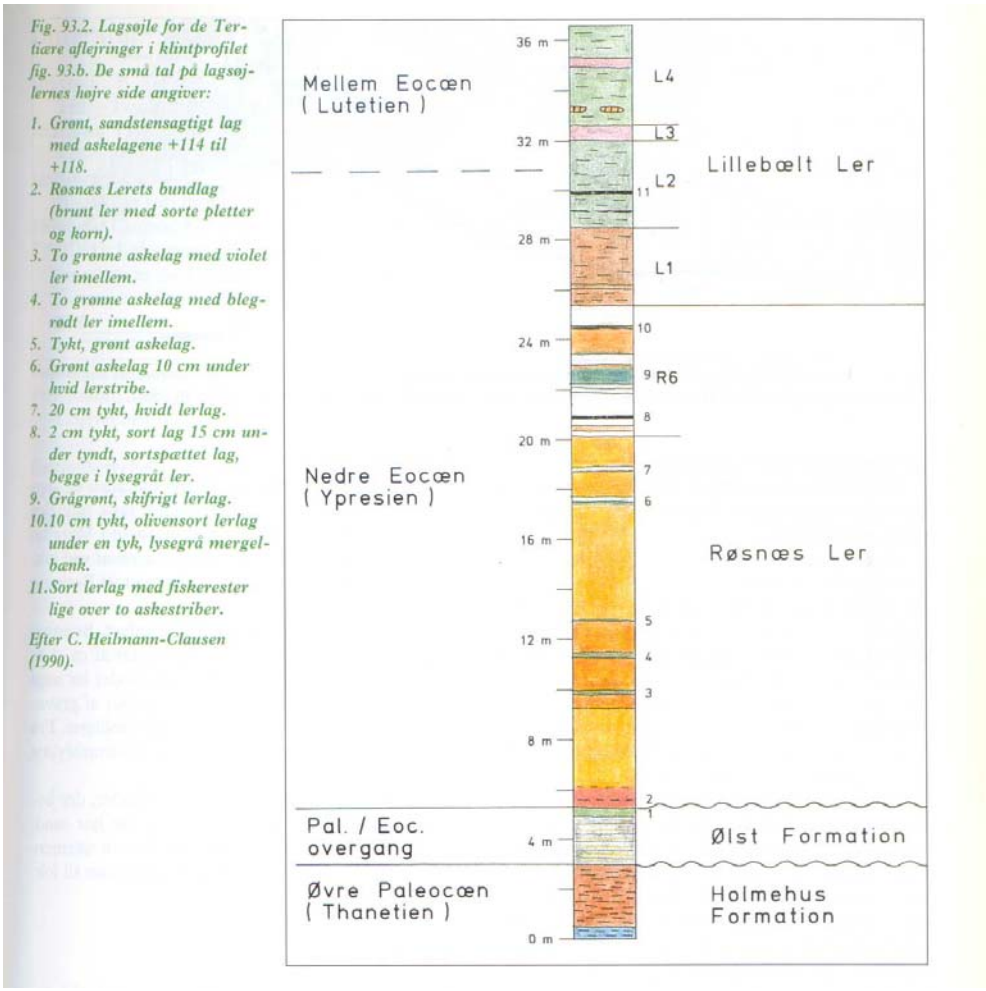


Figure11. Stratigraphical sceme for the Paleogene deposits at Albæk Hoved (From Heilmann-Clausen, 1990).

In the cliff section at Dykær just south of Juelsminde city, Oligocene deposits were former exposed.

According to the map of the pre-Quaternary deposits, the area should consist of Eocene or Oligocene deposits just below the Quaternary (Fig. 12).

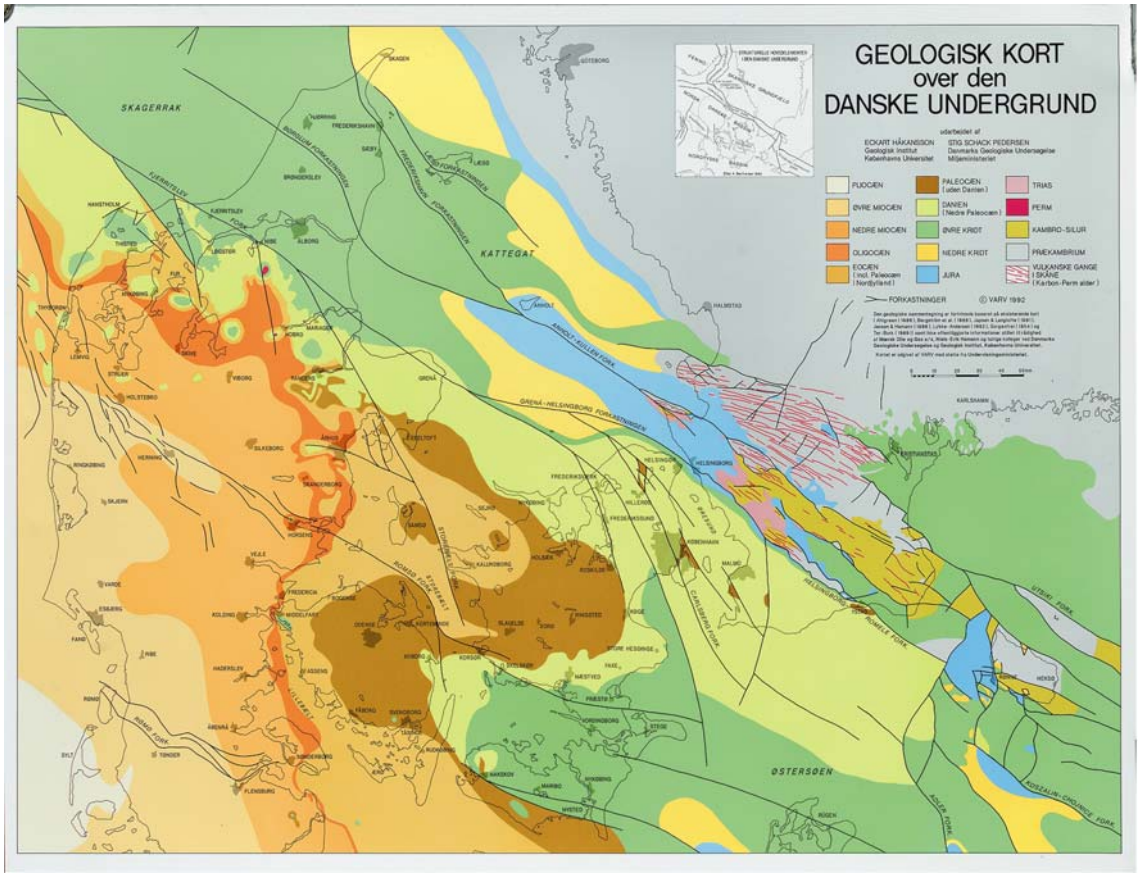


Figure 12. Map of the pre-Quaternary surface: Time units. Original scale: 1:50.000. Legend: Red lines: Precambrian intrusions; Grey: Precambrian; Olive: Cambrian-Silurian; Red: Permian; Light red: Triassic; Blue: Jurassic; Yellow: Lower Cretaceous; Green: Upper Cretaceous; Light green: Danian; Brown: Paleocene; Yellow olive: Eocene; Red brown: Oligocene; Light yellow brown: Lower Miocene; Very light yellow brown: Upper Miocene; White: Pliocene (Håkansson & Pedersen, 1992).

Examples of some of the different clay types are found in figs. 13, 14 and 15.

Figure 13. The Røsnæs Clay Formation at Albæk Hoved.

Figure 14. The Ølst Formation at Albæk Hoved.

Figure 15. The Lillebælt Clay Formation at Albæk Hoved.

Klejs

In the Klejs subarea, Oligocene deposits occur above Eocene clays. In the highest parts of the terrain, the Eocene reaches the surface. It has been proposed that the pre-Quaternary deposits are a floe in the glacial sediments but it has not been possible to drill through the clays to reach the glacial sediments in an 80 m deep borehole. Perhaps the upper parts are disturbed by glaciers as known from many other parts of Denmark and as indicated by the Albæk Hoved cliff, while the deeper layers are still in-situ.

The Late Oligocene deposits consist of brown and black fine-grained to sandy micaceous clays, normally non-calcareous, probably from the Brejninge Member (Formation). The deposits can be at least 17 m thick.

The oldest Eocene deposits are the red brown Røsnæs Clay Formation (5 m) followed by the grey green Lillebælt Clay Formation, 75 m thick. Some boreholes reach the Søvind Marl Formation of sticky light olive grey, calcareous clay (approx 10 m thick).

Sønderby

Towards the south, within the Sønderby subarea, the first Paleogene deposits below the thin Quaternary sediments are Oligocene silty and sandy brown black and black, micaceous, mainly non-calcareous but also weakly calcareous when a content of shells occur. The clay is up to 20 m thick and belongs to the Late Oligocene Brejninge Member. Below the Oligocene sediments follows the Late Eocene Søvind Marl Formation of fine-grained light green grey, and calcareous clay (up to 27 m thick).

Towards the north, the Eocene Søvind Marl is reached directly below 4 - 10 m Quaternary deposits. The marl is strongly calcareous and olive brown, 3 - 12 m thick. 10 m calcareous, probably Lillebælt clay is found below the Søvind Marl.

An example of Oligocene mica clay, probably from the Brejning Formation is seen in fig. 16.

Figure 16. Example of the Oligocene brown mica clay.

5.5.2 Quaternary deposits

The map of the Quaternary deposits (Figs. 5 and 17) show the distribution of the different sediments in the area.

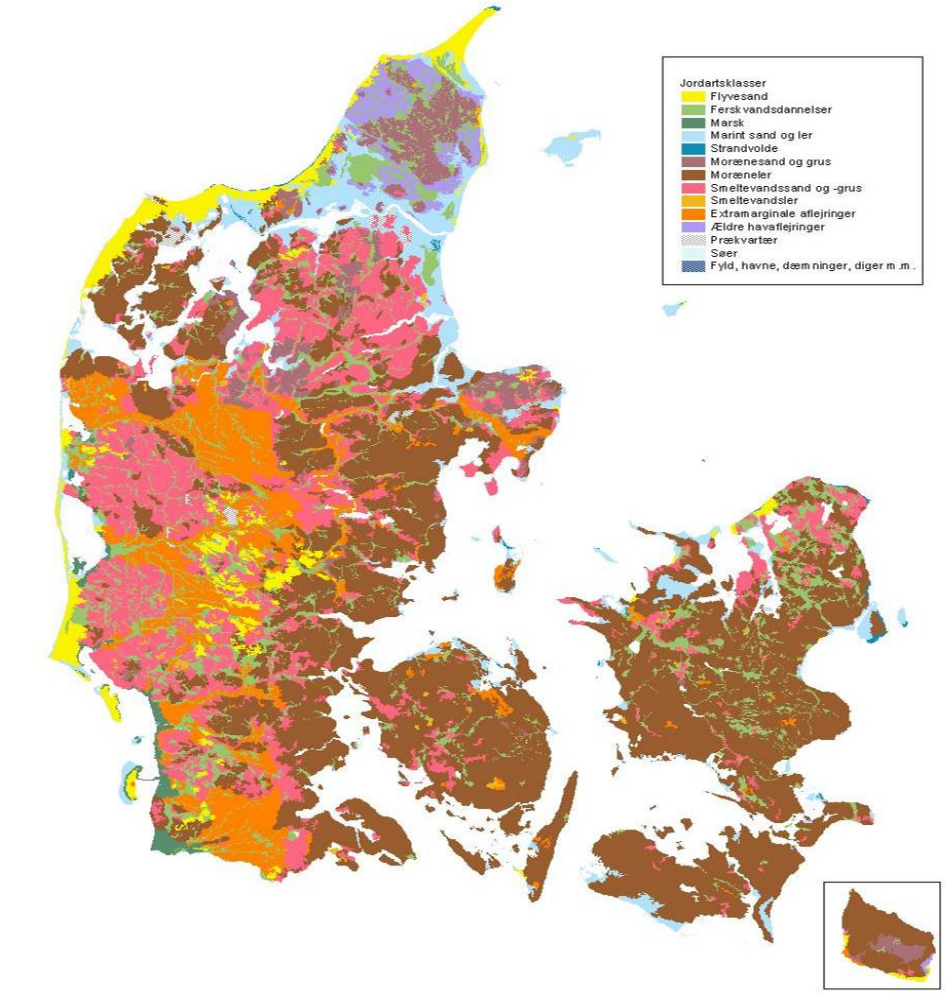


Figure 17. The map of the Quaternary surface deposits. Original scale: 1:200.000. Legend: Brown: Clayey till; Light brown: Sandy till; Red: Meltwater sand and gravel; Orange: Sandur sand and gravel; Purple: Late glacial marine deposits; Light blue: Holocene marine deposits. Green: Holocene freshwater deposits; Yellow: Aeolian sand (From Pedersen, 1989).

Klejs

The Quaternary deposits of clayey till and meltwater sand and gravel are relatively thin (approx. 2 - 10 m).

Sønderby

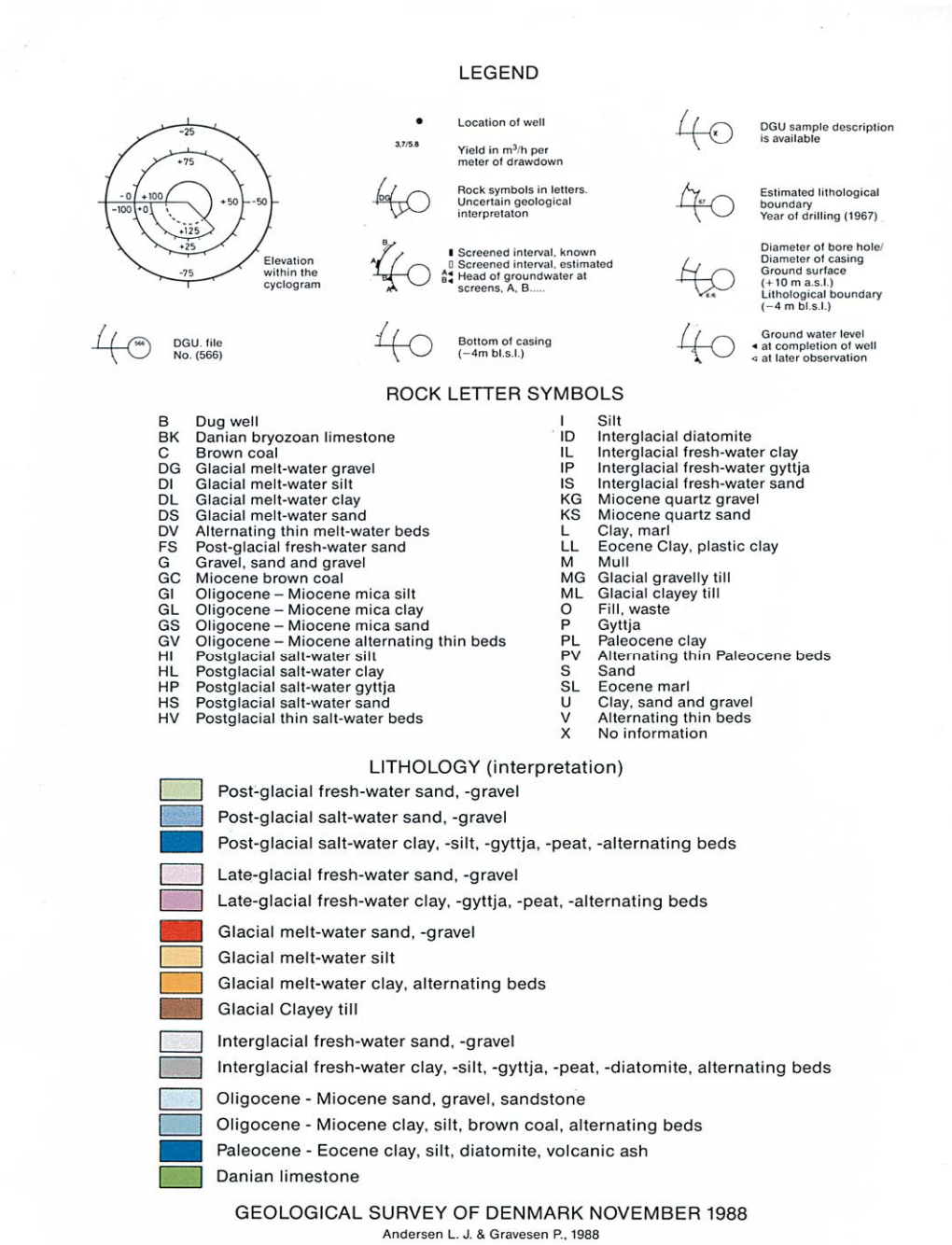
Silty, sandy clayey tills dominate in the area. The tills are yellow brown to grey brown and calcareous (Fig. 17). Several layers of meltwater sand and gravel up to 4 - 6 m thick occur below the tills. The Quaternary is approximately between a few meters to 20 m thick.

Figure 18. Section in clayey till with sub-vertical fractures (Photo. K.E.S. Klint).

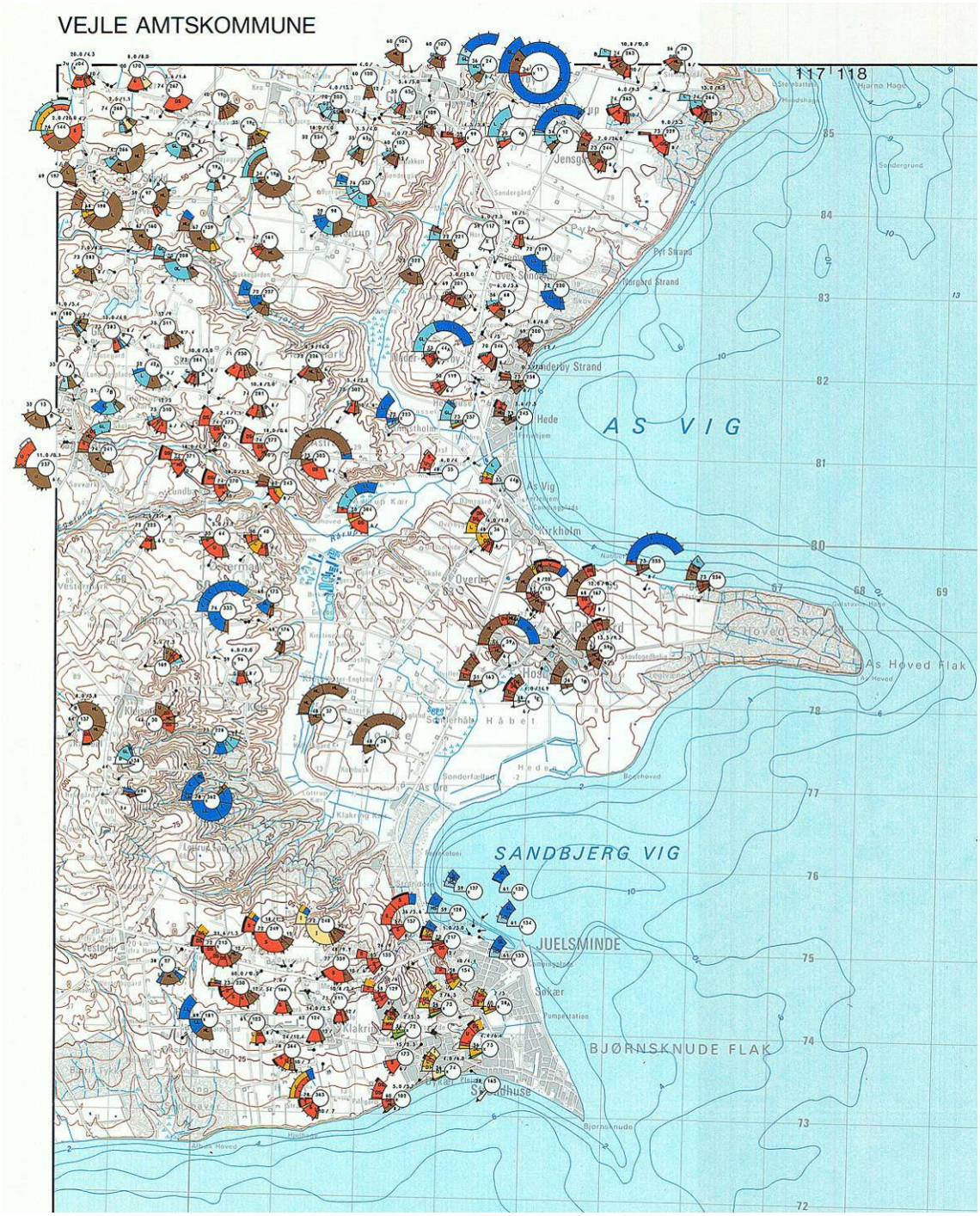
5.6 Tectonics, structures and seismic activity

5.6.1 Major tectonic structures

No major tectonic structures have been recognized crossing the area but a major hiatus occurs between the Late Eocene and the Late Oligocene indicating movements and erosion in the area. The borehole data are illustrated in fig. 19 where the structural conditions are depicted. A large valley in the pre-Quaternary surface is oriented NNW-SSE from Råbæk to As Hoved. The direction is parallel to major fault zones at Horsens Fjord (See also fig. 43). The two subareas mainly occur on high-laying clayey till plateaus which area bordered by meltwater valleys oriented NNE-SSW.


LEGEND
Location of well
3,7/5,8
Yield in m³/h per meter of drawdown
Rock symbols in letters. Uncertain geological interpretaton
Screened interval, known
Screened interval, estimated
Head of groundwater at screens, A, B.....
Bottom of casing (−4m bl.s.l.)
DGU sample description is available
Estimated lithological boundary
Year of drilling (1967)
Diameter of bore hole/ Diameter of casing
Ground surface (+10 m a.s.l.)
Lithological boundary (−4 m bl.s.l.)
Ground water level
at completion of well
at later observation
Elevation within the cyclogram
DGU. file No. (566)
ROCK LETTER SYMBOLS
B Dug well
BK Danian bryozoan limestone
C Brown coal
DG Glacial melt-water gravel
DI Glacial melt-water silt
DL Glacial melt-water clay
DS Glacial melt-water sand
DV Alternating thin melt-water beds
FS Post-glacial fresh-water sand
G Gravel, sand and gravel
GC Miocene brown coal
GI Oligocene – Miocene mica silt
GL Oligocene – Miocene mica clay
GS Oligocene – Miocene mica sand
GV Oligocene – Miocene alternating thin beds
HI Postglacial salt-water silt
HL Postglacial salt-water clay
HP Postglacial salt-water gyttja
HS Postglacial salt-water sand
HV Postglacial thin salt-water beds
I Silt
ID Interglacial diatomite
IL Interglacial fresh-water clay
IP Interglacial fresh-water gyttja
IS Interglacial fresh-water sand
KG Miocene quartz gravel
KS Miocene quartz sand
L Clay, marl
LL Eocene Clay, plastic clay
M Mull
MG Glacial gravelly till
ML Glacial clayey till
O Fill, waste
P Gyttja
PL Paleocene clay
PV Alternating thin Paleocene beds
S Sand
SL Eocene marl
U Clay, sand and gravel
V Alternating thin beds
X No information
LITHOLOGY (interpretation)
Post-glacial fresh-water sand, -gravel
Post-glacial salt-water sand, -gravel
Post-glacial salt-water clay, -silt, -gyttja, -peat, -alternating beds
Late-glacial fresh-water sand, -gravel
Late-glacial fresh-water clay, -gyttja, -peat, -alternating beds
Glacial melt-water sand, -gravel
Glacial melt-water silt
Glacial melt-water clay, alternating beds
Glacial Clayey till
Interglacial fresh-water sand, -gravel
Interglacial fresh-water clay, -silt, -gyttja, -peat, -diatomite, alternating beds
Oligocene - Miocene sand, gravel, sandstone
Oligocene - Miocene clay, silt, brown coal, alternating beds
Paleocene - Eocene clay, silt, diatomite, volcanic ash
Danian limestone
GEOLOGICAL SURVEY OF DENMARK NOVEMBER 1988
Andersen L. J. & Gravesen P., 1988

a.



b.

Figure 19. Geological Basic Data Map. a. Legend for the map (After Andersen & Gravesen, 1989), b. Part of Geological Basic Data map 1313 IV Juelsminde. Original Scale 1:50.000 (After Pedersen & Stockmarr, 1979a).

The Quaternary deposits seem to have been strongly tectonic disturbed by the Weichselian glaciers and several floes of Paleogene clays occur in the glacial sediments. In areas with

apparently in-situ occurrence of Paleogene clays, the upper parts of these clays may also be disturbed (Fig. 20).

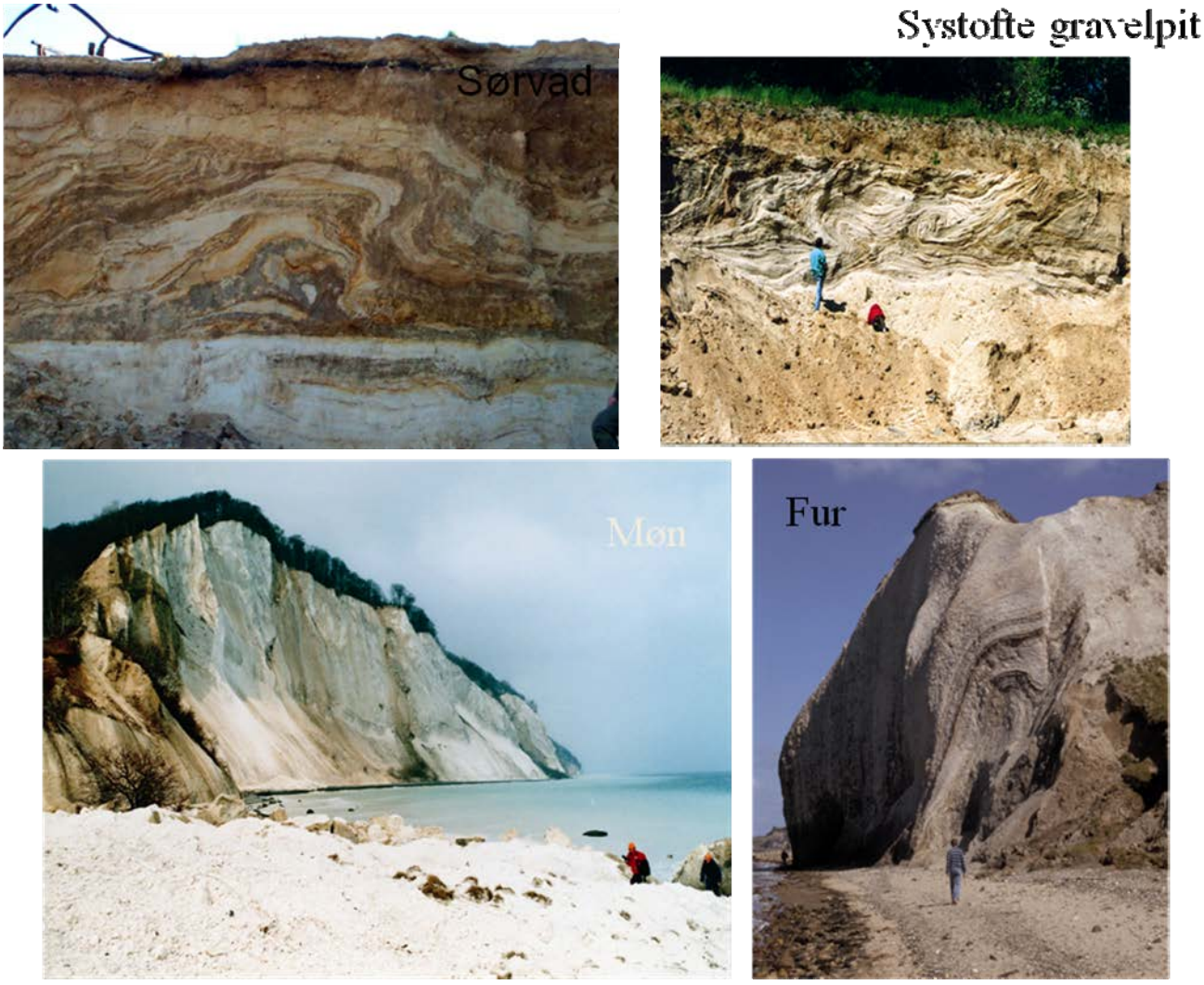


Figure 20. Examples of glaciotectonic disturbances of Quaternary and pre-Quaternary deposits from Sørvad, Sydtofte, Møn and Fur (Photos: K.E.S. Klint).

5.6.2 Fractures

The Quaternary tills are normally cut by vertical, sub-vertical and horizontal fractures down to at least 8 m depth. Many biopores often occur in the upper 2 - 3 m (Fig. 21).

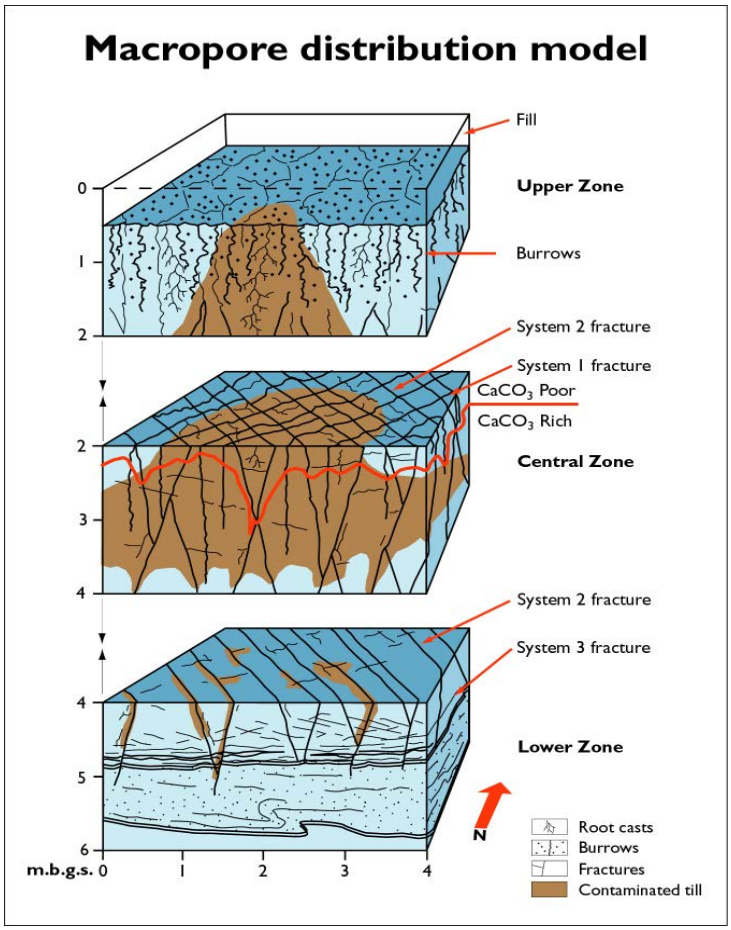


Figure 21. Fracture model in clayey till (From Klint & Gravesen, 1999).

The very fine-grained and plastic clays from Eocene and Oligocene contain fractures that may be a problem for ground stability.

5.6.3 Geological model

The geological model consists of four major units. The model comprises both subareas (Fig.22):

A. Quaternary deposits, mainly clayey till. Thickness 2 m to 20 m.

B. Oligocene Brejning Member (Formation) and perhaps the Vejle Fjord silt and sand. Black and brown mica clay. Thickness up to 20 m.

C. Eocene Søvind Marl Formation, up to 27 m thick but normally thinner.

D. Lillebælt Clay Formation and Røsnæs Clay Formation, at least 75 m thick.

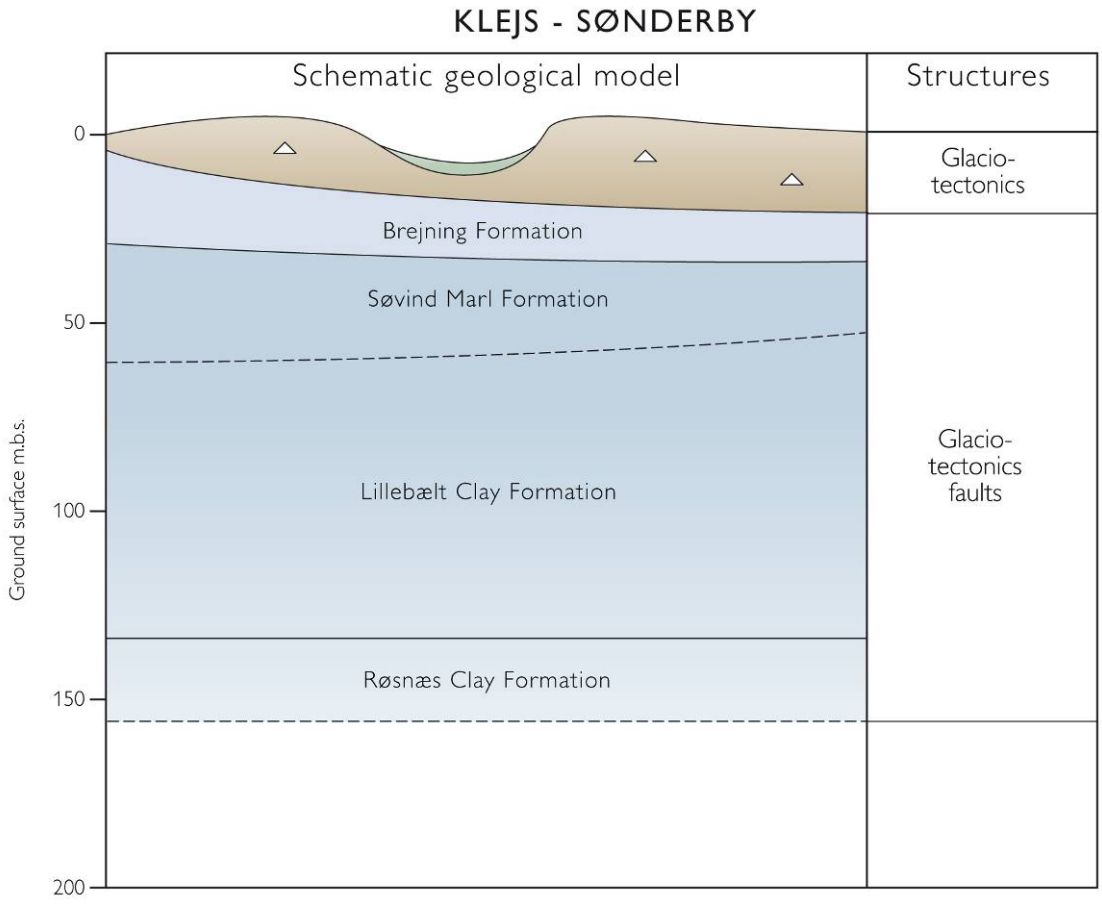


Figure 22. Schematic model of the geological and structural conditions of Area 12.

5.6.4 Earthquake activity

The seismic activity in east Jylland and the near surrounding sea is very low (Fig. 23). Therefore, it is impossible to relate recent seismic activity to the faults and fractures in the bedrocks. Other signs of recent movements along the faults and fractures have not been proven.

