DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2011/47

Low- and intermediate level radioactive waste from Risø, Denmark. Location studies for potential disposal areas. Report no. 7

Characterization and description of areas Langeland, Tåsinge and Fyn

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GEOLOGICAL SURVEY OF DENMARK AND GREENLAND
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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

Selection of potential areas on Langeland, Tåsinge, Fyn and two small islands has to fulfil the criteria and aims described and put forwards in Gravesen et al., (2010, Rapport no.1).

The areas chosen on Langeland and Tåsinge only include Quaternary and Paleogene deposits on the mid and southern parts of the Islands. On the southern part of Langeland, a disposal area will be relatively isolated while a locality in mid Langeland will be more exposed. On the small islands Siø and Strynø, an isolation of the waste will be possible. On southern part of Tåsinge near Bjerreby and Vemmenæs, a thick sequence of fine-grained Paleogene clays is found. On Fyn, two areas are recognized. At Kertinge Mark east of Kerteminde, a peninsula seems to be a potential disposal area in Paleocene Kerteminde Marl. At Hindsgavl and Fænø west of Middelfart, thick sequences of Oligocene, Eocene and Paleocene clay deposits can give good possibilities for a disposal site.

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

5. Area 7. Langeland south

5.1 The location of the area

Langeland is located southeast of Fyn (Fig. 1).The area is found in the southern part of Langeland between Sædballe and Gulstav (Fig. 2).

Figure 1. Location of the area 7. Langeland is located in the Baltic Sea southeast of Fyn.

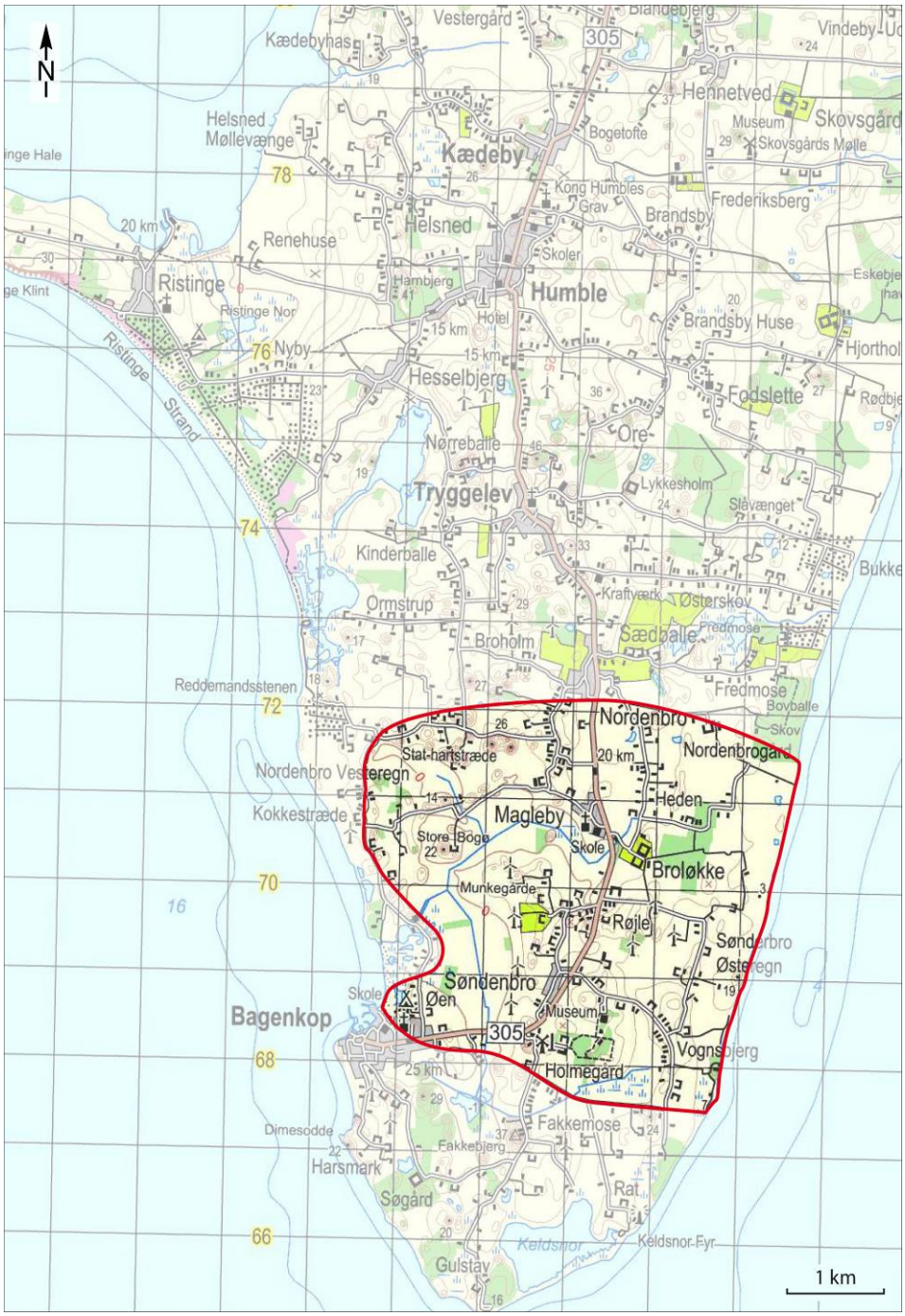


Figure 2. A detailed map of Area 7. Area 7 is located on the southern part of Langeland.

5.2 Terrain, topography and surface processes

The area is located on the southern part of Langeland and includes c. 17.4 km^2. Approximately half of the area is marked by a very plane, low-lying terrain (0 – 5 m above sea level), while the other half is undulating, marked by a large number of small but steeply sloping, local hills with the top levels typically situated 20 - 40 m.a.s. Toward the east, the delimitation of the area follows the coastline. The area holds some very small lakes towards

north and north-east and a few small streams/drainage ditches in the central, west and southern part of the area.

A few small villages, some farms, a number of houses (primarily located along the roads), several windmills, a traditional mill and a camping place are found in the area. Moreover, one main road and several minor roads cross the area. Nevertheless, it is possible to find open areas many places. Approximately 5-7 % of the area is woods; the remaining and dominating part is used for agriculture.

Owing to the low relief and intensive cultivation, the surface processes (soil creep, frost – thaw processes, soil development etc.) proceed slowly and undramatic. This counts for the steeply sloping hills as well, as long as they are protected and overgrown by vegetation. The coastal section is partly under erosion and low cliffs have developed locally. The coast-line is without coastal protection.

The north-western c. 1/3 of the area is included in an area of National Geological Interest (no. 132).

5.3 Surface geology and profiles

The surface geology mainly consists of clayey till but an area of meltwater sand and gravel is found in the northern part of the area and just outside the area. To the west along the coast, the tills are bordered by marine Holocene deposits. Just outside the area, a cliff section occurs at Ristinge Klint cliff that shows that the area is build up by glaciotectonic disturbed glacial and interglacial deposits. Along the south coast at Gustav, low cliffs consisting of clayey tills and meltwater sand and gravel are lsituated (Dovnsklint, Gulstav Klint) (Fig. 3).

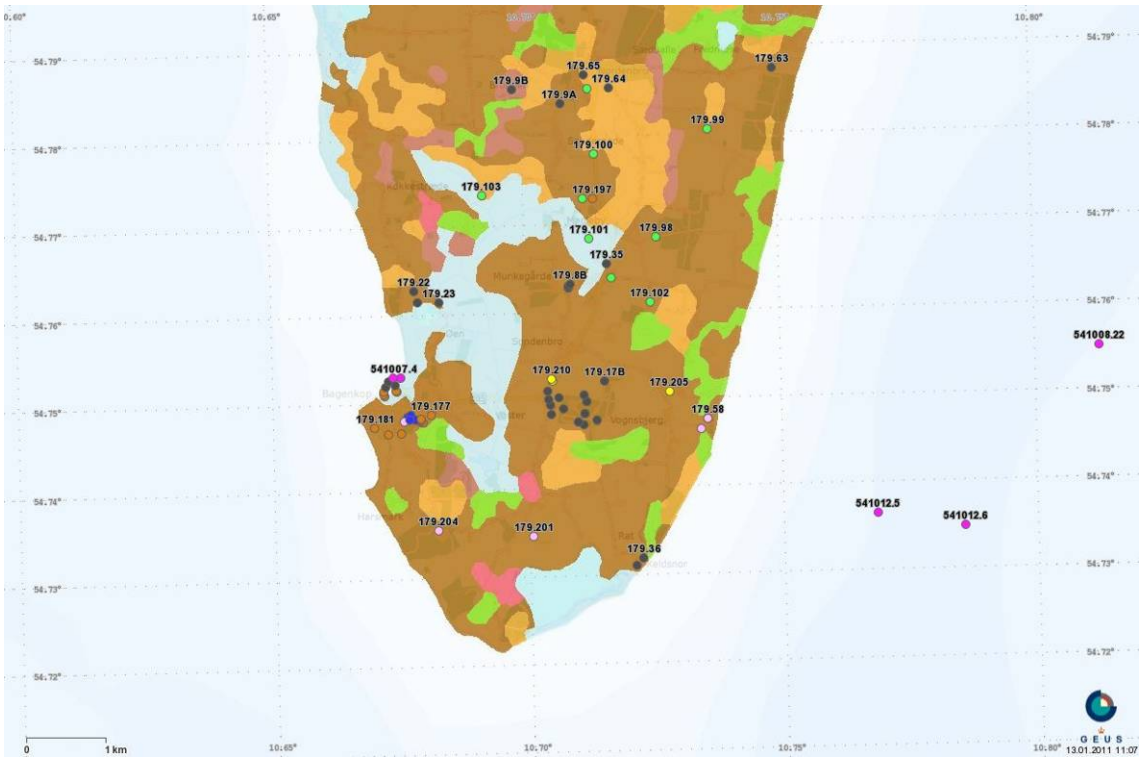


Figure 3. Map of the Quaternary surface deposits (From GEUS´s Homepage. After Pedersen, 1989). Legend: Brown: Clayey till, Red brow: Sandy till, Red and orange: Meltwater sand and gravel, Green: Holocene freshwater deposits, Light blue: Holocene marine deposits. Legend for boreholes: See fig.4.

5.4 Boreholes and geophysical surveys

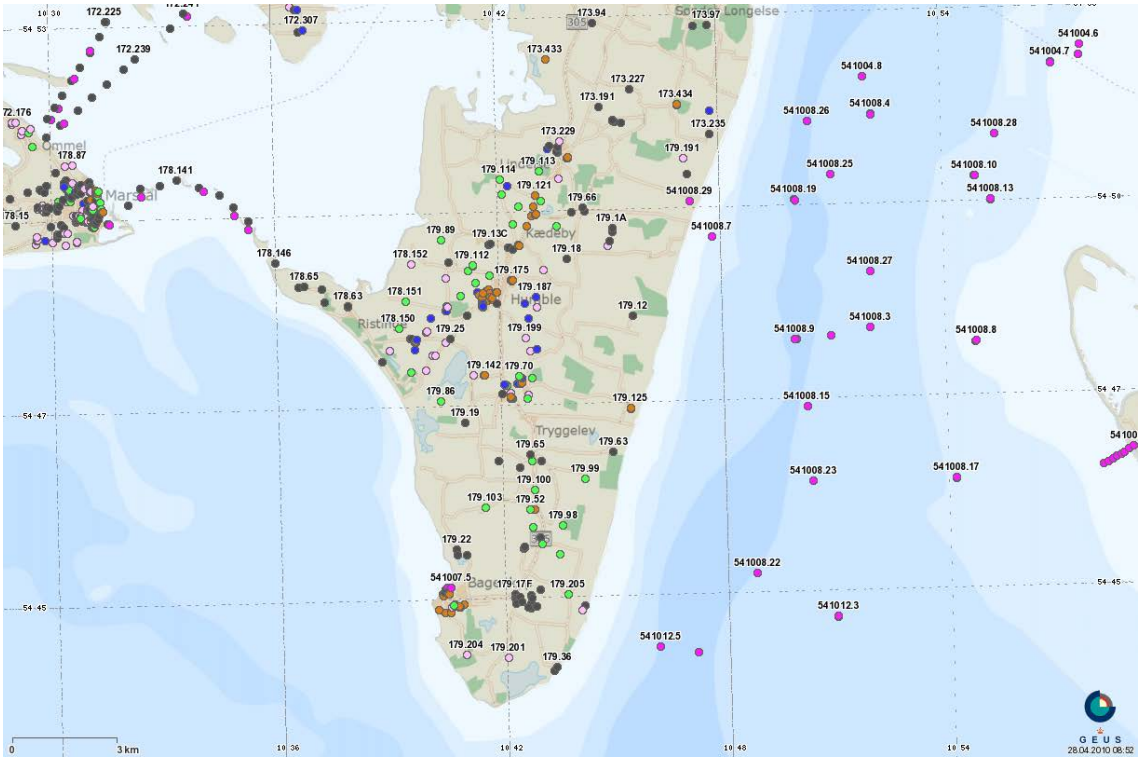


Figure 6. Map of the locations of boreholes from the Jupiter Database at GEUS. Legend: 179.17c: DGU no., Blue dot: Water supply well, Red dot: Geotechnical borehole, Pink dot: Raw material borehole, Green dot: Other borehole, Light red dot: Abandoned borehole, Black dot: Unknown purpose.

Relatively few boreholes are known from the area which can be used to describe the geological build up in the area (Figs. 4, 5). The main target is Paleogene clays probably from the Eocene and ten to fifteen boreholes reach the Paleogene clays in the area. It is a problem that most boreholes only reach the Eocene clay and only one sample is taken in this layer. In borehole DGU No.179.17b, 20 m of green Eocene clay is penetrated but no samples have been available. In another older borehole, almost 60 m of plastic clay is reached but no samples have been collected. A borehole example is seen in fig. 6.

Geophysical surveys just north of the area have been performed for the County of Fyn. The methods were seismic and geoelectric surveys.

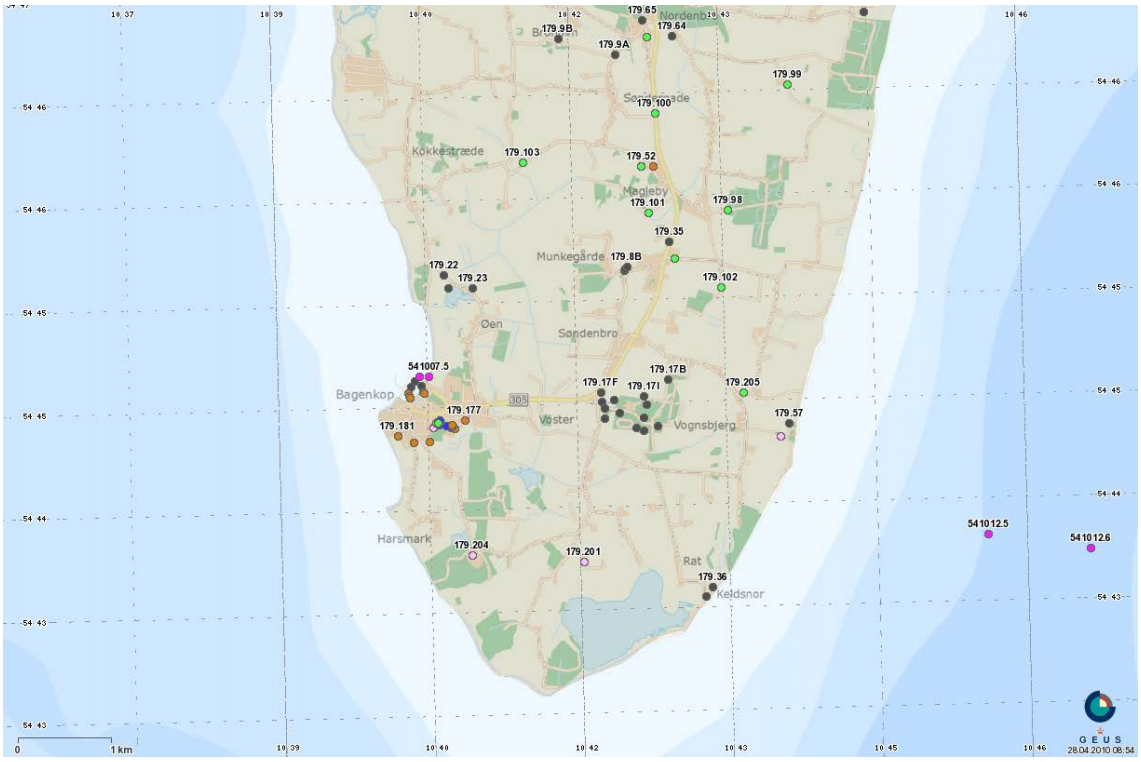


Figure 5. Location of boreholes in the area. (From GEUS Jupiter Well Database). Legend: Se fig. 4.