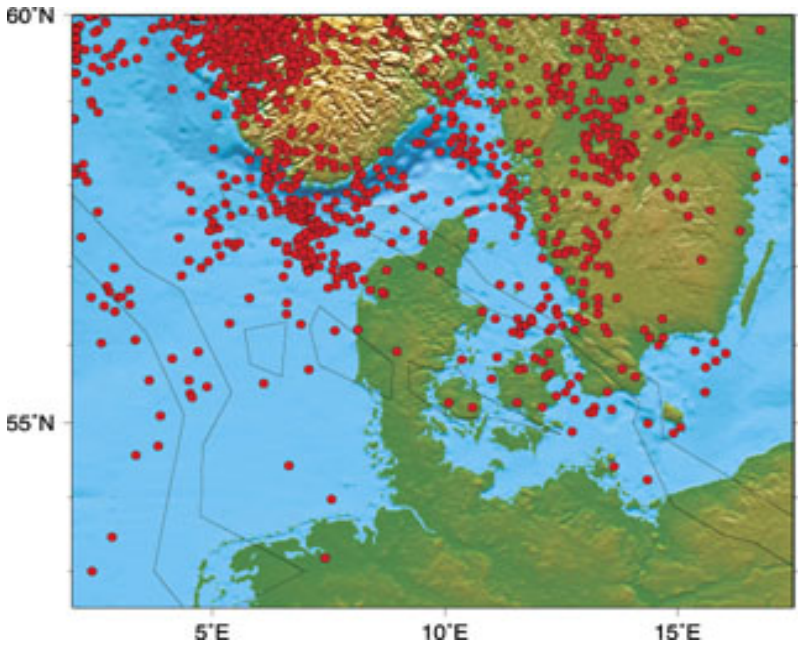


Figure 23. Map of epicentres from earthquakes in the Danish and surrounding areas. (From GEUS´s Home page).

5.7 Ground stability

The area is expected to have good ground stability. Nevertheless, it is always important to remember that constructions on and in plastic clays can give problems. This is caused by fractures in the clays and because of large changes in volume at drying and water filling.

Areas with slopes are especially exposed for sliding and flowing of plastic clay material towards lower areas.

5.8 Groundwater hydrogeology

5.8.1 Groundwater characteristics

The Klejs-Sønderby area (Area 12) is positioned in an area that is characterized by the absence of shallow groundwater bodies and existence of several smaller regional and deep groundwater aquifers (Figs. 24, 25 and 26). The subdivision into groundwater aquifers in water district 60 are thoroughly described by the former Vejle County in the basisanalysis part 1. In the Horsens Fjord catchment management plan (Hovedvandopland 1.9) from the Ministry of Environment, the regional groundwater bodies in the Juelsminde area are located within two sub catchments: Horsens Fjord (DK1.9.2.2) and Nordlige Bælthav (DK1.9.2.3 and DK1.9.2.6). Finally, there are three small deep groundwater aquifers, situated in a significant distance from each other within the Juelsminde area. These three aquifers are compiled into one administrative deep groundwater body (DK1.9.3.1) (Fig 26). All regional

and deep groundwater aquifers are meltwater sand deposits. The overall assessment of the chemical and quantitative status of the regional and deep groundwater aquifers is good (see Section 5.9).

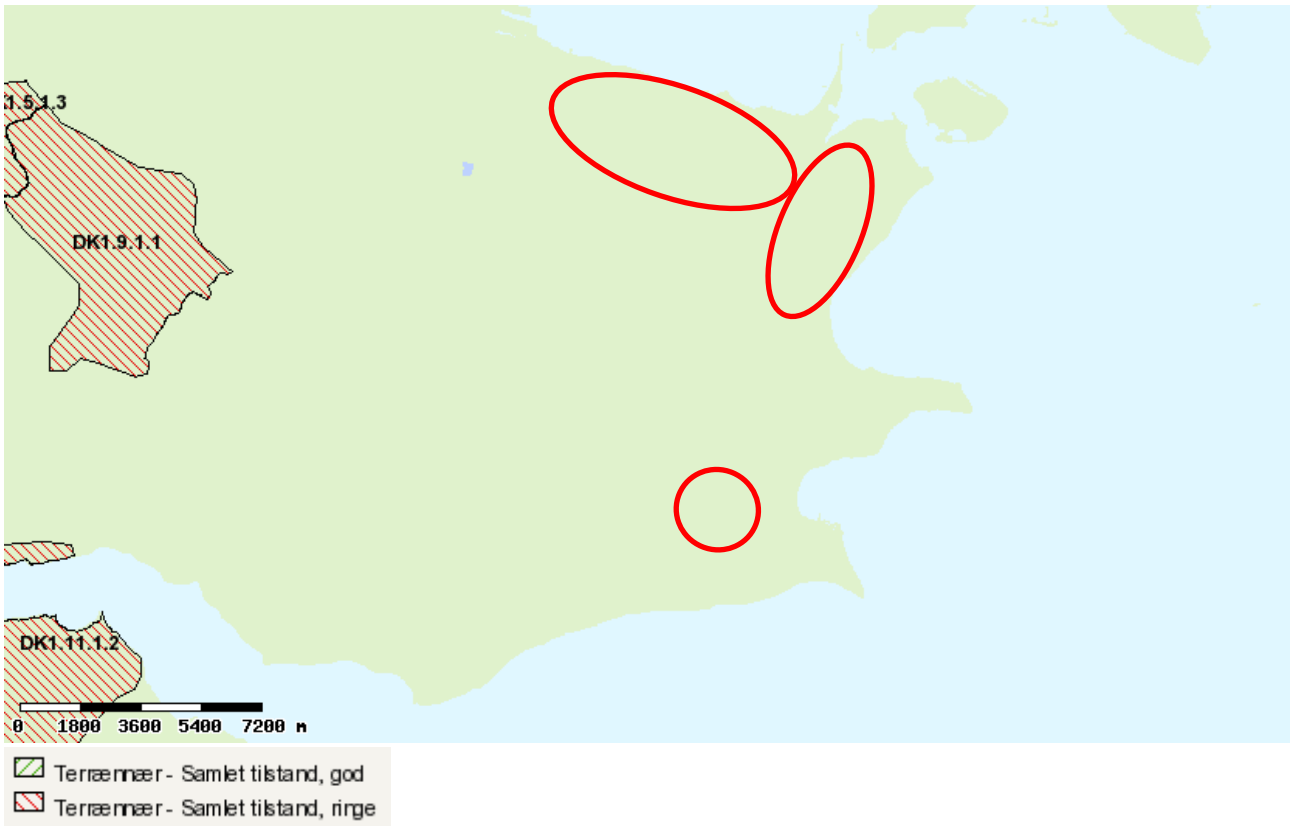


Figure 24. Shallow (or terrain near) groundwater bodies located west of the Juelsminde area (Area 13), shown in red circle (After Ministry of Environment, 2010).

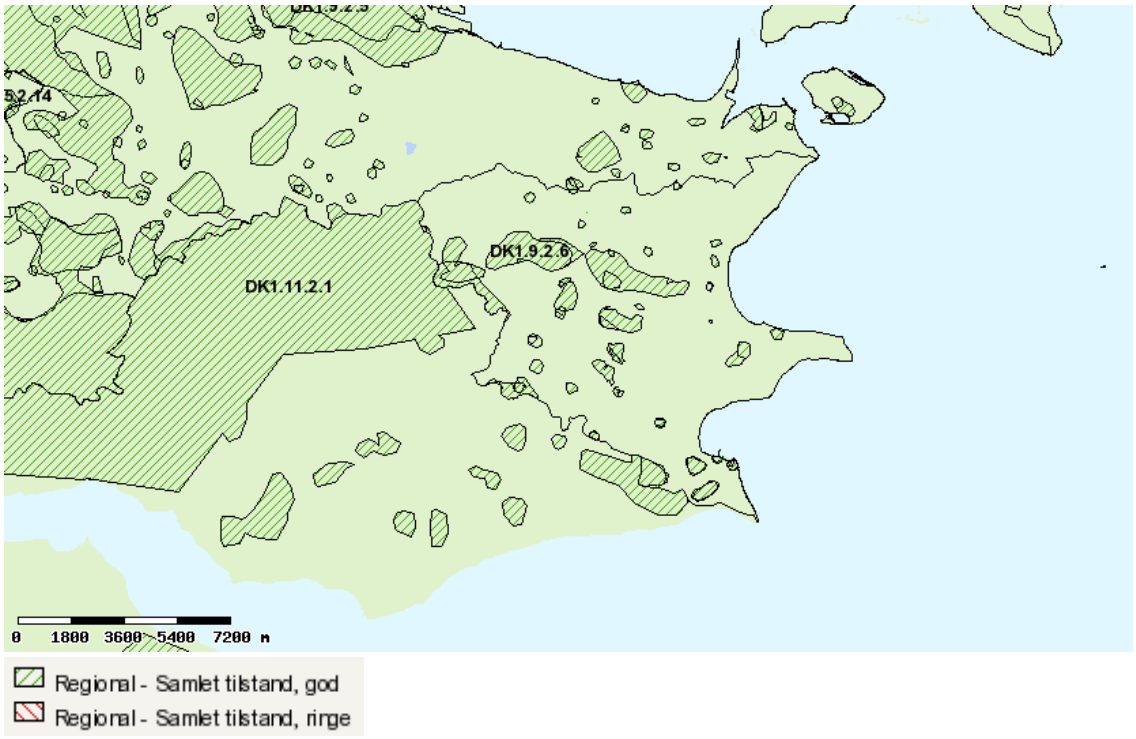


Figure 25. Regional groundwater bodies within and west of the Juelsminde area (Area 12). (After the Ministry of Environment, 2010).

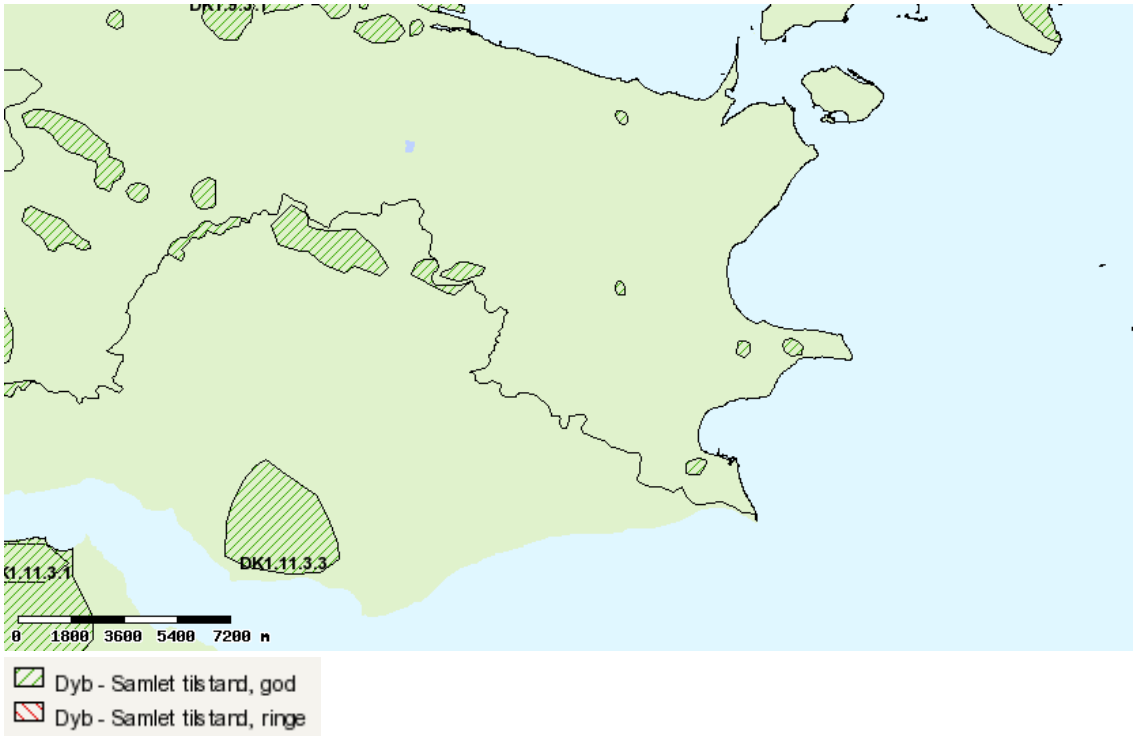


Figure 26. Deep groundwater bodies within and west of the Juelsminde area (After Ministry of Environment, 2010).

5.8.2 Drinking water areas

The groundwater has to be protected to ensure that our current and future need for clean drinking water can be met. It is the Environmental Centres (former counties) responsibility to do the planning, based on the two criteria: First, to make sure that the future necessary quantity of clean groundwater can be abstracted. Secondly, the groundwater aquifers must be protected against recent and future pollution.

As part of the Danish Government´s efforts to protect groundwater, the Environmental Centres have designated areas of major groundwater aquifers, so-called OSD-areas. OSD stands for "Areas of special drinking water interests" (Fig. 27).

The rest of the country is divided into "Areas with water interests" (OD-areas) where good sources of drinking water are also located and "Areas with limited drinking water interests", where it is difficult or impossible to obtain good groundwater quality because the water is more or less contaminated.

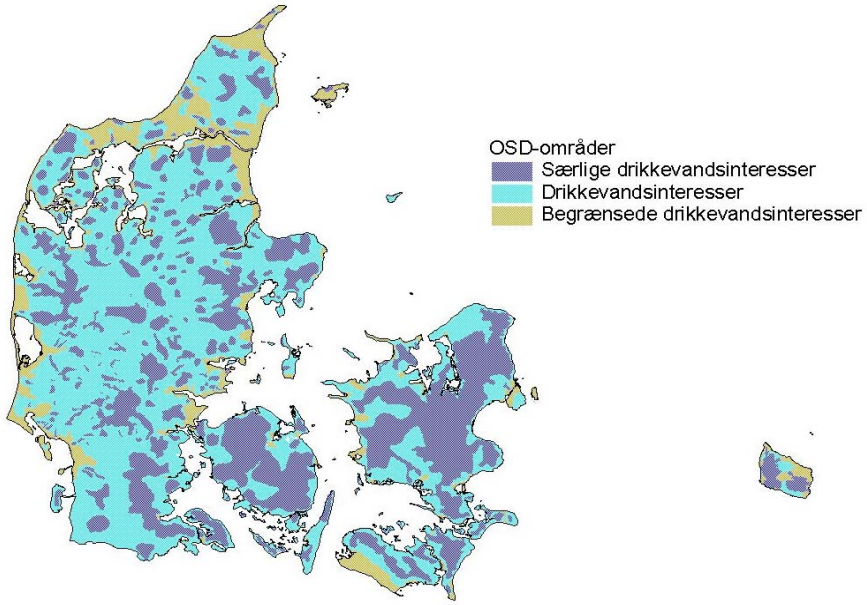


Figure 27. Areas of special drinking water interests (OSD): Dark blue and areas of drinking water interest (OD): Light blue. Areas with limited drinking water interests are olive brown (http://kort.arealinfo.dk/).

The drinking water areas in the Juelsminde area are given in fig. 28. The Klejs-Sønderby area is mainly classified as an area with limited or no drinking water interest but also partly on OD level. Groundwater abstraction is distributed as given in fig. 29.

Figure 28. Various drinking water areas situated in the Juelsminde area. Dark Blue: Areas of special drinking water interests (OSD); Light blue: Areas of some drinking water interests (OD); Yellow: Areas with limited or none drinking water interests (/kort.arealinfo.dk/).

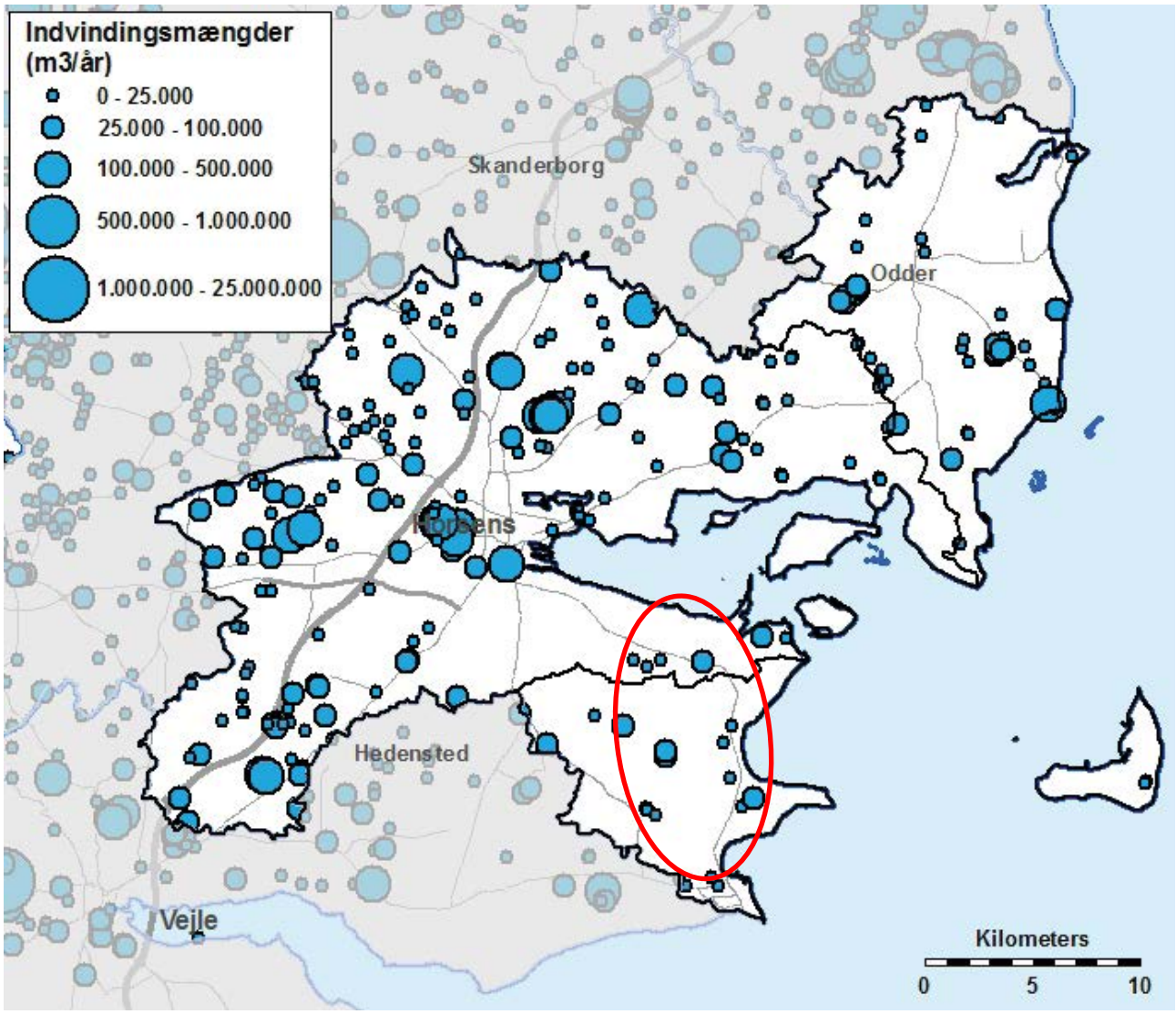


Figure 29. Annual abstraction (in average) from single wells in the period 2003-2005 (from Miljøstyrelsen, 2010).

5.9 Groundwater chemistry

The overall groundwater quality aiming for drinking water purpose has been assessed by the former Vejle and Århus counties and Environmental Centre Århus for the regional and deep groundwater bodies and reported in the catchment management plan "Hovedvandopland 1.9, Horsens Fjord" from the Ministry of Environment. The groundwater chemistry full fills the EU criteria to be of good status.

5.10 Climate and climate changes

The actual climate and the expected future climate changes and sea level development is described in Gravesen et al. (2010, Rep. No. 2).

Klejs

It is not expected that climate changes will affect this area seriously during this century, but it is very likely that more and more intense rain may cause erosion along the streams. The expected sea level rise of this century should not affect the Klejs Area.

Sønderby

It is not expected that climate changes will affect this area seriously during this century, although more and more intense rain will raise the discharge of the streams. The expected sea level rise may cause flooding of the coastal section toward north-west and the stream valleys toward the south.

5.11 Restrictions and limitations

There are no raw material digging and interest areas in Area 12.

The designated area north of Juelsminde has no restrictions in accordance to the NATURA 2000 regulation. An adjacent NATURA2000 habitat area is located along the south coast towards Vejle Fjord, outside the area (Fig. 30).

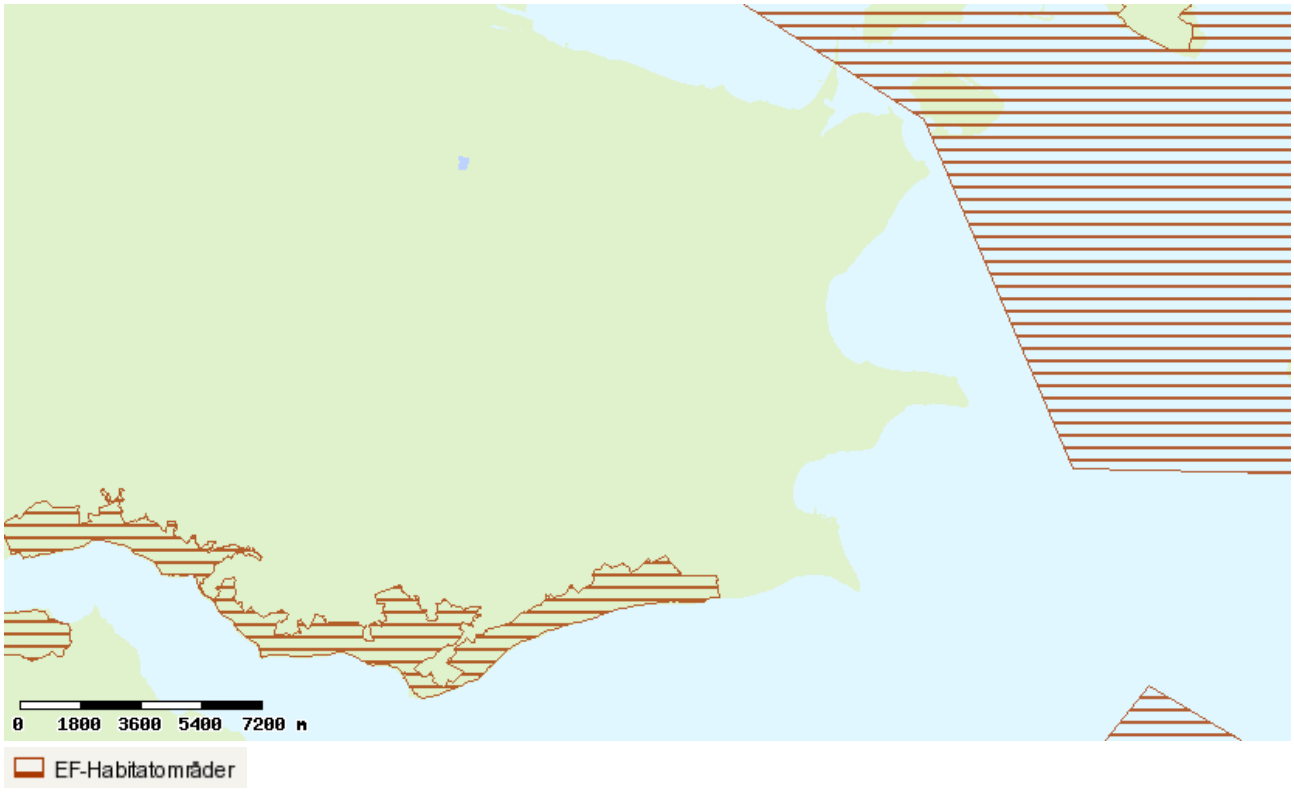


Figure 30. NATURA2000 habitat areas in the Lillebælt region (/kort.arealinfo.dk/).

5.12 Summary of the area conditions

Amount of data:
Sparse: Some relevant boreholes. No geophysical surveys.

Homogeneous conditions and isolation of the waste by low, permeability layers:
Perhaps perfect on depth below 20 m but the framework of the fractures below 10 m is unknown. The fracture problem has to be considered in relation to other areas.

Stability
Good stability on surface and depth but problems can occur on slopes.

Seismic activity and tectonic movements
No seismic and tectonic movements or problems.

Groundwater conditions
The groundwater conditions in clay deposits should be positive but the variation in the level of the groundwater table has to be analysed if the disposal has to be established under saturated conditions. The groundwater flow will be towards the sea.

Dilution of pollution and retention of pollution
No Danish studies have been carried to document dilution capabilities or retention of radio-nucleides in glacial till sediments.

Drinking water interests
No OSD areas within the Area 12. Only minor local supplies occur.

Groundwater chemistry, non- aggressive components
The groundwater contains apparently no aggressive components.

Ground surface conditions
Processes on the ground surface should not give problems on a disposal.

Climate extreme conditions
Climate changes and extremes as storms or heavy precipitation will not have influence on a disposal.

Other restrictions
Apparently no other restrictions will give problems.

5.13 Final Remarks

The Quaternary sediments mainly consist of clayey tills although sand and gravel layers occur. The two subareas reach Eocene and Oligocene deposits. It is a problem to describe the structural framework. The Eocene plastic clays are suitable for a disposal of radioactive

waste but the Oligocene clays are more coarse-grained with silt and sand inclusions why these sediments have to be analysed in detail.

6. Area 13. Thyrsted – Glud, Juelsminde peninsula, East Jylland

6.1 The location of the area

The area is located in east Jylland, east of Horsens (Fig. 31). The area is situated on the Juelsminde peninsula, between Tyrsted - Sejet and Glud on the northernmost part of the peninsula (Fig. 32).

Figure 31 Location of the area. The Juelsminde peninsula is located on the east coast of Jylland.

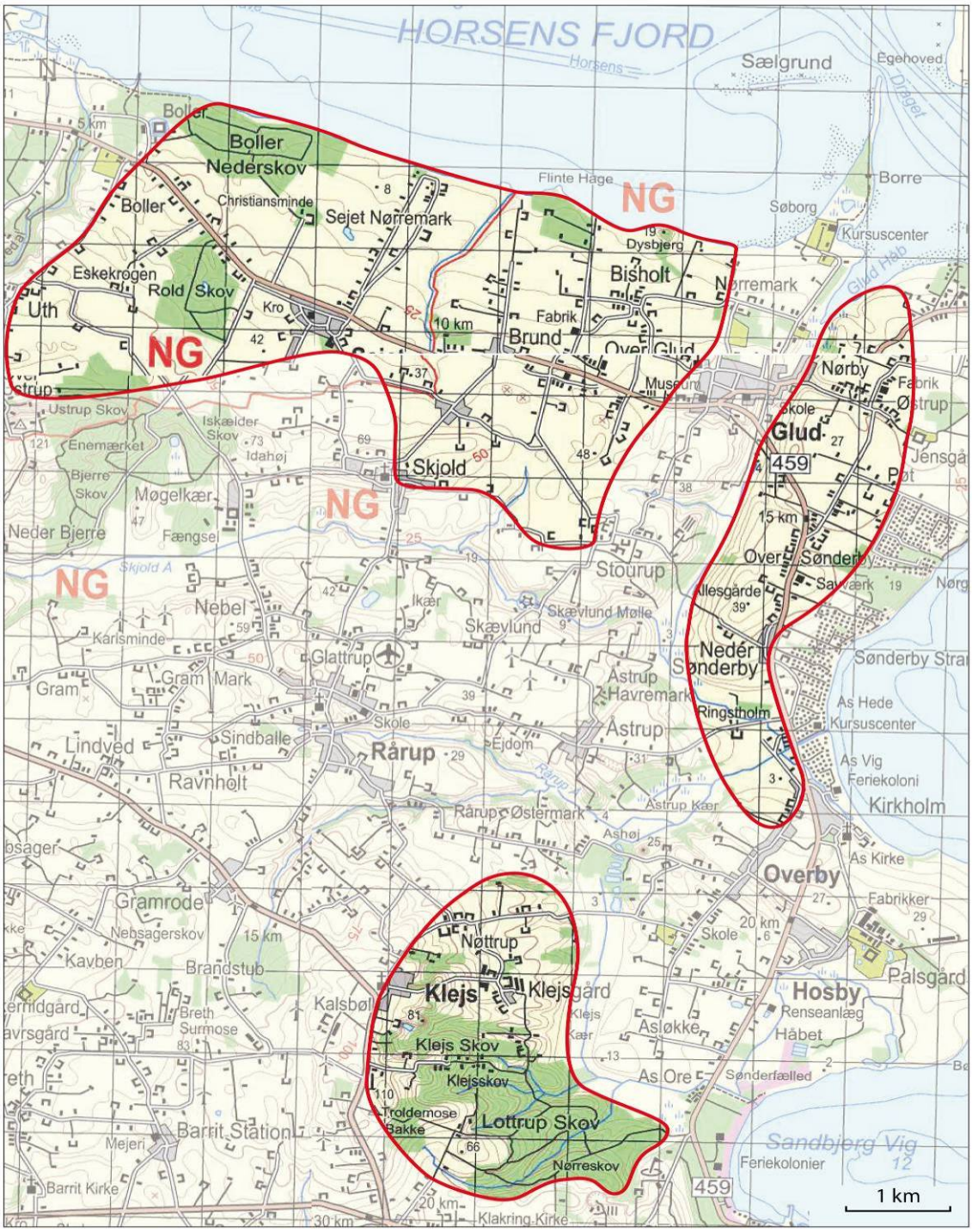


Figure 32. A detailed map of Area 13. The Area is located between Thyrsted/Uth and Glud.

6.2 Terrain, topography and surface processes

The Thyrsted – Glud area is located in the central northern part of the Juelsminde peninsula. The size of the area is c. 25 km^2. The highest part of this area is found along the southern/south-western delimitation of the area that is located around 50 meters above sea level (m.a.s.). From here, the landscape slopes very gently toward the northern delimitation of

the area, which is the coastline of Horsens Fjord. The overall impression of the landscape is one big gently sloping surface. Only the south-eastern and south-western parts of the area are partly undulating. A very small lake is found at Sejet Nørremark and one small stream crosses the area in approx. the central part. The coast seems to be very stable. Some sections of the coast are prograding and no signs of erosion are seen.

The predominating part of the area is used for agriculture. Some c. 10 % of the area is covered by woods. The main road between Horsens and Glud crosses the area. Several minor roads are also crossing the area. The small villages Sejet, Brund and Bisholt are located in the area. A number of houses are located along the roads.

Owing to the very gentle relief and intensive cultivation, the surface processes (soil creep, frost – thaw processes, soil development etc.) proceed slowly and undramatic. The most active surface processes are found at the coast, but the coast is facing the calm waters of Horsens Fjord and is furthermore sheltered by a relatively wide, shallow near shore zone.

A smaller part of the area toward south-east is part of an area of National Geological Interest (no. 91).

6.3 Surface geology and profiles

The Quaternary sediments in the area mainly consist of glacial clayey till but several valleys crossing the till areas contain Holocene freshwater deposits. These may be resting on meltwater sand and gravel (Fig. 33).

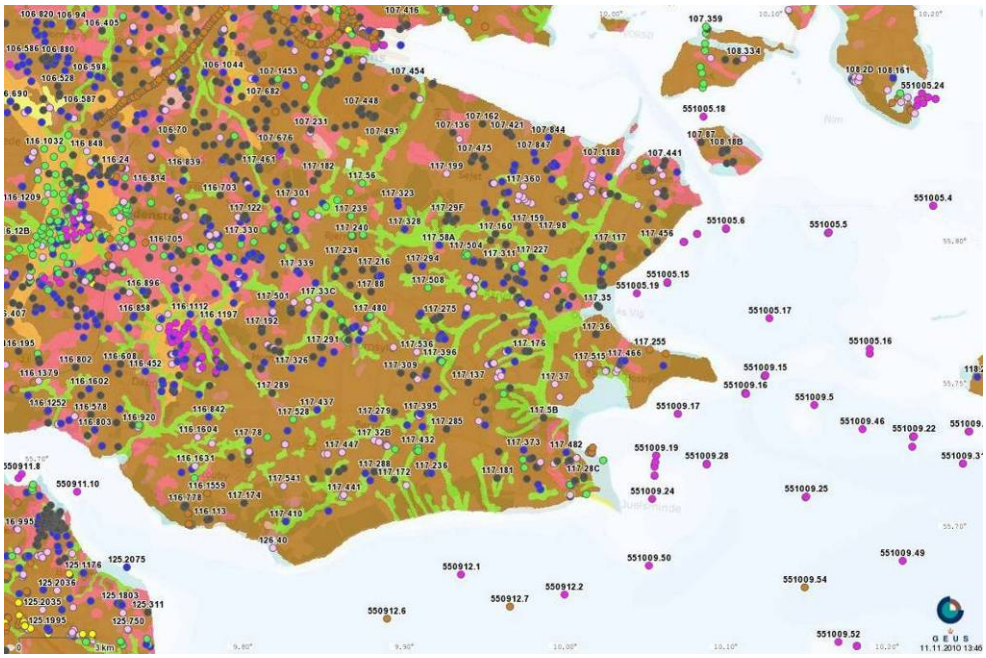


Figure 33. Map of the surface geology with boreholes from the Jupiter Database at GEUS. Originally in 1:200.000. Legend: Brown: Clayey till Red: Meltwater sand and gravel; Orange: Meltwater clay; Green: Holocene freshwater deposits. (From GEUS´s Homepage after Pedersen, 1989). Legend for the boreholes: See fig. 34.

6.4 Boreholes

Several boreholes in the area reach Paleogene clays and glacial clayey tills. Most of the samples from the boreholes are characterised lithological and are related to formal units but only few samples have been dated by microfossils. The locations of the boreholes in the area are seen in figs. 34, 35 and 36.

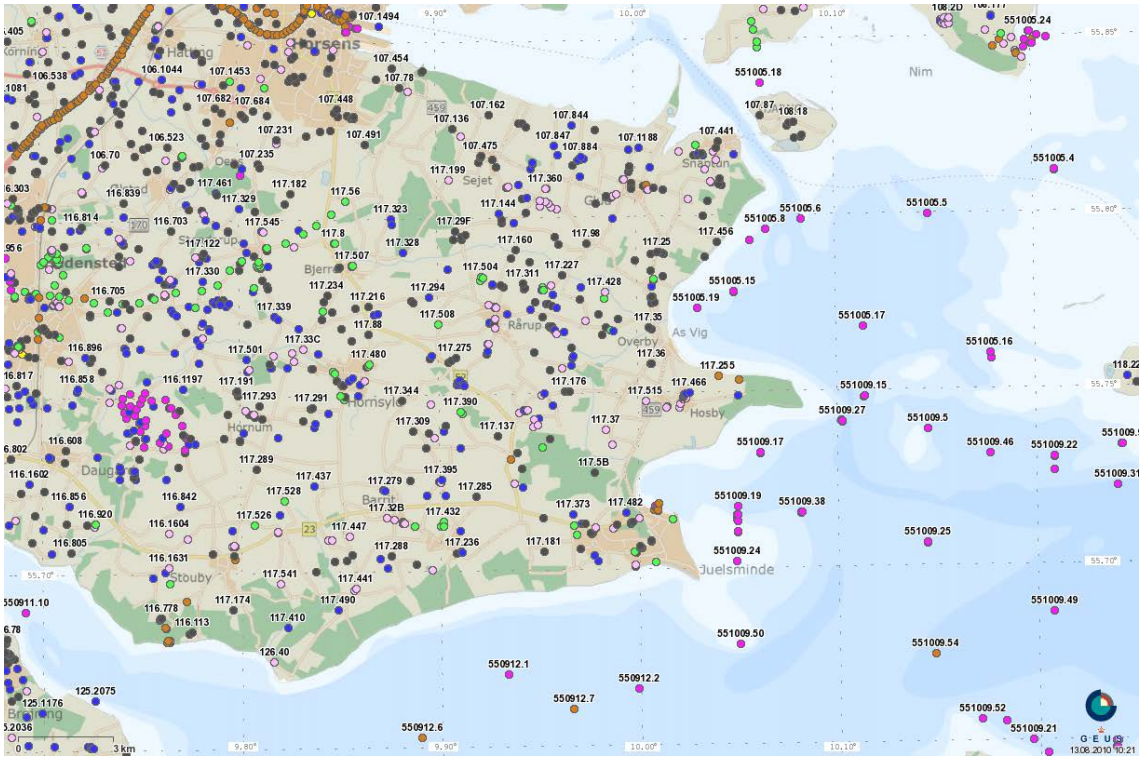


Figure 34. Map of the locations of boreholes on the Juelsminde Peninsula from the Jupiter database at GEUS. Legend: 107.491: DGU No., Blue dot: Water supply well; Red dot: Geotechnical borehole; Pink dot: Raw material borehole; Green dot: Other borehole; Light red dot: Abandoned borehole; Black dot: Unknown purpose.

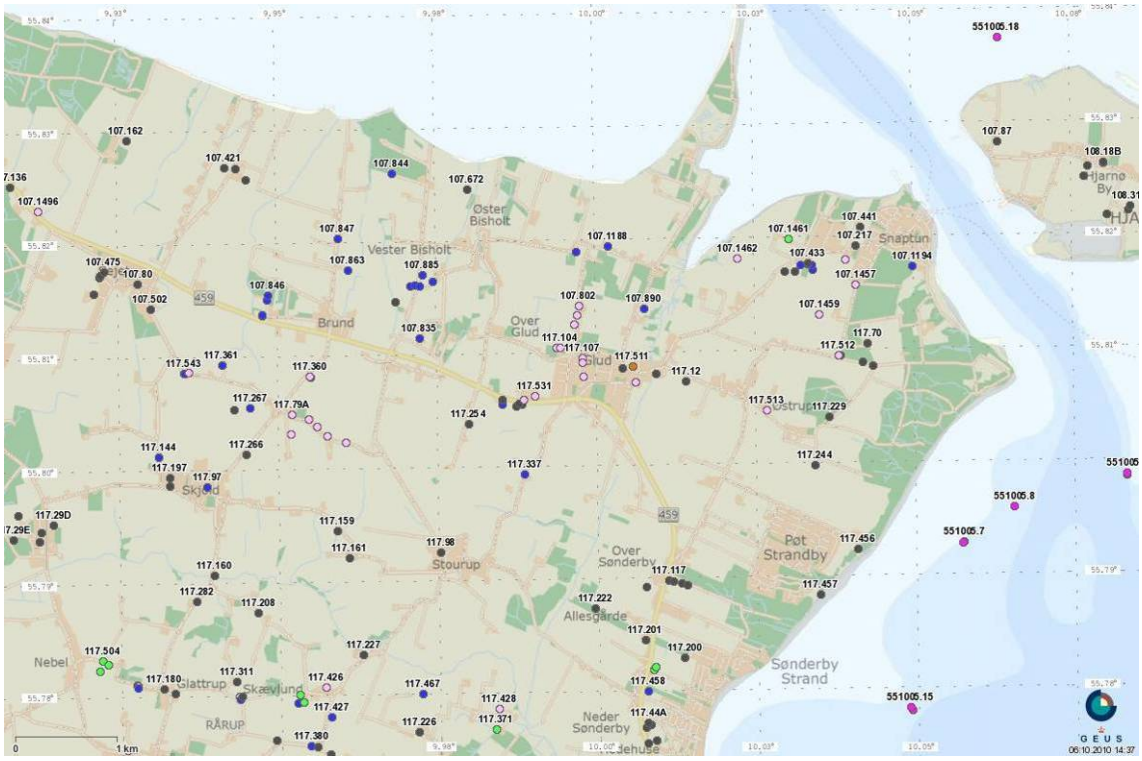


Figure 35. Boreholes in the area near Glud. Legend: see fig. 34.

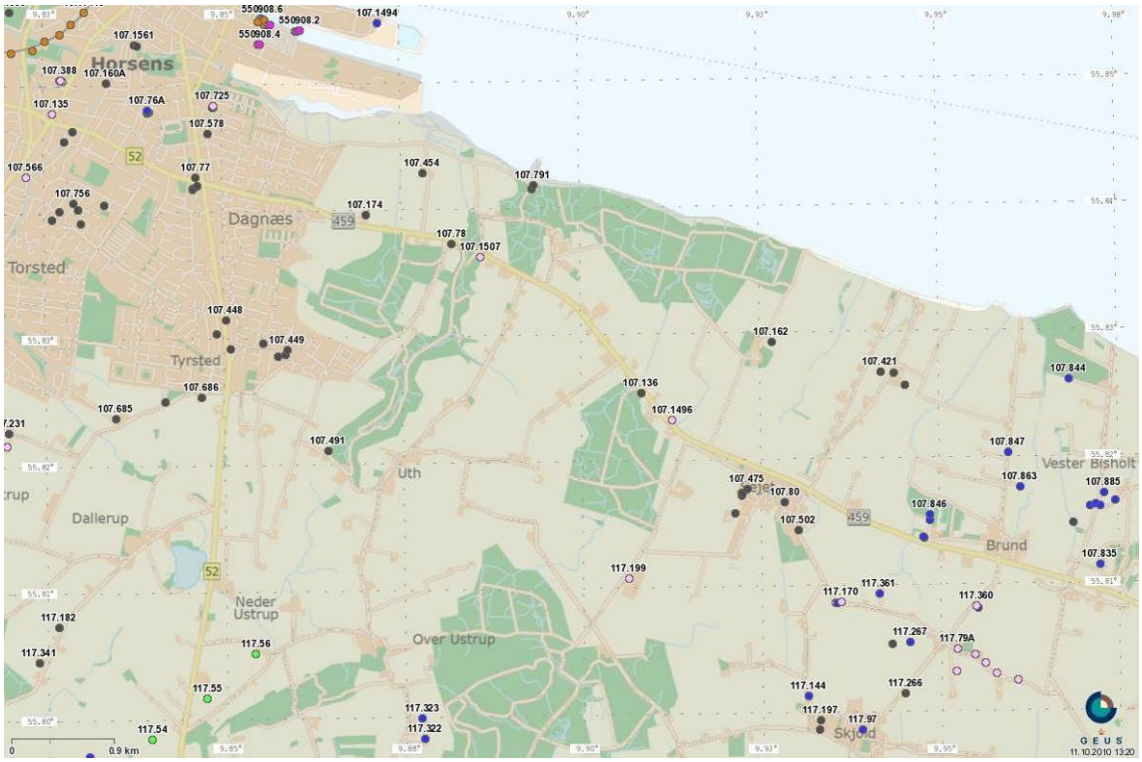


Figure 36. Boreholes in the area Between Sejet and Thyrsted. Legend: see fig. 34.

An example of the boreholes (DGU no.107.491) reaching the Oligocene clays is in fig. 37. Few geophysical surveys are known from the area.

De Nationale Geologiske Undersøgelser for Danmark og Grønland

Udskrevet 12/4 2011 Side 1

BORERAPPORT

DGU arkivnr: 107. 491

Borested : THYRSTED PR HORSENS THYRSTED VV
8700 Horsens

Kommune : Horsens
Region : Midtjylland

Boringsdato : 1/1 1965

Boringsdybde : 77.2 meter

Terrænkote : 58 meter o. DNN

Brøndborer :
MOB-nr :
BB-journr :
BB-bornr :

Prøver
- modtaget :
- beskrevet : **af** : G
- antal gemt :

Formål :
Anvendelse :
Boremetode :

Kortblad : 1214 IISØ
UTM-zone : 32
UTM-koord. : 554246, 6186715

Datum : ED50
Koordinatkilde :
Koordinatmetode : Dig. på koor.bord

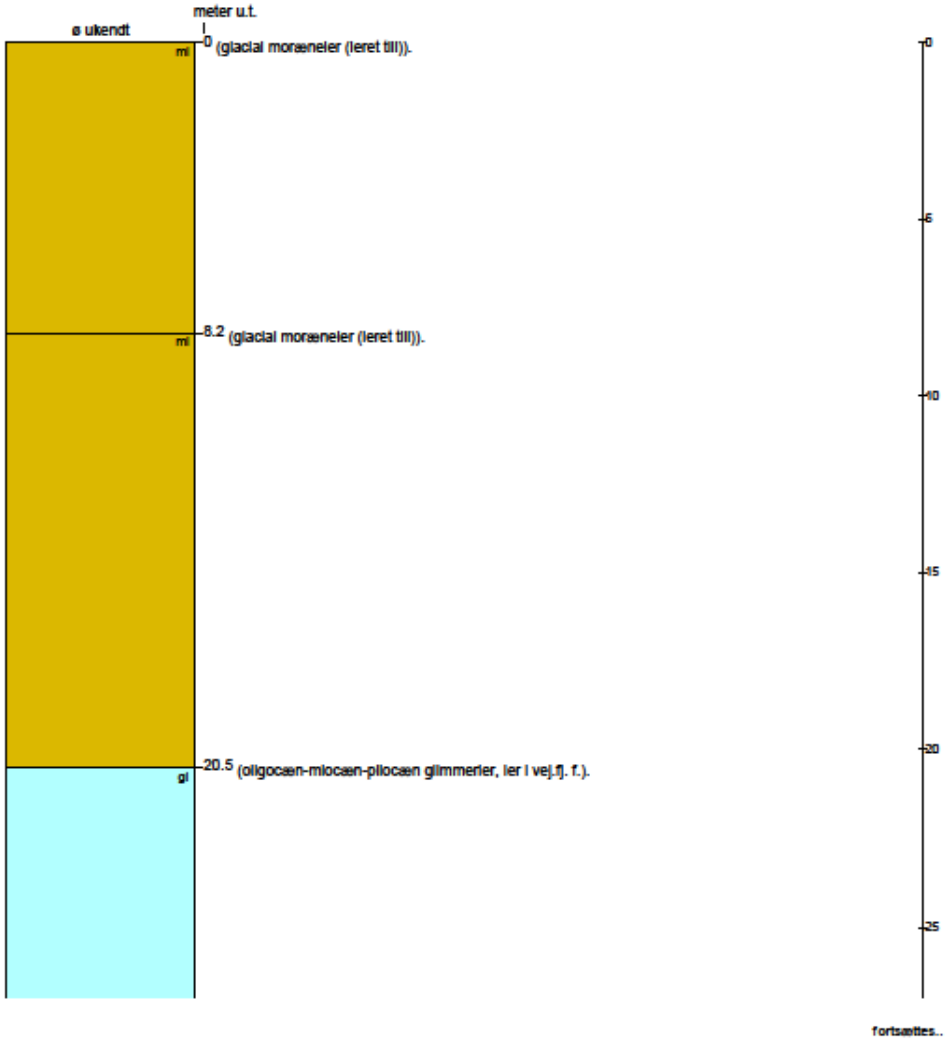


Figure 37. Borehole log from Thyrsted: DGU no. 107.491. The upper part of the 77.2 m deep borehole. Legend: ML. Clayey till, GL: Oligocen, Miocene mica clay.

6.5 Sediment and rock characteristics, mineralogy and chemistry

6.5.1 Pre-Quaternary deposits

According to the map of the pre-Quaternary deposits, the area should consist of Eocene or Oligocene deposits just below the Quaternary (Fig. 38).

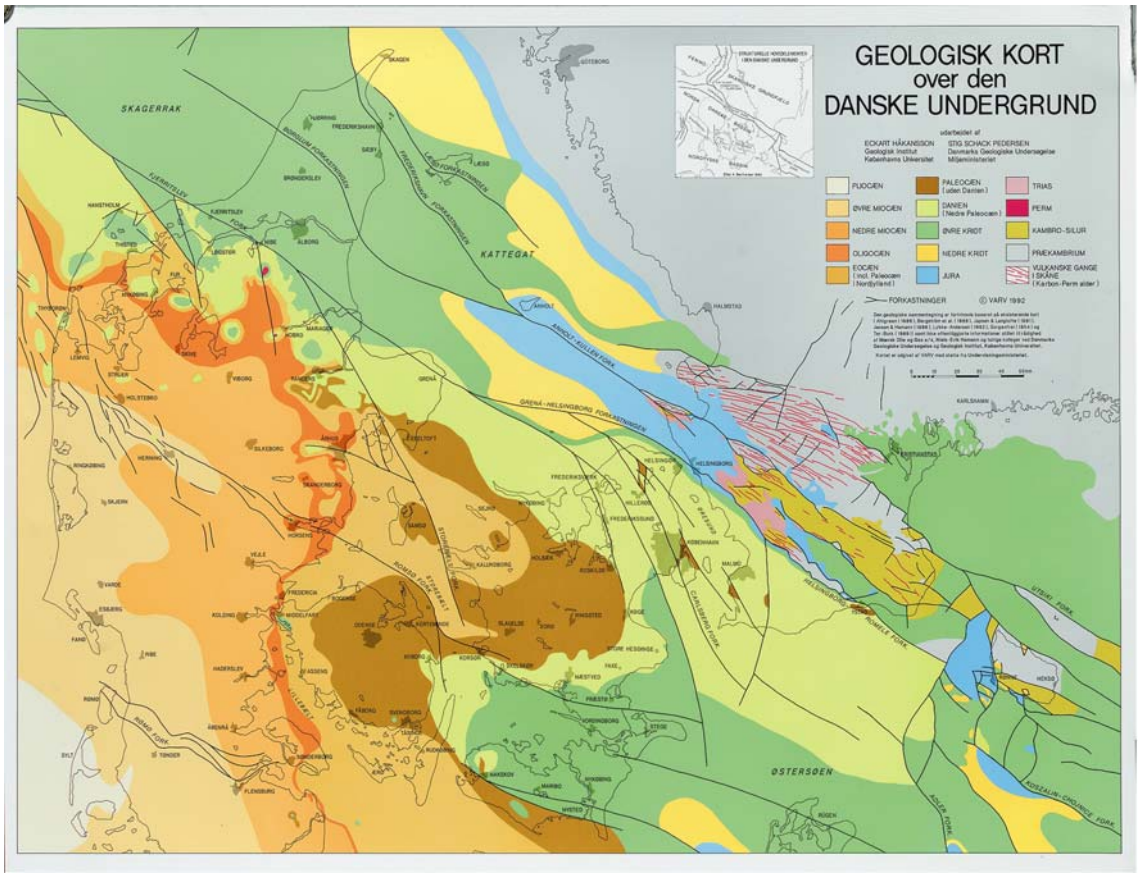


Figure 38. Map of the pre-Quaternary surface: Time units. Original scale: 1:50.000. Legend: Red lines: Precambrian intrusions; Grey: Precambrian; Olive: Cambrian-Silurian; Red: Permian; Light red: Triassic; Blue: Jurassic; Yellow: Lower Cretaceous; Green: Upper Cretaceous; Light green: Danian; Brown: Paleocene; Yellow olive: Eocene; Red brown: Oligocene; Light yellow brown: Lower Miocene; Very light yellow brown: Upper Miocene; White: Pliocene (Håkansson & Pedersen, 1992).

The topography around the area is a valley-plateau system and the distribution of the pre-Quaternary deposits in the boreholes is depending on this system.

At Glud, the Late Oligocene or Early Miocene deposits are first reached topmost on the plateau and consist of silty black and brown black, micaceous, non-calcareous clays mainly from the Brejning Member, in up to 15 - 20 m thick layers. Below occurs the Late Eocene Søvind Marl Formation of fine-grained green grey strongly calcareous clay, 20 - 30 m thick.

Towards the west, from Sejet to Tyrsted, the pre-Quaternary deposits occur below few m to 24 m Quaternary clay, silt and sand. The oldest clays belong to the Late Eocene Søvind Marl Formation, strongly calcareous, green grey to light grey yellow. The formation is up to 25 m thick. Above these clays follows Late Oligocene Brejning Clay which consist of brown and black micaceous clay. The clay is fine-grained to silty and lenses of silt and fine-grained sand occur. It is mainly non-calcareous but to the bottom of the Member, the clay is calcareous and contains shells and shell fragments. Glauconite in the lowermost layers just above the Søvind Marl gives a green black color. The Oligocene layers are up to 55 - 60 m thick.

6.5.2 Quaternary deposits

The map of the Quaternary deposits (Figs. 33 and 39) show the distribution of the different sediments.

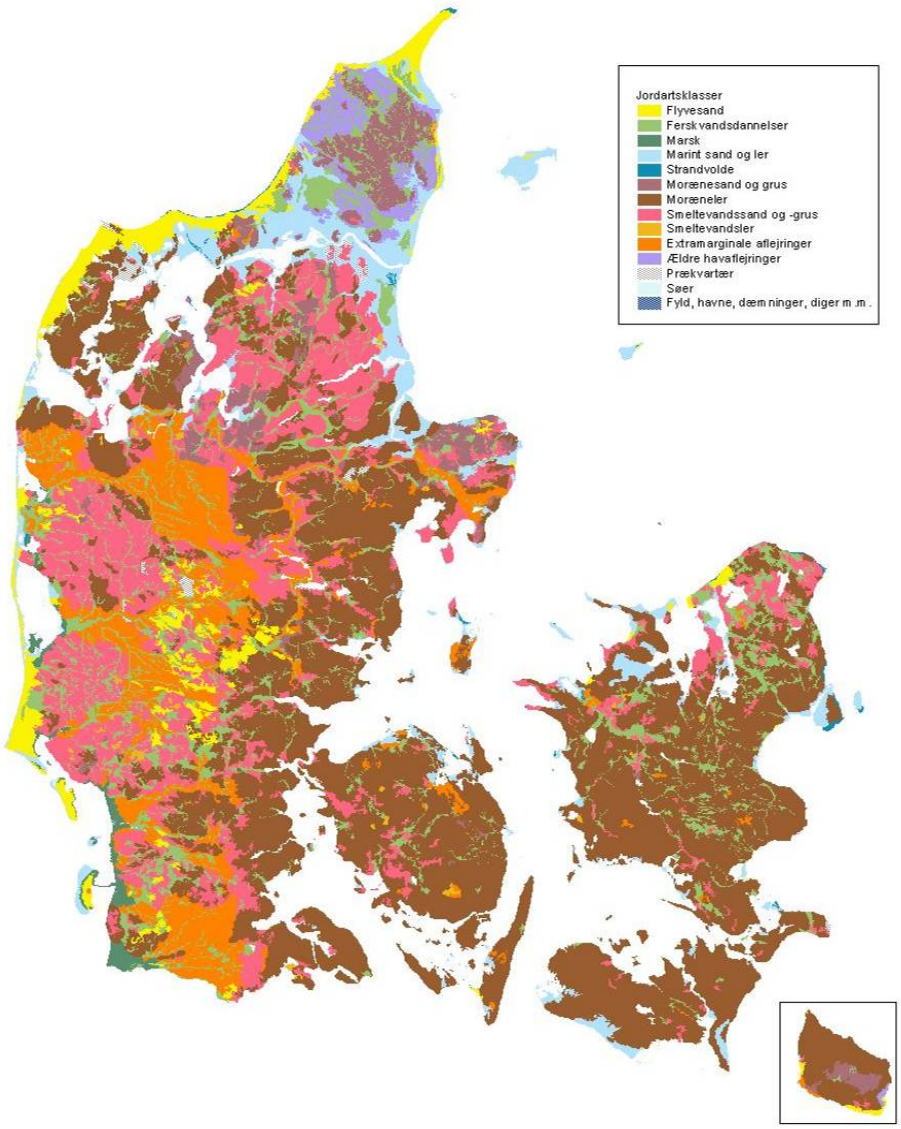


Figure 39. Map of the Quaternary surface deposits. Original scale: 1:200.000. Legend: Brown: Clayey till; Light brown: Sandy till; Red: Meltwater sand and gravel; Orange: sandur sand and gravel; Purple: Late glacial marine deposits; Light blue: Holocene marine deposits; Green: Holocene freshwater deposits; Yellow: Aeolian sand (From Pedersen, 1989).

At Glud, up to 10 m thick layers of clayey tills dominate the upper layers. Layers of meltwater sand and gravel, up to 10 m thick, are unevenly distributed.

Between Tyrsted and Sejet, the Quaternary deposits consist of olive grey and grey yellow sandy, silty calcareous clayey till and only very few, thin sand layers are found. Thickness: 5 - 20 m (Fig. 40).

Figure 40. Section in clayey till with sub-vertical fractures (photo K.E.S.Klint).

6.6 Tectonics, structures and seismic activity

6.6.1 Major tectonic structures

No major tectonic structures have been recognized crossing the area but a major hiatus occurs between the Late Eocene and the Late Oligocene indicating movements and erosion in the area. The borehole data are illustrated in figs. 41 and 42 where the structural conditions are depicted. The area consists of high-laying clayey till plateaus bordered by meltwater valleys oriented NNE-SSW.

The high laying Oligocene deposits along the northern coast of the Juelsminde peninsula are situated at the northern rim of a graben structure, where the fault lines reach down to at least the Cretaceous. The graben was formed later than the Oligocene (Fig. 43). In the middle part of the graben, more than 200 m of Quaternary sediments are deposited.

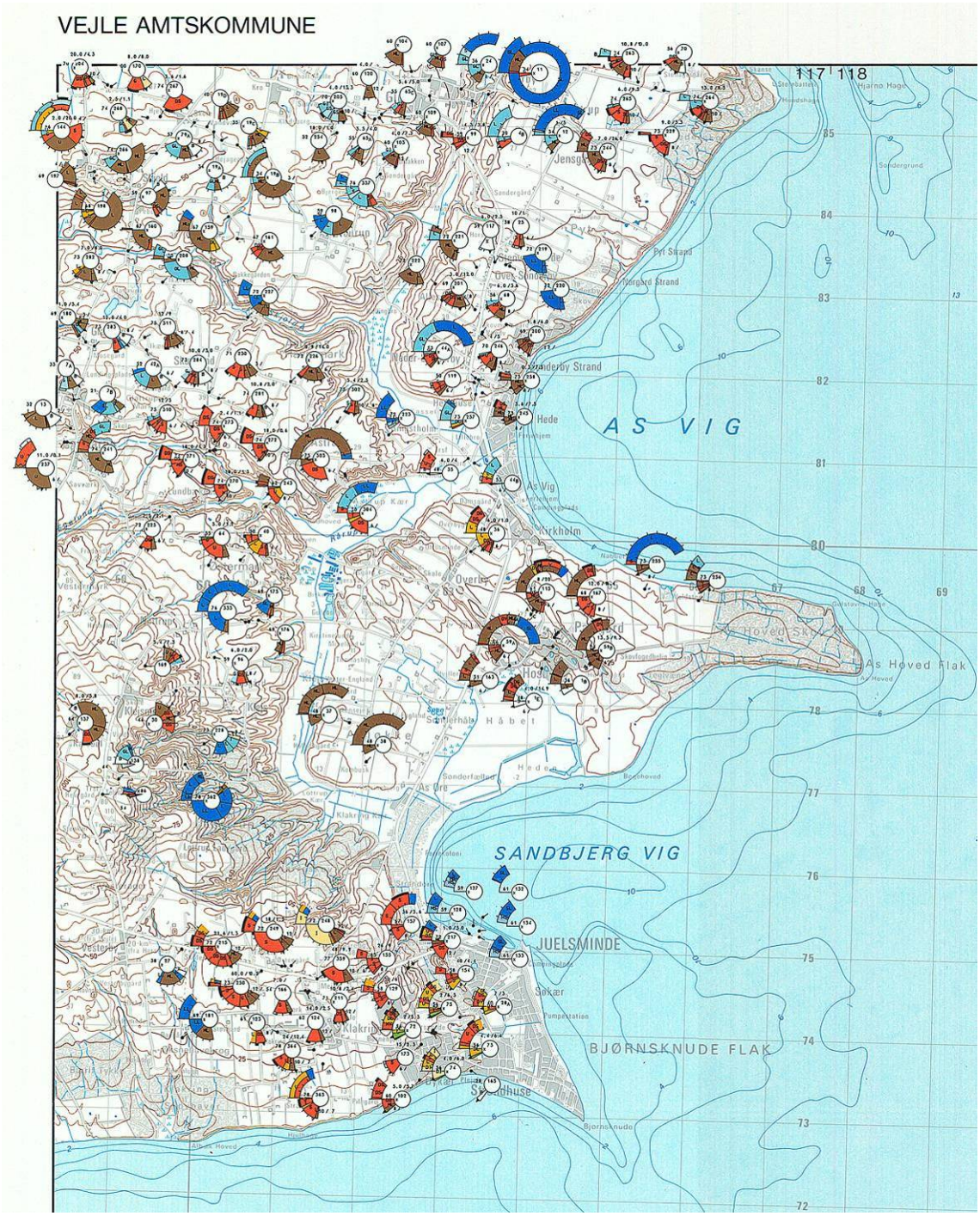


Figure 41. Part of Geological Basic Data map 1313 IV Juelsminde. Legend to the Map: See fig.19. Original Scale 1:50.000 (After Pedersen & Stockmarr, 1979a).

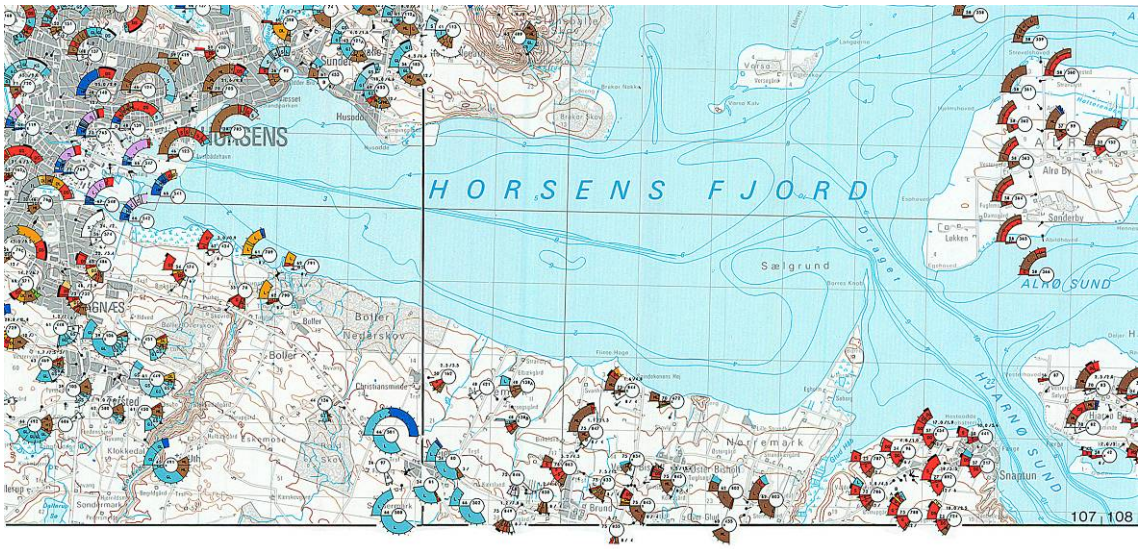
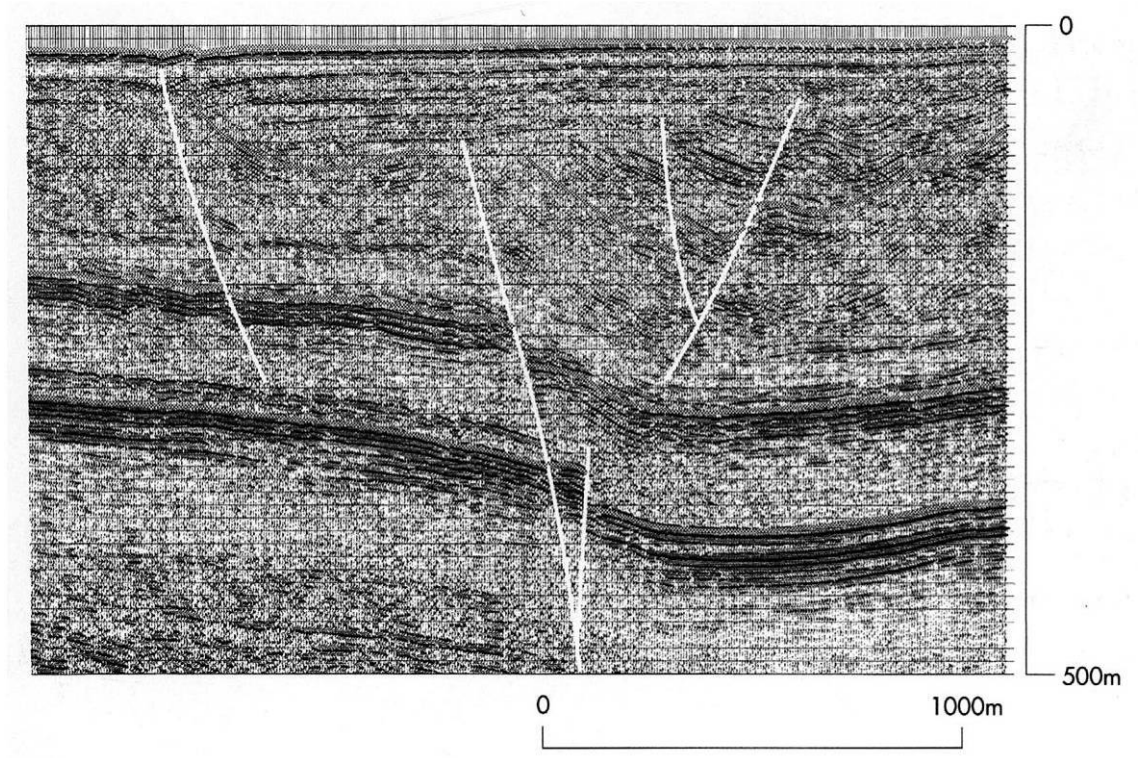
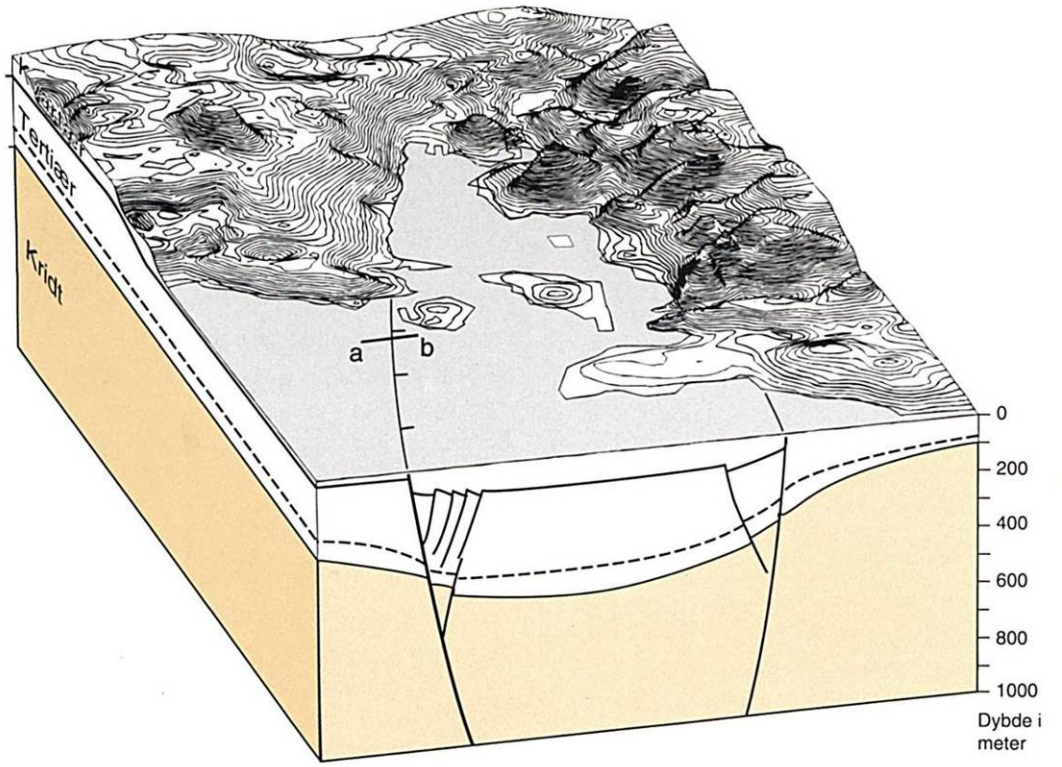


Figure 42. Parts of Geological Basic Data maps 1214 II Horsens and 1314 III Odder. Original scale 1:50.000 (After Pedersen and Stockmarr, 1979b, 1980.)



a.



b.

Figure 43. Graben structure in Horsens Fjord. a. Seismic section N-S in the fjord area located in fig. 21b as line a-b. b. Bloc diagram of the graben structure based on the seismic investigations and boreholes (From Lykke-Andersen,1995).

The Quaternary deposits seem to have been strongly tectonic disturbed by the Weichselian glaciers and several floes of Paleogene clays occur in the glacial sediments. In areas with apparently in-situ occurrence of Paleogene clays, the upper parts of these clays may be disturbed (Fig. 44).

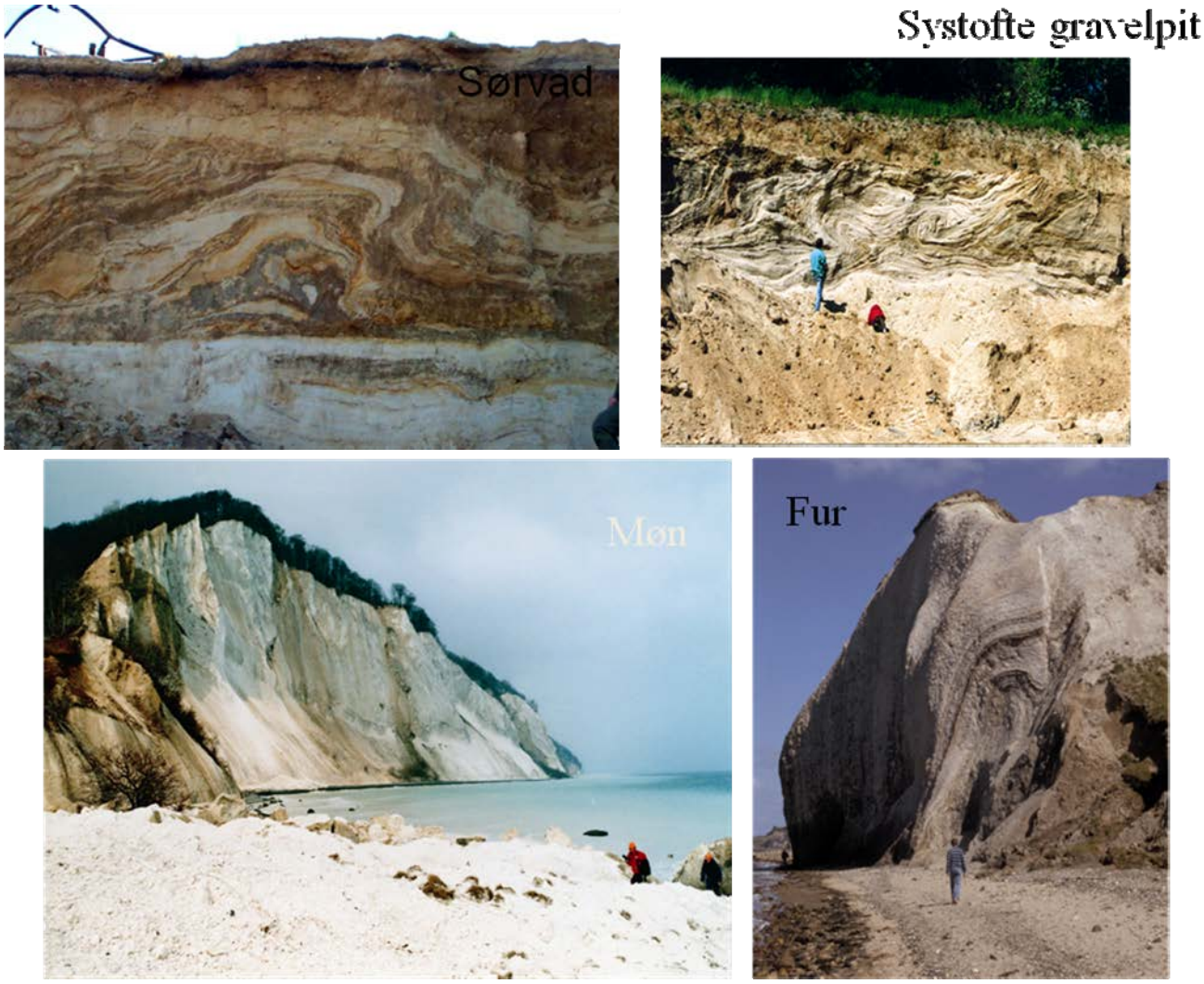


Figure 44. Examples of glaciotectonic disturbances of Quaternary and pre-Quaternary deposits from Sørvad, Sydtofte, Møn and Fur (Photos: K.E.S. Klint).