De Nationale Geologiske Undersøgelser for Danmark og Grønland

Udskrevet 28/4 2010 Side 1

BORERAPPORT

DGU arkivnr: 179. 17C

Borested : ØRNEBJERG HOLMEGÅRD SØVÆRNETS BYGNINGSVÆSEN
5935 Bagenkop

Kommune : Langeland
Region : Syddanmark

Boringsdato : 25/6 1952 **Boringsdybde** : 61 meter **Terrænkote** : 16 meter o. DNN

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

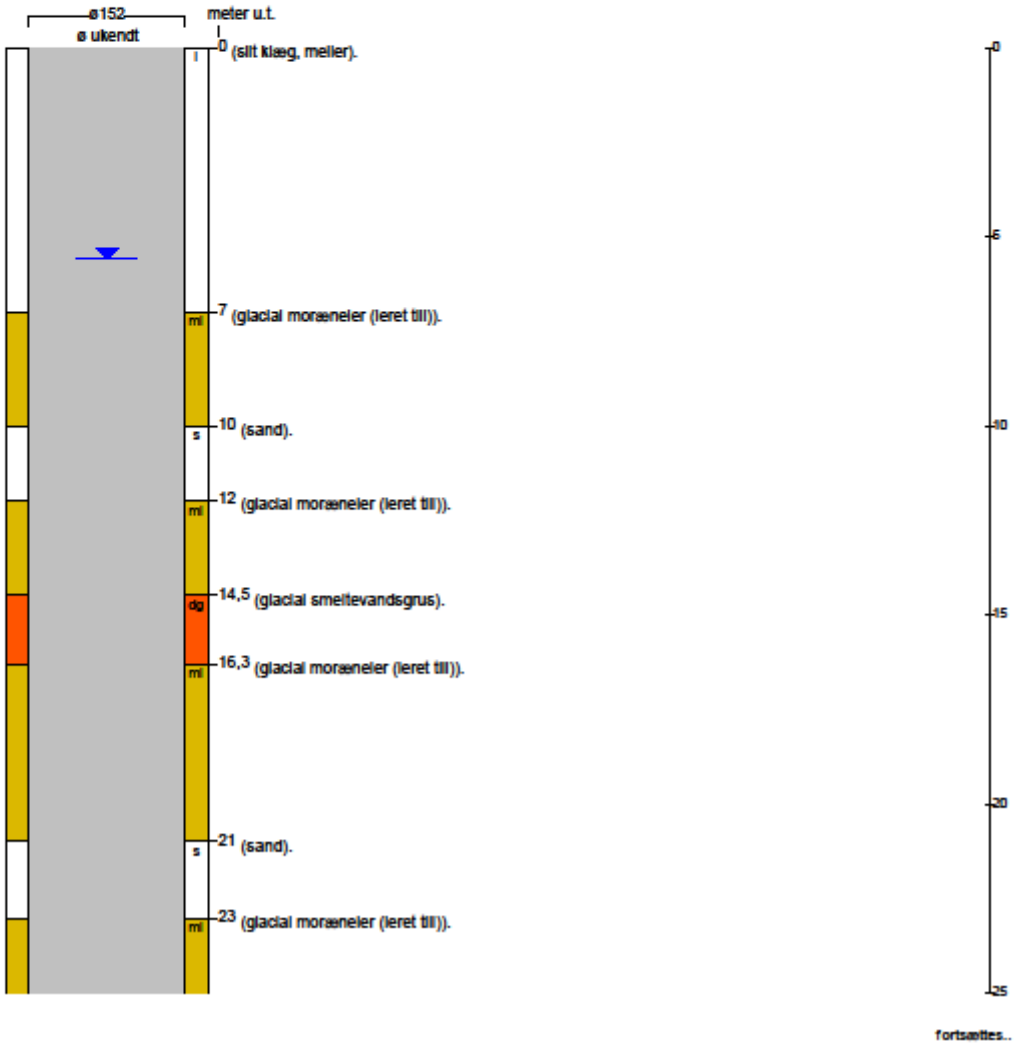
Prøver
- modtaget :
- beskrevet : **af** : G
- antal gemt :

Formål :
Anvendelse :
Boremetode :

Kortblad : 1311 IINØ
UTM-zone : 32
UTM-koord. : 610376, 6068261

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

		Ro-vandstand	Pejledato	Ydelse	Sænkning	Pumpetid
Indtag 1	(seneste)	5,6 meter u.t.	25/6 1952	0,5 m³/t	20,2 meter	



fortsættes...

Figure 6. Geological borehole log of DGU No. 179.17C. Upper part of the 61 m deep borehole. Legend: Brown: Clayey till, Red: Meltwater sand and gravel.

5.5 Sediment and rock characteristics, mineralogy and chemistry

5.5.1 Pre-Quaternary deposits

According to the map of the pre-Quaternary deposits (Fig. 7), the sediments below the Quaternary should belong to Eocene. The relatively few borehole samples are mainly lithological described as plastic, very fine-grained strongly calcareous to calcareous brown and red brown clay or green calcareous plastic clay. One green sample is dated by foraminifera to the Eocene. The clays could tentatively belong to the following formations: The green clays to the Lillebælt Clay Formation and the brown to the Røsnæs Clay Formation. Examples of the two clay types can be seen in figs. 8 and 9.

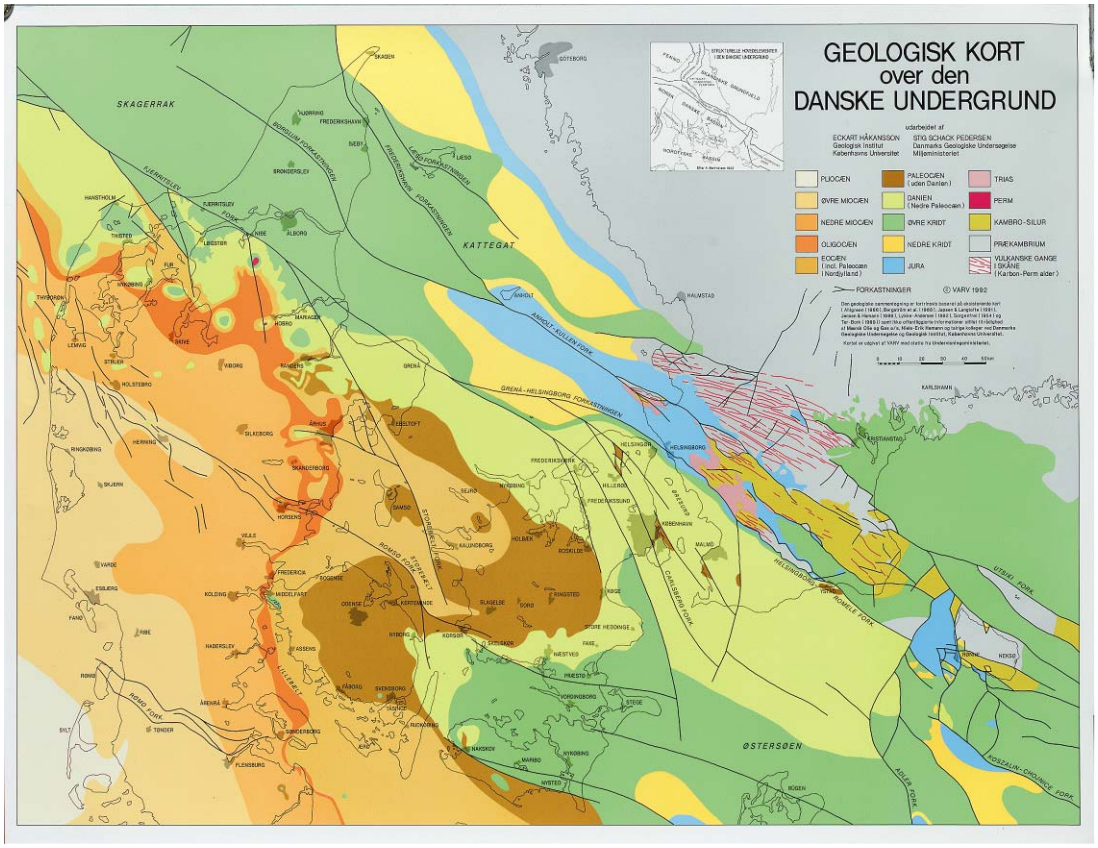


Figure 7. Map of the pre-Quaternary surface: Time units. Original scale: 1:50.000. Legend: Red lines: Precambrian intrusions, grey: Precambrian, olive: Cambrian-Silurian, red: Permian, light red: Triassic, blue: Jurassic, yellow: Lower Cretaceous, green: Upper Cretaceous, light green: Danian, brown: Paleocene, yellow olive: Eocene, red brown: Oligocene, light yellow brown: Lower Miocene, very light yellow brown: Upper Miocene, white: Pliocene (Håkansson & Pedersen, 1992).

Figure 8. Green plastic clay, probably the Eocene Lillebælt Clay Formation from Albæk Hoved Cliff, Jylland.

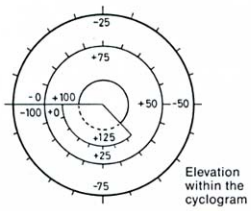
Figure 9. Section from the Albæk Hoved clift, Juelsminde, Jylland. Red and green plastic clays which are comparable clays with the Lillebælt Clay and Røsnæs Clay Formations.

In the southern part of the area at Holmegård (Langelandsfortet), the green and brown clays are reached approx. 30 m below the surface and are covered by clayey till and melt-water deposits.

At Bagenkop, the water wells reach the clays in the same depth. To the north, in the area at Broløkke, green plastic clays are covered by clayey tills and at Sædballe just north of the area, apparently approx. 50 m Quaternary tills cover the Eocene clays.

Towards the north, outside the area, the Eocene clays are reached in 25-30 m depth and at Hjortholm and Skovsgård 25-40 m clayey till rest on Eocene clays. The borehole data can be seen on the Geological Basic Data Map (Fig. 10).

LEGEND



Elevation within the cyclogram

Location of well

3,7/5.8 Yield in m^3/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.....

DGU. file No. (566)

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

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 10. Geological Basic Data Map. a. Legend to the map (From Andersen & Gravesen, 1989. b. Part of Geological Basic Data map 1311 I Rudkøbing showing borehole data from southern Langeland. Original scale 1:50.000 (From Gravesen, 1993).

5.5.2 Quaternary deposits

The area is dominated by relatively thick sequences of Quaternary sediments, mainly clayey tills but locally also thick meltwater sand and gravel layers (Figs. 3 and 12). All the information is from borehole sample descriptions but in Ristinge Klint cliff, some of the sediments can be recognized besides interglacial clays and silts from the Eemian.

The upper 5.5 m of clayey till is sandy and silty, gravelly, non-calcareous and slightly calcareous. The color is brown to yellow brown indicating the oxidized character of the sediment. The lower clayey till is sandy, silty and calcareous. The color is grey or olive grey and the till often contain chalk particles. This till is reduced (Fig. 11). Tills just above the pre-Quaternary sediments are called local tills because they contain material of the Eocene clays from below. Floes of Eocene clays also occur in the clayey tills.

The meltwater sediments consist of stony sand and gravel, fine to medium-grained sand and silt. These sediments are often intercalated in the tills but they are also found resting directly on the pre-Quaternary surface.

Figure 11. Example of clayey, sandy and stony till deposits.

The Glacial landscape on Langeland is specially known from the occurrence of circular hat-shaped hills (known as kames) on a lodgement till plain.

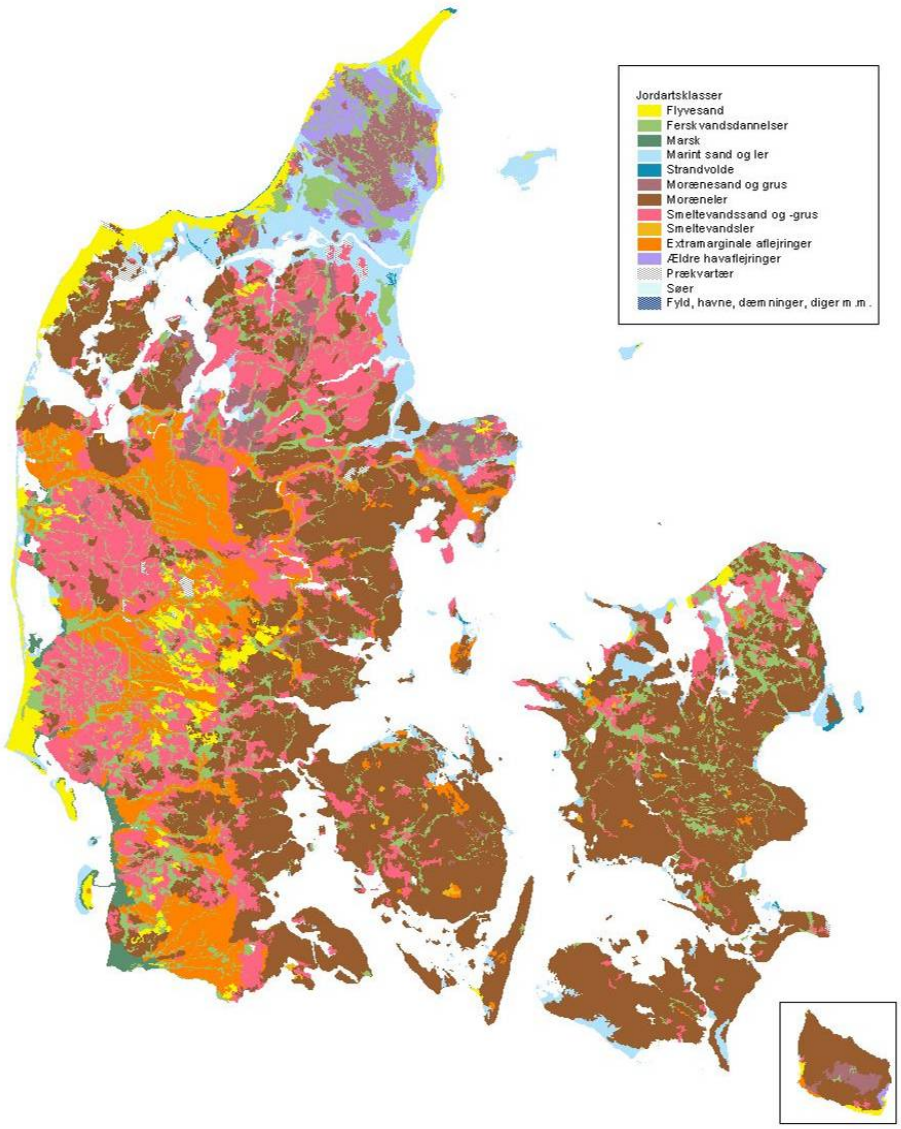


Figure 12. The map of the Quaternary surface deposits. Original scale: 1:200.000. Legend: Brown: Clayey till, light brown: Sandy till, red: meltwater sand and gravel, orange: sandur sand and gravel, purple: Late glacial marine deposits, light blue: Holocene marine deposits. Green: Holocene freshwater deposits, yellow: Aeolian sand (From Pedersen, 1989).

5.6 Tectonics, structures and seismic activity

5.6.1 Major tectonic structures

According to the map (Fig. 7) no structures crosses the pre-Quaternary surface within the area.

At the southern tip of Langeland, a borehole reaches the Eocene deposits in level -70.5 m and the Eocene clays seems be more than 60 m thick as the clay occurs in level -130 m.

The information from the borehole is sparse. Nevertheless, this means that the pre-Quaternary surface is inclined from level -25 – -30 m towards -70 m over a short distance.