The Oligocene deposits are the most important sediment in the area as these make up the core of the area and are probably also included in the glacial floes (Fig. 45).

Figure 45. Oligocene brown mica clay.

6.6.2 Fractures

The Quaternary tills are normally cut by vertical, sub vertical and horizontal fractures down to at least 8 m depth. Many biopores often occur in the upper 2 - 3 m (Fig. 46).

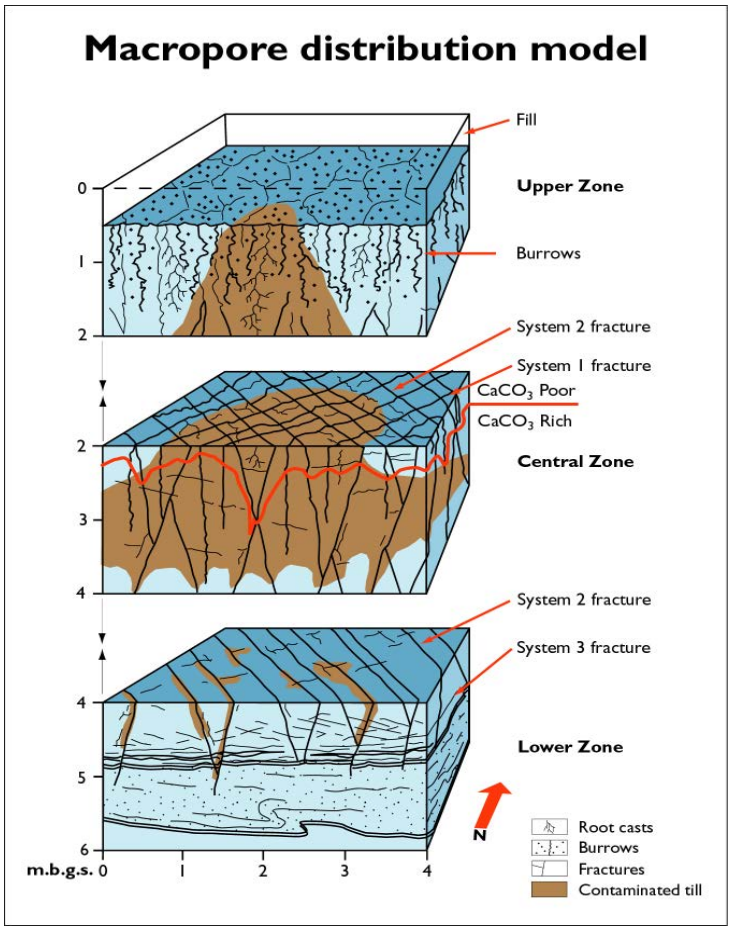


Figure 46. Fracture model in clayey till (From Klint & Gravesen, 1999).

The very fine-grained and plastic clays from Eocene and Oligocene contain fractures which can be a problem for ground stability.

6.6.3 Geological and structural model

The geological model consists of three major units (Fig.47):

A. Quaternary deposits, mainly clayey till. Thickness: 2 - 20 m.

B. Oligocene Brejning Member (Formation) and probably the Vejle Fjord silt and sand. Black and brown mica clay. Thickness: at least 55 - 60 m.

C. Eocene Søvind Marl Formation, up to at least 30 m thick but normally thinner.

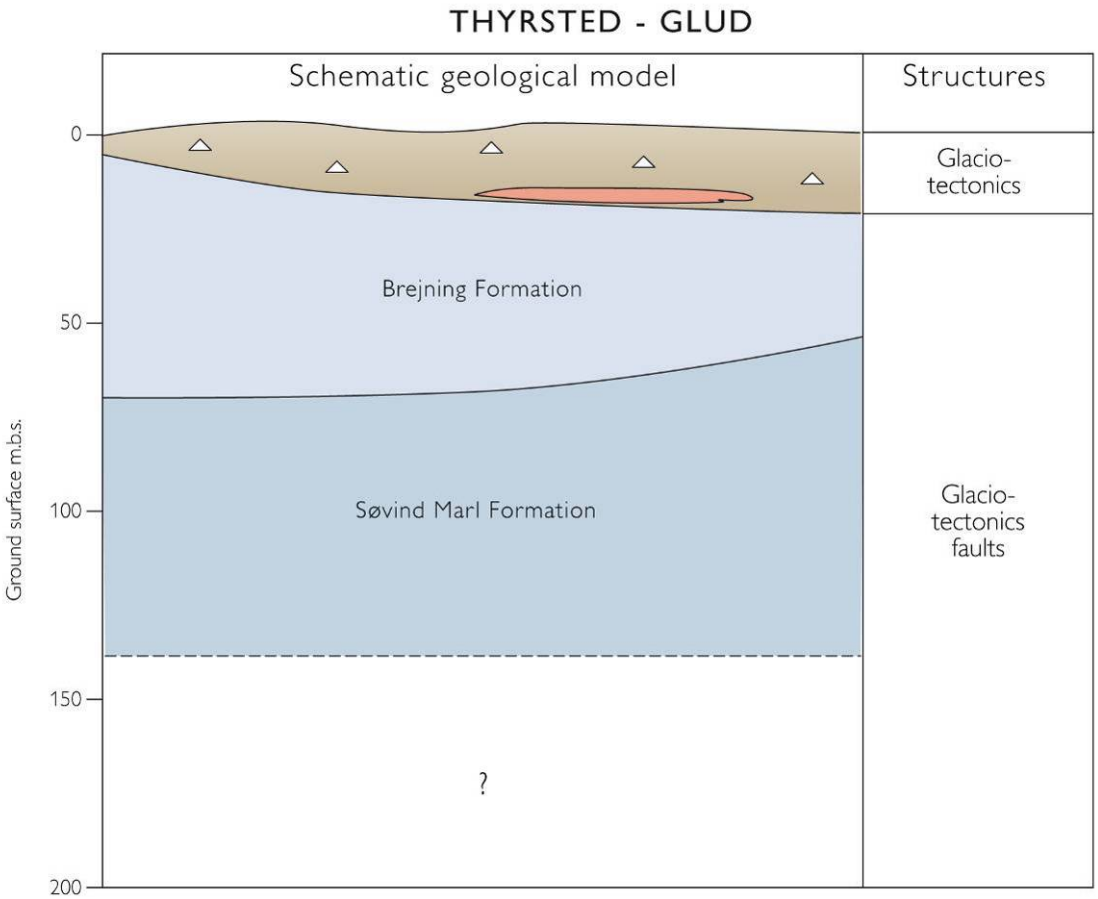


Figure 47. Schematic model of the geological and structural conditions of Area 13.

6.6.4 Earthquake activity

The seismic activity in east Jylland and the near surrounding sea is very low (Fig. 48). Therefore, it is impossible to relate recent seismic activity to the faults and fractures in the bedrocks Other signs of recent movements along the faults and fractures have not been proven.

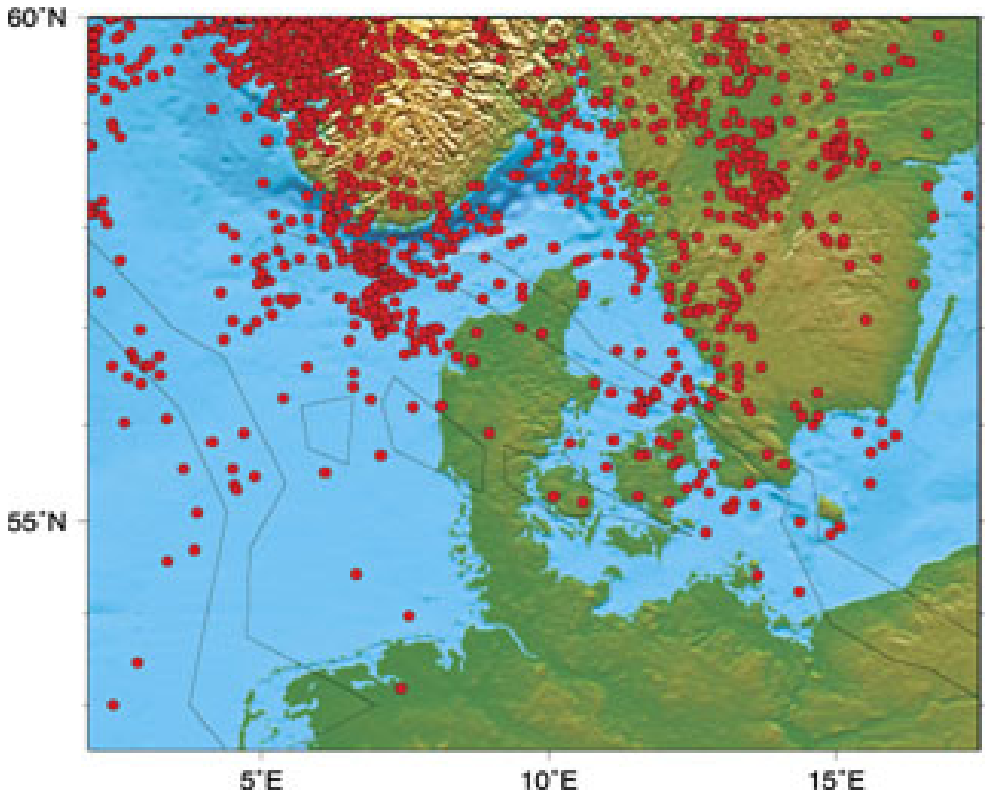


Figure 48. Map of epicentres from earthquakes in the Danish and surrounding area. (From GEUS´s Home page).

6.7 Ground stability

The area is expected to have good ground stability. Nevertheless, it is always important to remember that constructions on and in plastic clays can give problems. This is caused by fractures in the clays and because of large changes in volume at drying and water filling.

Areas with slopes are especially exposed for sliding and flowing of plastic clay material towards lower areas.

6.8 Groundwater hydrogeology

6.8.1 Groundwater characteristics

The Thyrsted - Glud area (Area 13) is positioned in an area characterized by the absence of shallow groundwater bodies and existence of several smaller regional and deep groundwater aquifers (Figs. 49, 50 and 51). The subdivision into groundwater aquifers in water district 60 are thoroughly described by the former Vejle County in the basisanalysis part 1. In the Horsens Fjord catchment management plan (Hovedvandopland 1.9) from the Ministry of Environment, the regional groundwater bodies in the Juelsminde area are located within two sub catchments: Horsens Fjord (DK1.9.2.2) and Nordlige Bælthav (DK1.9.2.3 and DK1.9.2.6). Finally, there are three small, deep groundwater aquifers, situated at a significant distance from each other within the Juelsminde area. These three aquifers are

compiled into one administrative deep groundwater body (DK1.9.3.1) (Fig. 51). All regional and deep groundwater aquifers are meltwater sand deposits. The overall assessment of the chemical and quantitative status of the regional and deep groundwater aquifers is good (see Section 6.9).

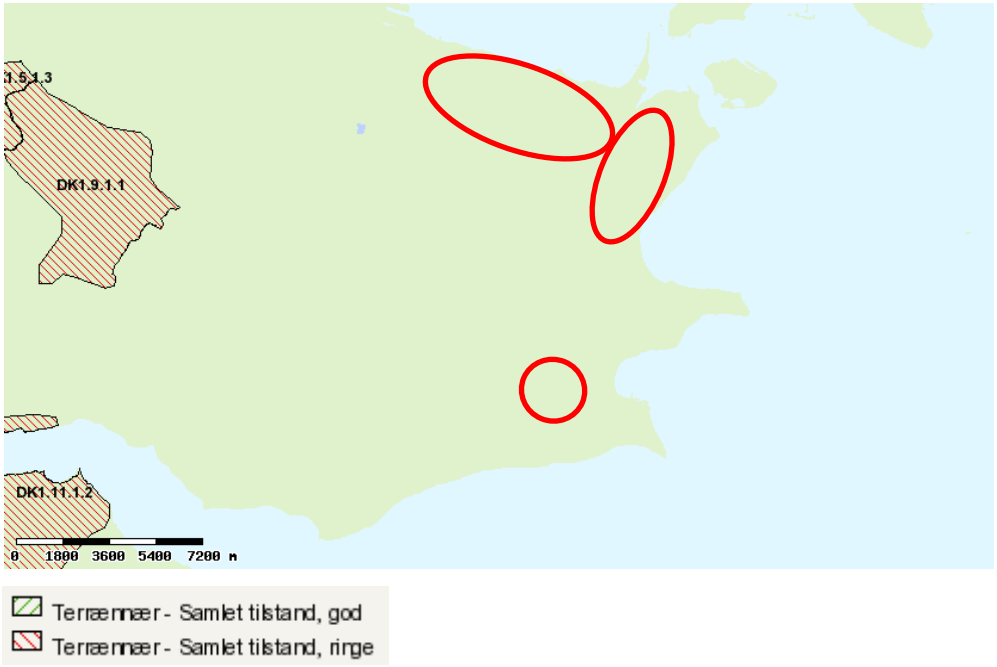


Figure 49. Shallow (or terrain near) groundwater bodies located west of the Juelsminde area (Area 13), shown in red circle (After Ministry of Environment, 2010).

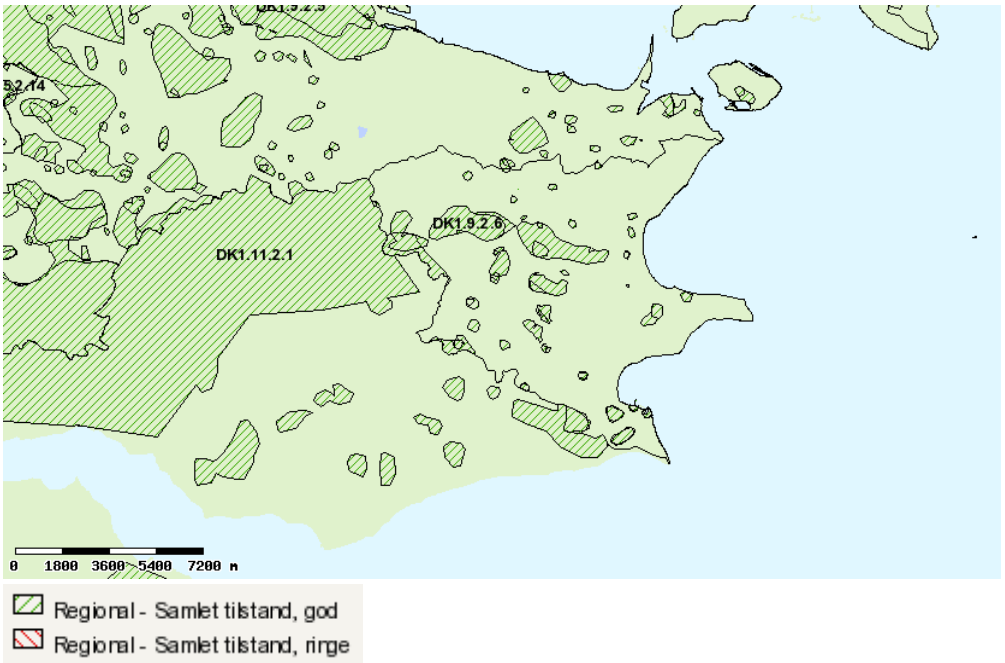


Figure 50. Regional groundwater bodies within and west of the Juelsminde area (Area 13). (After Ministry of Environment, 2010).

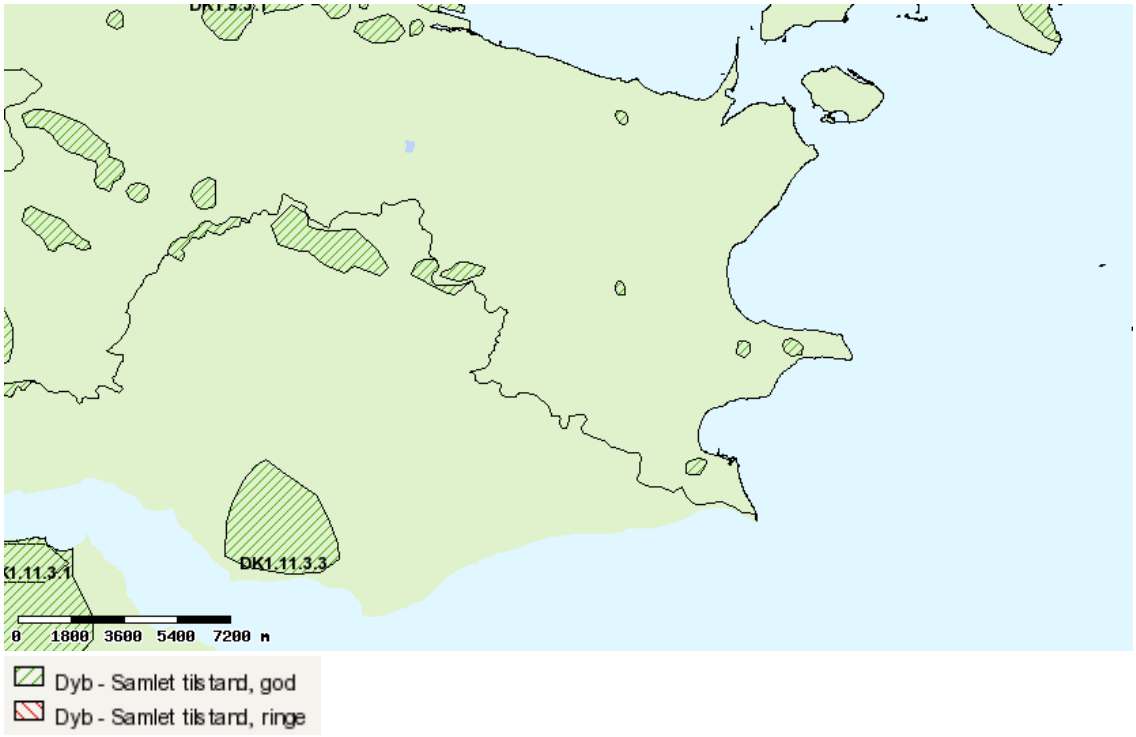


Figure 51. Deep groundwater bodies within and west of the Juelsminde area (After Ministry of Environment, 2010).

6.8.2 Drinking water areas

The groundwater has to be protected to ensure that our current and future need for clean drinking water can be met. It is the Environmental Centres (former counties) responsibility to do the planning, based on the two criteria: First, to make sure that the future necessary quantity of clean groundwater can be abstracted. Secondly, the groundwater aquifers must be protected against recent and future pollution.

As part of the Danish Government´s efforts to protect groundwater, the Environmental Centres have designated areas of major groundwater aquifers, so-called OSD-areas. OSD stands for "Areas of special drinking water interests" (Fig. 52).

The rest of the country is divided into "Areas with water interests" (OD-areas) where good sources of drinking water are also located and "Areas with limited drinking water interests", where it is difficult or impossible to obtain good groundwater quality because the water is more or less contaminated.

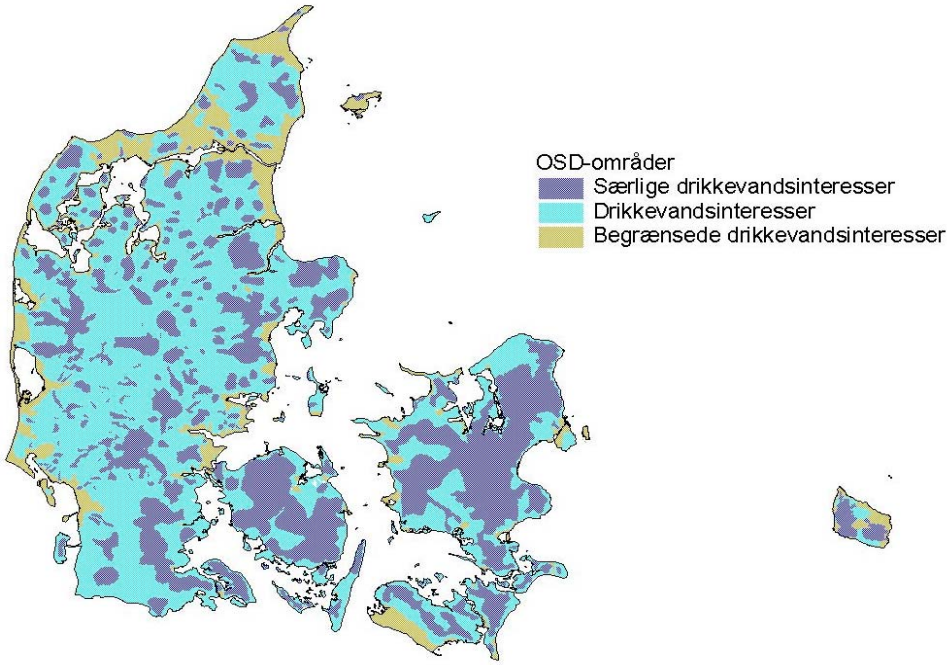


Fig.52. Areas of special drinking water interests (OSD): Dark blue and areas of drinking water interest (OD): Light blue. Areas with limited drinking water interests are olive brown.

The drinking water areas in the Juelsminde area are given in fig. 53. The designated area is mainly categorised as an area with limited or no drinking water interest or as OD area. Groundwater abstraction is distributed as given in fig. 55.

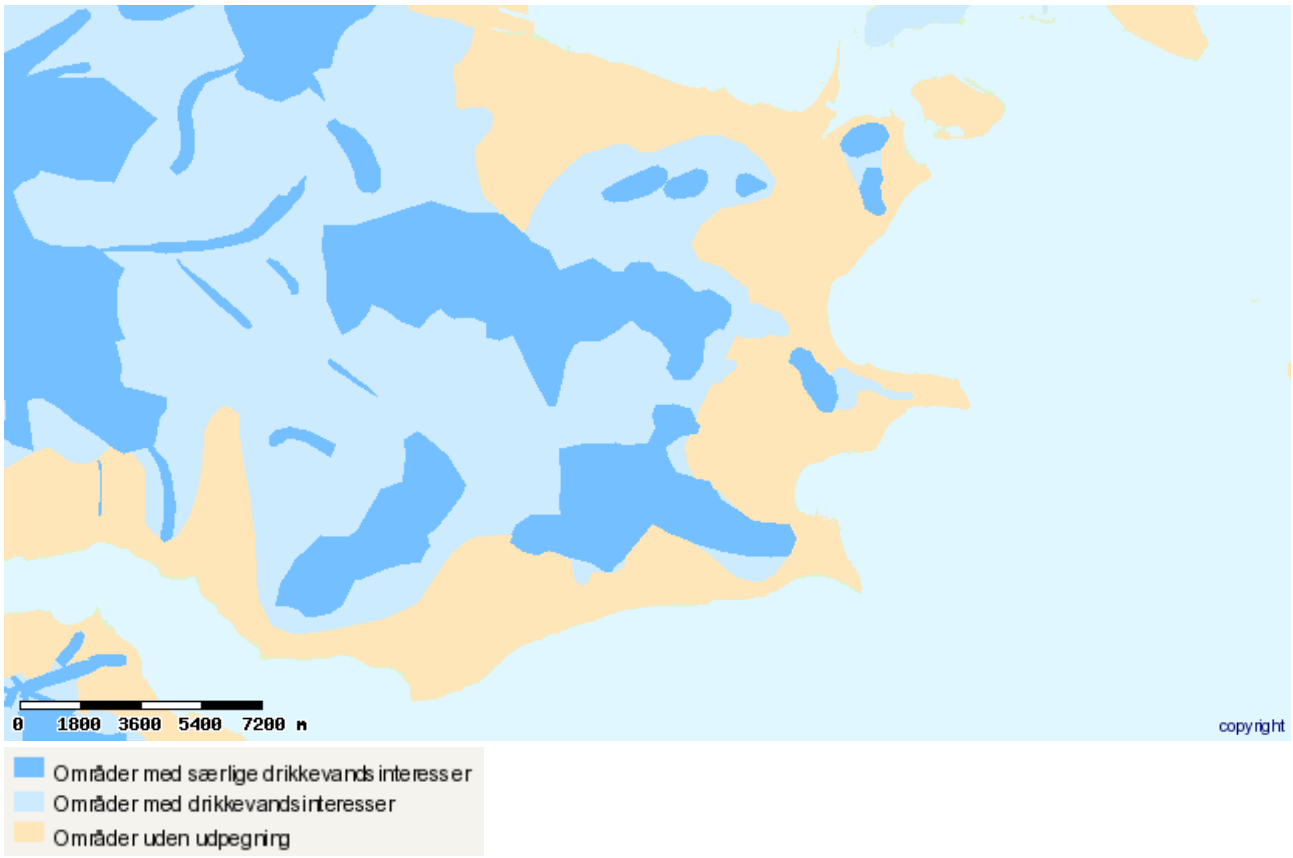


Figure 53. Various drinking water areas situated in the Juelsminde area. Dark Blue: Areas of special drinking water interests (OSD); Light blue: Areas of some drinking water interests (OD); Yellow: Areas with limited or none drinking water interests (http:kort.arealinfo.dk.dk/).

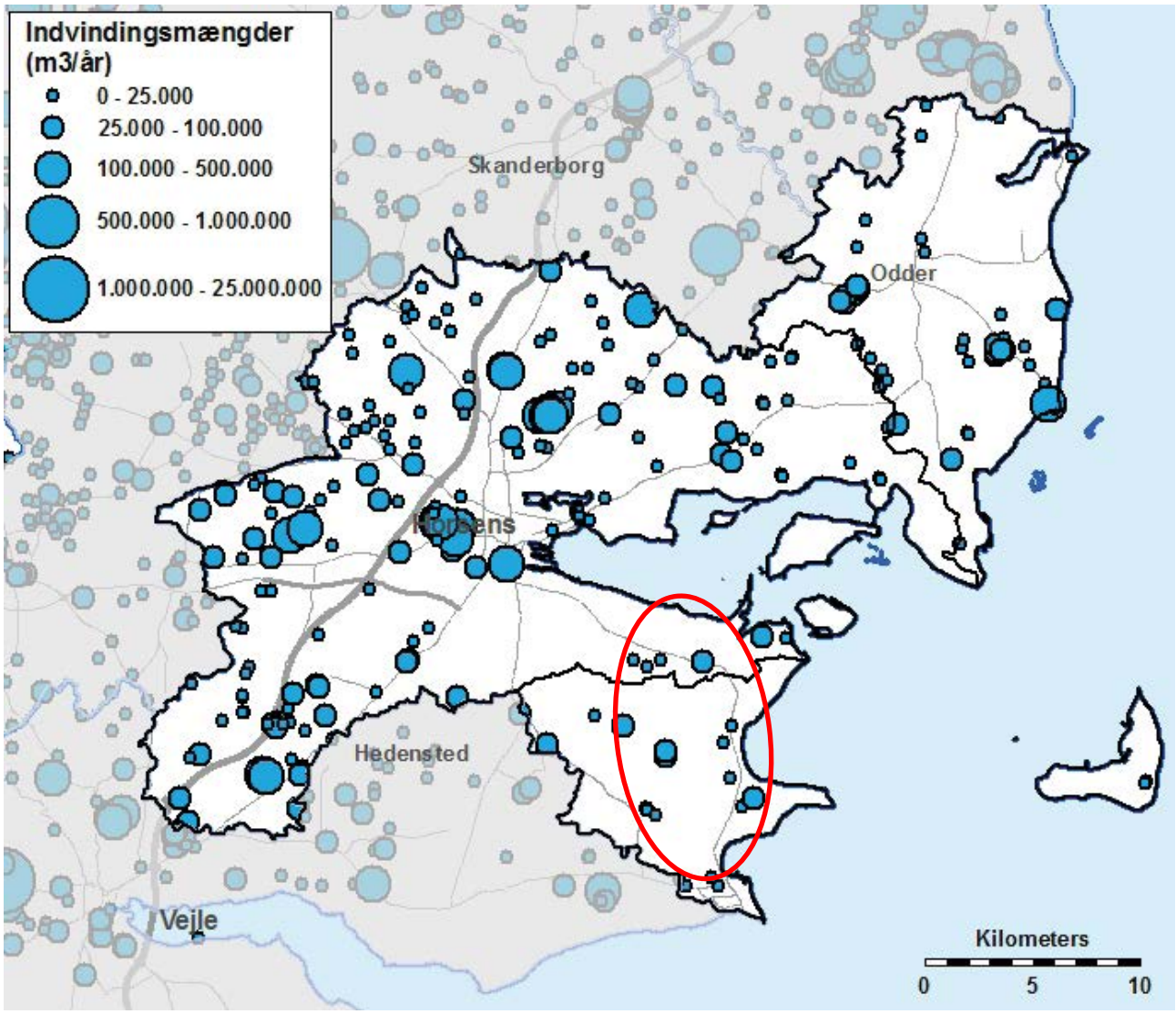


Figure 54. Annual abstraction (in average) from single wells in the period 2003-2005 (from Miljøstyrelsen, 2010).

6.9 Groundwater chemistry

The overall groundwater quality aiming for drinking water purpose has been assessed by the former Vejle and Århus counties and Environmental Centre Århus for the regional and deep groundwater bodies and reported in the catchment management plan "Hovedvandopland 1.9, Horsens Fjord" from the Ministry of Environment. The groundwater chemistry fulfils the EU criteria to be of good status.

6.10 Climate and climate changes

The actual climate and the expected future climate changes and sea level development is described in Gravesen et al. (2010, Rep. No. 2). It is not expected that climate changes will

affect the area during this century. The expected sea level rise may cause flooding of the coastal section but will not necessarily cause erosion.

6.11 Restrictions and limitations

There are no raw material digging and interest areas in Area 13.

The designated area north of Juelsminde has no restriction in accordance to the NATURA 2000 regulation. An adjacent NATURA2000 habitat area is located along the south coast towards Vejle Fjord (Fig. 55).

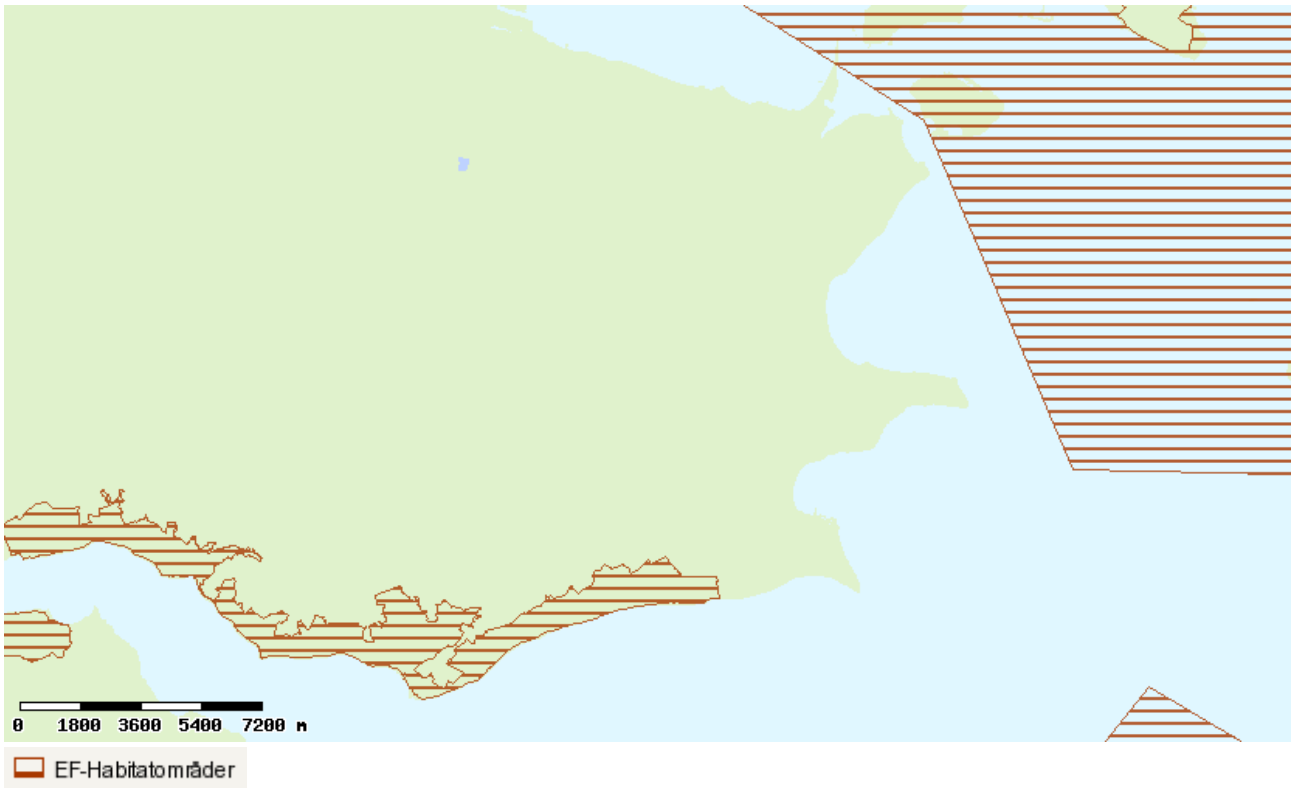


Figure 55. NATURA2000 habitat areas in the Lillebælt region (After Ministry of Environment, 2010).

6.12 Summary of the area conditions

Amount of data:
Sparse: Relatively few boreholes. No geophysical surveys.

Homogeneous conditions and isolation of the waste by low, permeability layers:
Perhaps perfect on depth below 30 m but the framework of the fractures below 10 m is unknown. The fracture problem has to be considered in relation to other areas.

Stability
Good stability on surface and depth but problems can occur on slopes.

Seismic activity and tectonic movements
No seismic and tectonic movements or problems.

Groundwater conditions
The groundwater conditions in clay deposits should be positive but the variation in the level of the groundwater table has to be analysed if the disposal has to be established under saturated conditions. The groundwater flow will be towards the sea.

Dilution of pollution and retention of pollution
No Danish studies have been carried to document dilution capabilities or retention of radio-nucleides in glacial till sediments.

Drinking water interests
No OSD areas within the Area 13. Only minor local supplies occur.

Groundwater chemistry, non- aggressive components
The groundwater contains apparently no aggressive components.

Ground surface conditions
Processes on the ground surface should not give problems on a disposal.

Climate extreme conditions
Climate changes and extremes as storms or heavy precipitation will not have influence on a disposal.

Other restrictions
Apparently no other restrictions will give problems.

6.13 Final Remarks

The Quaternary sediments mainly consist of clayey tills although sand and gravel layers occur. The area reaches Eocene and Oligocene deposits. It is a problem to describe the structural framework. The Eocene plastic clays are suitable for disposal of radioactive waste but the Oligocene clays are more coarse-grained with silt and sand inclusions why these sediments and have to be analysed in detail.

7. Area 14. Lysnet Hills, Haslund – Vissing, East Jylland

7.1 The location of the area

The area is located between Haslund and Vissing on the Lysnet hill plateau east of Ølst and Hinge and southwest of Randers (Figs. 56 and 57).

Figure 56. Location of the area. Area 14 is located in eastern Jylland, south-west of the city of Randers.

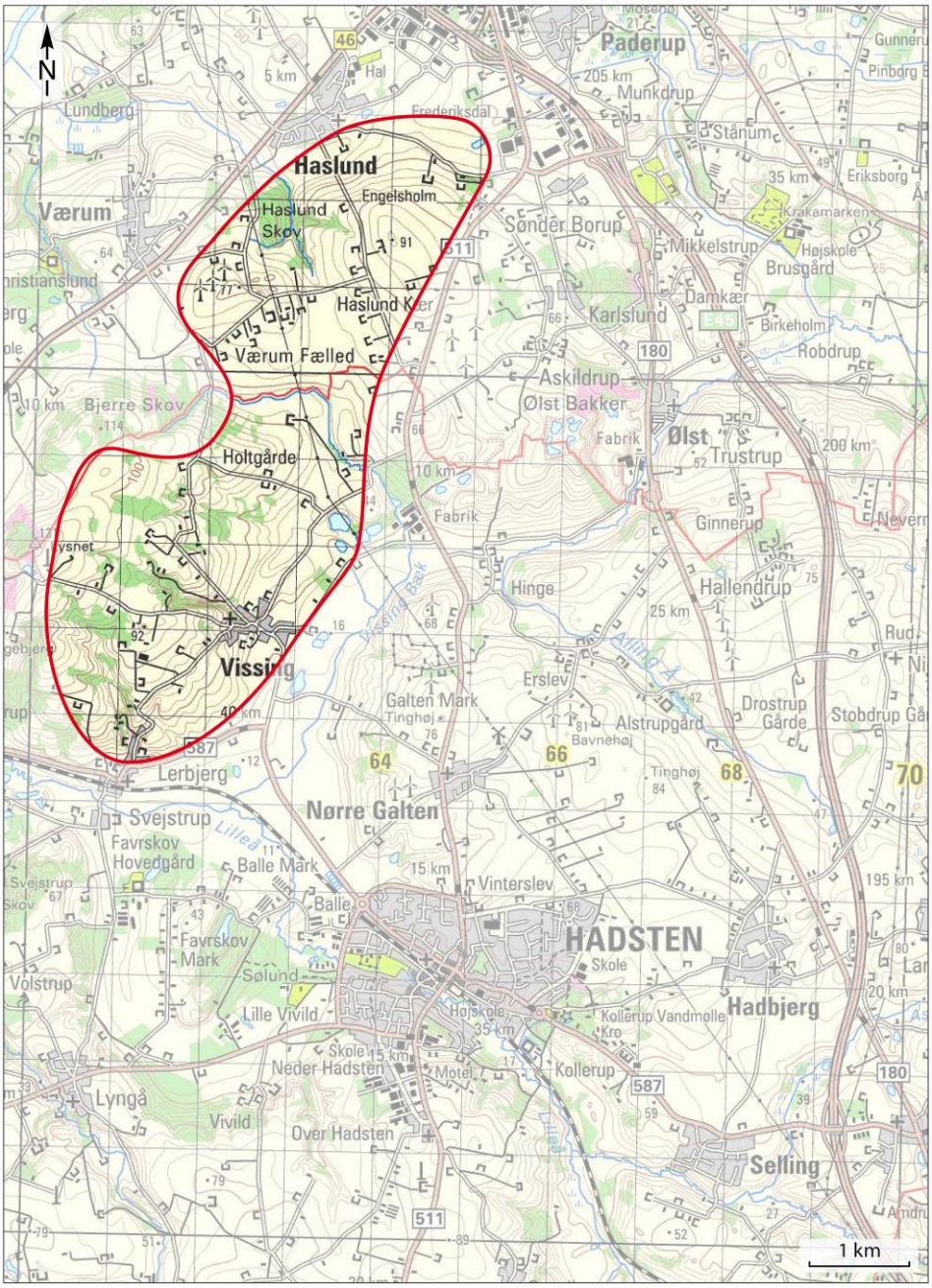


Figure 57. A detailed map of area The Lysnet Hill area is found east of Ølst and Hinge.

7.2 Terrain, topography and processes

The area is located in the central part of eastern Jylland. The size of the area is c. 17.5 km^2. The area is characterized by a great hilly landscape. No more than three large hills fill out the area, two in the northern part of the area and one very big in the southern part. The tops of the hills are situated 77, 91 and 110 meters above the sea level. From the top of the hills, the landscape slopes more or less deeply down to levels around 15 – 20 m.a.s. The lowest areas are found in the central and eastern parts of the area. Two streams are found

in the area; one toward north-west and one crossing the central part. Southeast of the central stream, some small lakes are located.

The predominating part of the area is used for agriculture. Some c. 10 % of the area is covered by woods. Several minor roads cross the area. The small village Vissing is located toward southeast. A number of houses are located along the roads, especially in the northern part of the area that also includes a cluster of windmills. The central and northern part of the area is crossed by some major (NW-SE running) supply cables for electricity.

Owing to the relatively gentle relief and intensive cultivation, the surface processes (soil creep, frost – thaw processes, soil development etc.) proceed slowly and undramatic. The most active surface processes are found in/along the streams.

The southern half of the area is part of an area of National Geological Interest (no. 47).

At fig. 58, the high plateau area towards the west is seen.

Figure 58. A view towards the hill plateau of the area.

7.3 Surface geology and profiles

The geological surface map shows that the area is dominated by approx. 50 % clayey tills and meltwater sand and gravel and 50 % plastic clays (Fig. 59). Clay pits occur just outside the area at Ølst and Hinge but a sand and gravel pit is found at Lysnet.

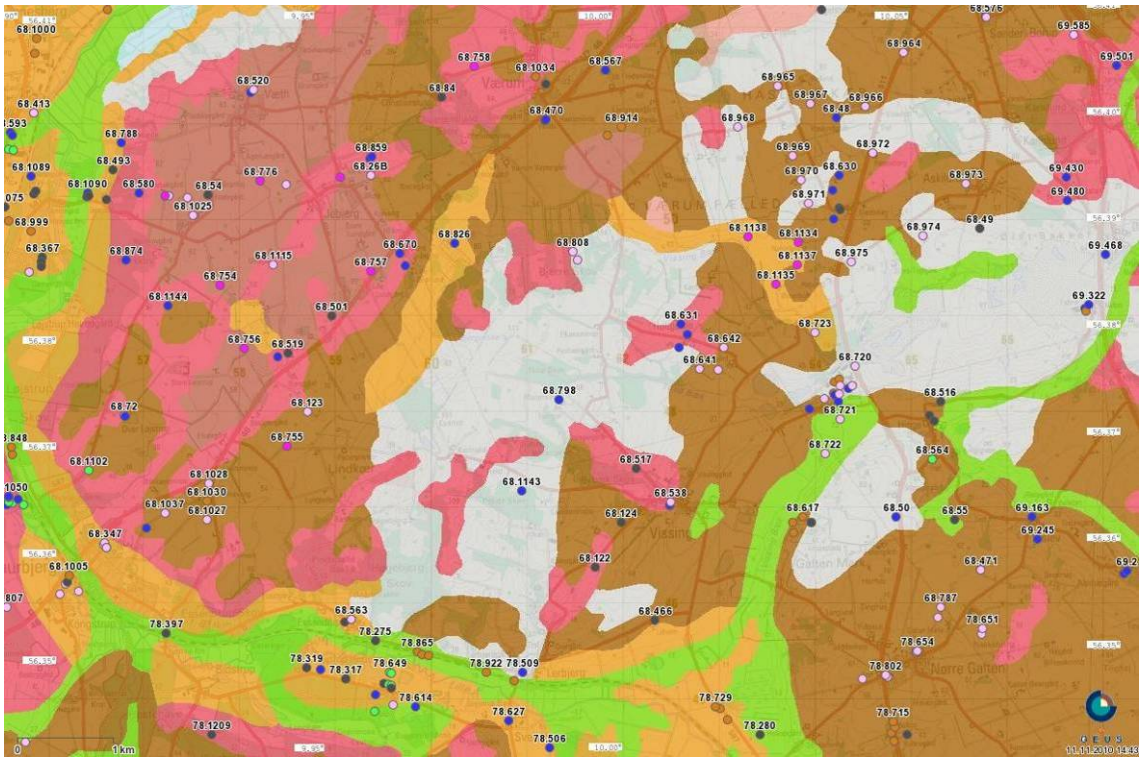


Figure 59. Quaternary surface map from the area with the boreholes from the Jupiter Database at GEUS. Originally scale 1:200.000 (GEUS´s Homepage, after Pedersen, 1989). Legend: Brown: Clayey till; Red and orange; Meltwater sand and gravel; Green: Holocene freshwater deposits; White: Pre-Quaternary deposits. Legend for boreholes: See fig. 60.

7.4 Boreholes

Several boreholes are located in the area but most of them are situated near the boundary of the area. Especially the middle part of the area lacks information. Many samples are lithological described and related to formation but only a few samples have been investigated for microfossils and dated. The area is covered by geophysical surveys as e.g. SkyTem.

The larger area with the boreholes can be seen in fig. 60. A more detailed map is shown in fig. 61. A borehole log from DGU no. 68.1134 shows the build up of the upper layers in the area (Fig. 62).

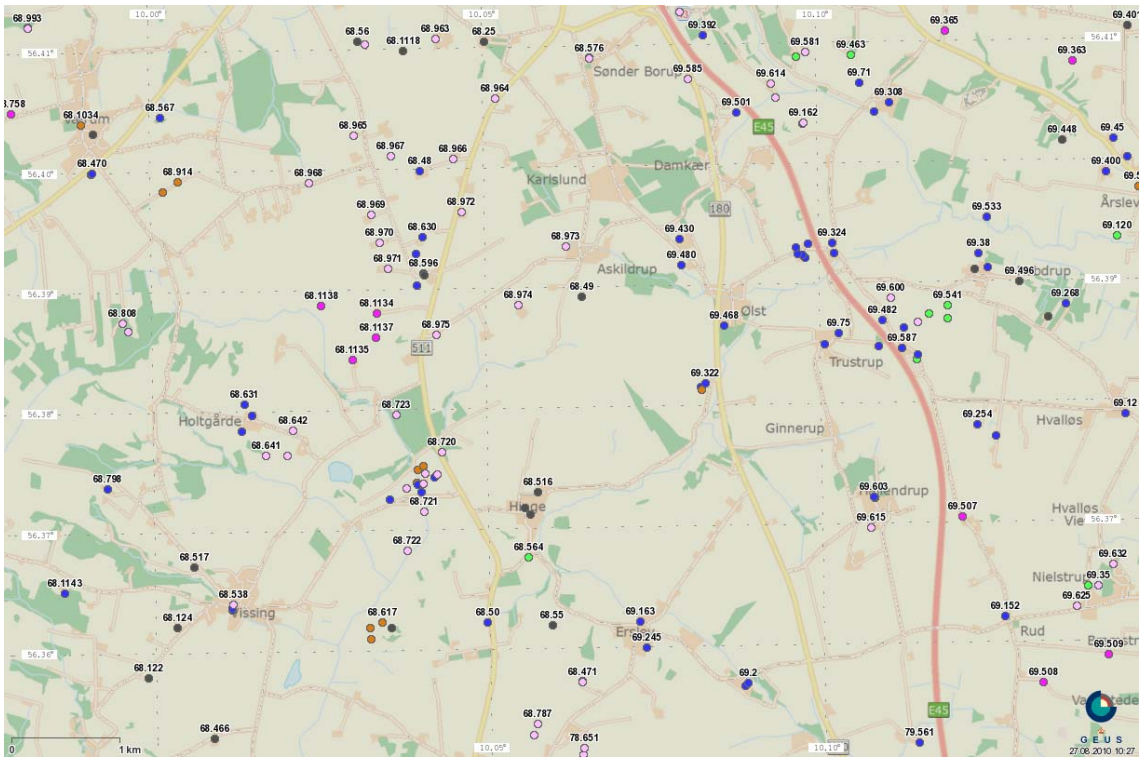


Figure 60. Map of the locations of boreholes from the Jupiter database at GEUS. Legend: 68.1134: DGU No., Blue dot: Water supply well; Red dot: Geotechnical borehole; Pink dot: Raw material borehole; Green dot: Other borehole; Light red dot: Abandoned borehole; Black dot: Unknown purpose.

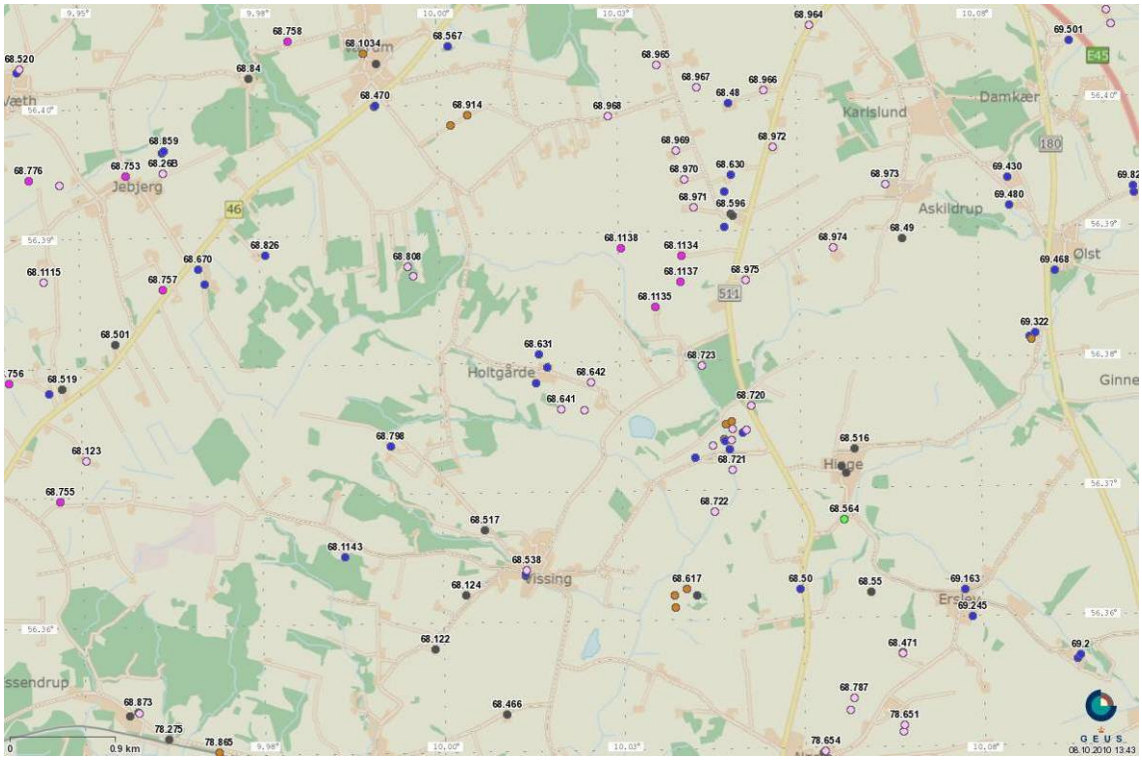


Figure 61. Detailed map of the borehole locations in the area. Legend: see fig. 60.

De Nationale Geologiske Undersøgelser for Danmark og Grønland

Udskrevet 27/8 2010 Side 1

BORERAPPORT

DGU arkivnr: 68. 1134

Borested : Randersvej 85, Nyborggård
8370 Hadsten

Kommune : Favrskov
Region : Midtjylland

Boringsdato :

Boringsdybde : 15 meter

Terrænkote : 54,5 meter o. DNN

Brøndborer : Poul Christiansen,Højslev
MOB-nr :
BB-journr :
BB-bornr :

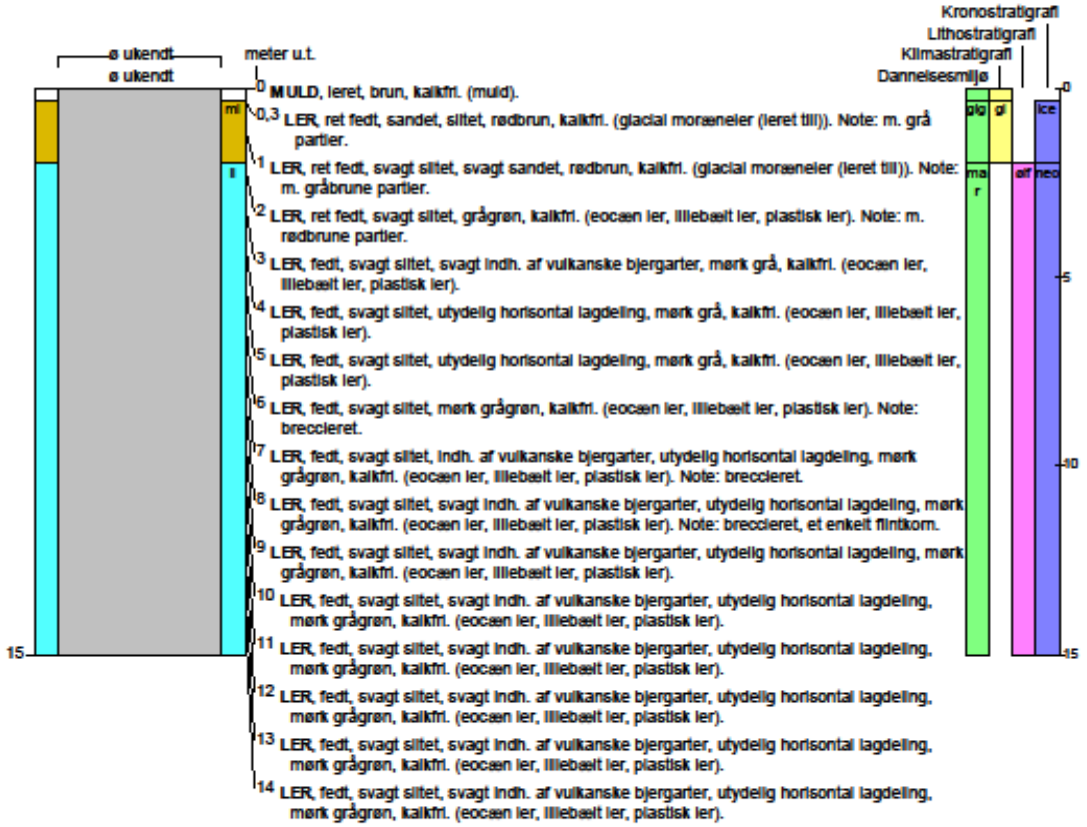
Prøver
- **modtaget** : 18/11 2009 **antal** : 15
- **beskrevet** : 5/2 2010 **af** : AMN/CDI
- **antal gemt** : 0

Formål : Råstofboring
Anvendelse :
Boremetode :

Kortblad : 1315IIINV
UTM-zone : 32
UTM-koord. : 563821, 6249752

Datum : EUREF89
Koordinatkilde : GEUS
Koordinatmetode : GPS

Notater : 3 -15 m Formodentlig Stolleklint Ler. Nærmere undersøgelser pågår. (Farven er subjektivt beskrevet).



Aflejringsmiljø - Alder (klima-, krono-, litho-, biostratigrafi)

meter u.t.			
0	-	0,3	terrigen - postglacial
0,3	-	2	glacigen - glacial - pleistocæn (icenien)
2	-	15	marin - nedre eocæn (ølst formation)

Figure 62. Geological borehole log for DGU no. 68. 1134. Legend: ML: clayey till, L: Paleogene clays.

7.5 Sediment and rock characteristics, mineralogy and chemistry

7.5.1 Pre-Quaternary deposits

The map of the pre-Quaternary deposits is seen in fig. 63.

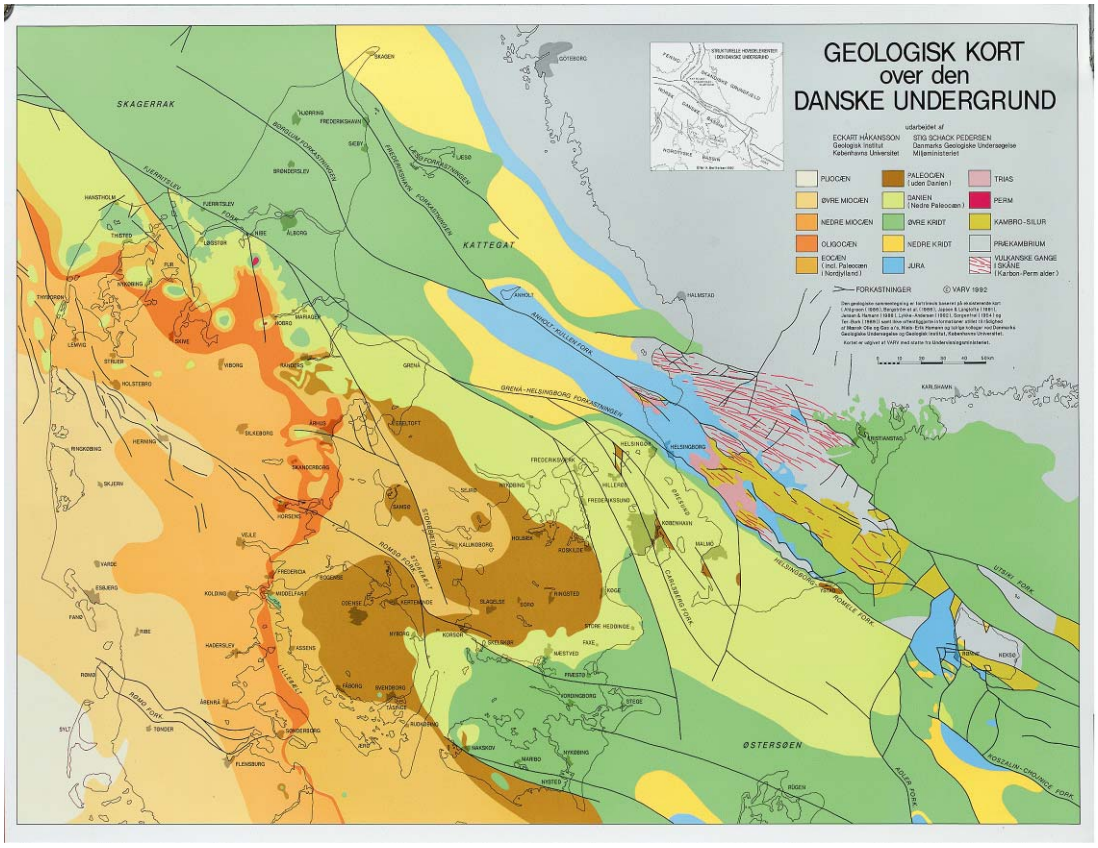


Figure 63. Map of the pre-Quaternary surface: Time units. Original scale: 1:50.000. Legend: Red lines: Precambrian intrusions; Grey: Precambrian; Olive: Cambrian-Silurian; Red: Permian; Light red: Triassic; Blue: Jurassic; Yellow: Lower Cretaceous; Green: Upper Cretaceous; Light green: Danian; Brown: Paleocene; Yellow olive: Eocene; Red brown: Oligocene; Light yellow brown: Lower Miocene; Very light yellow brown: Upper Miocene; White: Pliocene (Håkansson & Pedersen, 1992).

The pre-Quaternary deposits east of the area are known from the clay pits at Ølst and Hinge Bakker (hills) southwest of Randers where plastic clays have been dug for many years and from an old road cut at Ølst. Some boreholes in the area also contribute to the knowledge of the clays. In the pits, the Paleogene deposits consist of the Holmehus Formation, the Ølst Formation, the Røsnæs Clay Formation, the Lillebælt Clay Formation, the Søvind Marl Formation and the Viborg Formation with a total thickness of approx. 100 m. The deposits have been strongly deformed by glaciers several times during the Elsterian,

Saalian and Weichselian. At present, it is especially the 40 m thick green grey non-calcareous Lillebælt Clay Formation that is exploited.

The clay fraction is 60 - 90 % and smectite minerals dominate.

The mapping of the Quaternary deposits has shown that the plastic clay occur very close to the surface in large parts of the area (Fig. 59).

From the boreholes within the area (which is a hill plateau up to 130 m.a.s.), only few information can be obtained but boreholes just outside the area can give some information about the following formations:

Towards the north, at Værum, two deep boreholes show nearly 80 - 100 m very fine-grained, plastic dark grey, green and brown clays probably, from the Eocene and Paleocene, above Danian limestone described as hard and flint bearing.

Towards the west, the Paleogene deposits occur below 72 m Quaternary sediments. These sediments consist of very fine-grained plastic brown and olive grey non-calcareous clay with horizontal lamination (at least 22 m thick). The clay may belong to the Lillebælt Clay Formation. The clays seems to be eroded by the Quaternary glaciers which deposited tills and meltwater sediments along the margin of the clay area.

The Paleogene clays are reached 21 m below surface towards the south and again, the Quaternary glaciers have eroded and deposited in this area.

In the middle part of the area only few boreholes give information. The Eocene plastic clays are found near the ground surface at Holtgårde and in some boreholes, the clays occur down to c. 14 - 32 m below ground surface. At Vissing, the clays occur between 7 and 26 m below ground surface. Just outside the area, at Hinge, a deep borehole reaches clays 18 m below surface and the following 50 m consist of Paleocene and Eocene plastic clays, probably from the Røsnæs Clay Formation, Ølst Formation, Holmehus Formation/ Ælbelø Formation, Kerteminde Marl Formation, probably resting on Danian Limestone.

In the area just north-west of Hinge, the boreholes show deposits from the Røsnæs Clay Formation: Red brown and grey sticky plastic clay up to 18 m thick and the Ølst Formation: Dark grey and grey green fine-grained to silty clay, faintly laminated, non-calcareous and with volcanic ash layers, 14 m thick. Towards the east, just outside the area, Oligocene fine-grained clays from the Viborg Formation are the top layers.

In the northeastern corner of the area, at Haslund Kær, several boreholes for clay exploitation are drilled. In this area, very fine-grained clays from the Lillebælt Clay Formation, Røsnæs Clay Formation and the Ølst Formation are reached below 2 - 3 m Quaternary tills. The borehole information points to a large clay body disturbed by glaciotectonic.

Examples of the clay types from the Albæk Hoved can be seen on figs. 64, 65, and 66. The clay pit at Ølst is seen in fig. 67.

Figure 64. The Ølst Formation, Eocene. Clay with green volcanic ash layers below red brown plastic clay from the Røsnæs Clay Formation. Albæk Hoved Klint. Juelsminde.

The geophysical SkyTem surveys of the area have mapped the limestone deposits below the up to 80 m thick plastic clays.

Figure 65. Green plastic clay, probably the Eocene Lillebælt Clay Formation from Albæk Hoved Klint, Juelsminde.

Figure 66. Section from the Albæk Hoved Klint, Juelsminde, Jylland. Red and green plastic clays from the Lillebælt Clay and Røsnæs Clay Formations.

Figure 67. The clay pit at Ølst seen from the east.

7.5.2 Quaternary deposits

The Quaternary deposits in the hill plateau area consist of clayey tills and meltwater sand and gravel (Fig. 59).

Along the margin of the hills in the valleys, Quaternary clayey tills, sand and gravel up to 30 m thick are found. The tills are silty and gravelly. The upper 10 m can be oxidized and non-calcareous and olive brown. The underlying till is olive brown and calcareous. Further down, more olive grey and calcareous meltwater sand and clay can occur. The meltwater sand is fine to medium-grained and often gravelly. The upper approx 3 - 10 m layers can be oxidized and non-calcareous (Fig. 68).

On top of the very fine-grained Paleogene clays on the hills, a thin cover of clayey or sandy till occurs. The clayey till is silty, sandy, yellow brown and mainly non-calcareous. The sandy till is yellow, clayey, stony and non-calcareous. The layers are 1 - 5 m thick and sometimes the Paleogene clays occur at the ground surface (Fig. 59). Clayey till is often rather stony (Fig. 68).

Figure 68. Example of clayey, sandy and stony till deposits.

7.6 Tectonics, structures and seismic activity

7.6.1 Major tectonic structures

In the map of the pre-Quaternary deposits (Fig. 63) no structures are marked. Borehole data around in the Ølst and Hinge indicate a fault line north-south between Hinge and Ølst with a slip/sping high in the Danian limestone of 25-30 m. Fault activities along this fault line can also have disturbed the Paleocene, Eocene and Oligocene deposits.

The outcrops in the Ølst and Hinge clay pits show that parts (at least 80 m) of the Paleogene clays have been disturbed by several glacier advances during the Saalian to the Weichselian and only the lower parts of the Ølst Formation and older Paleocene clays seem to be in-situ in the pits. Also younger landslides are occurring in the clays which have moved material towards lower areas. The hill plateau has been interpreted as an erosion remnant from the Saalian and information from the Lysnet pit indicate glaciotectonic disturbances from the S and SE. The Paleogene clays have probably been pushed up, faulted and folded by Saalian glaciers.

The hill plateau has been eroded in the margins and valleys are crossing the area and bordering the plateau (Fig. 69).

Figure 69. Hill plateau towards the west.

7.6.2 Fractures

The Quaternary tills are normally cut by vertical, sub-vertical and horizontal fractures down to at least 8 m depth. Many biopores often occur in the upper 2 - 3 m.

The very fine-grained and plastic clays from Eocene and Oligocene contain fractures which can be a problem for ground stability.

7.6.3 Geological Model

The model of the area consists of the following units (Fig. 70):

A. Quaternary, mainly clayey till with meltwater sand and gravel intercalations, 0 - 5 m thick on the hill area but up to 30 m thick in the valleys.

B. Oligocene deposits, perhaps found in the area.

C. Eocene and Paleocene clays, up to 80 - 100 m thick (Holmehus, Ølst, Røsnæs Clay and Lillebælt Clay Formations)

D. Danian limestone from 80 - 100 m below surface.

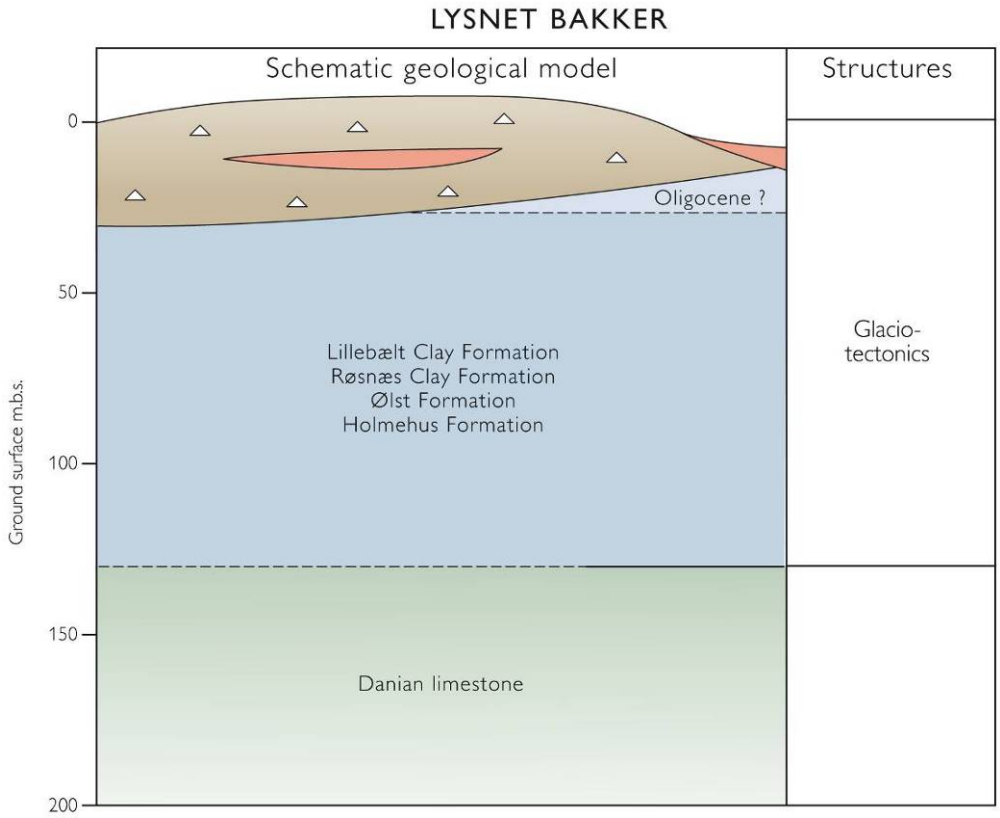


Figure 70. Schematic geological model of the area.

7.6.4 Earthquake activity

The seismic activity in east Jylland and the surrounding sea is very low (Fig. 71). Therefore it is impossible to relate recent seismic activity to the faults and fractures in the bedrocks. Other signs of recent movements along the faults and fractures have not been proven.

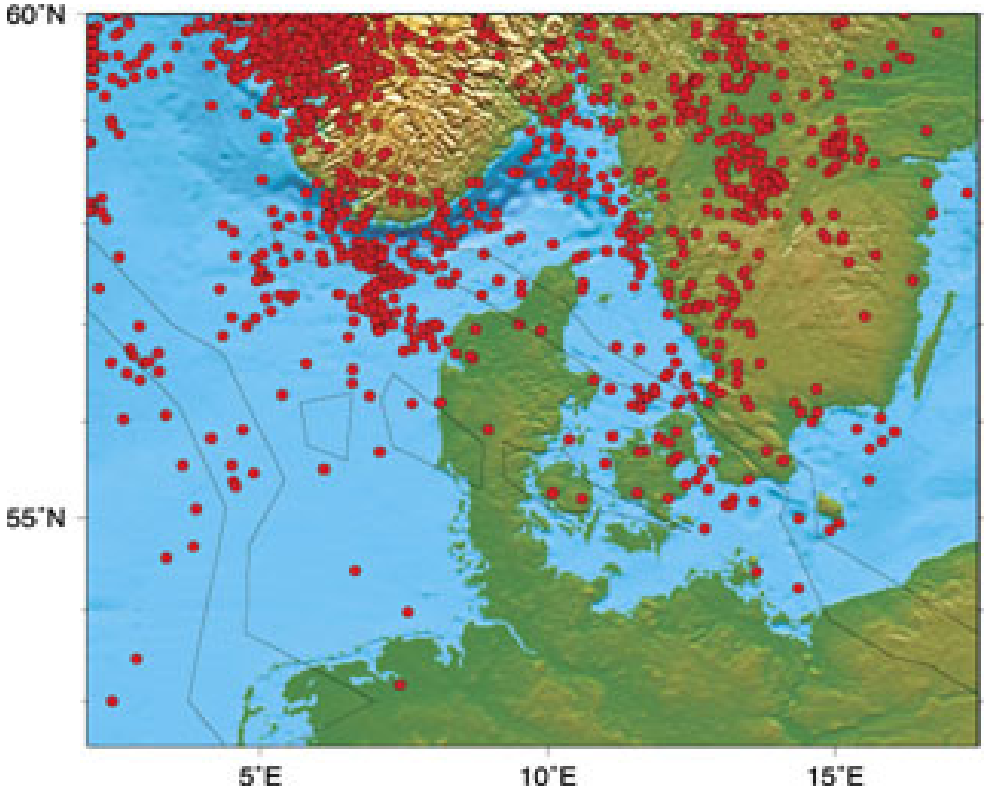


Figure 71. Map of epicentres from earthquakes in the Danish and surrounding areas. (From GEUS's Home page).

7.7 Ground stability

The area is expected to have good ground stability. Nevertheless, it is always important to remember that constructions on and in plastic clays can give problems. This is caused by fractures in the clays and because of large changes in volume at drying and water filling.

Areas with slopes are especially exposed for sliding and flowing of plastic clay material towards lower areas.

7.8 Groundwater hydrogeology

7.8.1 Groundwater Characteristics

The Lysnet bakker area (Area 14) is positioned in an area characterized by presence of all three categories of groundwater bodies: one shallow (DK1.5.1.1); parts of four regional (DK1.5.2.3; DK1.5.2.5; 1.5.2.10; DK1.5.2.10) and one deep groundwater bodies (DK1.5.3.8) (Fig. 72, 73 and 74). Subdivision into groundwater bodies are thoroughly described by the former Århus County in the basisanalysis part 1. All the groundwater bodies belong to the Randers Fjord main catchment and are described in the catchment management plan (Hovedvandopland 1.5 Randers Fjord) of the Ministry of Environment. The shallow and regional groundwater bodies are all consisting of sand materials and the deep groundwater body of limestone deposits. The overall assessment of the chemical and quantitative status of the shallow and of some of the regional bodies is poor. Meanwhile, the other part of the regional and the only deep groundwater bodies are assessed to have a good status (see Section 7.9).