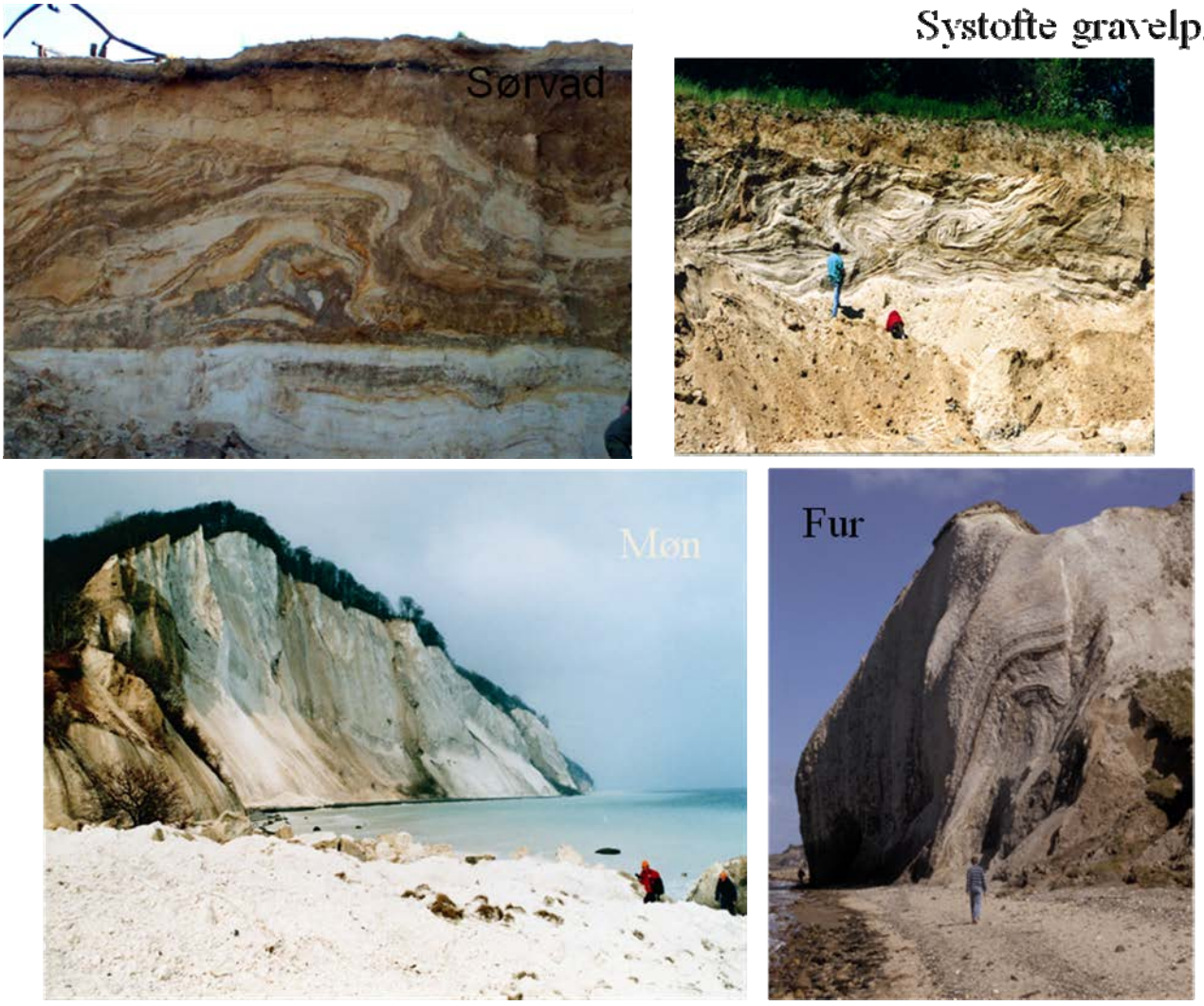


Figure 13. Examples of glaciotectonic disturbances of Quaternary and pre-Quaternary deposits from Sørvad, Sydtofte, Møn and Fur (Photos: K.E.S. Klint).

Field investigations at Ristinge Klint cliff show that the Quaternary deposits are disclosed and inclined slices of sediment have been pushed up. It can be seen in some boreholes that least the upper parts of the Quaternary deposits have been deformed by glaciers from the northeast and east. The Young Baltic advance has pushed up the ice borderline, which can be followed from north to south on Langeland (Fig. 13).

5.6.2 Fractures

There is no information from the boreholes. From the cliff sections, fractures in the clayey till have been recognized to 5 m below ground surface (Fig. 14 and 15). Fractures in the fine-grained Tertiary clays have to be expected.

Figure 14. Example of fractures in clayey till (Photo: K.E.S. Klint).

5.6.3 Geological model

The geological model of the area is rather simple in relation to lithology and the structural conditions.

Model of the area is as follows (Fig. 15):

A. Quaternary Clayey till with meltwater gravel sand and clay, 25-50 m thick. The till can be glaciotectonic displaced.

B. Eocene sticky clay from the Røsnæs Clay Formation and/or the Lillebælt Clay Formation which are at least 60 m thick.

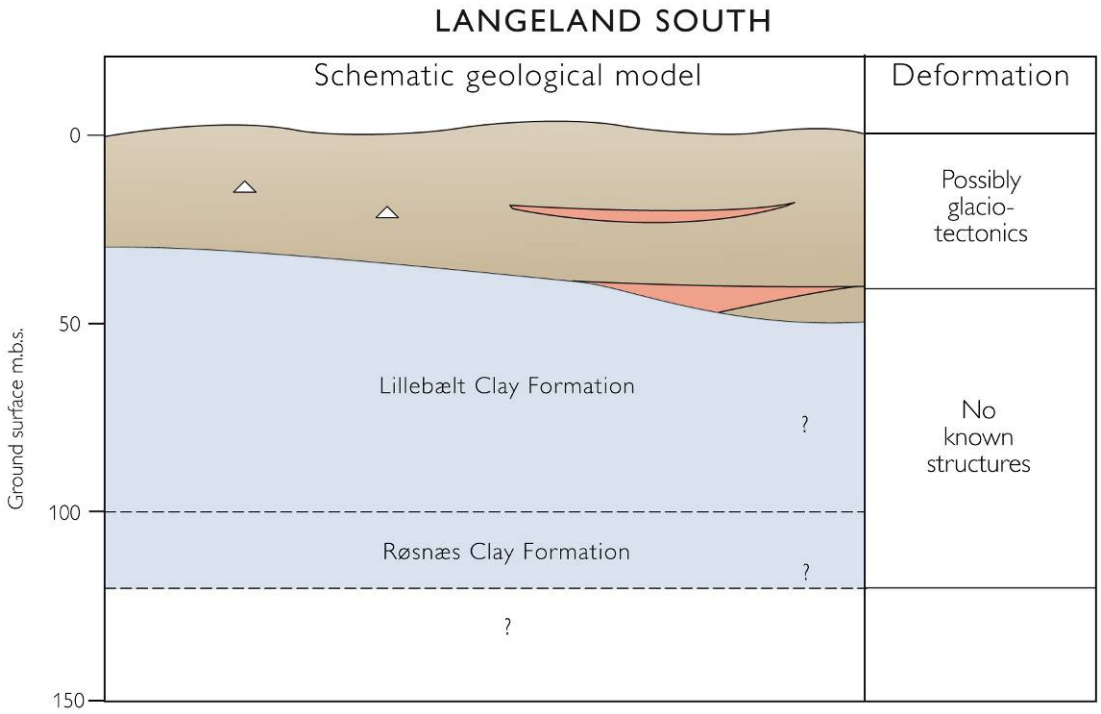


Figure 15. Schematic model of the geological conditions of Area 7.

5.6.4 Earthquake activity

The seismic activity in southern Langeland and the near surrounding sea is very low (Fig. 16). 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.

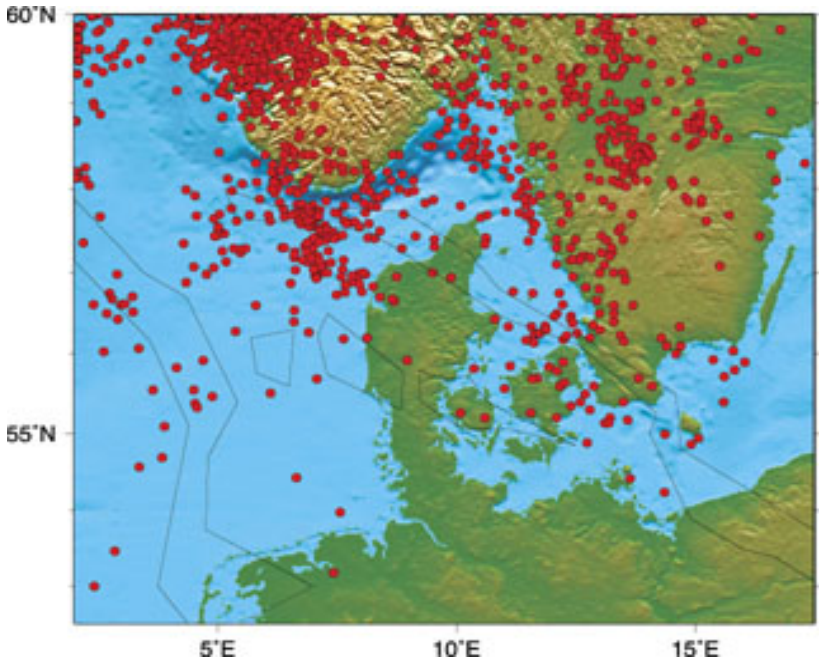


Figure 16. Map of the seismic activities in Denmark and surrounding areas. Red dots show positions of earthquake epicentres (From GEUS´s Home Page).

5.7 Ground stability

The stability of the area is considered as very good. But it is important to remember that constructions on and in plastic clays can give problems.

5.8 Groundwater hydrogeology

5.8.1 Groundwater characteristics

The boreholes show thick clay layers of Eocene plastic clay and clayey till with only thin layers of meltwater sand and gravel. It is not possibly to abstract enough amounts of water from the sand layers.

Langeland South (Area 7) is positioned in an area that is characterized by the presence of two shallow groundwater bodies (DK1.14.1.3 and DK1.15.1.4) and one regional groundwater body (DK1.15.2.4) (Figs. 17 and 18). All three groundwater bodies consist of meltwater sand deposits. Deep groundwater bodies have not been identified in or near Area 7 in the catchment management plan. The subdivision into groundwater bodies is described as part of the basis analysis carried out by the former Fyn Amt (www.ode.mim.dk). The overall assessment of the chemical and quantitative status of the shallow and regional groundwater bodies is poor, due to a poor qualitative status (see Section 5.9).

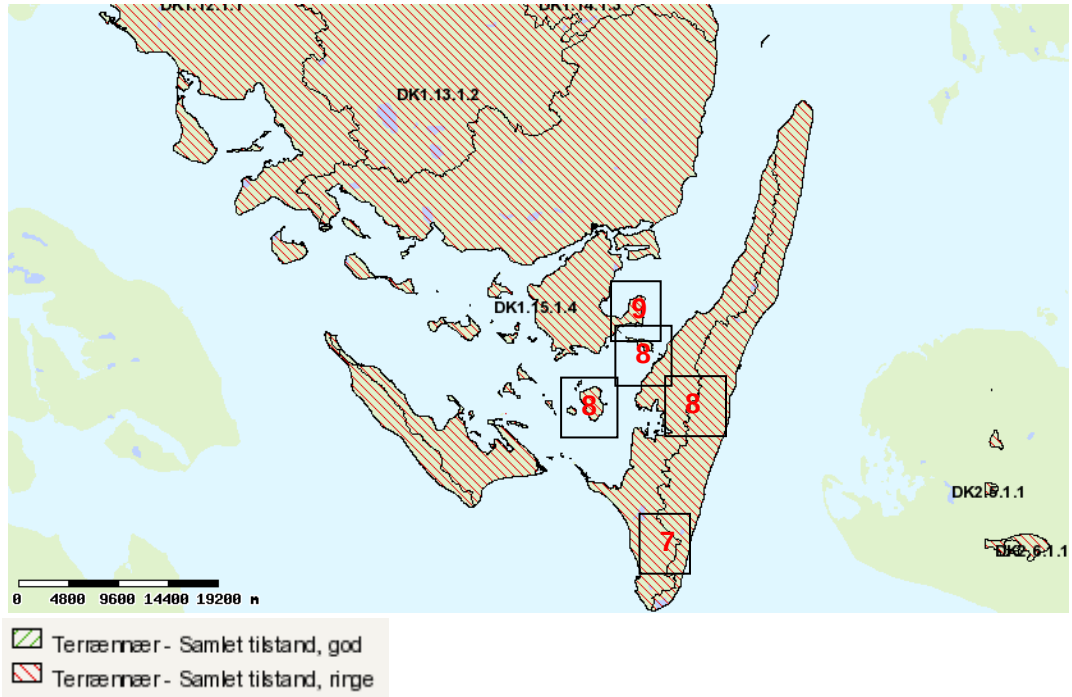


Figure 17. Shallow (or terrain near) groundwater bodies DK1.14.1.3 and DK1.15.1.4 at the areas Langeland South (Area 7), Langeland Mid, Siø & Strynø (Area 8), and Vemmenæs (Area 9). The overall assessment of chemical and quantitative status of all three areas: poor status (Red shaded area). (After Ministry of Environment, 2010).

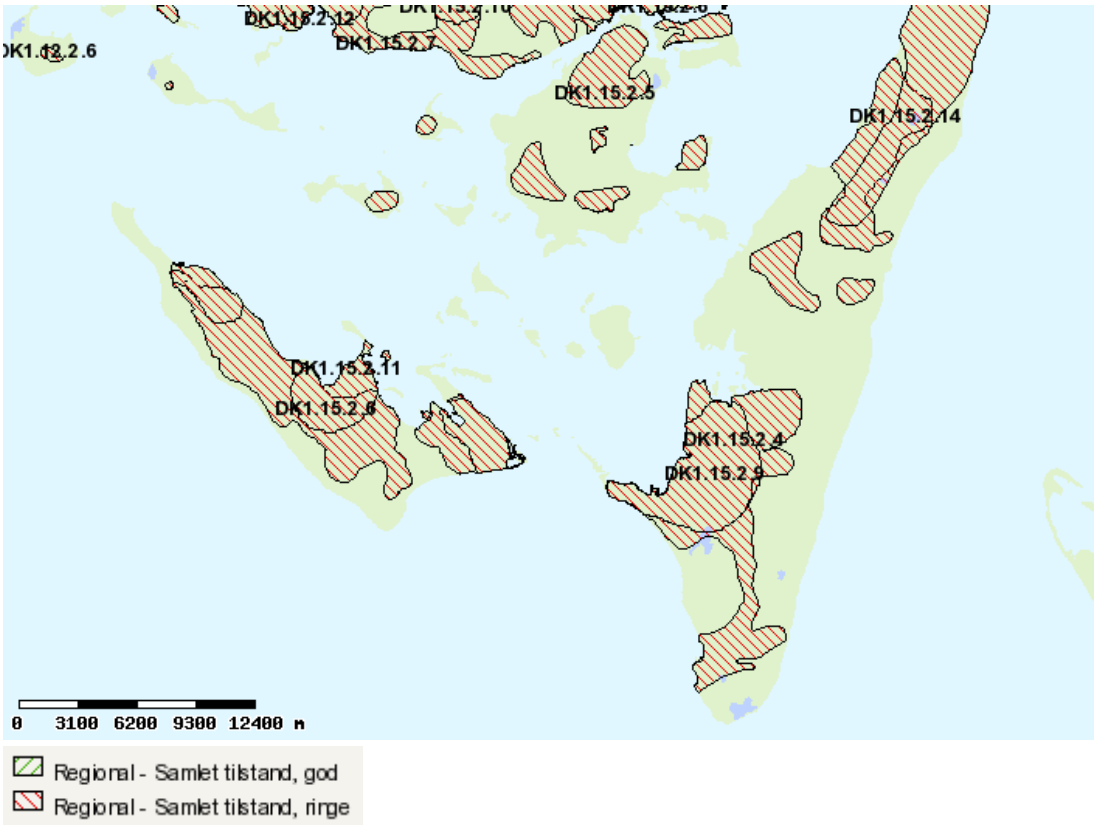


Figure 18. Regional groundwater bodies in the Langeland-Tåsinge region. Near Langeland South area (Area7): DK1.15.2.4; Near Langeland Mid Area 8): DK1.15.2.9; At Vemmenæs (Area 9): DK1.15.2.5. The overall assessment of chemical and quantitative status for all three areas: poor status (Red shaded area) (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. 19).

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.

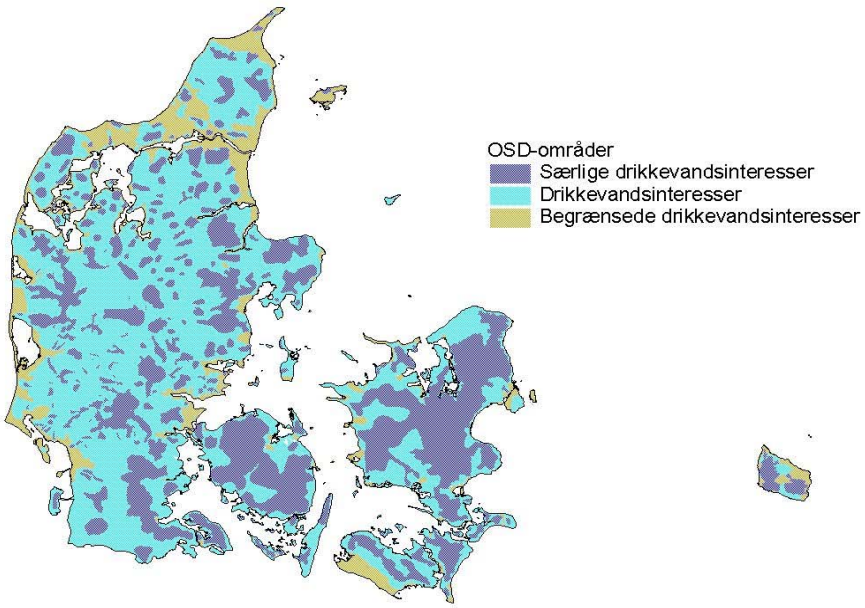


Figure 19. Areas of special drinking water interests (OSD): Dark blue and areas of drinking water interest (OD): Light blue. Areas with limited drinking water interests are olive brown. (http://kort.arealinfo.dk/).

The drinking water areas categorised by the Environmental Centre Odense for the Langeland-Tåsinge region is shown in Fig. 20. The Langeland South is located in an area with drinking water interests (OD) at the southern tip of Langeland. It is important to notice that Bagenkop town is supplied by Bagenkop waterwork that is abstracting groundwater within Area 7 together with waterworks in Humble, Tryggelev and Hesselbjerg that all three are located north of Area 7.

The status for the mapping of the groundwater resources is seen in fig. 21.

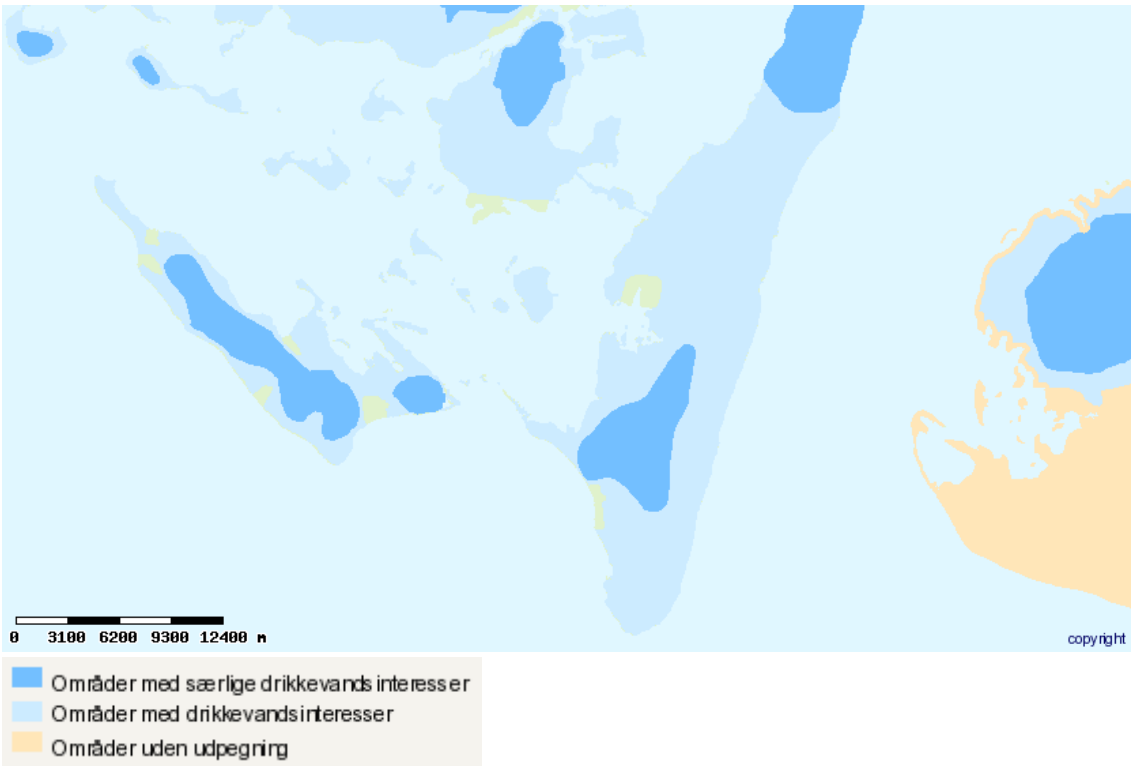


Figure 20. Various drinking water areas situated in the Langeland-Tåsinge region. Dark Blue: Areas of special drinking water interests (OSD); Light blue: Areas of some drinking water interests (OD); Yellow: Areas with limited or none drinking water interests.(http://kort.arealinfo.dk/).

5.9 Groundwater chemistry

The overall groundwater quality aiming for drinking water purpose has been assessed by the former Fyns Amt and Environmental Centre Odense for each groundwater body and reported in the catchment management plans “Hovedvandopland 1.15, Det Sydfynske Øhav” and “Hovedvandopland 1.14, Storebælt“. The groundwater bodies have a poor status due to findings of total phosphorus and chlorinated solvents in concentrations that exceed the acceptable limits in groundwater.

Saltwater intrusion is not a general problem in Hovedopland 1.15. However, Area 7 located at the southern tip of Langeland has a distance from coast to coast of 4 km. Groundwater levels in wells registered in JUPITER within Area 7 indicate groundwater levels placed few meters above present sea level. Sea level rise due to climate change can potentially raise the salt/freshwater transition to the critical depth at less than 100 m below terrain. However, this scenario is considered less likely.

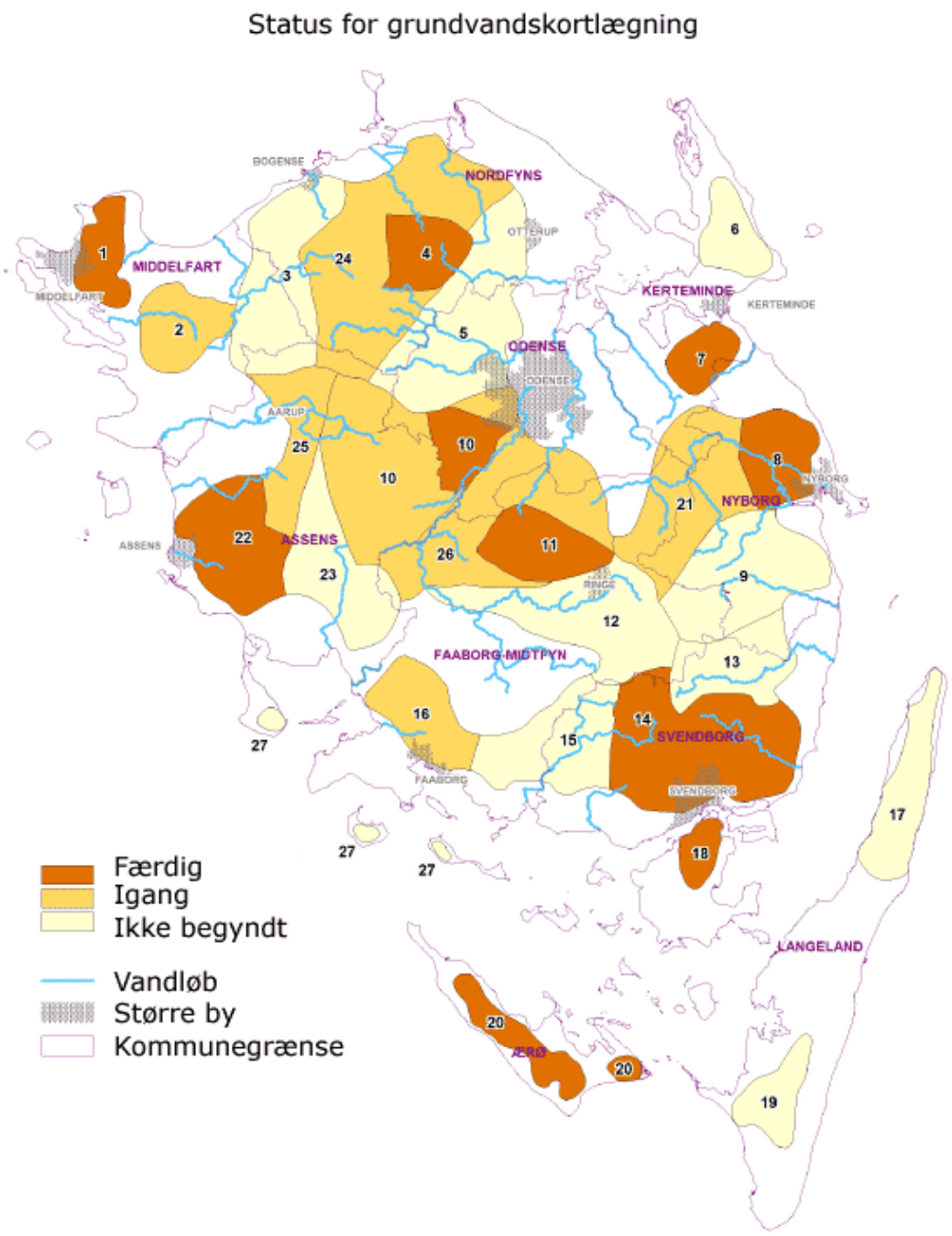


Figure 21. The finished (Orange), ongoing (Yellow) and future (Light Yellow) mapping of the groundwater resources. (From Environment Centre Odense Home Page).

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). The expected increase in precipitation and a sea level rise may cause flooding problems to the low-lying parts of this area during this century. Moreover, the sea level rise may increase the ongoing erosion of the coast along the eastern delimitation of the area.

5.11 Restrictions and limitations

Parts of the area are included in the National Geological Interest Area 133 Gustav. The western shoreline and the area within a distance of 200-500 meter from the shoreline is categorised as a NATURA2000 habitat (Fig. 22). Furthermore, there are areas protected in accordance to Naturbeskyttelsesloven (law for nature protection). The salt/freshwater transition underneath Area 7 is considered less likely to rise as result of climate change driven sea level rise.

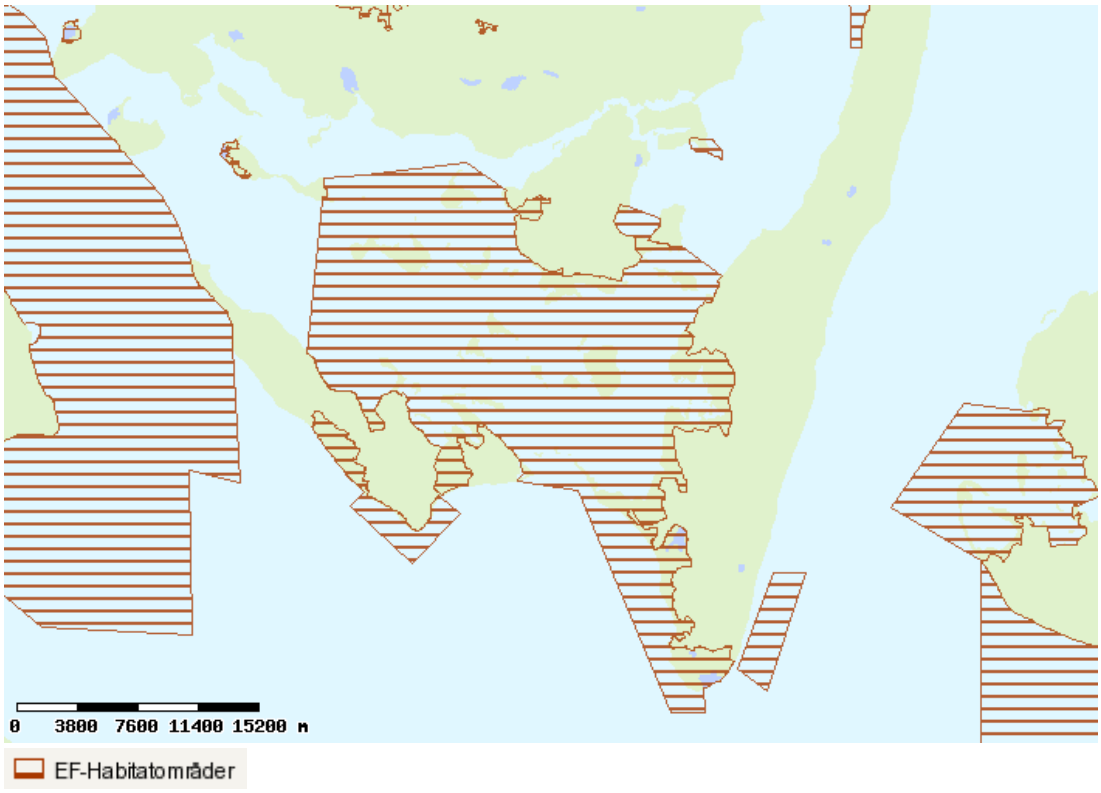


Figure 22. NATURA2000 Habitat areas in the Langeland-Tåsinge region.

5.12 Summary of the area conditions

Amount of data:
Sparse: Few boreholes and geophysics.

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.

Stability
Good stability on surface and depth but the conditions of plastic clays have to be considered.

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

Groundwater conditions
The groundwater conditions in the Eocene clays and the overlaying tills and meltwater deposits should be positive with slow flow towards the sea but the variation in 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 an OD area. Local well supplies to Bagenkop are located north of the area and the area is also outside the recharge area to the water supply wells.

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
Sea level rises according to future climate changes have to be evaluated. Climate changes and extremes as storms and heavy precipitation will probably not influence on a disposal situated below ground surface.

Other restrictions
Apparently, no other restrictions will give problems.

5.13 Final remarks

Area 7 holds some important geological characters in relation to a potential waste disposal because of the abundant Quaternary and pre-Quaternary clay deposits but the amount of data is too limited to make a clear conclusion.