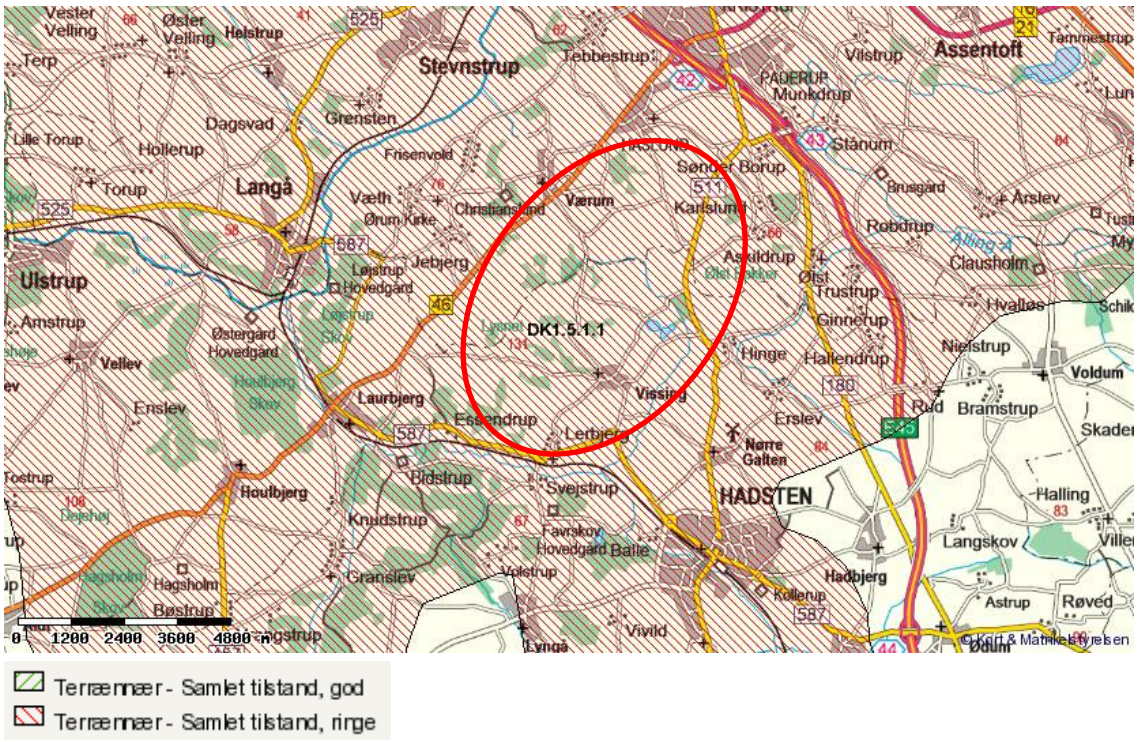


Figure 72. Shallow (or terrain near) groundwater body in the Lysnet bakker area (Area 14) located between Randers and Hadsten, shown in red circle (After Ministry of Environment, 2010).

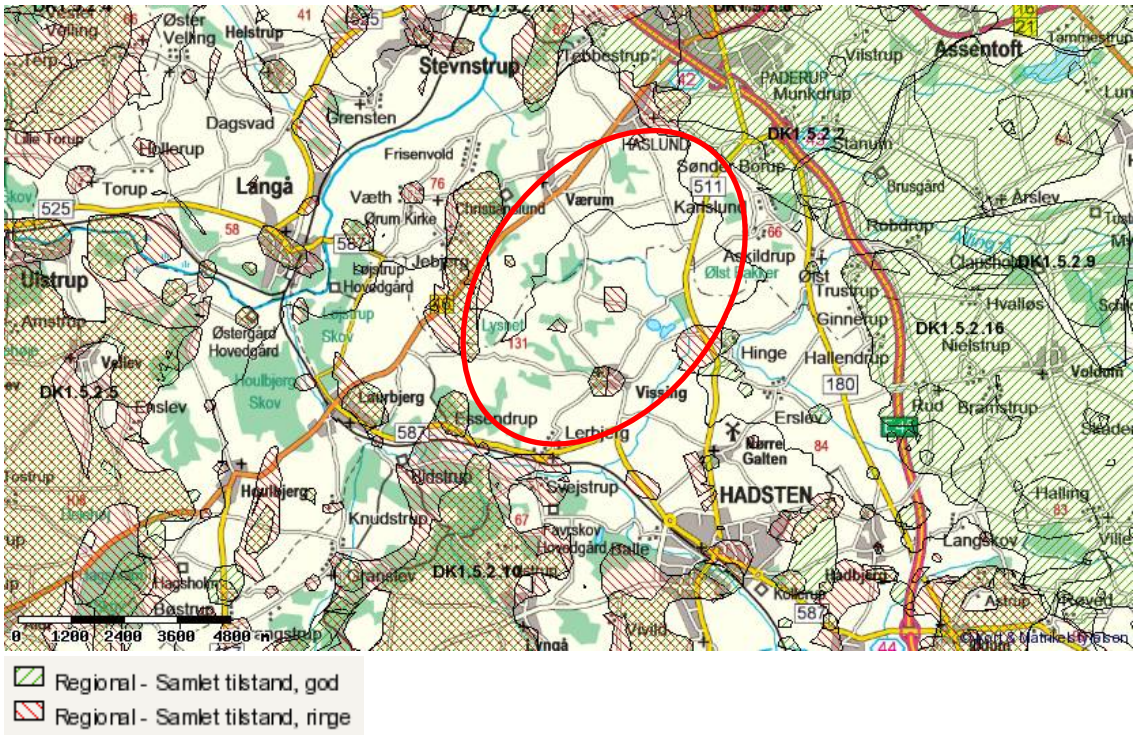


Figure 73. Regional groundwater bodies in the Lysnet bakker area (Area 14). (After Ministry of Environment, 2010).

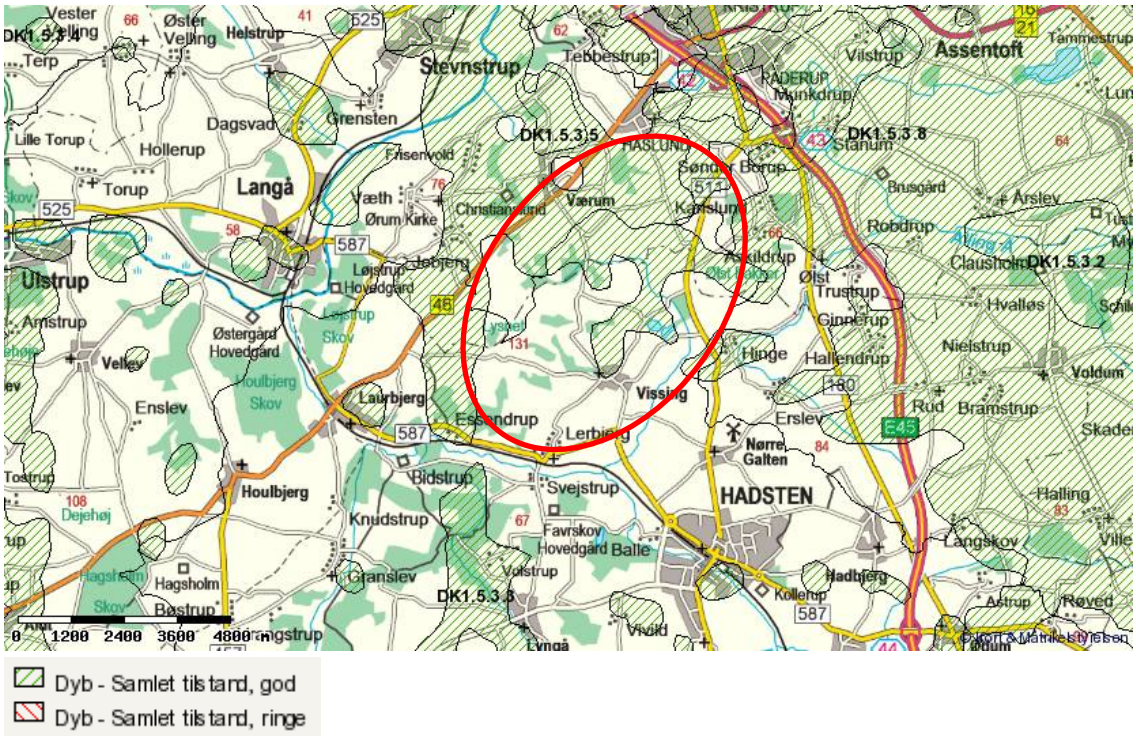


Figure 74. Deep groundwater body within the Lysnet bakker area (After Ministry of Environment, 2010).

7.8.2 Drinking water areas

The groundwater has to be protected to ensure that our current and future need for clean drinking water can be met. It is the Environmental Centres (former counties) responsibility to do the planning, based on the two criteria: First, to make sure that the future necessary quantity of clean groundwater can be abstracted. Secondly, the groundwater aquifers must be protected against recent and future pollution.

As part of the Danish Government´s efforts to protect groundwater, the Environmental Centres have designated areas of major groundwater aquifers, so-called OSD-areas. OSD stands for "Areas of special drinking water interests" (Fig. 75).

The rest of the country is divided into "Areas with water interests" (OD-areas) where good sources of drinking water are also located and "Areas with limited drinking water interests", where it is difficult or impossible to obtain good groundwater quality because the water is more or less contaminated.

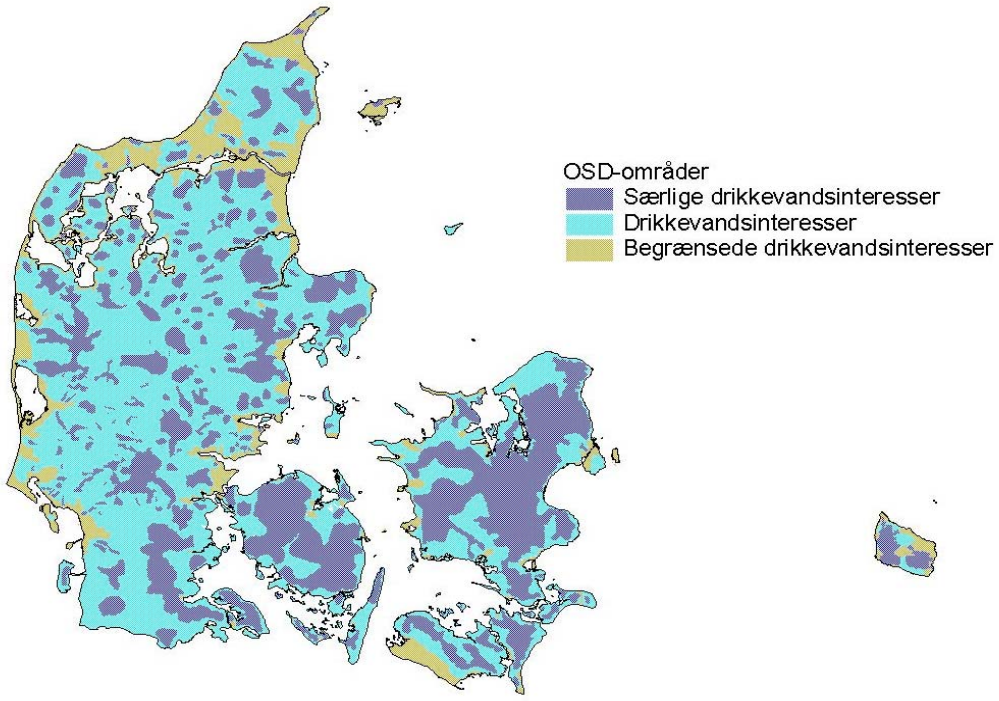


Fig. 75. Areas of special drinking water interests (OSD): Dark blue and areas of drinking water interest (OD): Light blue. Areas with limited drinking water interests are olive brown (/kort.arealinfo.dk/).

The drinking water areas in the Lysnet bakker area is given in fig. 76. The majority of the Lysnet bakker area is classified as OD area. The shown area of limited groundwater interests is identical to the Ølst bakker area. Groundwater abstraction is distributed as given in Fig. 77. Værum By, Lerbjerg-Svejdrup and Vissing water works are abstracting groundwater within Area 14. In addition, several private water wells are located in Area 14 for household purposes.

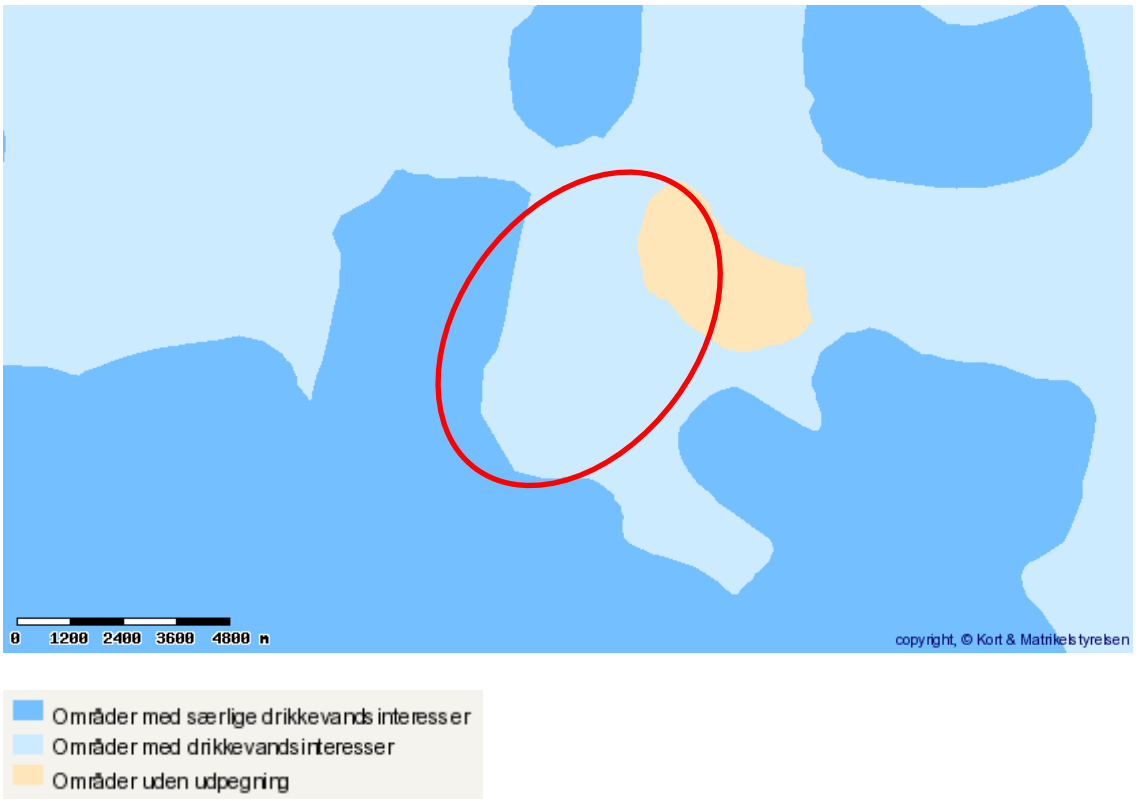


Figure 76. Various drinking water areas situated in the Juelsminde area. Dark Blue: Areas of special drinking water interests (OSD); Light blue: Areas of some drinking water interests (OD); Yellow: Areas with limited or none drinking water interests (/kort.arealinfo.dk/).

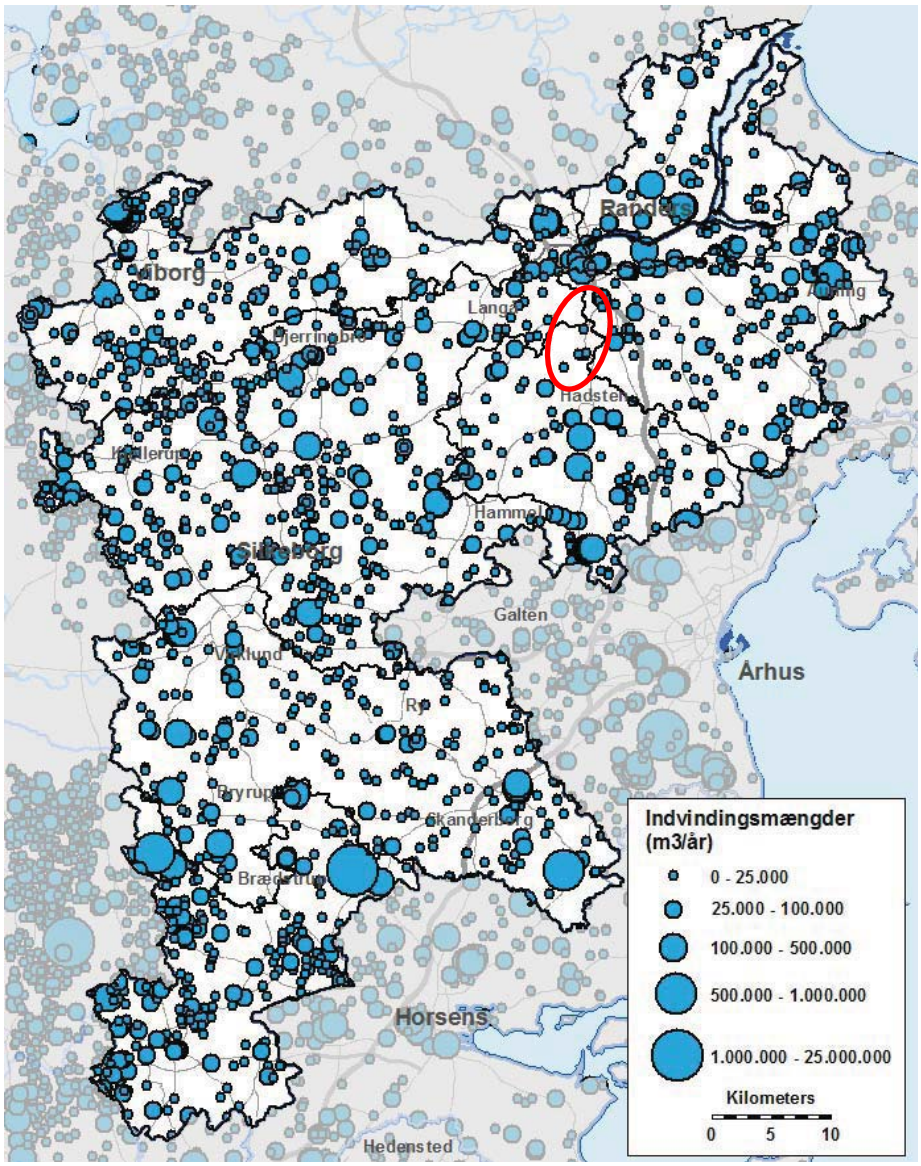


Figure 77. Annual abstraction (in average) from single wells in the period 2003-2005 (from Miljøstyrelsen, 2010).

7.9 Groundwater chemistry

The overall groundwater quality aiming for drinking water purpose has been assessed by the former Århus County and Environmental Centre Århus for the groundwater bodies and reported in the catchment management plan “Hovedvandopland 1.9, Horsens Fjord“. The groundwater chemistry fulfils the EU criteria to be of good status in some of the regional and deep groundwater bodies. The shallower regional and the terrain near ground-water bodies have a poor status.

Salinization of the groundwater within Area 14 is not a problem at present or considered to be a problem in future due to the far distance to the nearest coast and absence of salt diapirs in Area 14.

7.10 Climate and climate changes

The actual climate and the expected future climate changes and sea level development is described in Gravesen et al. (2010, Rep. No. 2). It is not expected that climate changes will have any special affection on the landscape in the area during this century. More and more intense rain will increase the discharge of the streams and possibly cause local erosion in the steepest sections of the area.

7.11 Restrictions and limitations

The Ølst and HInge pits are the largest excavation areas for plastic clay in Denmark. The county of Århus made a reservation for excavation in the present digging area and extended the area towards the northwest to Haslund Kær. This area is included in the present plan for Region Midtjylland areas of permission, excavation and areas of interests.

There are no major restrictions in Area 14 except for two minor areas adjacent to the town Værum that has NATURA2000 habitat status and is protected in accordance to Naturbeskyttelsesloven (law for nature protection) (Chapter 6) (Fig. 78).

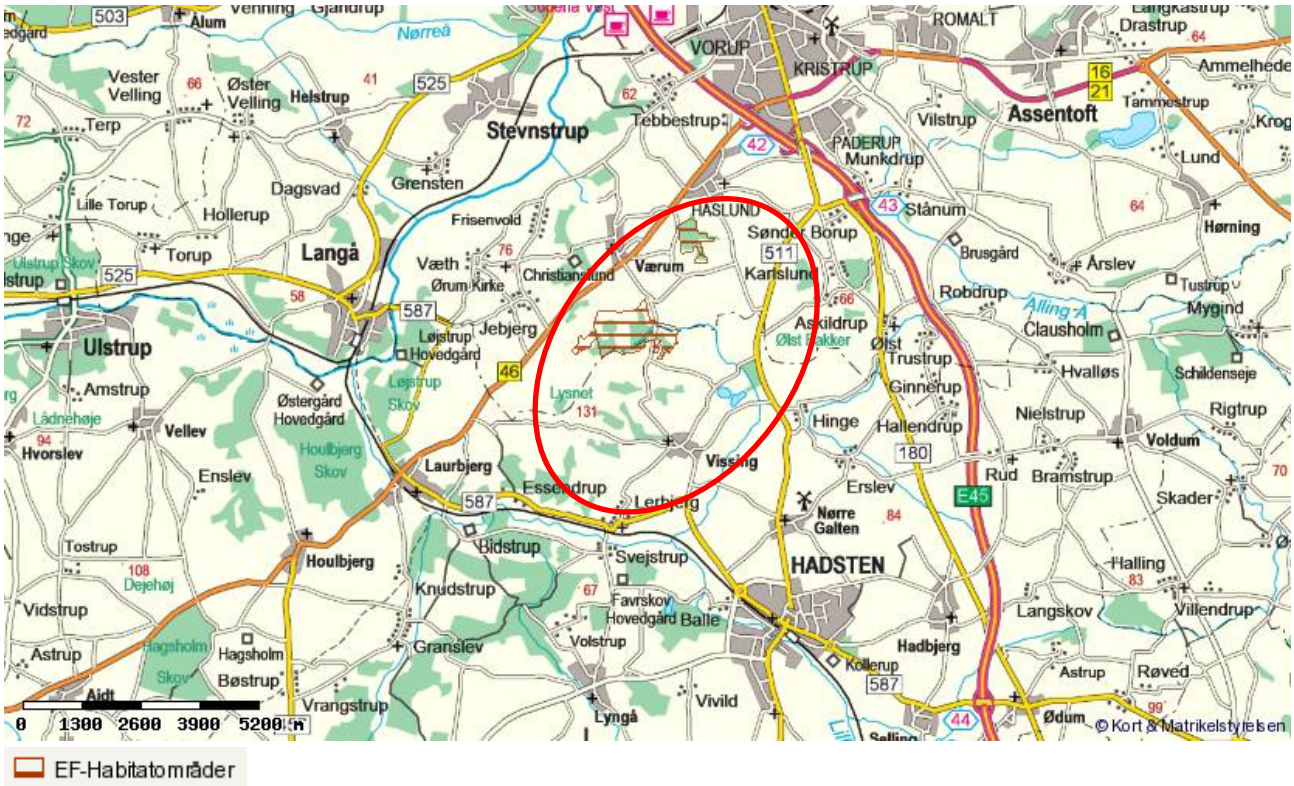


Figure 78. NATURA2000 habitat areas within the Lysnet bakker area (After Ministry of Environment, 2010).

7.12 Summary of areas conditions

Amount of data:
Sparse: Some boreholes and some important geophysical surveys.

Homogeneous conditions and isolation of the waste by low, permeability clay layers:
Perhaps perfect on depth below 30 - 50 m in the Eocene plastic clay formations. The distribution of the clay and the characters of the deposits have to be investigated.

Ground Stability
Good stability on surface and depth but the conditions of plastic clays have to be considered, including sliding on slopes.

Seismic activity and tectonic movements
No seismic and tectonic movements or problems are known in the area. The structural set up has to be investigated.

Groundwater conditions
The groundwater conditions in the Eocene clays and overlaying tills and meltwater deposits should be positive with slow flow towards the surrounding areas but the variation in the level of the groundwater table has to be analysed if the disposal has to be established under saturated conditions.

Dilution of pollution and retention of pollution
No Danish studies have been carried to document dilution capabilities or retention of radionucleides in glacial till sediments.

Drinking water interests
The area is mainly an OD area. Local well supplies in the area are located in low-laying valley areas outside the area.

Groundwater chemistry, non- aggressive components
The groundwater contains apparently no aggressive components.

Ground surface conditions
Processes on the ground surface should not give problems on a disposal although surface water run-off can contribute to water in the valleys.

Climate extreme conditions
Climate changes and extremes as storms and heavy precipitation will probably not have influence on a disposal below ground surface.

Other restrictions

Apparently no other restrictions should give major problems but the relation to the raw material restriction should be solved.

7.13 Final remarks

The Lysnet hill area seems be very comparable with the Ølst - Hinge area. The structural framework should be described in detail with respect to the relation between glaciotectonic clay deposits and in-situ clay deposits.

The surface and groundwater run-off and flow in the hill area have to be evaluated in relation to the local water supplies in the valleys.

8. Area 15. Støvring – Østrup, Randers Fjord, East Jylland.

8.1 The location of the area

The area is located in Eastern Jylland (Fig. 79). The area is found north of Randers Fjord, east of Randers city, between the villages Støvring and Østrup including the forest areas of Nørreskov, Sønderskov and Østrup skov (see fig. 80).

Figure 79. Location of the area. The area is located north of Randers Fjord, east Jylland.

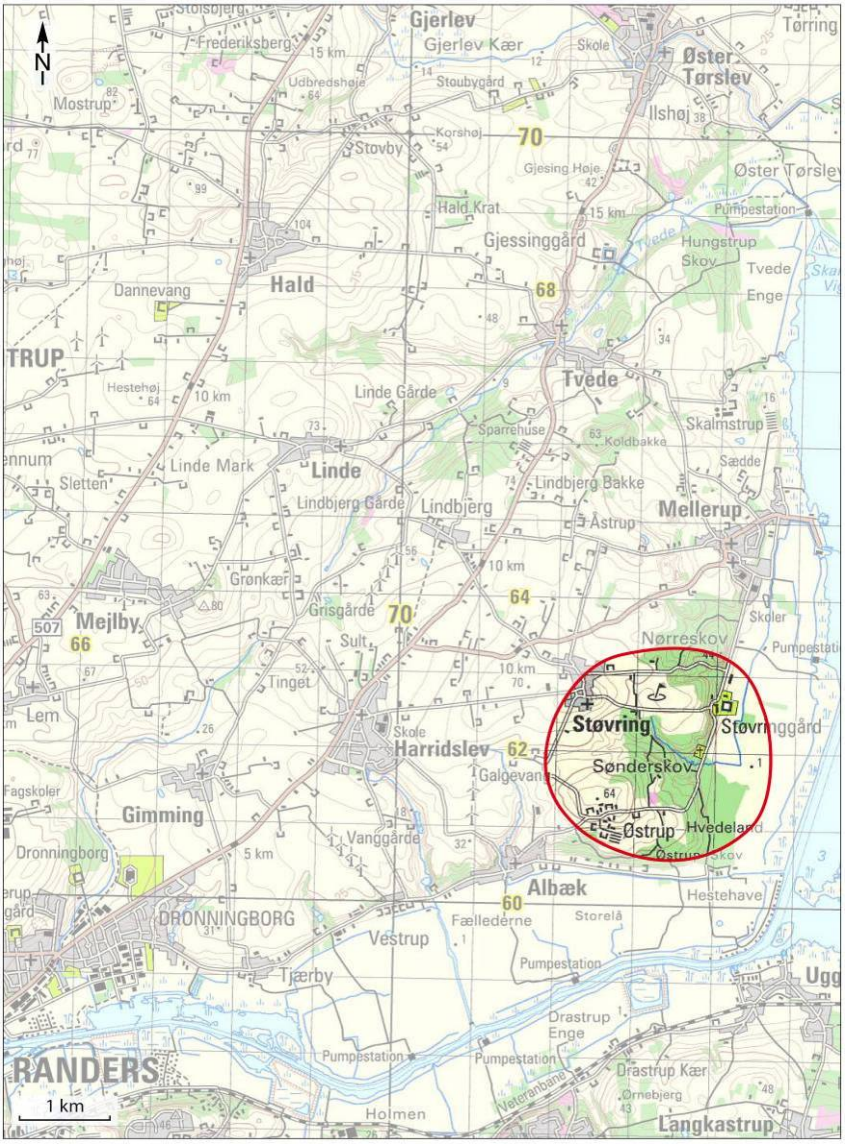


Figure 80. A detailed map of Area 15, located at Støvring and Østrup.

8.2 Terrain, topography and processes

The area is located in the eastern part of Jylland, next to the inner part of Randers Fjord. The size of the area is c. 5.4 km^2. The area includes two very different kinds of landscape. The major part, toward west, is a high-lying, undulating moraine landscape. The smaller part, toward east, is a low-lying plane marine foreland. The two segments are separated by an inactive and overgrown cliff. The moraine landscape is situated between c. 10 and 64 m above sea level (m.a.s.). It does not include any lakes but a small stream is found in the area. The stream is running down the cliff to the marine foreland, where it turns toward north. The marine foreland is located between 0 and 5 m.a.s. and the outermost part of this area seems to be reclaimed and protected from flooding (?).

The Area 15 is crossed by a few minor roads. The small villages Støvring and Østrup are located in the western and southern part of the area, respectively. A larger farm, Støvringgård is located on the passage between the moraine landscape and the marine foreland and a golf course is found in the northern part of the area. Except from the villages, there are only very few scattered houses in the area, all located on the moraine. Approximately half of the area is used for agriculture and the other half is woods.

Owing to the cultivation, the protecting cover from the woods and the protection of the reclaimed area, the surface processes (soil creep, frost – thaw processes, soil development etc.) proceed slowly and undramatic.

8.3 Surface geology and profiles

The Quaternary mapping of the areas is not yet finished but preliminary maps and the ongoing investigations indicate that clayey till dominates the area but also that the Paleogene clays are situated near the ground surface (Fig. 81).

Older clay pits have existed at Dronningborg, Randers.

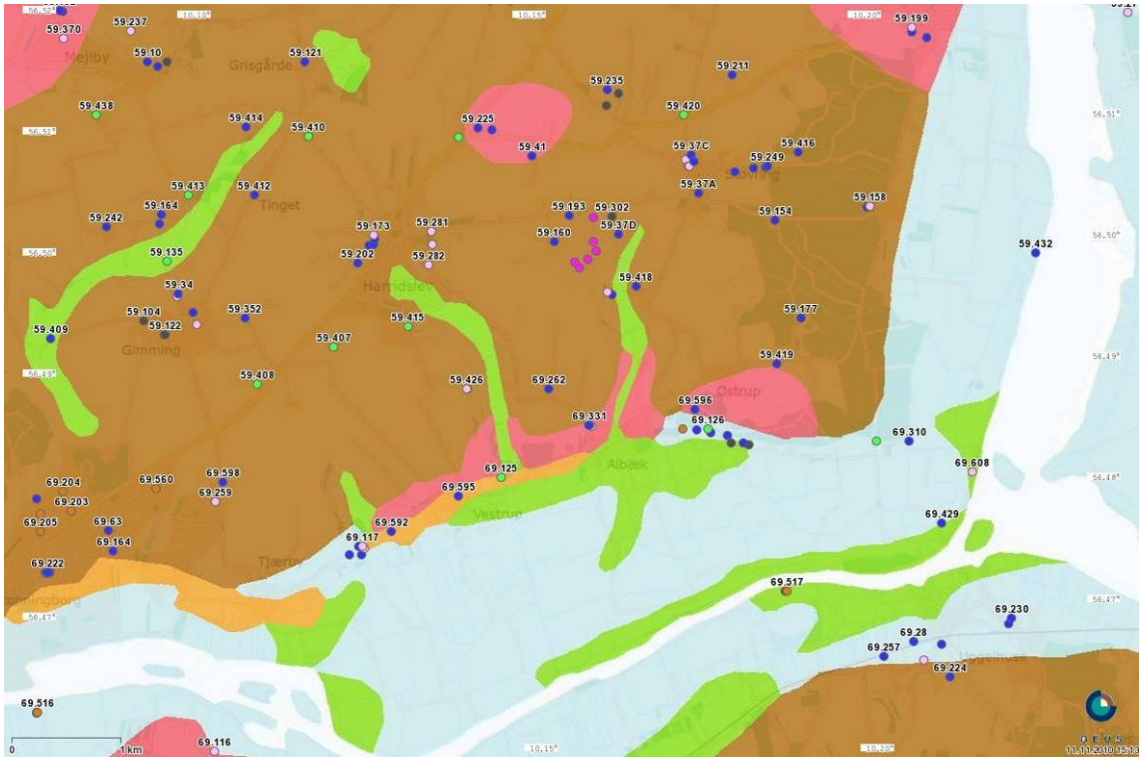


Figure 81. Quaternary surface map from the area with the boreholes from the Jupiter Database at GEUS. Originally scale 1:200.000 (GEUS´s Homepage, after Pedersen, 1996). Legend: Brown: Clayey till; Red and orange: Meltwater sand and gravel; Green: Holocene freshwater deposits; Light blue: Holocene marine deposits. Legend for the boreholes: See fig. 82.

8.4 Boreholes

Several boreholes are located in the area but the main part of the boreholes is situated near the boundary of the area. Especially the middle part of the area lacks information. Some samples are lithological described and related to formation and microfossils from the samples have been investigated in three boreholes and the deposits have been dated. The area is not covered by geophysical surveys.

The locations of the boreholes are shown in fig. 82. An example of the borehole log from DGU no. 59.380 is in fig. 83.

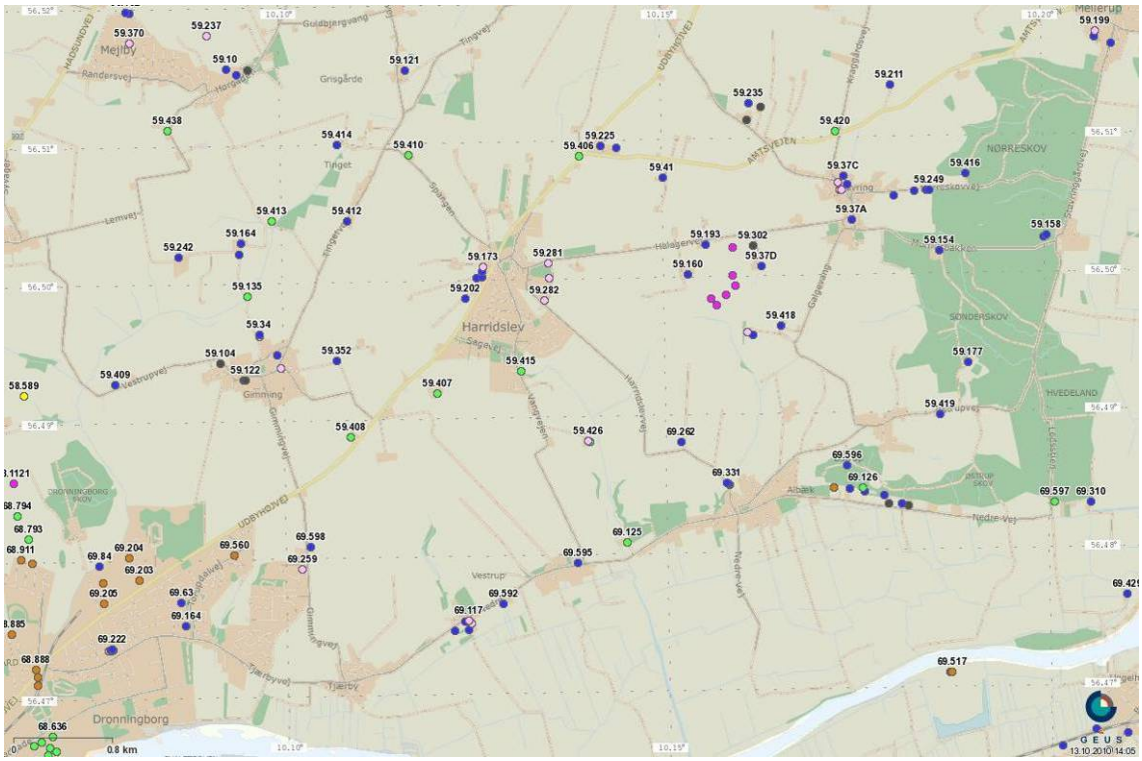


Figure 82. Map of the locations of boreholes from the Jupiter Database at GEUS. Legend: 59.380: DGU No., Blue dot: Water supply well; Red dot: Geotechnical borehole; Pink dot: Raw material borehole; Green dot: Other borehole; Light red dot: Abandoned borehole; Black dot: Unknown purpose.