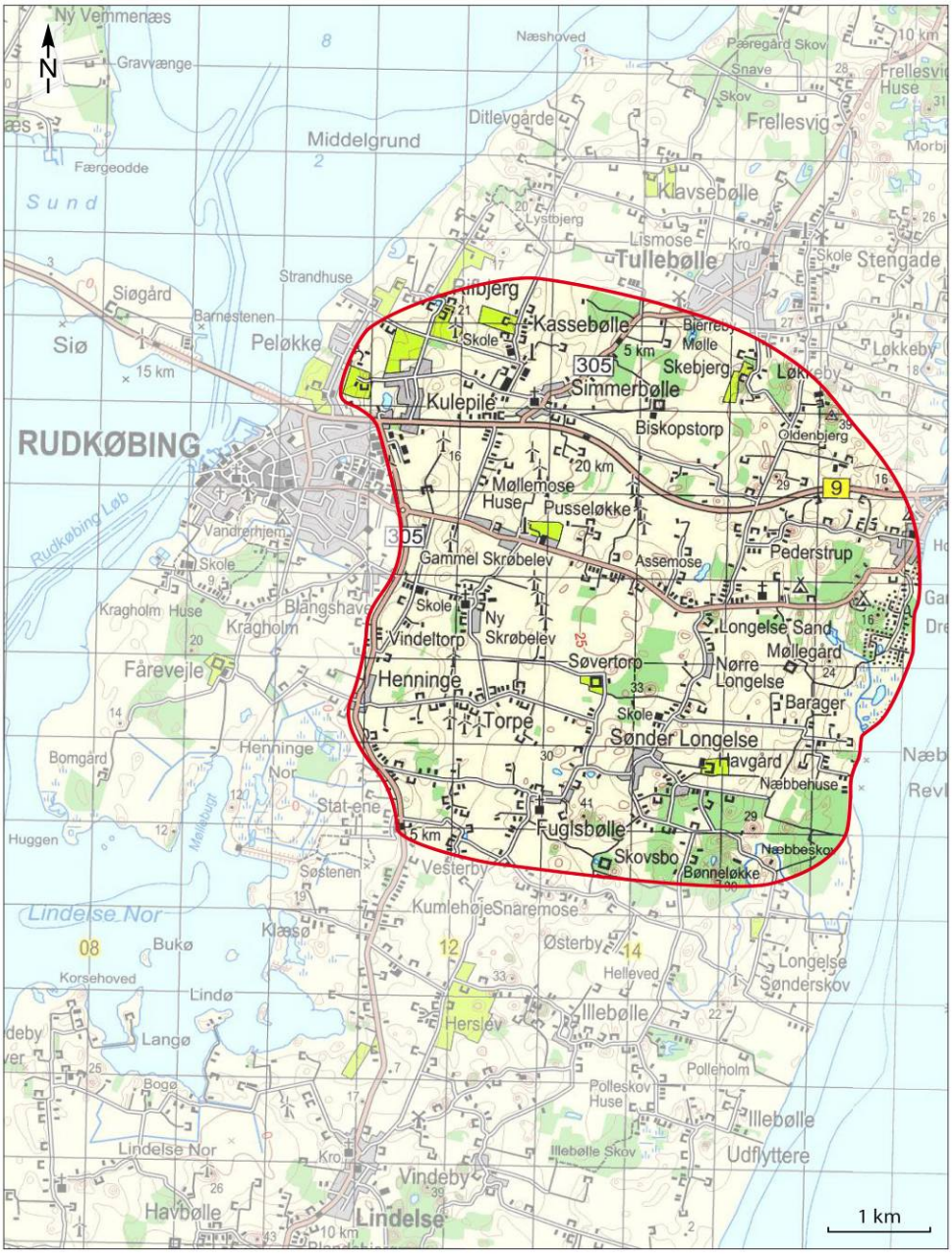
6. Area 8. Mid Langeland, Strynø and Siø

6.1 The location of the area

Langeland is situated southeast of Fyn (Fig. 23).

The area is situated from east of the city of Rudkøbing to Spodsbjerg in the west and from Tullebølle in the east and Fuglsbølle in the south. The two islands east of Langeland Siø and Strynø are included in this area (Fig. 24).

Figure 23. Location of the area 9. Langeland is located in the Baltic Sea southeast of Fyn.


N
Ny Vemmenæs
Gravvænge
Færgeodde
Sund
Middelgrund
Næshoved
Ditlevgårde
Frellesvig
Klavsebølle
Lismose
Tullebølle
Stengade
Strandhuse
Siøgård
Barnestenen
Siø
Peløkke
15 km
Kassebølle
Skole
5 km
305
Simmerbølle
Skebjerg
Kulepile
RUDKØBING
Biskopstorp
Oldenbjerg
20 km
Møllemose
Huse
Pusseløkke
9
Vandrerhjem
Skole
Gammel Skrøbelev
Assemose
Pederstrup
Rudkøbing Løb
Kragholm Huse
Kragholm
Blangshave
Ny
Skrøbelev
Vindeltorp
Longelse Sand
Møllegård
Nørre
Longelse
Farevejle
Søvertorp
Henninge
Torpe
Barager
Sønder Longelse
Havgård
Næbbehuse
Bomgård
Henninge
Nor
Stat-ene
Fuglsbølle
Skovsbo
Næbbeskov
Bønneløkke
Huggen
Søstenen
Vesterby
Lindelse Nor
Kumlehøje
Snaremose
Klæsø
Bukø
08
12
Østerby
14
Helleved
Longelse
Sønderskov
Korsehoved
Lindø
Herslev
Illebølle
Langø
Polleholm
Polleskov
Huse
Bogø
Illebølle
Lindelse Nor
Illebølle Skov
Udflyttere
Vindeby
Havbølle
Lindelse
10 km
1 km

a.

b.

Figure 24. A detailed map of Area 8. Area 8 is located on: a. the central part of Langeland and b. on Siø and Strynø.

6.2 Terrain, topography and processes

The terrain is situated just above sea level to up to x m above sea level.

Mid Langeland

The area is located on the central part of Langeland and includes c. 37 km^2. The landscape is undulating, marked by a large number of small but steeply sloping, local hills. Most of the area is situated between 10 and 20 meters above sea level (m.a.s.) but the top levels of the

hills are typically situated 25 - 40 m.a.s. Toward the east, the delimitation of the area follows the coastline and here, a small marine foreland with a lagoon is found. The area holds some very small lakes (at Kulepile, Assemose, Fuglsbølle and Longelse Sand) and two small streams are located toward south-east and at the marine foreland.

A few small villages, some farms, a larger number of houses (primarily located along the roads), several groups of windmills, a few camping places and a cluster of summer cottages are found in the area. Moreover, three main roads and a number of minor roads cross the area. Nevertheless, it is possible to find open areas many places. Approximately 10 % of the area is woods; the remaining and dominating part is used for agriculture.

Owing to the low relief and intensive cultivation, the surface processes (soil creep, frost – thaw processes, soil development etc.) proceed slowly and undramatic. This counts for the steeply sloping hills as well, as long as they are protected and overgrown by vegetation. The coastal section in front of the Gammel Spodsbjerg summer cottages/residential neighbourhood (?) is protected by 10 - 12 smaller groins. The remaining part of the coastal section seems to be without erosional problems.

The eastern approx. half of the area is included in an area of National Geological Interest (no. 132).

Strynø

The area is a small island of c. 4.9 km^2. In the central part, the level is c. 10-12 meters above sea level. From here, the landscape slopes gently towards the coast. The area is without lakes and streams. Smaller marine forelands are found on the south and south-western part of the coast. The coastline as a whole is a beach ridge type, almost without coastal protection as the island is situated in very calm and shallow waters surrounded by islands in all directions.

The small village Strynø is located in the central part of the island. Moreover, several smaller roads, scattered houses, a windmill and an old-fashioned mill are found in the area. The area is used for agriculture.

Owing to the low relief and intensive cultivation, the surface processes (soil creep, frost – thaw processes, soil development etc.) proceed slowly and undramatic. The island is situated in low-energy, shallow waters and coastal development proceeds slowly.

The island is included in an area of National Geological Interest (no. 128).

Siø

The area is a small island of c. 1.4 km^2. The landscape is plane and low-lying, between 0 m along the coast to less than 3 meter above sea level, where it is highest. The island is intersected by the main road connecting Langeland to Tåsinge/Fyn. A major farm is located in the central part of the islands and a few (summer-?) houses are located on the eastern part of the island. The island is used for agriculture.

Sections of the coastline (especially toward north, facing the longer fetch from the Langelands Belt) are protected by groynes or stone revetments. The coastline sections at the junction points for the main road are protected as well. A marine foreland is found on the south-eastern part of the island.

Owing to the low relief and intensive cultivation, the surface processes (soil creep, frost – thaw processes, soil development etc.) proceed slowly and undramatic. The island is situated in relatively low-energy waters and coastal development proceeds slowly. The coastal section towards north/north-east, facing the longer fetch from the Langelands Belt, is a little more exposed and partly protected.

The island is included in an area of National Geological Interest (no. 128).

6.3 Surface geology and profiles

The area is mainly covered by clayey till with a few occurrences of sandy till. Spots of meltwater sand and gravel and Holocene freshwater deposits can be found. No surface exposures are available (Fig. 25).

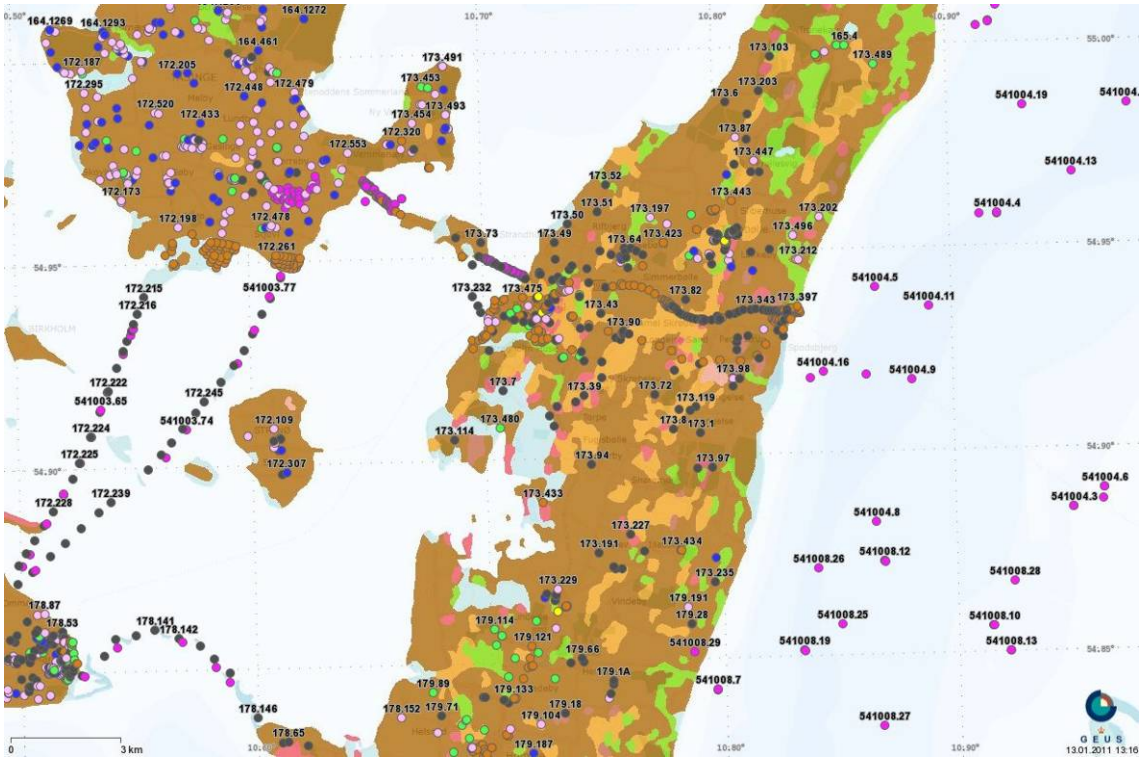


Figure 25. Map of the Quaternary surface deposits (From GEUS Homepage. After Pedersen, 1989). Legend: Brown: Clayey till, Red brown: Sandy till, Red and orange: Meltwater sand and gravel, Green: Holocene freshwater deposits, Blue: Holocene marine deposits. Legend for boreholes: see fig. 26.

6.4 Boreholes and geophysical surveys

The target is Eocene/Paleocene clays and several boreholes within the area reach these clays. Many ditch samples have been collected and described lithological. No sample has been dated by microfossils (Figs. 26, 27, 28 and 29). An example of borehole data can be seen in fig. 30.

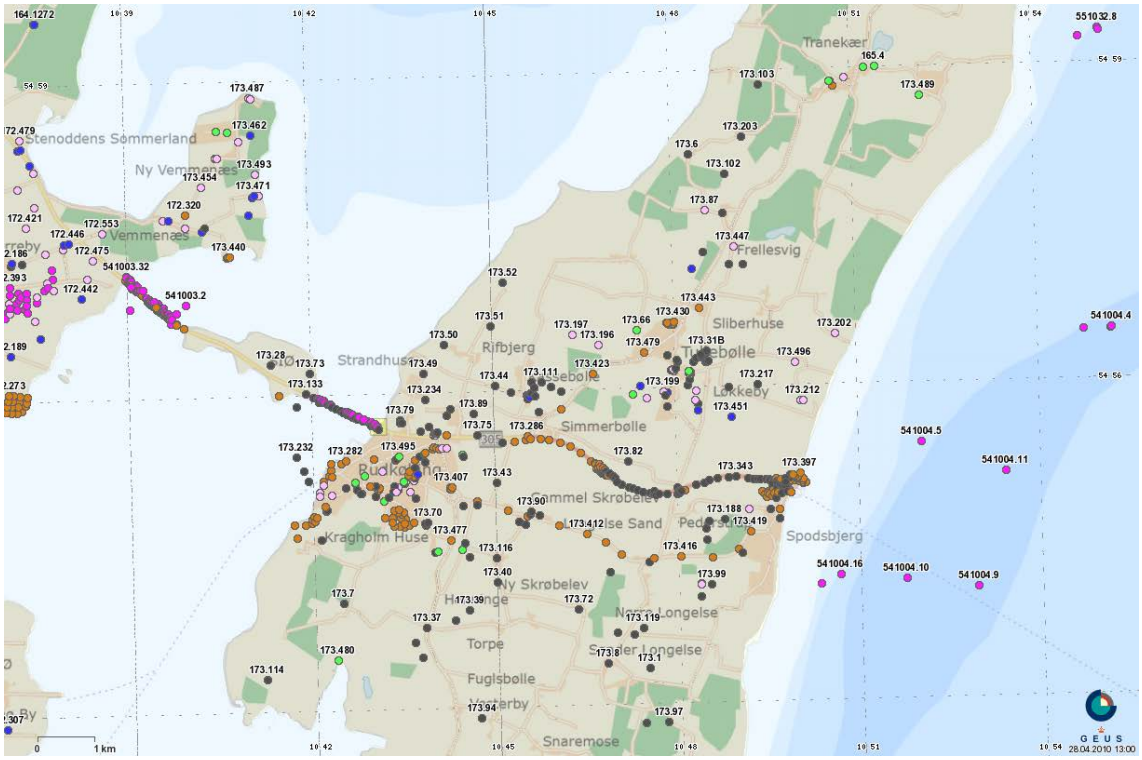


Figure 26. Map of the locations of boreholes from the Jupiter Database at GEUS. Legend: 173.4: DGU No., Blue dot: Water supply well, Red dot: Geotechnical borehole, Pink dot: Raw material borehole, Green dot: Other borehole, Light red dot: Abandoned borehole, Black dot: Unknown purpose.

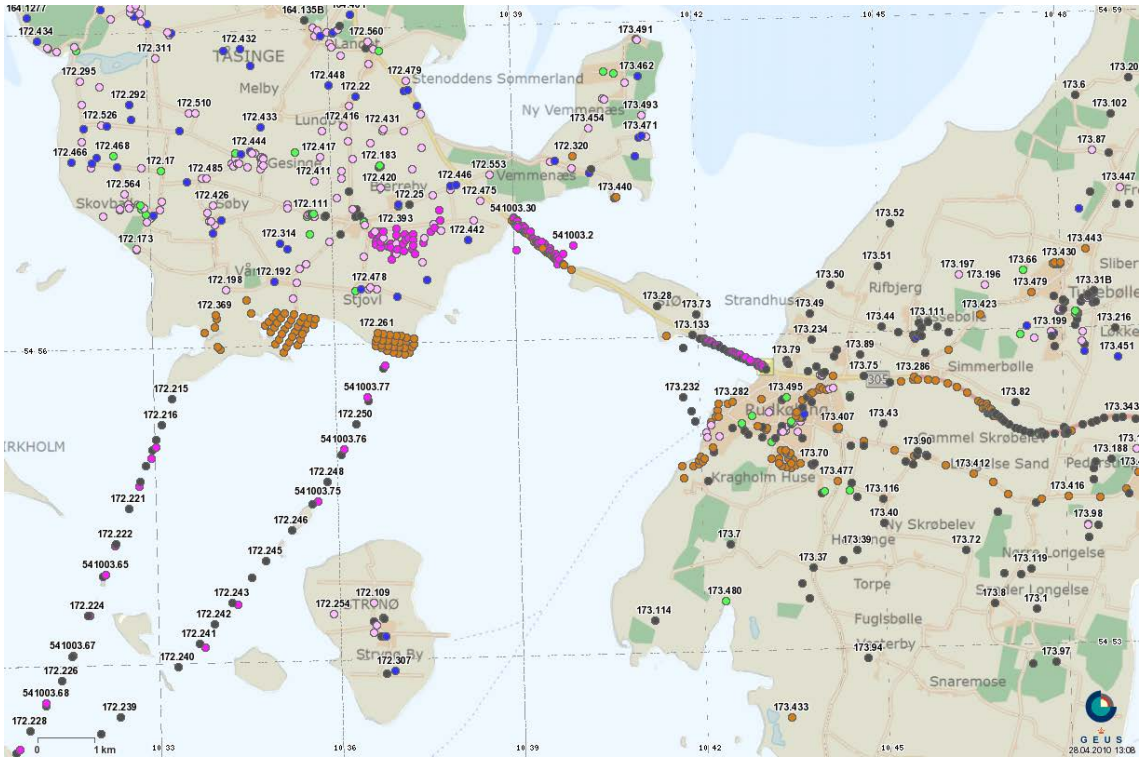


Figure 27. Details of borehole locations. Legend: See Fig. 26 .