De Nationale Geologiske Undersøgelser for Danmark og Grønland

Udskrevet 3/11 2010 Side 1

BORERAPPORT

DGU arkivnr: 59. 380

Borested : Voresmark, Støvring
9541 Suldrup

Kommune : Randers
Region : Midtjylland

Boringsdato : 6/3 2001

Boringsdybde : 29 meter

Terrænkote : 57,6 meter o. DNN

Brøndborer : Poul Christiansen,Højslev
MOB-nr :
BB-journr : 18/01
BB-bornr : støvring 2

Prøver
- modtaget :
- beskrevet : 6/3 2001 **af** : G
- antal gemt : 0

Formål : Råstofboring
Anvendelse :
Boremetode :

Kortblad : 1315 IVSØ
UTM-zone : 32
UTM-koord. : 571262, 6262360

Datum : ED50
Koordinatkilde : GEUS
Koordinatmetode : KMS digitale kort

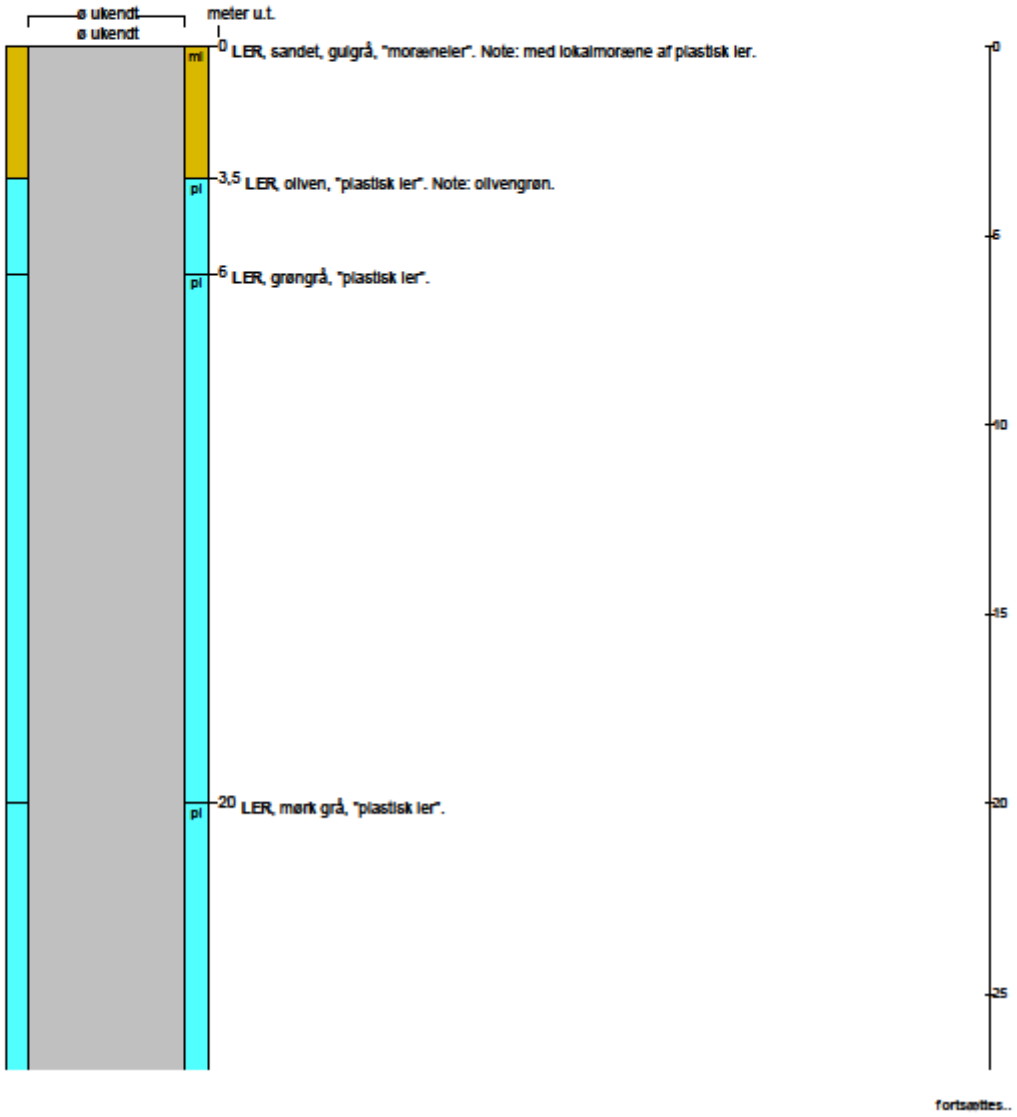


Figure 83. Borehole log from DGU no. 59.380. Upper part of the 29 m deep borehole. Legend: Ml. Clayey till, PL: Paleocene clay.

8.5 Sediment and rock characteristics, mineralogy and chemistry

8.5.1 Pre-Quaternary deposits

The pre-Quaternary map is found in fig. 84.

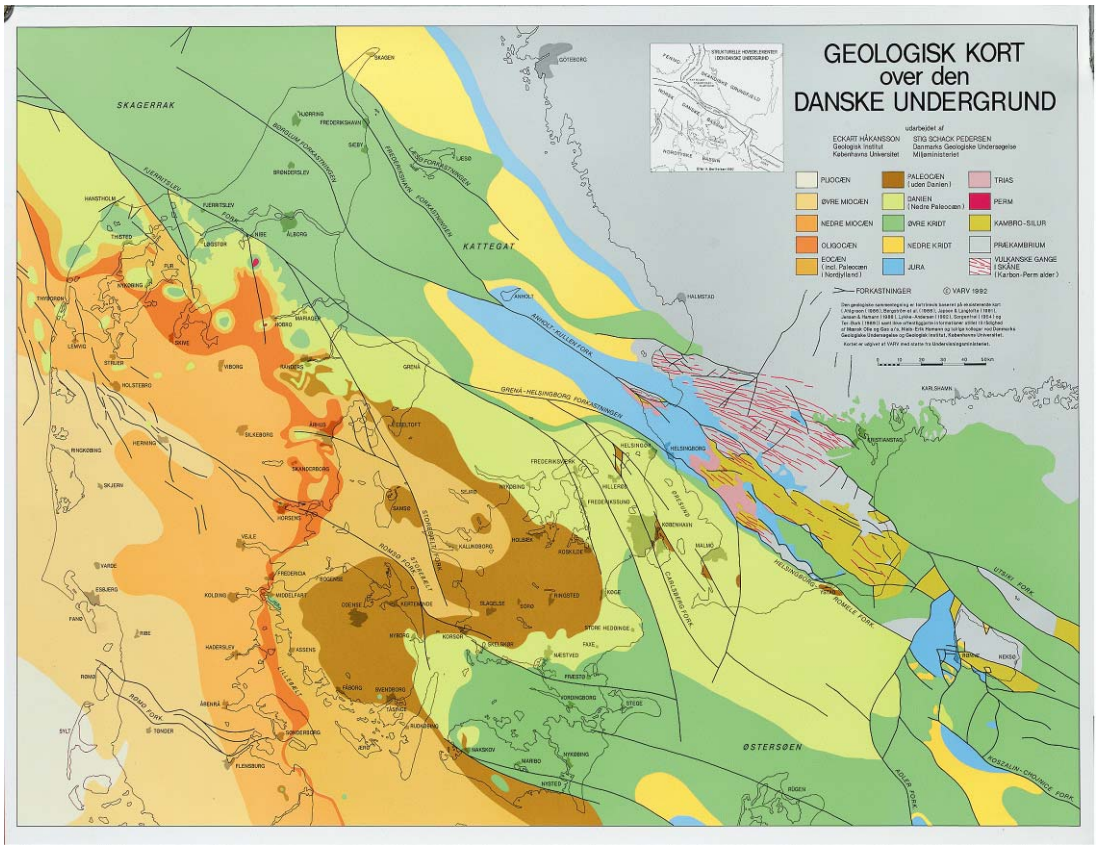


Figure 84. Map of the pre-Quaternary surface: Time units. Original scale: 1:50.000. Legend: Red lines: Precambrian intrusions; Grey: Precambrian; Olive: Cambrian-Silurian; Red: Permian; Light red: Triassic; Blue: Jurassic; Yellow: Lower Cretaceous; Green: Upper Cretaceous; Light green: Danian; Brown: Paleocene; Yellow olive: Eocene; Red brown: Oligocene; Light yellow brown: Lower Miocene; Very light yellow brown: Upper Miocene; White: Pliocene (Håkansson & Pedersen, 1992).

The Paleocene plastic clays have been investigated in smaller areas east of Randers at Dronningborg, Lem and Støvring with the purpose to find clays of bentonite quality. At the outskirt of Randers, outside Area 15, grey green and greenish black plastic clay from the Holmehus Formation (Fig. 85) seems to hold a fair quality (Fig. 86).

Figure 85. Greenish black plastic clay from the Holmehus/Ølst Formation at Dronningborg, Randers.

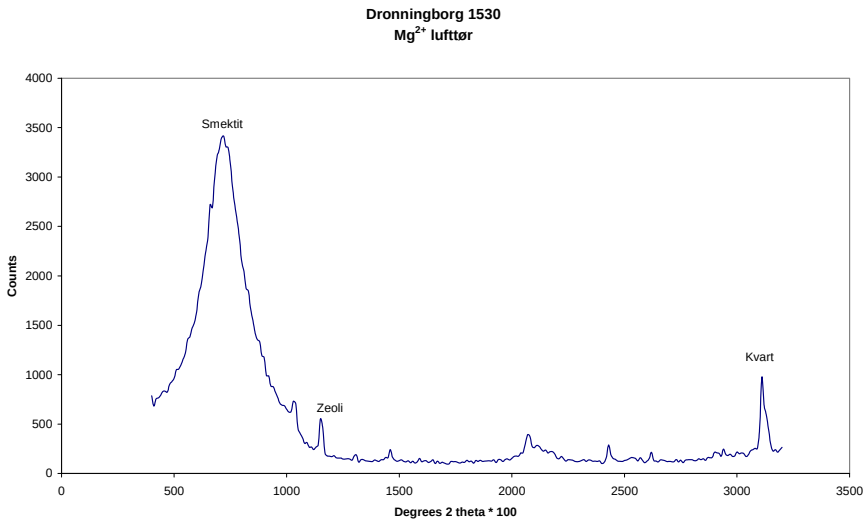
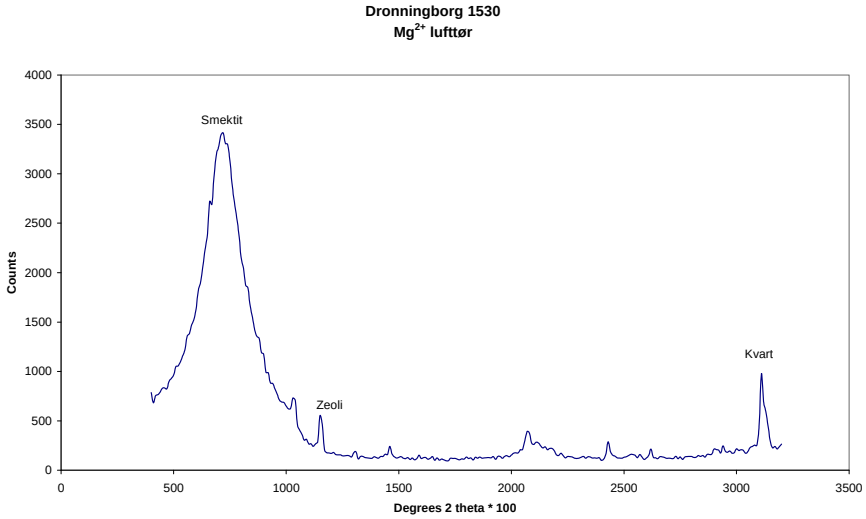


Figure 86. Clay mineralogy of the bentonite from Dronningborg showing a clear smectite peak (From Pedersen et al., 2007).

West of the area at Dronningborg several clay pits have occurred with fine-grained grey, brown and yellow grey plastic clay with many layers of grey brown, grey and black volcanic ash, probably belonging to the Ølst Formation. Several cemented and silicified layers occurred. The formation was up to 10 m thick and glaciotectonic disturbed probably from the NE.

In the Area 15, south-west of Støvring, between Harridsvej and Galgevang, a series of boreholes have demonstrated at least 25 - 30 m of very fine-grained green grey plastic clay covered by a few meters of Quaternary sediments. The clays are from the Holmehus Formation, Ølst Formation and Røsnæs Clay Formation (Paleocene-Eocene).

The clay mineralogy demonstrates a high content of smectite and some of the layers can be classified as bentonite (Fig. 87)



.

Figure 87. Clay mineral analyses from DGU no. 59.379 showing a smectite peak (From Pedersen et al., 2001).

At the village Støvring, 20 m of grey micaceous sand and silt deposits from the Miocene or Oligocene are reached below 36 m of Quaternary deposits. Then follows 40 m of fine-grained green grey clay from the Oligocene, Eocene or Paleocene. At 93 m depth 20 m of Danian cemented limestone is reached.

At Østrup, Oligocene sand is reached at 6 - 8 m depth (17 m thick). Then follow Oligocene, Eocene and Paleocene fine-grained clays down to 50 m below surface. Danian limestone finished the borehole at 106 m depth.

In the wood Sønderskoven, two boreholes show that fine-grained olive grey clays with layers of volcanic ash, mainly calcareous, are reached 59 m below ground surface, covered by clayey tills. Cemented Danian limestone with flint occurs at 83 m.

An example of the Eocene plastic clay from the Røsnæs clay Formation is found in fig. 88.

Figure 88. Section from the Albæk Hoved Klint, Juelsminde, Jylland. Red and green plastic clay from the Røsnæs Clay Formation.

8.5.2 Quaternary deposits

The Quaternary deposits consist mainly of clayey tills with some intercalations of meltwater sand and gravel (Fig. 81 and 89). The variations are as follows:

At Støvring, the Quaternary deposits can be up to 36 m thick, consisting of fine-grained grey and yellow meltwater sand on the top of silty, calcareous olive grey clayey till. Meltwater silt can also occur. Southwest of Støvring, a few meters of yellow brown clayey till rest on Paleogene plastic clays. Sometimes, the plastic clay reaches the ground surface.

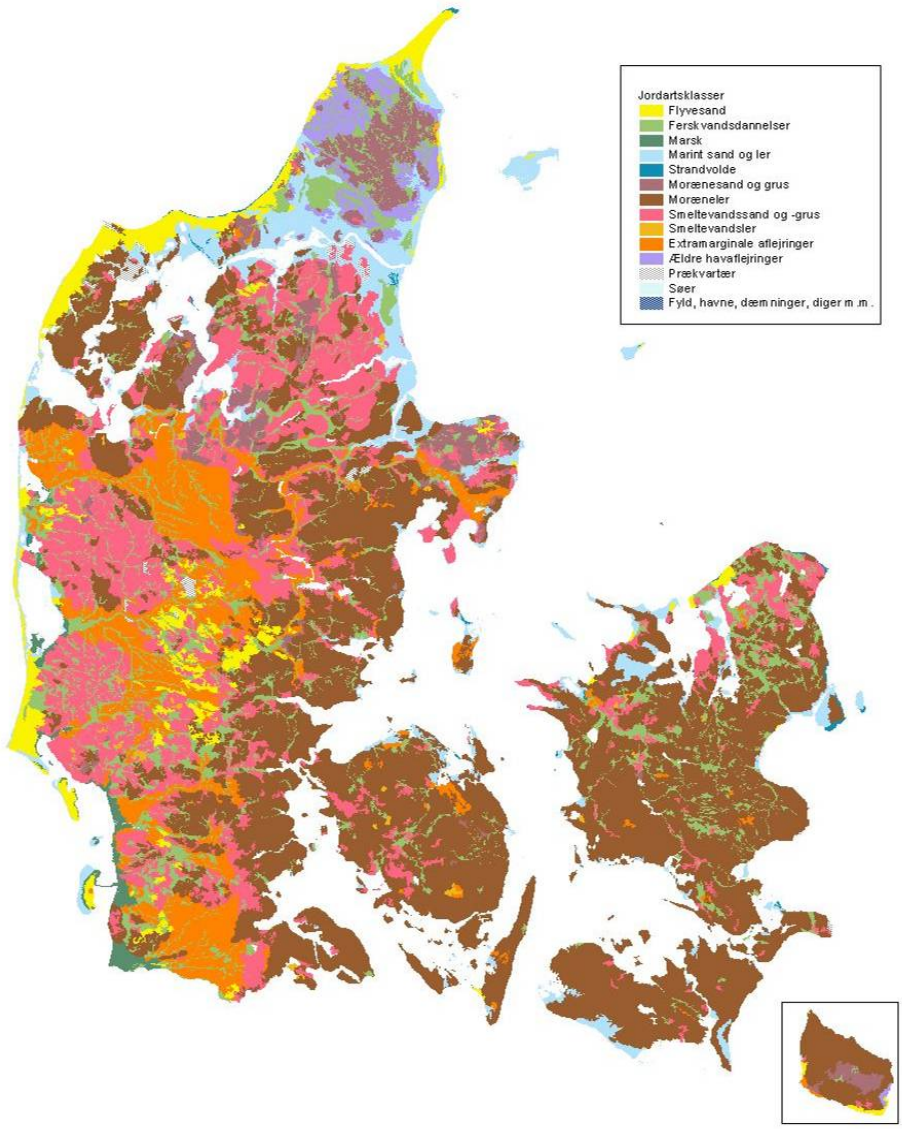


Figure 89. Map of the Quaternary surface deposits. Original scale: 1:200.000. Legend: Brown: Clayey till; Light brown: Sandy till; Red: Meltwater sand and gravel; Orange: Sandur sand and gravel; Purple: Late glacial marine deposits; Light blue: Holocene marine deposits. Green: Holocene freshwater deposits; Yellow: Aeolian sand (From Pedersen, 1989).

At Østrup, approx. 7 m meltwater sand rest on Paleogene clays. In Sønderskov, 30 - 60 m olive grey, calcareous clayey till with sand intercalations occur upon the Paleogene clays. An example of clayey till with sub-vertical fractures is shown in fig. 90.

Figure 90. Sub-vertical factures in clayey tills.

8.6 Tectonics, structures and seismic activity

8.6.1 Major tectonic structure

The distribution of the Paleocene and Eocene deposits are dependent on the movements in Gassum salt pillow structure as the deposits have been uplifted on the southern slope of the structure (Fig. 91). The pre-Quaternary surface is also cut by a series of valleys which have produced several separate areas with clays deposits from Paleocene and Eocene (Fig. 92).

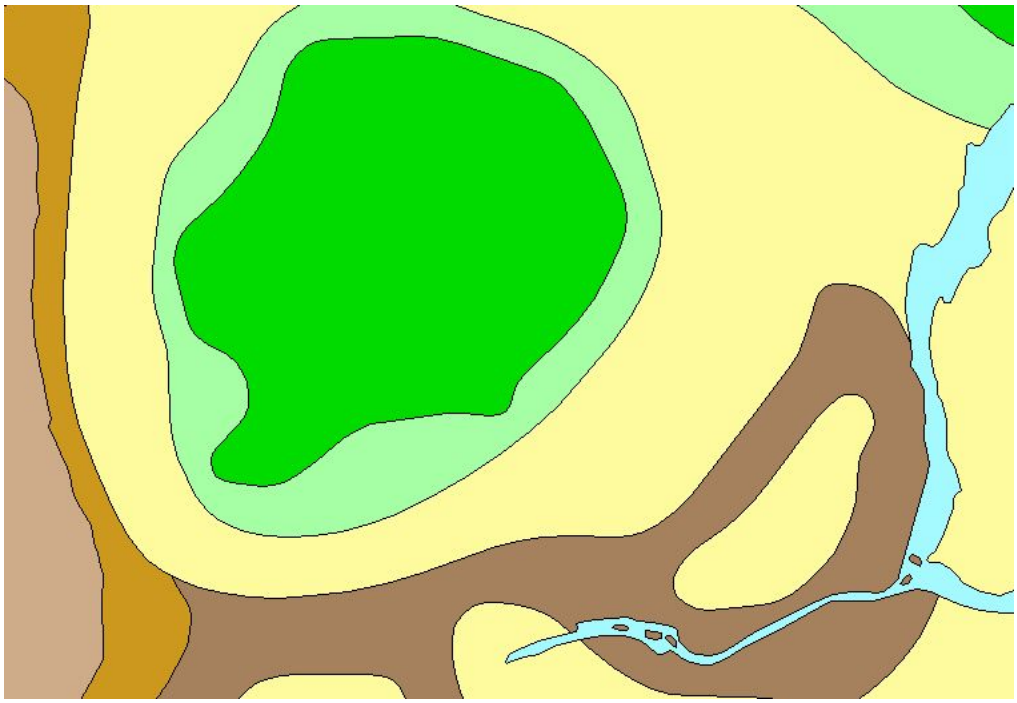


Figure 91. Geological map of the Gassum structure north of Randers and area 15. The structure is formed by a deep laying Permian salt pillow which has lifted the younger deposits. Legend: Dark green: Maastrichtian chalk, Green: Danian limestone, Yellow: Early Paleocene limestone and clays. Dark brown: Late Paleocene and Eocene clays, Two brown colours: Oligocene and Miocene deposits.

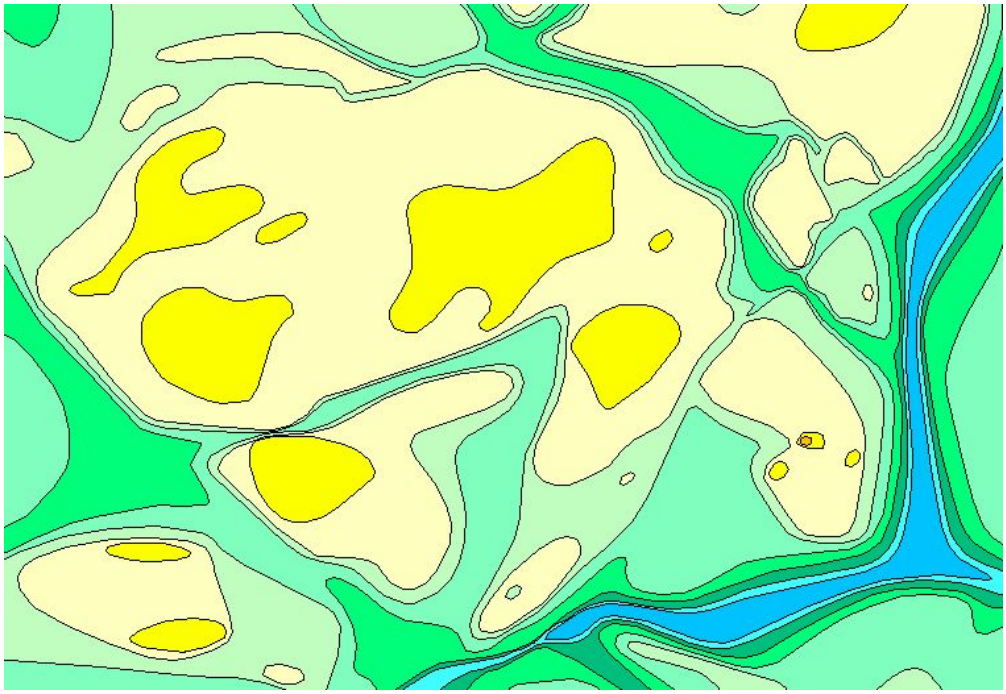


Figure 92. Map of the elevation of the pre-Quaternary surface. The map shows a series of valleys cut down into the producing several areas of high laying clay deposits in between the valleys. Legend: blue: Sea level, each colour: 25 m contours.

A geological section from Støvring (Fig. 93) shows that the dark green plastic clay reaches down to at least 30 m below surface but is probably more than 50 m thick. The top of the Maastrictian chalk is probably situated 150 m below surface. Inclined clay sheets and floes also reach the ground surface. The section demonstrates the glaciotectonic disturbances in the area which also have been proved in the pits at Dronningborg.

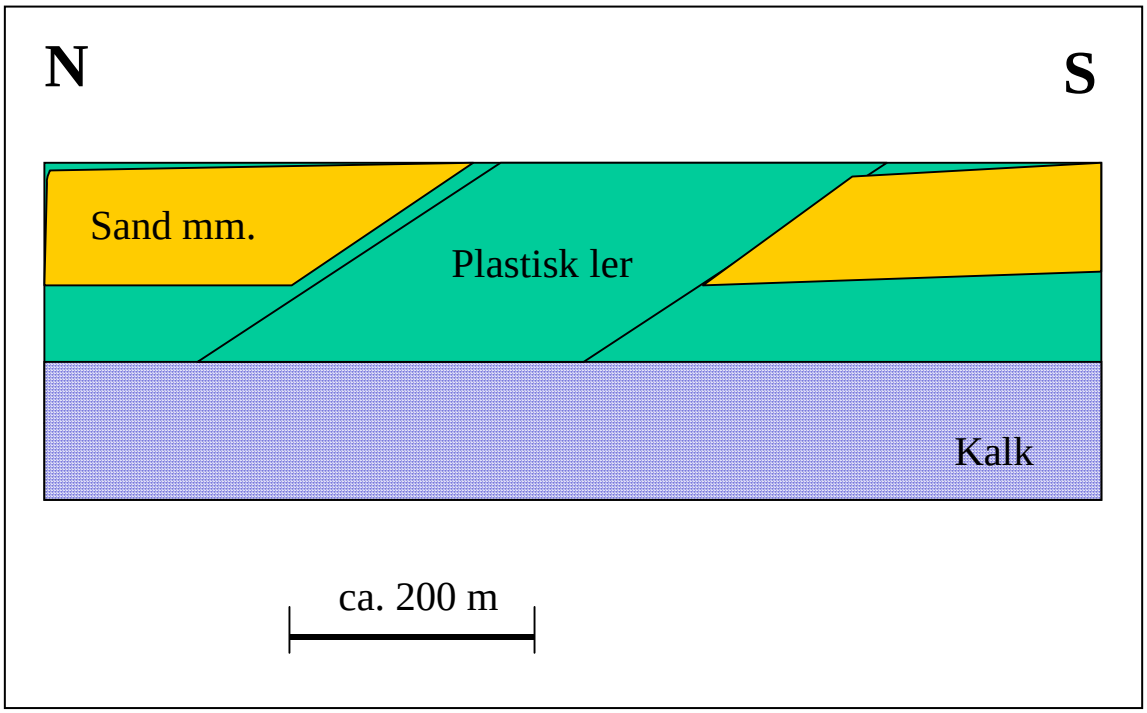


Figure 93. Geological section from the Støvning area where at least one large sheet of plastic clays has been pushed up by a glacier from the N (From Pedersen et al., 2007). Legend: Green: Plastic Clay, Blue: Limestone. Orange: Sand.

An example of the green Paleocene plastic clay is seen in fig. 94.

Figure 94. Green plastic from the Paleocene.

8.6.2 Fractures

The Quaternary tills are normally cut by vertical, sub-vertical and horizontal fractures down to at least 8 m depth. Many biopores often occur in the upper 2 - 3 m.

The very fine-grained and plastic clays from Eocene and Oligocene contain fractures which can be a problem for ground stability.

8.6.3 Geological model of the area

The geological model consists of the following units (Fig. 95):

A. Quaternary deposits, mainly clayey till with many layers of meltwater sand and gravel, from a few meters up to 36 m thick.

B. Oligocene sand, silt and clay (perhaps also Miocene), 20 m ? thick.

C. Eocene Røsnæs Formation, Ølst Formation and Paleocene clays, approx. 30 - 50 m thick.

D. Danian cemented limestone (kalksandskalk), at least 50 m thick.

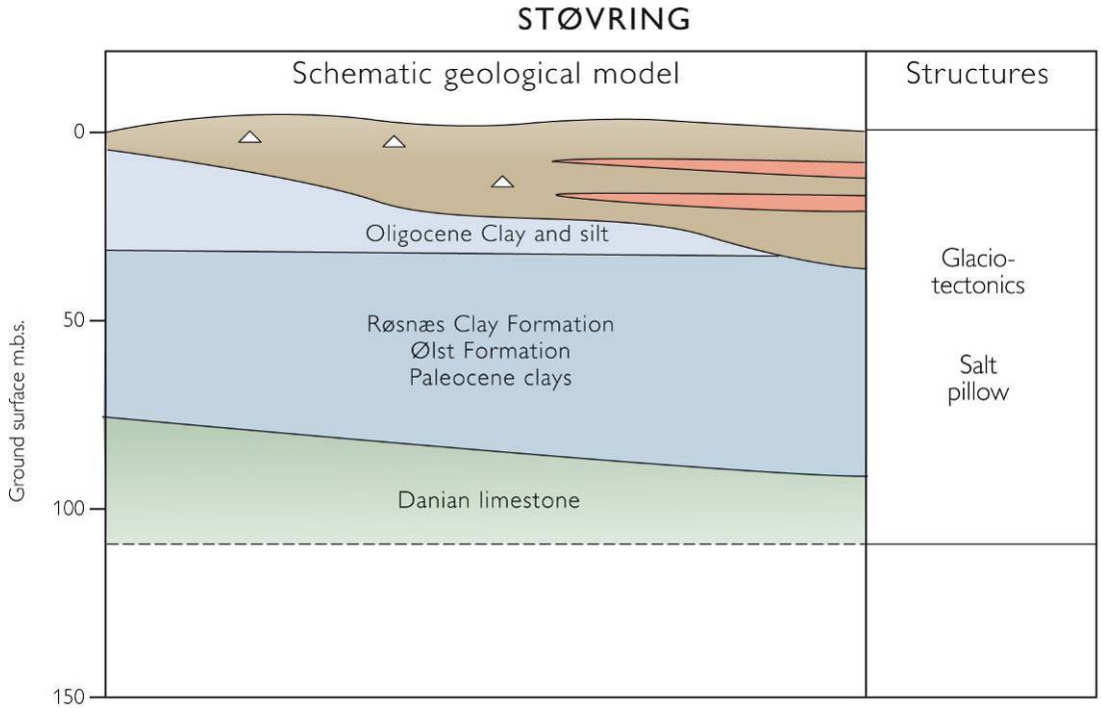


Figure 95. A Schematic geological model of the area.

8.6.4 Earthquake activity

The seismic activity in Støvring - Ørby area and the near surrounding sea is very low (Fig. 96).

Therefore, it is impossible to relate recent seismic activity to the faults and fractures in the bedrocks. Other signs of recent movements along the faults and fractures have not been proven.

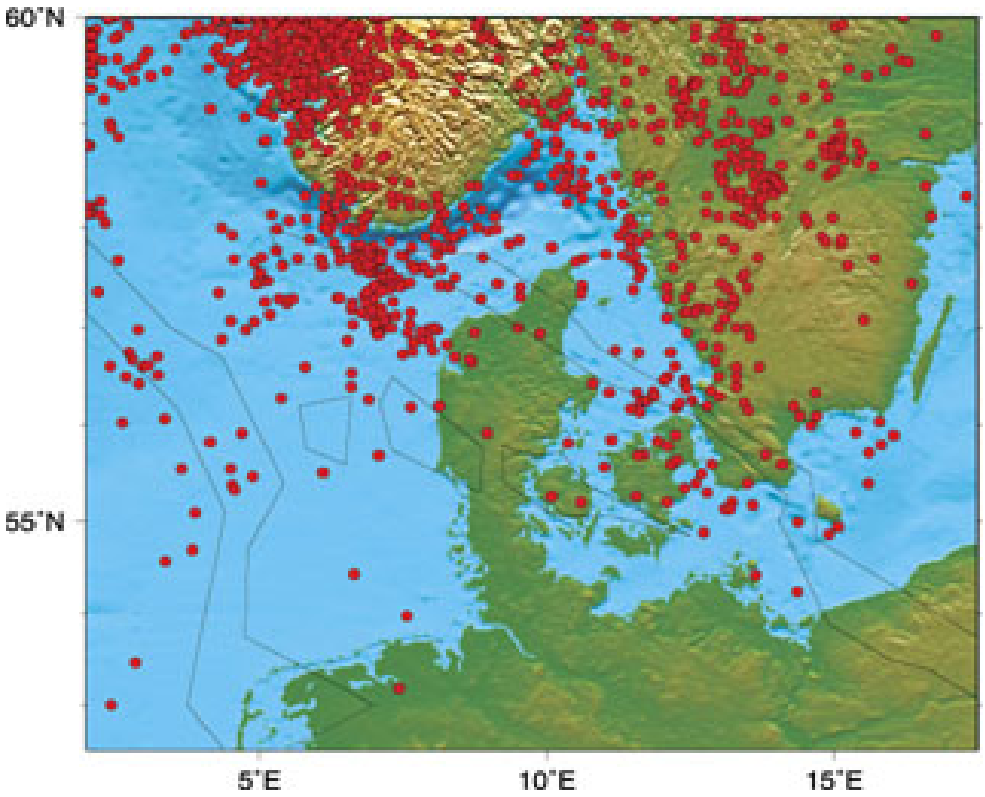


Figure 96. Map of epicentres from earthquakes in the Danish and surrounding areas. (From GEUS´s Home page).

8.7 Ground stability

The area is expected to have good ground stability. Nevertheless, it is always important to remember that constructions on and in plastic clays can give problems. This is caused by fractures in the clays and because of large changes in volume at drying and water filling.

Areas with slopes are especially exposed for sliding and flowing of plastic clay material towards lower areas.

8.8 Groundwater hydrogeology

8.8.1 Groundwater characteristics

The Støvring area (Area 15) is positioned in an area characterized by the presence of all three categories of groundwater bodies: one shallow (DK1.5.1.1) with large extent; two smaller regional (DK1.5.2.1; DK1.5.2.8) and one deep groundwater body (DK1.5.3.8) also with a significant horizontal extent (Fig. 97, 98 and 99). Subdivision into groundwater bodies are thoroughly described by the former Århus County in the basisanalysis part 1. All the groundwater bodies belong to the Randers Fjord main catchment and are described in the

catchment management plan of the Ministry of the Environment (Hovedvandopland 1.5 Randers Fjord). The shallow and regional groundwater bodies are all consisting of sand materials and the deep groundwater body of limestone deposits. The overall assessment of the chemical and quantitative status of the shallow and of some of the regional bodies is poor. Meanwhile, the other part of the regional and the only deep groundwater bodies are assessed to have a good status (see section 8.9).