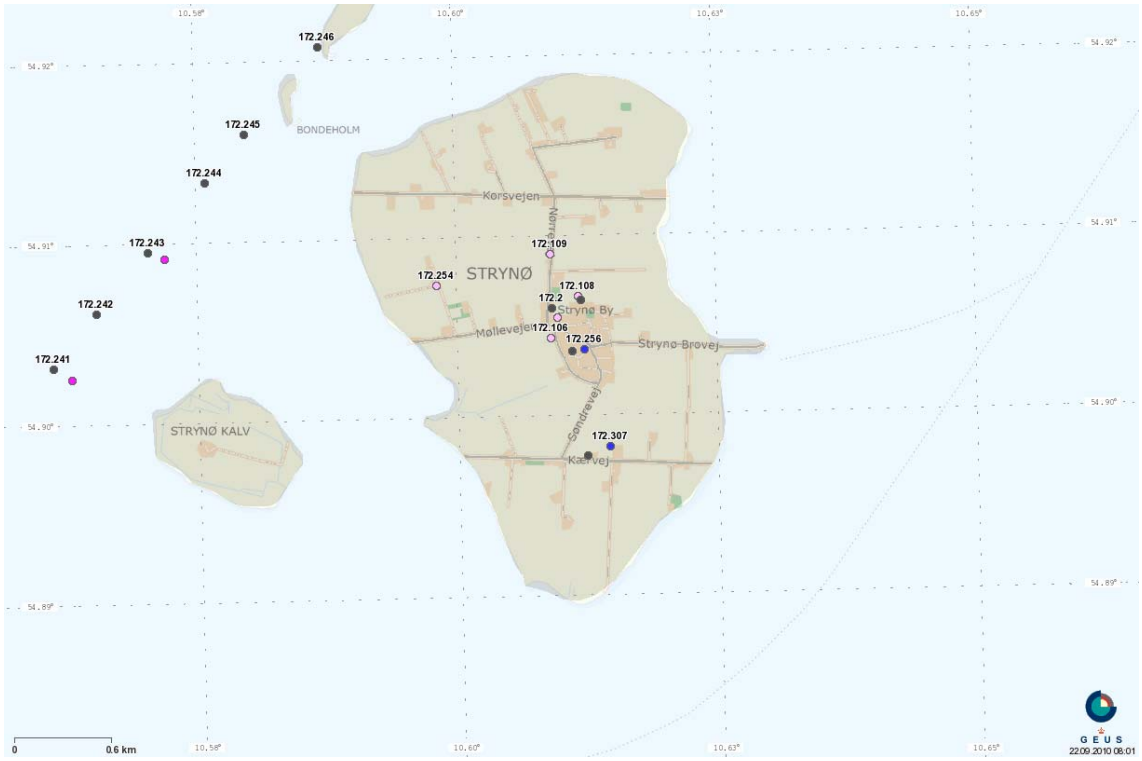


Figure 28. Details about the borehole locations on Strynø. Legend: See fig.26.

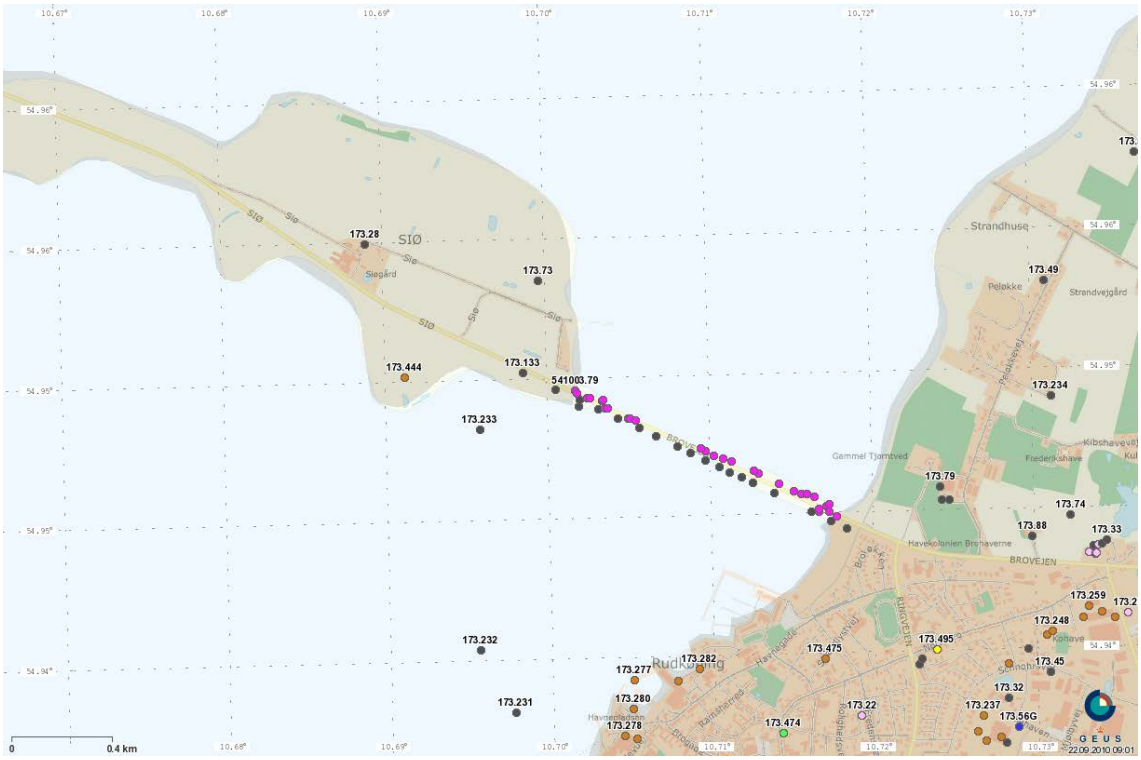


Figure 29. Details about the borehole locations on Siø. Legend: see fig. 26.

De Nationale Geologiske Undersøgelser for Danmark og Grønland

Udskrevet 28/4 2010 Side 1

BORERAPPORT

DGU arkivnr: 173. 4

Borested : SKRØBELEV,MEJERI
5900 Rudkøbing

Kommune : Langeland
Region : Syddanmark

Boringsdato : 20/1 1905 **Boringsdybde** : 119 meter **Terrænkote** : 17 meter o. DNN

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

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

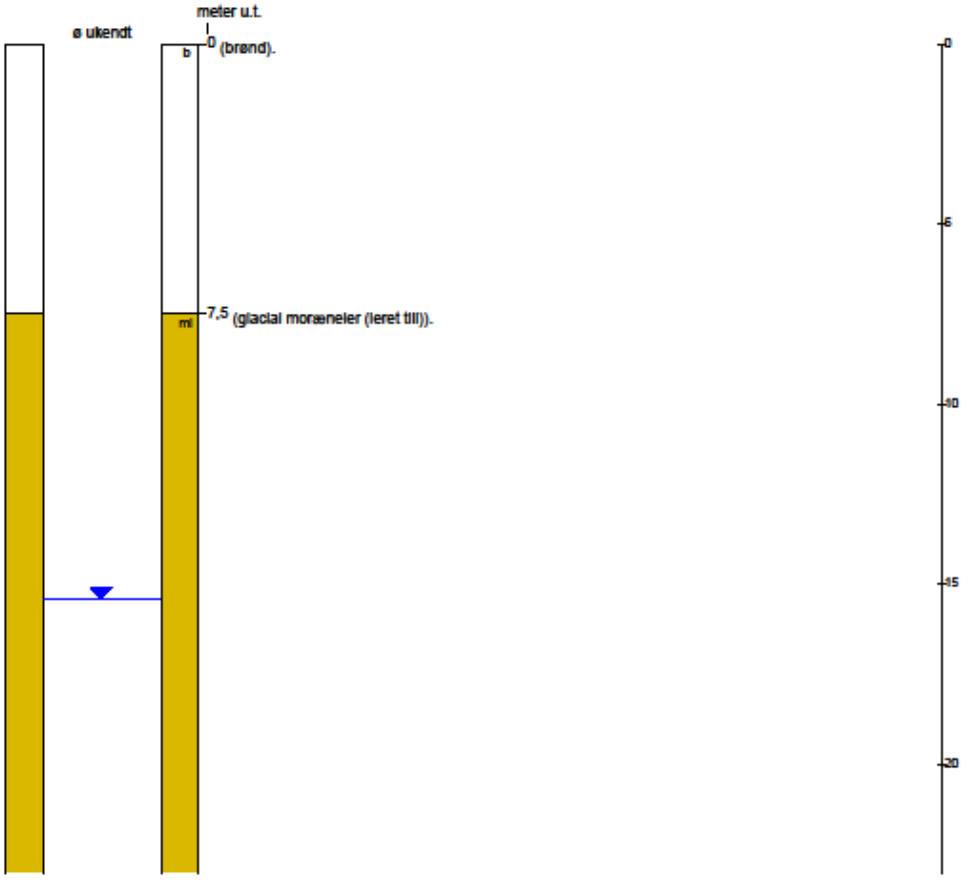
Formål :
Anvendelse :
Boremetode :

Kortblad : 1311 INØ
UTM-zone : 32
UTM-koord. : 612811, 6088668

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

		Ro-vandstand	Pejledato	Ydelse	Sænkning	Pumpetid
Indtag 1	(seneste)	15,4 meter u.t.	1/1 1905	0,2 m³/t	0 meter	

Notater : Brøndborer: Artesisk Borecompagni, H.C.Ørstedvej 4, Købbenhavn V.



fortsættes..

Figure 30. Geological log from the borehole DGU no. 173.4 from the Jupiter Database. Upper parts of the 119 m deep borehole. Legend: ml: Clayey till, l. Paleogene Clay.

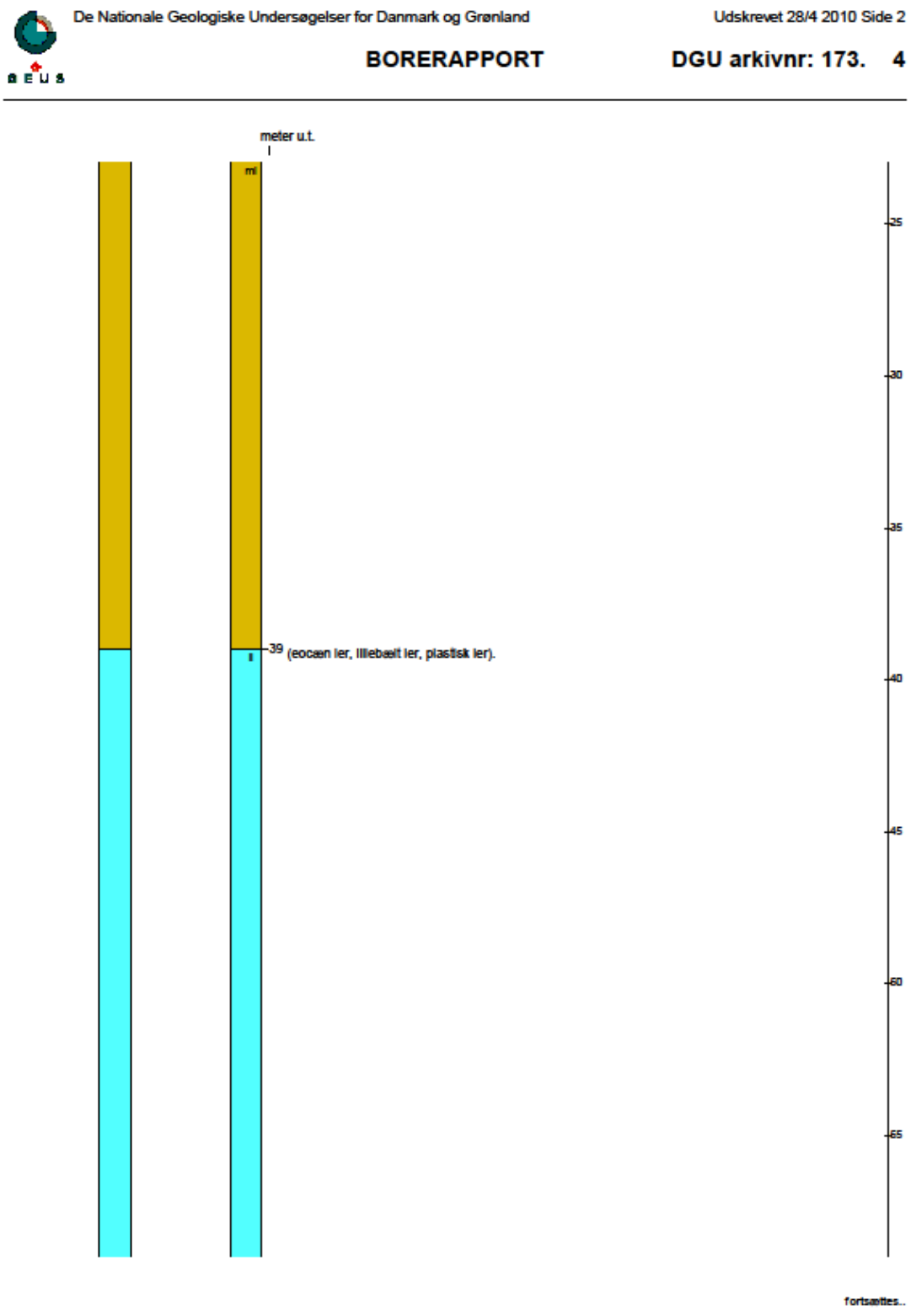


Figure 30, continued.

Geophysical investigations: seismic, geoelectric and electromagnetic surveys are carried out on some parts of Langeland.

6.5 Sediment and rock characteristics, mineralogy and chemistry

6.5.1 Pre-Quaternary deposits

According to the map of the pre-Quaternary deposits (Fig. 31), the formations in the area are from the Paleocene and Eocene. The county of Fyn has mapped Paleogene clays close the ground surface north of Lindelse Nor, on Siø and on Strynø. Some borehole samples have been identified as Paleocene/Eocene from lithological description but no samples have been related to a formal lithostratigraphical unit or have been dated by microfossils.

Mid Langeland

In an area from Rudkøbing in west to Spodsbjerg in the east, towards Tullebølle in the north and Fuglsbølle in the south, deposits from Eocene and Paleocene are found below the Quaternary clayey till deposits. The Paleogene deposits occur 20 m to 30 m below ground surface but outside the area, in the city of Rudkøbing, between 10 m and 20 m below ground surface.

Towards the south in the area, Eocene clays are reached below the tills. In a few very deep boreholes, Paleocene clays occur above Danian limestones. The Paleogene can have a thickness of 75 m.

The Eocene plastic clays have red, brown, grey and green colors often with volcanic ash layers in the red and brown parts. The clays are very fine-grained and calcareous or non-calcareous. Some samples contain glauconite. It is difficult to distinguish between the Røsnæs Clay Formation and the Lillebælt Clay Formation in the area but the Røsnæs clay is nearly always calcareous. The Eocene deposits are approximately 20-40 m thick in the central part of the area and probably 25 m at Tullebølle (if present)(Fig. 32).

The Eocene/Paleocene deposits are up to 30-50 m thick and consist of black and grey, non-calcareous to weakly calcareous fine-grained clays with glauconite. They belong probably to different formations. The calcareous content is increasing downwards where also a higher sand content is found.

The grey plastic non-calcareous clay with volcanic ash layers probably belongs to the Ølst Formation or the Holmehus Formation. Brown grey and grey non-calcareous very fine-grained plastic clay is characteristic for the Holmehus Formation. These deposits are approx. 27 m thick. Dark grey fine-grained clay which is little sandy, glauconitic and non-calcareous probably belongs to the older Æbelø Formation (21 m thick).

Below these clays, 4 m of grey marly silicified calcareous clay with glauconite content could possibly also point to the older $CaCO_3$ rich Paleocene formations as Kerteminde Marl (see DGU no. 173.4). Danian bryozoan limestone is found below the Paleogene clays.

Siø

The pre-Quaternary clays are situated close to the ground surface and are only covered by 5-10 m clayey till. The plastic clay is brown and red brown, very fine-grained and calcareous. Indications of the volcanic ash layers are found in few samples. The clay probably belongs to the Røsnæs Clay Formation.

Strynø

The pre-Quaternary sediments occur approximately 25 to 45 m below ground surface covered by mainly clayey tills. Several boreholes reach green plastic clay but the few samples are not investigated in detail. The green plastic clay probably belongs to the Lillebælt Clay Formation.

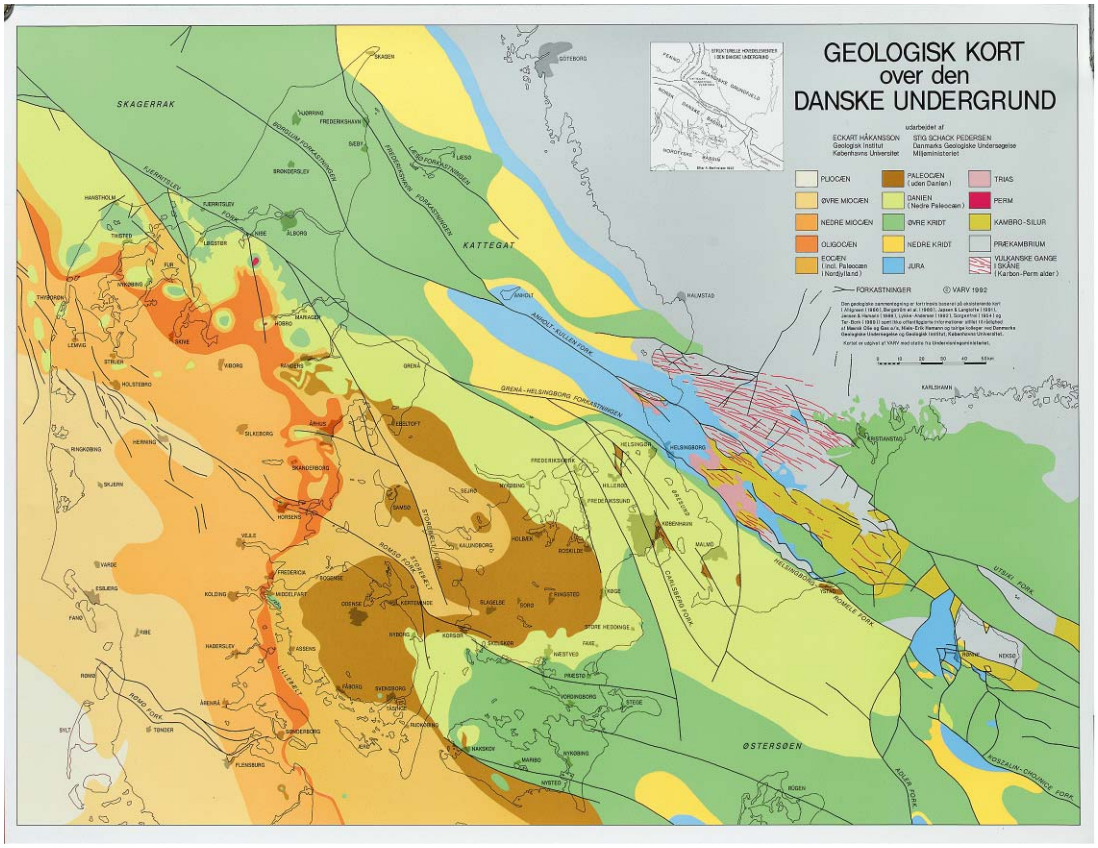


Figure 31. Map of the pre-Quaternary surface: Time units. Original scale: 1:50.000. Legend: Red lines: Precambrian intrusions, grey: Precambrian, olive: Cambrian-Silurian, red: Permian, light red: Triassic, blue: Jurassic, yellow: Lower Cretaceous, green: Upper Cretaceous, light green: Danian, brown: Paleocene, yellow olive: Eocene, red brown: Oligocene, light yellow brown: Lower Miocene, very light yellow brown: Upper Miocene, white: Pliocene (Håkansson & Pedersen, 1992).

Figure 32. Section from the Albæk Hoved cliff, Juelsminde, Jylland. The plastic clay is lithological comparable to the plastic clays from the Røsnæs and Lillebælt Formations.

6.5.2 Quaternary deposits

The Quaternary deposits in the area mainly consist of clayey tills as seen on figs. 25 and 33.

Mid Langeland

Clayey till deposits are the totally dominating sediments in the area. Only in the Rudkøbing area thicker deposits of meltwater sand and gravel occur.

From east of Rudkøbing and Skrøbelev to Spodsbjerg, the Quaternary deposits have a thickness of 30-50 m. The upper 3-4 m of the clayey till is sandy to strongly sandy, yellow brown and calcareous while the lower parts are sandy, silty, grey and calcareous. This clayey till often contains clasts of limestones, chalk and Paleogene clay.

At Tullebølle, the Quaternary deposits are approx. 30 m thick and in some boreholes the samples show tills strongly modified by the Paleogene clays.

Siø

On Siø, the clayey tills dominate. The till is silty and very sandy with gravel and stones. It is often very calcareous. The thickness is 2-10 m. The tills are bordered by thin Holocene deposits.

Strynø

The 25-40 m thick Quaternary deposits mainly consist of clayey till with few thin layers of medium to coarse-grained meltwater sand. The upper 0-4 m thick clayey till is silty and gravelly, oxidized, yellow brown and non-calcareous. The lower clayey tills are silty, gravelly, olive grey and calcareous.

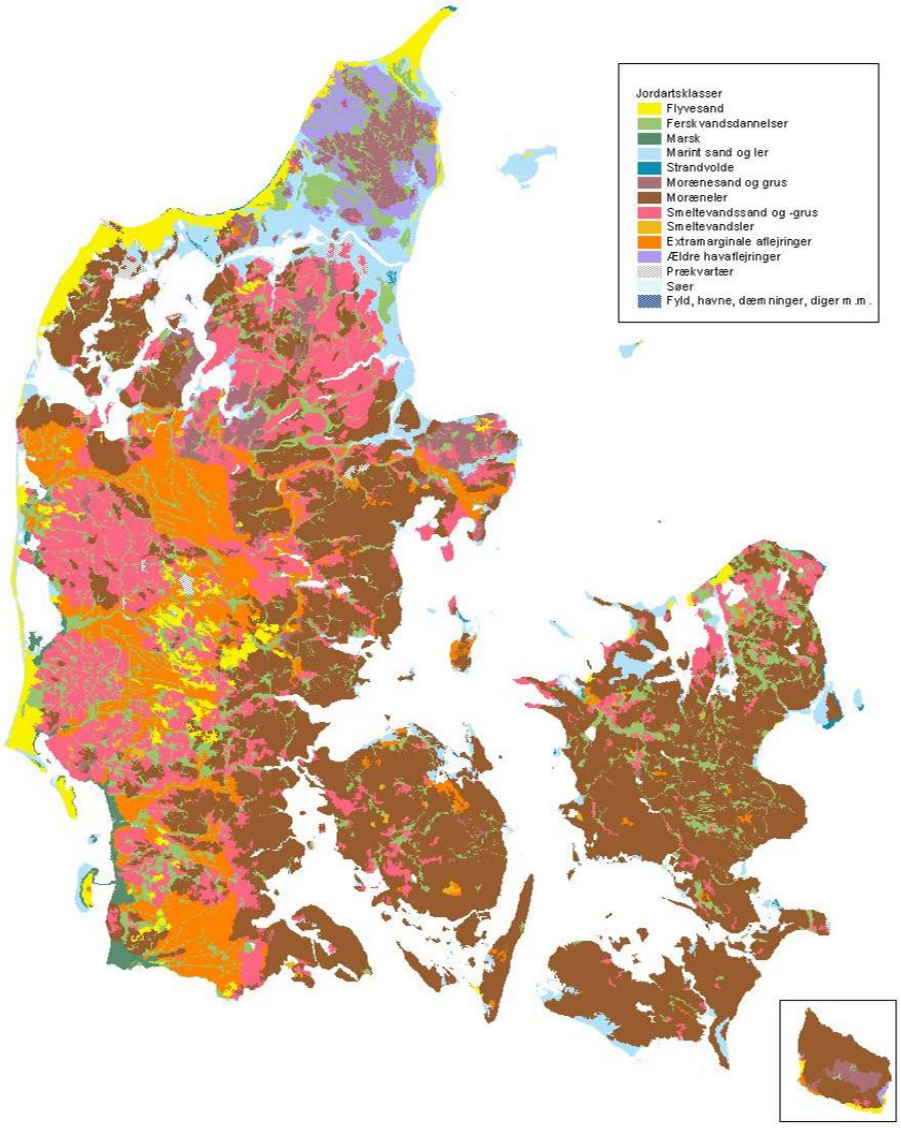


Figure 33.The map of the Quaternary surface deposits. Original scale: 1:200.000. Legend: Brown: Clayey till, light brown: Sandy till, red: Meltwater sand and gravel, orange: Sandur sand and gravel, purple: Late glacial marine deposits, light blue: Holocene marine deposits. Green: Holocene freshwater deposits, yellow: Aeolian sand (From Pedersen, 1989).

6.6 Tectonics, structures and seismic activity

6.6.1 Major tectonic structures

A major hiatus seems to occur between the Danian limestone deposits and the Paleocene plastic clays as deposits from the Lower Paleocene Selandian corresponding to the greensand, limestone and clay from The Lellinge Greensand Formation. So, maybe the Kerteminde Marl is missing. The few and poor ditch samples from the boreholes is a problem in this respect. The characters of the boundary are not known. The boundary could probably be a major fault crossing Langeland in continuation of the fault on southern Lolland (Fig.31). The borehole data points to fault activity and erosion and perhaps a series of faults bringing different Paleogene deposits to the pre-Quaternary surface (Figs. 34, 35). Glacial erosion has formed valleys where thick sequences of clayey tills afterwards became deposited.

Mid Langeland

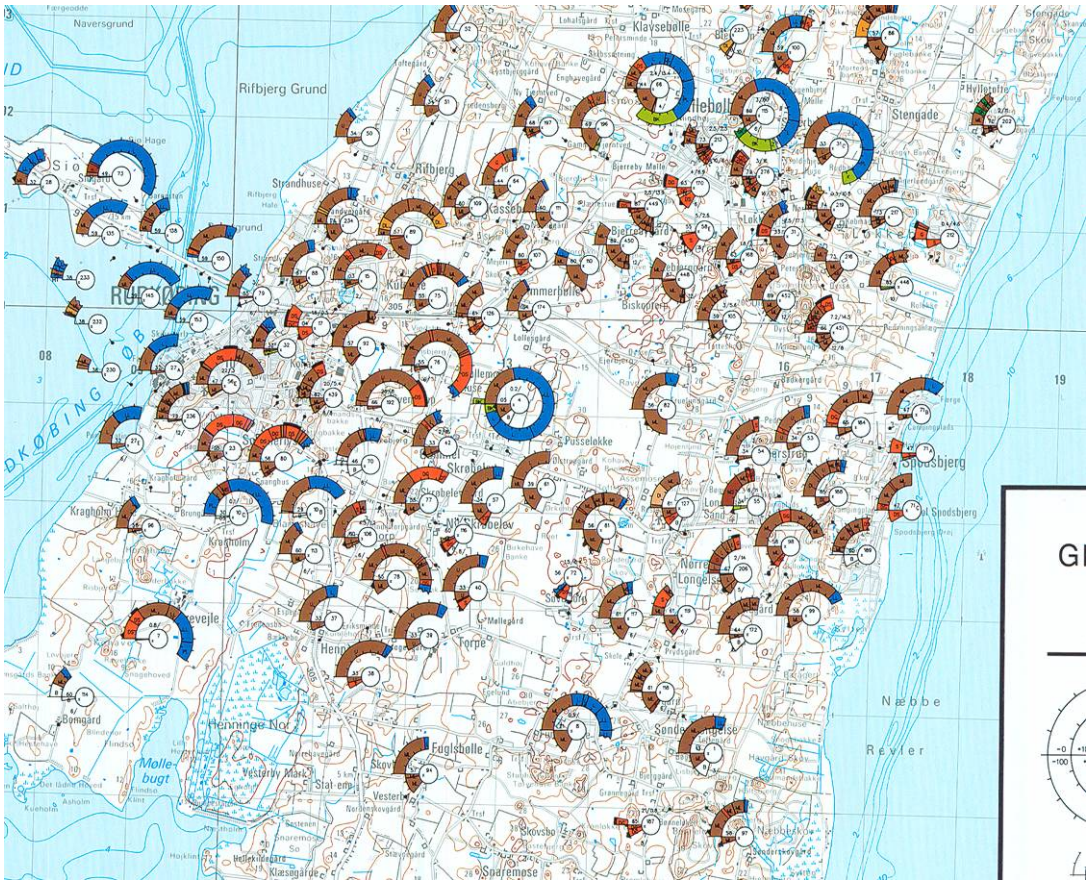
The pre-Quaternary surface is situated from 20 to 50 m below ground surface with an inclination from north towards south. The boundary between the Eocene and The Paleocene on the Pre-Quaternary surface is situated between Tullebølle and Frellesvig but it is difficult to place it exactly (see above).

Siø

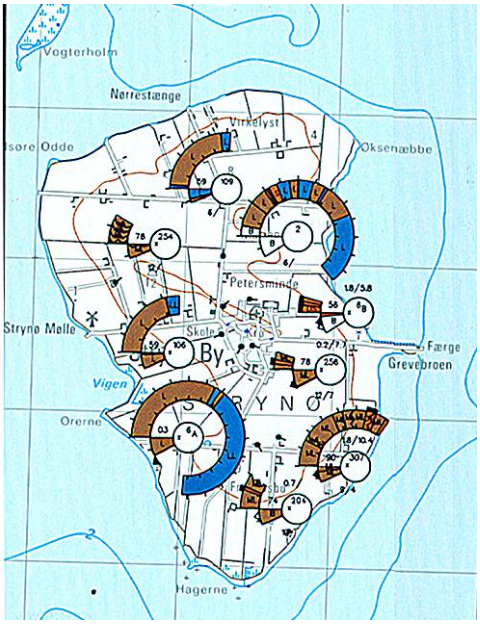
The pre-Quaternary Eocene clays are reached between 6 and 16 m below ground surface. The boreholes along the bridge between Langland and Siø show the same variations which indicate glacier erosion into the Eocene clays.

Strynø

The Pre-Quaternary surface below the island is situated 40 m below surface and inclined from north towards south. The occurrence of several floes of the plastic clay in the tills makes this judgement problematic.



a.



b.

Figure 34. Part of Geological Basic Data map 1311 I Rudkøbing showing boreholes from mid Langeland area. a. Mid Langeland and Siø, b. Strynø. Original scale 1:50.000. Legend: see fig. 10 (From Gravesen, 1993).