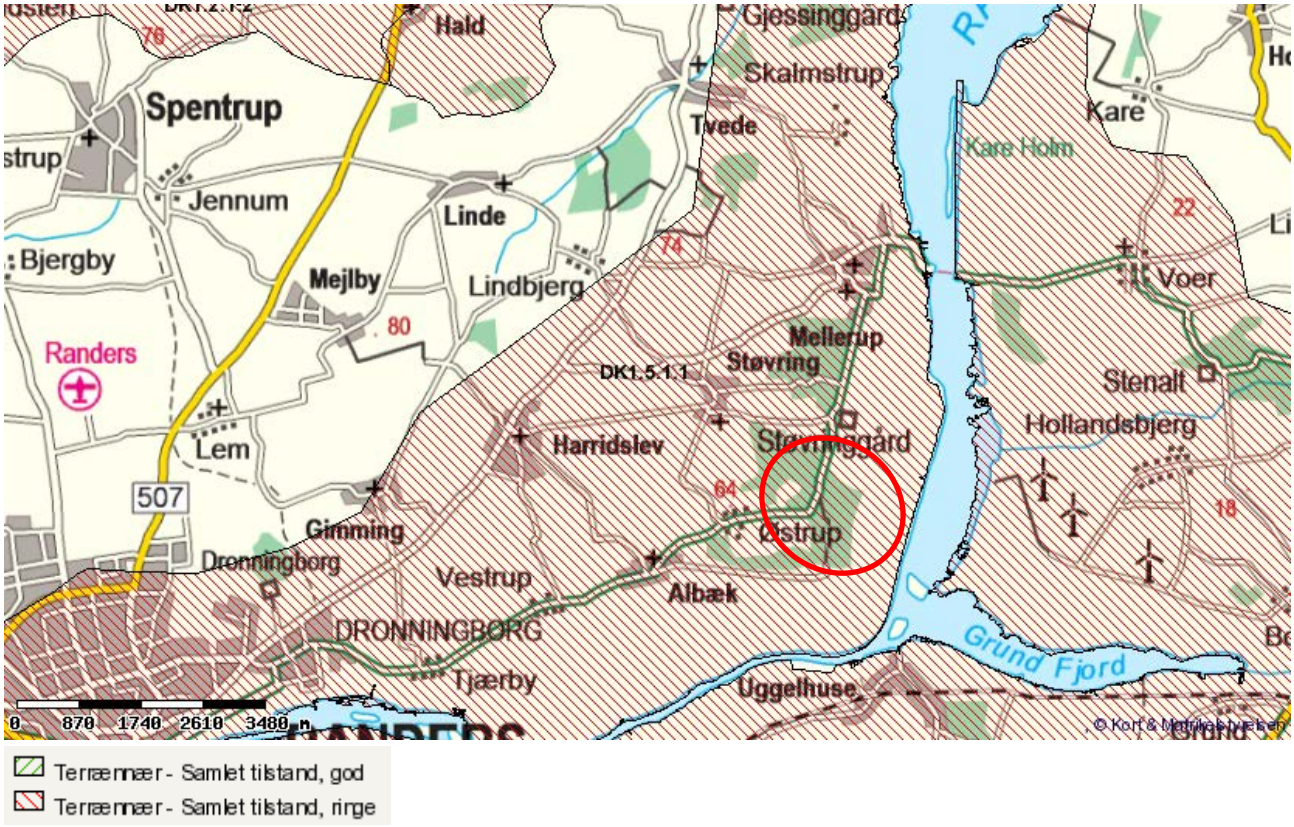


Figure 97. Shallow (or terrain near) groundwater body in the Støvring area (Area 15) located east of Randers (in red circle). (After Ministry of Environment, 2010).

Figure 98. Regional groundwater bodies in the Støvring area (Area 15). (After Ministry of Environment, 2010).

Figure 99. Deep groundwater body within the Støvring area (After Ministry of Environment, 2010).

The Quaternary and Palaeogene sediments include approximately 100 m of clays without groundwater reservoir characteristics. The groundwater in the clays will move slowly towards the sea.

8.8.2 Drinking water areas

The groundwater has to be protected to ensure that our current and future need for clean drinking water can be met. It is the Environmental Centres (former counties) responsibility to do the planning, based on the two criteria: First, to make sure that the future necessary quantity of clean groundwater can be abstracted. Secondly, the groundwater aquifers must be protected against recent and future pollution.

As part of the Danish Government´s efforts to protect groundwater, the Environmental Centres have designated areas of major groundwater aquifers, so-called OSD-areas. OSD stands for "Areas of special drinking water interests" (Fig. 100).

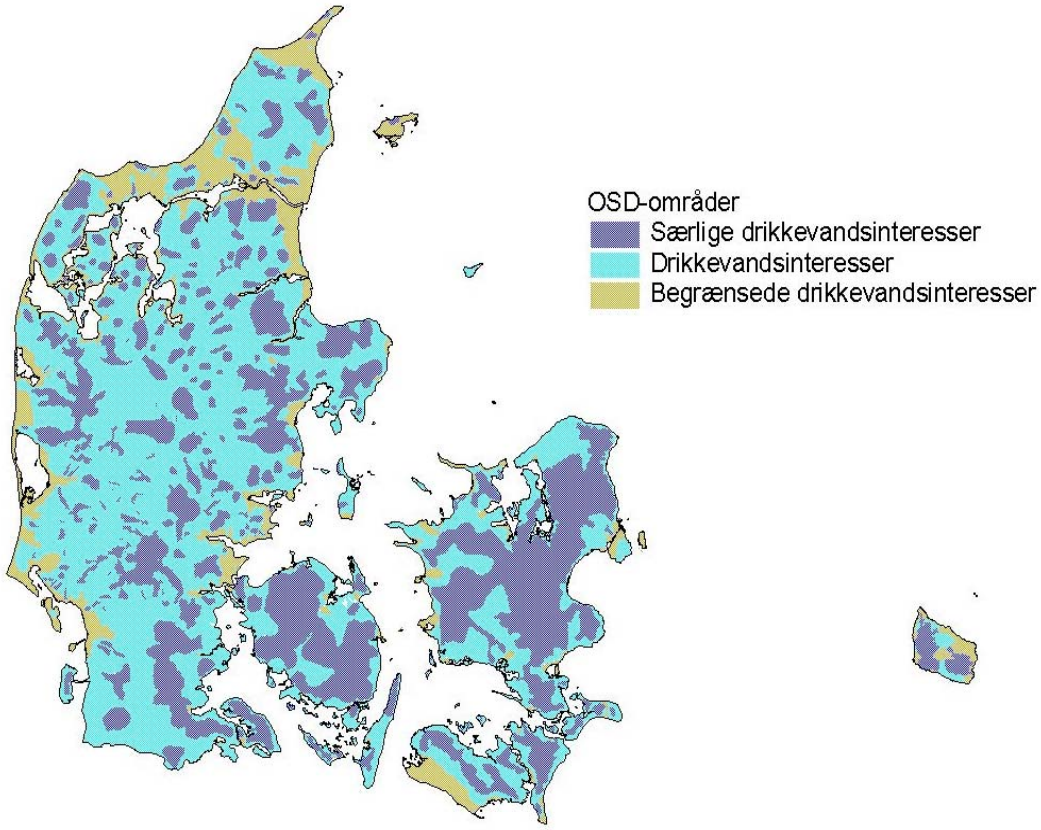


Figure 100. Areas of special drinking water interests (OSD): Dark blue and areas of drinking water interest (OD): Light blue. Areas with limited drinking interests are olive brown (/kort.arealinfo.dk/).

The rest of the country is divided into "Areas with water interests" (OD-areas) where good sources of drinking water are also located and "Areas with limited drinking water interests",

where it is difficult or impossible to obtain good groundwater quality because the water is more or less contaminated.

The drinking water interests in the Støvring area are given in Fig.101. There are predominantly OD areas and areas of limited or no drinking water interest within the Støvring area. However, an OSD area has it´s extent immediately west of Area 15. Østrup Skov waterwork (750.000m^3 in 2009) is located just west of Area 15.

Figure 101. Various drinking water areas situated in the Støvring area. Dark Blue: Areas of special drinking water interests (OSD); Light blue: Areas of some drinking water interests (OD); Yellow: Areas with limited or none drinking water interests (/kort.arealinfo.dk/).

8.9 Groundwater chemistry

The overall groundwater quality aiming for drinking water purpose has been assessed by the former Århus County and Environmental Centre Århus for all the groundwater bodies and reported in the catchment management plan “Hovedvandopland 1.9, Horsens Fjord“. The groundwater chemistry fulfils the EU criteria to be of good status in some of the regional and deep groundwater bodies. The shallower regional and the terrain near ground-

water bodies have a poor status. Saltwater intrusions should not be a problem although the area is situated close to the Randers Fjord.

8.10 Climate and climate changes

The actual climate and the expected future climate changes and sea level development is described in Gravesen et al. (2010, Rep. No. 2). It is not expected that climate changes will affect the high-lying part of the area during this century, but the marine foreland may very likely suffer from flooding problems when the sea level rises.

8.11 Restrictions and limitations

An area close to Støvring has been investigated in relation to finding possible plastic clay/bentonite resources. The area is regarded as a raw material interest area.

There are no major restrictions in Area 15. However, east of Area 15 a Natura2000 habitat area extents along the Randers Fjord and the shoreline on the landside (Fig. 102). In addition, two very small areas are protected in accordance to Naturbeskyttelsesloven (law for nature protection) (Chapter 6).

Figure 102. NATURA2000 habitat areas within the Støvring area (After Ministry of Environment, 2010).

8.12 Summary of the area conditions

Amount of data

Sparse, but in some parts of the area several boreholes are found. No geophysical surveys.

Homogeneous conditions and isolation of the waste by low, permeability layers

Perhaps perfect at depth of 50 to 100 m but the framework of the fractures is unknown. Probably fracture problems have to be considered in relation to other areas.

Stability

Good stability on surface and depth but plastic clays can give problems.

Seismic activity and tectonic movements

No seismic and tectonic movements or problems are expected. The area is probably ?? fault bounded towards the north.

Groundwater flow conditions

The groundwater flow in the area is slow because of the comprehensive clay deposits. The level of the groundwater table has to be analysed if the disposal has to be established under saturated conditions.

Dilution of pollution and retention of pollution

No Danish studies have been carried to document dilution capabilities or retention of radionucleides in glacial till sediments.

Drinking water interests

The area is classified partly as an OD area and partly as an area with limited or no drinking water interests.

Groundwater chemistry, non- aggressive components

The groundwater contains apparently no aggressive components.

Ground surface conditions

Processes on the ground surface should not give problems on a disposal.

Climate extreme conditions

Climate changes and extremes as heavy precipitation and storms will not have influence on a disposal.

Other restrictions

Apparently no other restrictions will give problems.

8.13 Final remarks

The Paleogene clays together with the clayey tills could host a waste disposal. The structural framework of the Paleogene clays has to be investigated in relation to the Gassum salt pillow and the glaciotectonic structures.

9. Investigation reports from the project:

Low- and intermediate level radioactive waste from Risø, Denmark. Location studies for potential disposal areas. Published in GEUS Report Series.

Report No. 1. Gravesen, P., Nilsson, B., Pedersen, S.A.S. & Binderup, M., 2010: Data, maps, models and methods used for selection of potential areas. GEUS Report no. 2010/122, 47 pages.

Report No. 2. Gravesen, P., Nilsson, B., Pedersen, S.A.S. & Binderup, M., 2010: Characterization of low permeable and fractured sediments and rocks in Denmark. GEUS Report no. 2010/123, 78 pages.

Report No. 3. Pedersen, S.A.S. & Gravesen, P.., 2010: Geological setting and tectonic framework in Denmark. GEUS Report no. 2010/124, 51 pages.

Report No. 4. Gravesen, P., Nilsson, B., Pedersen, S.A.S. & Binderup, M., 2011: Characterization and description of areas. Bornholm. GEUS Report no. 2011/44.

Report No. 5. Gravesen, P., Nilsson, B., Pedersen, S.A.S. & Binderup, M., 2011: Characterization and description of areas. Falster and Lolland. GEUS Report no, 2011/45.

Report No. 6. Gravesen, P., Nilsson, B., Pedersen, S.A.S. & Binderup, M., 2011: Characterization and description of areas. Sjælland. GEUS Report no. 2011/46.

Report No. 7. Gravesen, P., Nilsson, B., Pedersen, S.A.S. & Binderup, M., 2011: Characterization and description of areas. Langeland, Tåsinge and Fyn. GEUS Report no. 2011/47.

Report No. 8. Gravesen, P., Nilsson, B., Pedersen, S.A.S. & Binderup, M., 2011: Characterization and description of Areas. Eastern Jylland. GEUS Report no. 2011/48.

Report No. 9. Gravesen, P., Nilsson, B., Pedersen, S.A.S. & Binderup, M., 2011: Characterization and description of areas. Limfjorden. GEUS Report 2011/49.

Report No. 10. Gravesen, P., Nilsson, B., Pedersen, S.A.S. & Binderup, M., 2011: Characterization and description of areas. Nordjylland. GEUS Report 2011/50.

Report No. 11. Gravesen, P., Nilsson, B., Pedersen, S.A.S. & Binderup, M., 2011: Dansk og engelsk resume. Danish and English resume. GEUS Report no. 2011/51.

10. References/Literature

Andersen, L.J. & Gravesen, P., 1989: Cyclogram Maps in the Interpretation of Pumping Tests. Recent Advances in Groundwater Hydrology. American Institute of Hydrology, 589-604 + map.

Andersen, L.J., 1958: Nye forekomster af eocæne akselag ved Randers. Meddr dansk geol, Foren. 13, 449-470.

Andersen, S.A., 1937: De vulkanske Askelag i Vejgennemskæringen ved Ølst og deres Udbredelse i Danmark. Danm. Geol. Unders. II Series, No. 59, 50 pages.

Atomenergikommissionen, 1976: Affald fra kernekraftværker, Handelsministeriet april-maj 1976, 133 pages.

Broholm K, Nilsson B, Sidle RC Arvin E 2000. Transport and biodegradation of creosote compounds in clayey till, a field experiment. Journal of Contaminant Hydrology, 41, 239-260.

Bull, N., Kallesøe, R. & Kærgaard, H., 1976: Rapport over Hydrogeologisk kortlægning af et område ved Horsens. Udført for Horsens Vandforsyning. DGU Juni 1976, 58 pages + maps.

Bøggild, O.B., 1918: Den vulkanske Aske i Moleret. Danm. Geol. Unders. Ser. II, 33, 84 pages.

Bøggild, O.B., 1943: Danmarks Mineraler. Danm. Geol. Unders., II række, Nr. 71, 68 pages.

Cartwright, D.J., 2001: Using hydraulic testing to determine vertical transport properties of a fractured clay aquitard. M.Sc. thesis. University College of London.

Christensen, L. & Ulleberg, K., 1973: Sedimentology and micropaleontology of the Middle Oligocene sequence at Sofienlund, Denmark. Bull. Geol. Soc. Denmark, vol. 22, 283-305.

Clausen & Huuse, 2002: Mid-Paleocene palaeogeography of the Danish area. Bull. Geol. Soc. Denmark, Vol. 49, Part 2, 171-186.

Dinesen, A., Michelsen, O. & Lieberkind, 1977: A survey of the Paleocene and Eocene deposits of Jylland and Fyn. Geol. Survey of Denmark, Series B, No.1, 15 pages.

Duun-Christensen, J.T., 1992: Vandstandsændringer i Danmark.- I : Miljøministeriet, 1992: Drivhuseffekt og klimaændringer – hvad kan det betyde for Danmark.

Dybkjær, K. & Rasmussen, E.S., 2000: Palynological dating of the Oligocene-Miocene successions in the Lille Bælt area, Denmark. Bull. Geol. Soc. Denm. Vol 47.

Ernstsen, V., 1998: Clay minerals of clayey subsoils of Weichselian Age in the Zealand - Funen area, Denmark. Bull. Geol. Soc. Denm. 45, 39-51.

Fenger, Jes, Buch, E. & Jakobsen, P.R., 2001: Monitoring and Impacts of Sea Level Rise at Danish Coasts and Near Shore Infrastructures.- I: Jørgensen, A.M.K., Fenger, J. og Halsnæs, K. (Red.): Climate Change Research, DMI, 237-254.

Fredericia, J., 1990. Saturated Hydraulic Conductivity of Clayey Tills and the Role of Fractures. Nordic Hydrology, 21(2), 119-132.

Grambo-Rasmussen, A., 1995: Geologisk kort over Danmark. 1:50.000. Kortbladet 1213 Ii Fredericia. Geologisk Basisdatakort. Danm. Geol. Unders. Kortserie Nr 43, 3-8.

Gravesen, P. & Pedersen, S.A.S., 2005: De geologiske forhold ved Risø. Redegørelse udarbejdet på basis af eksisterende data. Danmarks og Grønlands Geologiske Undersøgelse Rapport 2005/30, 40 pages.

Gravesen, P. & Pedersen, S.A.S., 2009: Vurdering af lerforekomster i Danmark med henblik på anvendelse i cement. Danm. og Grønl. Geol. Unders. Rapport 2009/85, 25 pages.

Gravesen, P., Jakobsen, P.R., Kelstrup, N. & Ernstsen, V., 1999: Kortlægning af radon i danske jordarter 1. Indsamlinfg af grunddata. Danm. og Grønl. Geol. Unders. Rapport 1999/81, 37 pages + appendices.

Gravesen, P., Jakobsen, P.R., Binderup, M. & Rasmussen, E.S., 2004: Geologisk set - Det sydlige Jylland. En beskrivelse af områder af national geologisk interesse. GEUS, Geografforlaget, Skov- og Naturstyrelsen, 188 pages.

Gry, H., 1935: Petrology of the Paleocene Sedimentary Rocks of Denmark. Geol. Surv. of Denmark, II Series, No. 61, 171 pages.

Haldorsen, S. & Krüger, J., 1990: Till genesis and hydro geological properties. Nordic Hydrology, 21(2), 81-94.

Harrar, W.G., 2004: Transient infiltration (flux) and fracture transmissivity in clayey till. In: Ernstsen, V (Ed.). Afprøvning af undersøgelsesmetoder med henblik på etablering af et zoneringskoncept for danske lerjorde: Statusrapport. ISBN 87-7871-142-8.

Harrar, W.G., Murdoch, L.C., Nilsson, B. & Klint, K.E.S. (2007). Field characterization of vertical bromide transport in a fractured glacial till. Hydrology Journal, 15(8), 1473-1488.

Heilmann-Clausen, C., 1985: Dinoflagellate stratigraphy of the uppermost Danian to Ypresian in the Viborg 1 borehole, central Jylland, Denmark. Danm. Geol. Unders., Serie A, No.7, 69 pages.

Heilmann-Clausen, C., 1990: Tertiæret ved Aalbæk Hoved –Et fedt profil. Varv nr. 4 1990, 99-118.

Heilmann-Clausen, C., 1995: Palæogene aflejringer over Danskekalken. In: Nielsen, O.B. (red.): Danmarks geologi fra Kridt til i dag. Aarhus Geokompendier Nr. 1. Geologisk Institut, Aarhus Universitet, 69-114.

Heilmann-Clausen, C., Nielsen, O.B. & Gersner, F., 1985: Lithostratigraphy and depositional environments in the Upper Paleocene and Eocene of Denmark. Bull. Geol. Soc. Denmark, vol. 33, 287-323.

Heilmann-Clausen, C. & Surlyk, F., 2006: Kapitel 10. Koralrev og lerhav. Palæogen. Naturen i Danmark. Geologien, Gyldendal, 181-226.

Hermansen, B., Pedersen, S.A.S. & Bjerregaard, C., 1999: Digitalt kort over Danmarks jordarter 1:200.000. Danm. og Grønl. Geol. Unders. Rapport 1999/47. CD – rom.

Houmark-Nielsen, 1987: Pleistocene stratigraphy and glacial history of the central part of Denmark. Bull. Geol. Soc. Denmark, Vol. 36, part 1-2, 187 pages.

Hyde, G., Pedersen, K.E. & Pedersen, D., 1993: Bentonit – især på Lolland. Varv nr.2 1993, 55-62.

Håkansson, E. & Pedersen, S.A.S., 1992: Geologisk kort over den danske undergrund. VARV, 1992.

IAEA, 1994: Siting of Near Surface Disposal Facilities. Safety Guides. Safety series no. 111-G-3.1, 37 pages.

IAEA, 1999: Near Surface Disposal of Radioactive Waste. Requirements. IAEA Safety Standards Series No. WS-R-1, 29 pages.

IAEA, 2005: Borehole Facilities for the Disposal of Radioactive Waste. IAEA Safety Standards Series, 102 pages.

Indenrigs- og Sundhedsministeriet, 2005: Slutdepot for radioaktivt affald i Danmark. Hvorfor? Hvordan? Hvor?. Juni 2005, 18 pages.

Indenrigs- og Sundhedsministeriet, 2007: Beslutningsgrundlag for et dansk slutdepot for lav – og mellemaktivt affald. Udarbejdet af en arbejdsgruppe under Indenrigs – og Sundhedsministeriet, april 2007, 47 pages.

Jakobsen P.R. & Klint K.E.S., 1999. Fracture distribution and occurence of DNAPL in a clayey lodgement till. Nord. Hydr., 30(4/5), 285-300.

Japsen, P. & Langtofte, C., 1991: Geologisk kort over Danmark. 1:400.000. Det danske Basin. "Basis kalk" og Kalk Gruppen. Danm. Geol. Unders. Kortserie Nr. 29, 2 pages + maps.

Jones, E.H., 1999: Hydraulic characterization of a fractured clayey till aquitard, Western Sjælland, Denmark. M.Sc. thesis. University College of London.

Jørgensen P.R. & Fredericia, J., 1992. Migration of nutrients, pesticides and heavy metals in clayey till, Géotechnique, 42, 67-77.

Jørgensen, P.R., Hoffmann, M., Kistrup, J.P., Bryde, C., Bossi, R & Villholth, K.G., 2002: Preferential flow and pesticide transport in a clay-rich till: Field, laboratory, and modeling analysis WRR, 38(11), 28-1 – 28-11.

Jørgensen, F & Sandersen, P.B.E. (2006). Buried and open tunnel valleys in Denmark—erosion beneath multiple ice sheets. Quaternary Science Reviews 25 (2006) 1339–1363

Klint, K.E.S., 2001: Fractures in Glacigene Deposits; Origin and Distribution. Ph.D. Thesis. Danm. og Grønl. Geol. Unders. Rapport 2001/129, 40 pages + Appendices.

Klint, K.E.S. & Gravesen, P., 1999: Fractures and Biopores in Weichselian Clayey Till Aquitards at Flakkebjerg, Denmark. Nordic Hydrology, Vol. 30, No. 4/5, 267-284.

Klitten, K., 2003: Log-stratigrafi for Selandien Lellinge Grønsand formationen og Kertemindе Mergel formationen. Geologisk Tidsskrift 2003/2, 20-23.

Knudsen, B., 1993: Plastisk ler – geotekniske problemer. GeologiskNyt 1/93, 9-11.

Larsen, G., 2002: Geologisk Set – Fyn og Øerne. En beskrivelse af områder af national geologisk interesse. Fyns amt, Geografforlaget, Skov- og Naturstyrelsen, 144 pages.

Larsen, G. & Dinesen, A., 1959: Vejle Fjord Formationen ved Brejning. Sedimenterne og foraminiferfaunaen (Oligocæn-Miocæn). Danm. Geol. Unders. II series, nr. 82., 114 pages

Larsen, G. & Kronborg, C., 1994: Geologisk set. Det mellemste Jylland. En beskrivelse af områder af national geologisk interesse. Geografforlaget, Skov- og Naturstyrelsen, 272 pages.

Larsen, G., Liboriussen, J. & Villumsen, A., 1972: Kvartærgeologiske undersøgelser på kortbladet Randers. Dansk Geol. Foren. Årsskrift for 1971, 27-40.

Larsen, G., Baumann, J., Tychsen, J., 1982: Storebælt, geological relations of the Eastern channel. Danish geotechnical Institute, DGI Bulletin No 34, 79 pages.

Larsen, G., Jørgensen, F.H. & Priisholm, S., 1977: The stratigraphy, structure and origin of glacial deposits in the Randers area, eastern Jutland. Danm. Geol. Unders. II Series No. 111, 36 pages.

Larsen, G., Frederiksen, J., Villumsen, A., Fredericia, J., Gravesen, P., Foged, N., Knudsen, B. & Baumann, J., 1988: Vejledning i Ingeniørgeologisk prøvebeskrivelse. Bulletin Dansk Geoteknisk Forening, nr. 1, 144 pages.

Lykke-Andersen, H., 1988: Viborgegnens Geologi. Viborg Leksikon 6, 40 pages.

Lykke-Andersen, H., 1995: Om tunneldalens natur. GeologiskNyt 3/95, 17-19.

Madsen, V., 1900: Beskrivelse til geologisk kort over Danmark. 1:100.000. Kortbladet Bogense. Danm. Geol. Unders, I Series no. 7, 112 pages + map.

Madsen, V., Nordmann, V. & Hartz, N.,1908: Eem –zonerne, Studier over Cyprinaleret og andre Eem-aflejringer I Danmark, Nordtyskland of Holland. Danm. Geol. Unders. II Series, No. 17, 302 pages + atlas.

McKay, L., Fredericia, J., Lenczewski, M., Morthorst, J. & Klint, K.E.S., 1999. Spatial variability of Contaminant Transport in a Fractured Till, Avedøre, Denmark. Nordic Hydrology, Vol. 30, 4/5, 333-360.

Mertz, E.L., 1928: Lillebeltler og London Clay. Danm. Geol. Unders., II Rk., nr. 51, 66 sider.

Miljøministeriet (2010a). Forslag til Vandplan 2010-15. Hovedvandopland 1.9 Horsens Fjord. By By- og Landskabsstyrelsen, Miljøministeriet. Hearing version, October 2010 http://www2.blst.dk/download/Vandplaner/DetSydfynske_Fyn.pdf

Miljøministeriet (2010b). Forslag til Vandplan 2010-15. Hovedvandopland 1.5 Randers Fjord. By By- og Landskabsstyrelsen, Miljøministeriet. Hearing version, October 2010 http://www.naturstyrelsen.dk/NR/rdonlyres/ED778AF3-41F4-4A51-889E-9E484F220D81/0/15RandersFjordhoeringokt2010.pdf

Miljøstyrelsen (2010a). Teknisk baggrundsnotat til Vandplan 1.5 Randers Fjord. Bilag 3. http://www2.blst.dk/Publikationer/haraldsgade/15-RandersFjord-tekbaggrund011010.pdf

Miljøstyrelsen (2010b). Teknisk baggrundsnotat til Vandplan 1.9 Horsens Fjord. Bilag 3. http://www.naturstyrelsen.dk/NR/rdonlyres/4FA4A210-0D96-4D26-B86B-380494BC8B34/0/19Horsensfjordtekbaggrund011010.pdf

Milnes, A.G., Stephens, M.B., Wahlgren, C.-H. & Wikström, L., 2008: Geoscience and high-level nuclear waste disposal: the Nordic scene. Episodes, vol. 31, no. 1, 168-175.

Møller, R.R. & Richard, N.L., 2006: Kerteminde mergels hydrauliske egenskaber i Ringsted kortlægningsområde. Memo carried out by Rambøll A/S.

Nielsen, O.B., 1973: Eocæne aflejringer i Ølst-området og deres indpasning i områdets Kvartærgeologi. Dansk Geol. Foren. Årsskrift 1972, 100-110.

Nilsson, B., Sidle, R.C., Klint, K.E., Bøggild, C.E. & Broholm, K., 2001: Mass transport and scale-dependent hydraulic tests in a heterogeneous glacial till - sandy aquifer system. Journal of Hydrology 243, 162-179.

Nordmann, V., 1958: beskrivelse til Geologisk Kort over Danmark, 1:100.000. Kortbladet Fredericia. Danm. Geol. Unders. I Series, no..22-A, 125 pages.

Olsen, G.V., 1955: Mellem-oligocænet ved Odder. Meddr Dansk Geol. Foren. 12, 580-592.

Pedersen, D.L., 2004: En geologisk og hydrogeologisk undersøgelse af inhomogeniteter i moræneler. Kandidatafhandling, Geologisk Institut, Københavns Universitet. Juni 2004. + appendix.

Pedersen, S.A.S., 1985: Forudsigelse af jordskælv.- Varv nr. 3, 1985, 85-93.

Pedersen, S.A.S., (ed.)1989: Jordartskort over Danmark 1:200.000. Four maps: Nordlylland, Midtjylland, Sydjylland og Fyn, Sjælland, øer og Bornholm. Danmarks Geologiske Undersøgelse, 1989.

Pedersen, S.A.S., Fries, K. & Lindgreen, 2007: Undersøgelser vedrørende forekomsten af bentonit ved Randers, Region Midtjylland. Danm. og Grønl. Geol. Unders. Rapport 2007/72, 31 pages.

Pedersen, S.A.S., Fries, K., Lindgren, H., Møller, L.L. & Poulsen, N.E., 2001: Råstiofgeologisk undersøgelse af bentonitforekomsten ved Støvring. Danam. Og Grønl. Geol. Unders, rapoort 2001/119, 32 pages.

Pedersen, S.A.S, Sheldon, E., Friis, K., Lindgreen, H., Ditlefsen, C. & Nielsen, A.M., 2010: Undersøgelse efter plastisk ler ved råstofgraveområdet I Ølst, Favrskov Kommune, Region Midtjylland. Danm. og Grønl. Geol. Unders. Rapport 2010/70.27 pages.

Pedersen, K. & Stockmarr, J., 1979a: Geologisk Basisdatakort 1313 IV Juelsminde. 1:50.000. Vejle Amtskommune. Danm Geol. Unders.

Pedersen, K. & Stockmarr, J., 1979b: Geologisk Basisdatakort 1314 III Odder. 1:50.000., Vejle Amtskommune. Danm. Geol. Unders.

Pedersen, K. & Stockmarr, J., 1980: Geologisk Basisdatakort 1214 Ii Horsens. 1:50.000. Vejle Amtskommune. Danm. Geol. Unders.

Rambøll, 2004: Vejle Amt. Retolkning af eksisterende TEM fra Vejle Amt, marts 2004, 7 pages + appendiks.

Rasmussen, L.B., 1960: Geology of north-eastern Jylland, Denmark. Guide to excursions, Int. Geol. Congress 1960, 38 pages.

Rasmussen, E.S., Dybkjær, K. & Piasecki, S. 2010: Lithostratigraphy of the Upper Oligocene – Miocene succession of Denmark. Bull. Geol. Surv. Denm. and Greenl. 22, 92 pages + plates.

Region Midtjylland, 2008: Råstofplan 2008 for Region Midtjylland, 36 pages + maps.

Region Midtjylland, 2009: Bentonit. Støvring og Dronningborg. Randers Kommune. Råstofkortlægning nr. 1, 2009. Regional udvikling, Jord & Råstoffer, 17 pages.

Region Syddanmark, 2008: Råstiofplan for Region Syddanmark, 36 pages + maps.

Rørdam, K., 1890: Undersøgelse af mesozoiske Lerarter og Kaolin paa Bormholm i geologisk og teknisk Henseende. Danm. Geol. Unders. I Series, no. 1, 109 pages.

Sandersen, P.B.E. & Jørgensen, F., 2003: Buried Quaternary valleys in western Denmark—occurrence and inferred implications for groundwater resources and vulnerability. Journal of Applied Geophysics 53 (2003) 229– 248.

Scharling, P., Rasmussen, E.S., Sonnenborg, T.O., Engesgaard, P., Hinsby, K., 2009: Three-dimensional regional-scale hydrostratigraphic modeling based on sequence stratigraphic methods: a case study of the Miocene succession in Denmark. Hydrogeology Journal, Online First, DOI 10.1007/s10040-009-0475-6

Seifert, D., Sonnenborg, T.O., Scharling, P. & Hinsby, K., 2008: Use of alternative conceptual models to assess the impact of a buried valley on groundwater vulnerability. Hydrogeology Journal, 16, 659–674.

Sheldon, E. & Nøhr-Hansen, H., 2010: Fehmarn Belt Fixed Link Pre-Quaternary Biostratigraphy – a mid-term status report for Rambøll/-Arup JV. Geol. Surv. Denm Greenl. Report 2010/27, 32 pages + appendix.

Sidle R.C., Nilsson, B., Hansen, M. & Fredericia, J., 1998: Spatially varying hydraulic and solute transport characteristics of a fractured till determined by field tracer tests, Funen, Denmark. Water Resources Research, Vol. 34, No. 10, 2515-2527.

Skov – og Naturstyrelsen, 1989: Noget om ler. Kvalitetsserie 4, Miljøministeriet, 88 pages.

Smed, P., 1962: Studier over den fynske øgruppes landskabsformer. Meddr. Dansk Geol. Foren. vol. 15, 1-74.

Sorgenfrei, Th. & Berthelsen, O., 1970: Geologi og vandboring. Danm Geol. Unders. Series III, no. 31, 106 pages.

Stockmarr, J., 1976: Hydrogeologisk kortlægning af Juelsminde kommune. Dan, Geol. Unders. Okt. 1976, 40 pages + maps.

Stockmarr, 1978: Den prækvartære overflade ved Juelsminde, Danmark. Danm. Geol. Unders. Årbog 1976, 49-52 + map.

Sundberg, P., 2000: Hindsgavl profilet, Vejle Fjord Formationen fra Øvre Oligocæn. GeologiskNyt 5/00, page 8.

Sundhedstyrelsen, 1987: Radioaktive stoffer i drikkevand. SIS, 23 pages.

Tank, R.W., 1963: Clay Mineralogy of some Lower Tertiary (paleogene) sediments from Denmark. Danm. Geol. Unders., IV ser., no. 9, 54 pages.

Thomsen, E., 1995: Kalk og kridt i den danske undergrund. In: Nielsen, O.B.(red.): Danmarks geologi fra Kridt til i dag. Aarhus Geokompendier Nr. 1, Geologisk Institut, Aarhus Universitet, 31-67.

Thomsen, E. & Heilmann-Clausen, C., 1985: The Danian-Selandian boundary at Svejstrup with remarks on the biostratigraphy of the boundary in western Denmark. Bull. Geol. Soc. Denm. 33, 3-4, 339-360.

Troldborg, L., Jensen K.H., Engesgaard, P., Refsgaard, J.C., Hinsby, K., 2008: Using Environmental Tracers in Modeling Flow in a Complex Shallow Aquifer System Journal of hydrologic engineering, 13(11), 1037-1048.

Vejbæk, O. V., 1997: Dybe strukturer i danske sedimentære bassiner.- Dansk Geologisk Forenings Nyheds og informationskrift, hæfte 4, 1- 31.

Vejle Amt (2004). Basisanalyse for vandstrikt 60 – Vejle. Vandrammedirektivets artikel 5. http://www.vandognatur.dk/NR/rdonlyres/2A5CB6F5-7AD1-4116-A0D5-03EDC7F97232/0/Vejle_Basisanalyse_delI.pdf

Watertech, 2006: Århus Amt. SkyTEM kortlægning ved Ølst. Databehandling og Geofysisk tolkning, nov. 2005, 17 pages + appendices.

Århus amt, 2002: Råstofindvindingsområde I Ølst Bakker. Vurdering af virkninger på miljøet. Oktober 2002, 118 pages + appendix.

Århus Amt (2004). Basisanalyse Del 1. Web rapport. http://www.vandognatur.dk/NR/ rdonlyres/5B9B7F9B-3BAE-4DAD-9ADF-4866B5A33EE/0/BasisanalysedelI2004web.pdf

Besides the literature cited above geological maps at GEUS have been used: Maps of the geological surface deposits, geological basis data maps showing the geology in shallow wells, maps of the deep seated geology and structures, maps of the pre-Quaternary surface, transmissivity and groundwater potential maps. Also information from GEUS Jupiter database containing data on approx. 250.000 shallow wells has been included.

The specific maps and wells will be cited in the report describing the approx. 20 localities.