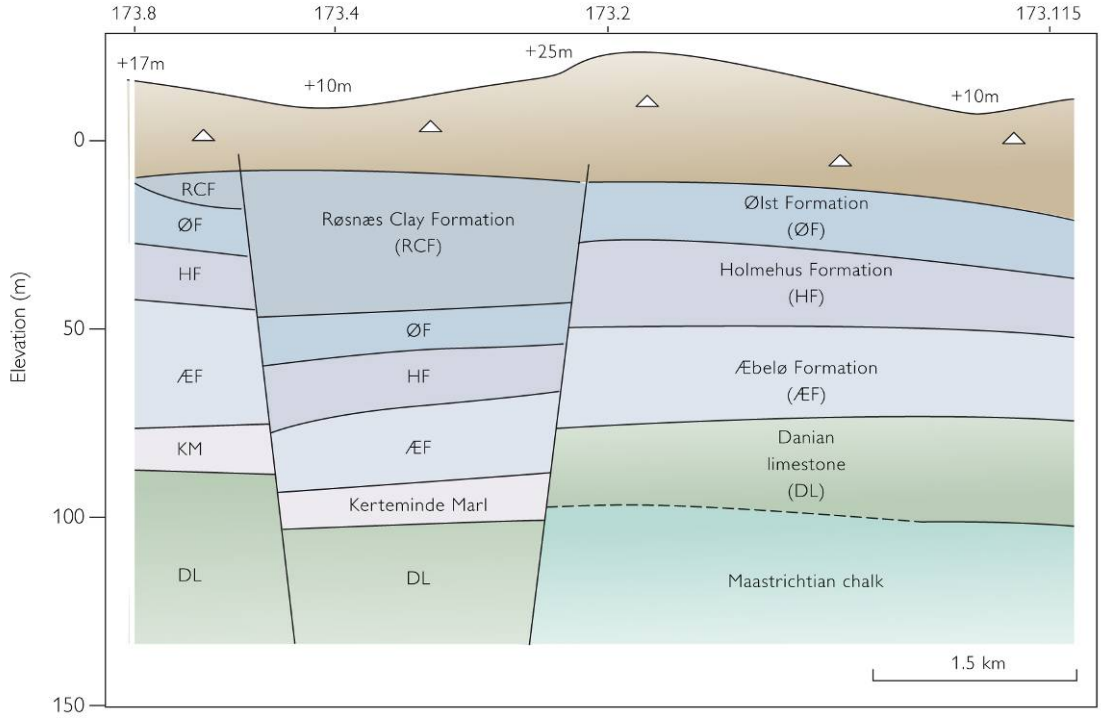


Figure 35. Geological section from central mid Langeland between Torpe and Tullebølle, oriented NE-SW.

6.6.2 Fractures

The plastic clays often contain fractures and some small faults or fractures. The clayey tills are always cut by fractures but the conditions on southern Lolland are not investigated because of lack of field localities (Fig. 36).

Figure 36. Fractures in clayey tills.

6.6.3 Geological model

The geological model of the area comprises six units (Fig. 37).

A. Quaternary till 2 m to 50 m thick: Sandy, gravelly clayey till with thin meltwater sand layers at some locations.

B. Eocene plastic clays from the Røsnæs Clay Formation and the Lillebælt Clay Formation. 20-40 m thick.

C. Eocene/Paleocene clays from the Ølst and/or the Holmehus Formation are up to 27 thick.

D. The Paleocene Æbelø Formation is approx. 21 m thick.

E. Paleocene calcareous clays (Kerteminde Marl ?) is 4 m thick.

F. Danian bryozoan limestone, at least 25 m thick and perhaps overlaying Maastrichtian chalk.

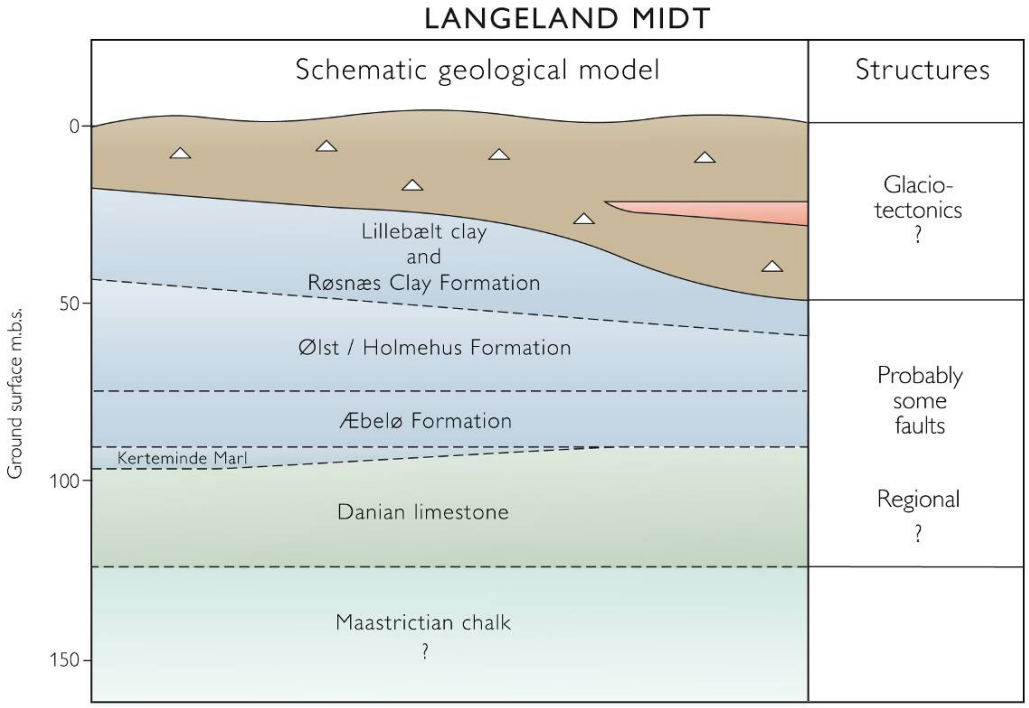
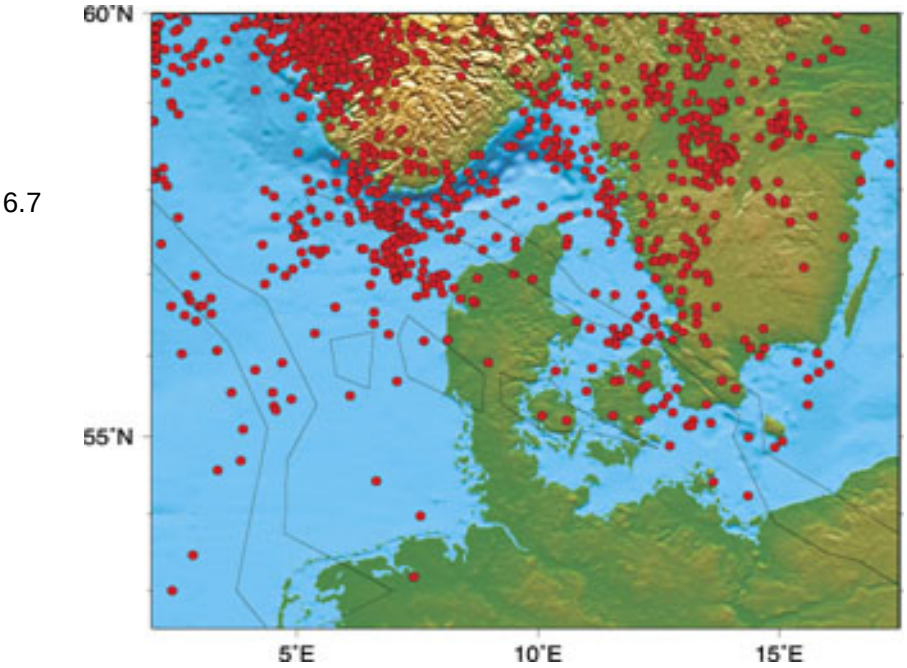


Figure 37. Schematic geological model of the area.

6.6.4 Earthquake activity

The seismic activity in mid Langeland and the near surrounding sea is very low (Fig. 38). 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.



6.7

Figure 38. 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.

6.8 Groundwater hydrogeology

6.8.1 Groundwater characteristics

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

Area 8 is divided into a central part of Langeland (Langeland Mid) and the two smaller islands Siø and Strynø (Fig. 39). Langeland Mid is characterized by the presence of two shallow groundwater bodies (DK1.14.1.3 and DK1.15.1.4) and, in the northern margin, of a regional groundwater body (DK1.15.2.4) (Figs. 39 and 40). The two islands Siø and Strynø do both contain the shallow groundwater body DK1.15.1.4. All three groundwater bodies that exist within the three subareas of Area 8 consist of meltwater sand deposits. Deep groundwater bodies have not been identified in or near Area 9 in the catchment management plan. The subdivision into groundwater bodies is described as part of the basis analysis carried out by the former Fyn Amt (www.ode.mim.dk). The overall assessment of the chemical and quantitative status of the shallow and regional groundwater bodies is poor, due to a poor qualitative status (see Section 6.9).

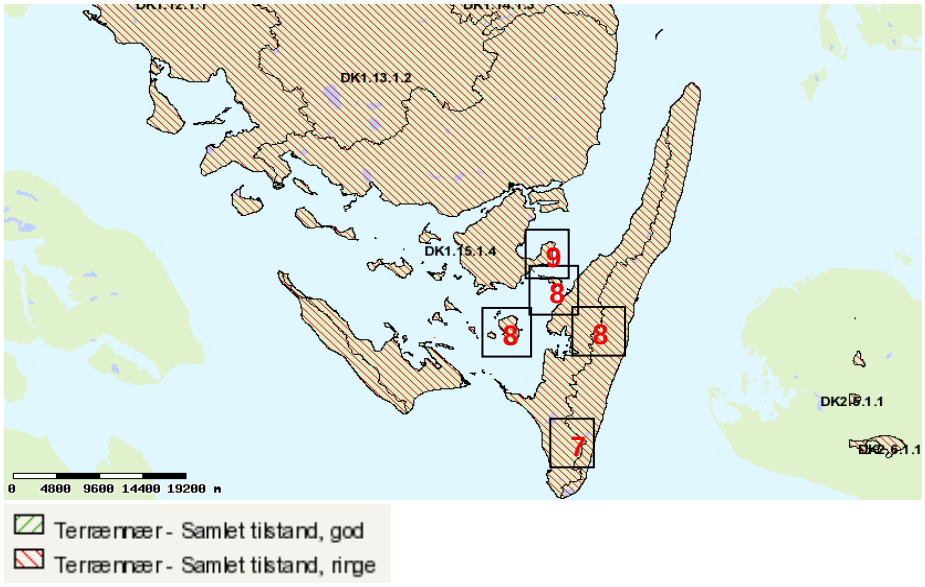


Figure 39. Shallow (or terrain near) groundwater bodies DK1.14.1.3 and DK1.15.1.4 at the areas Langeland South (Area 7), Langeland Mid, Siø & Strynø (Area 8), and Vemmenæs (Area 9). The overall assessment of chemical and quantitative status of all three areas: poor status (Red shaded area)(After Ministry of Environment, 2010).

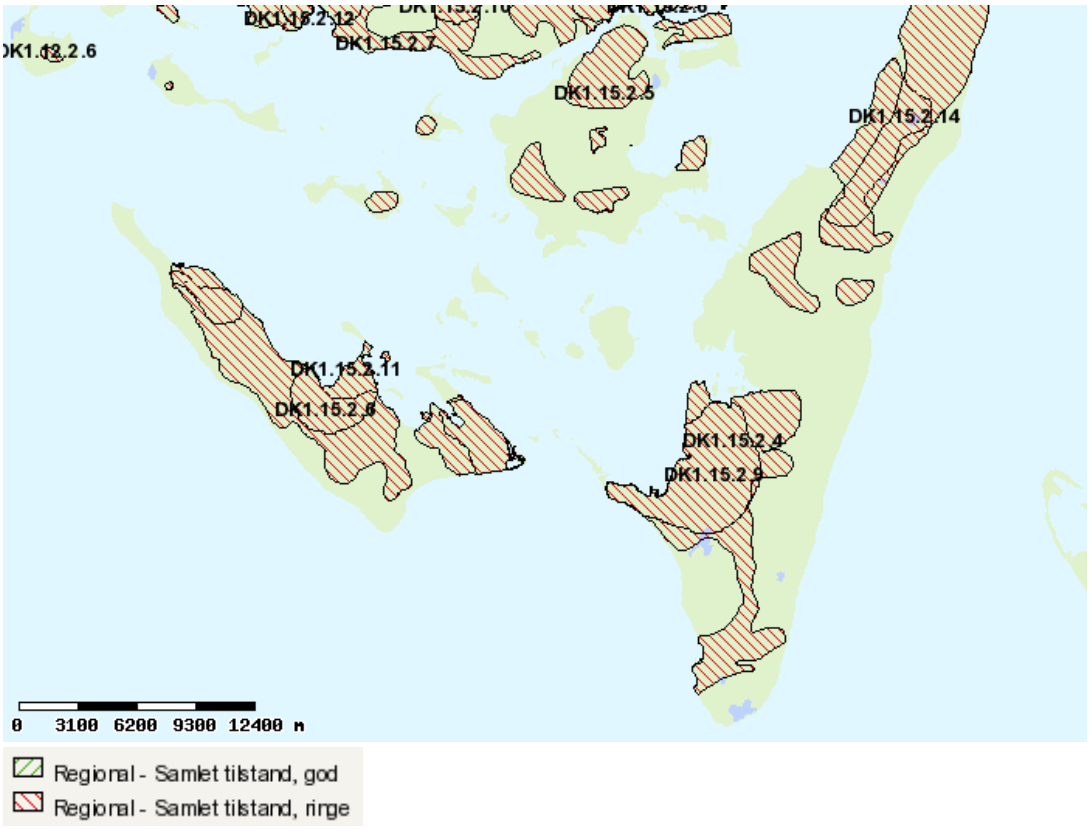


Figure 40. Regional groundwater bodies in the Langeland-Tåsinge region. Near Langeland South area (Area 7): DK1.15.2.4; Near Langeland (Mid Area 8): DK1.15.2.9; At Vemmenæs (Area 9): DK1.15.2.5. The overall assessment of chemical and quantitative status for all three areas: poor status (Red shaded area) (After Ministry og 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. 41).

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.

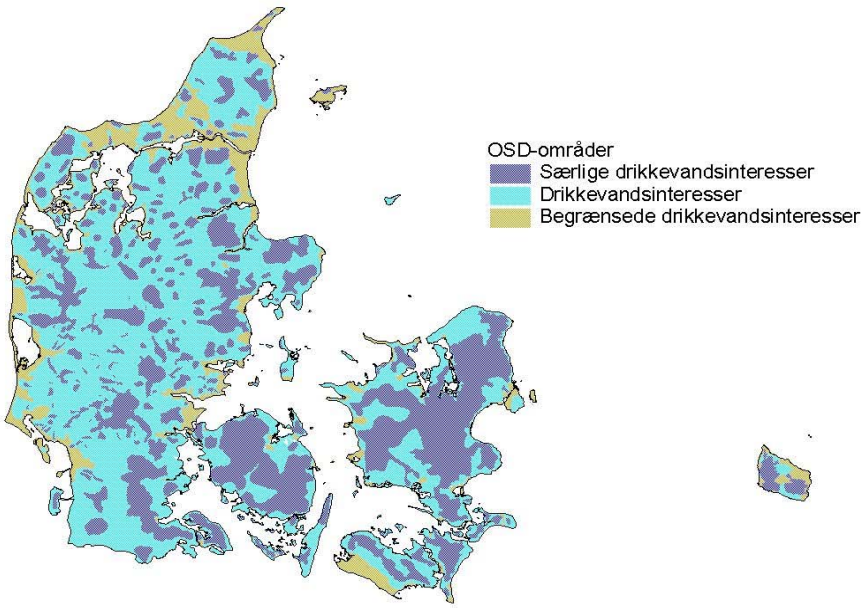


Figure 41. Areas of special drinking water interests (OSD): Dark blue and areas of drinking water interest (OD): Light blue. Areas with limited drinking water interests are olive brown.

Langeland Mid, Siø and Strynø are all located within areas with drinking water interests (OD) (Fig. 42). However, at Strynø and Siø there is no water works and only few private abstraction wells. Drinking water to the two islands is piped from the water supply at Langeland. Rudkøbing town is located at the western margin of the Langeland Mid subarea. Rudkøbing is primarily supplied with drinking water from the northern part of Langeland (Lej-bølle waterwork) from the regional limestone groundwater body (DK1.15.2.14). In the eastern part of the Langeland Mid area, Tullebølle waterwork is situated, consisting of several abstraction wells and a permission for groundwater abstraction of 70.000m^3 per year in total.

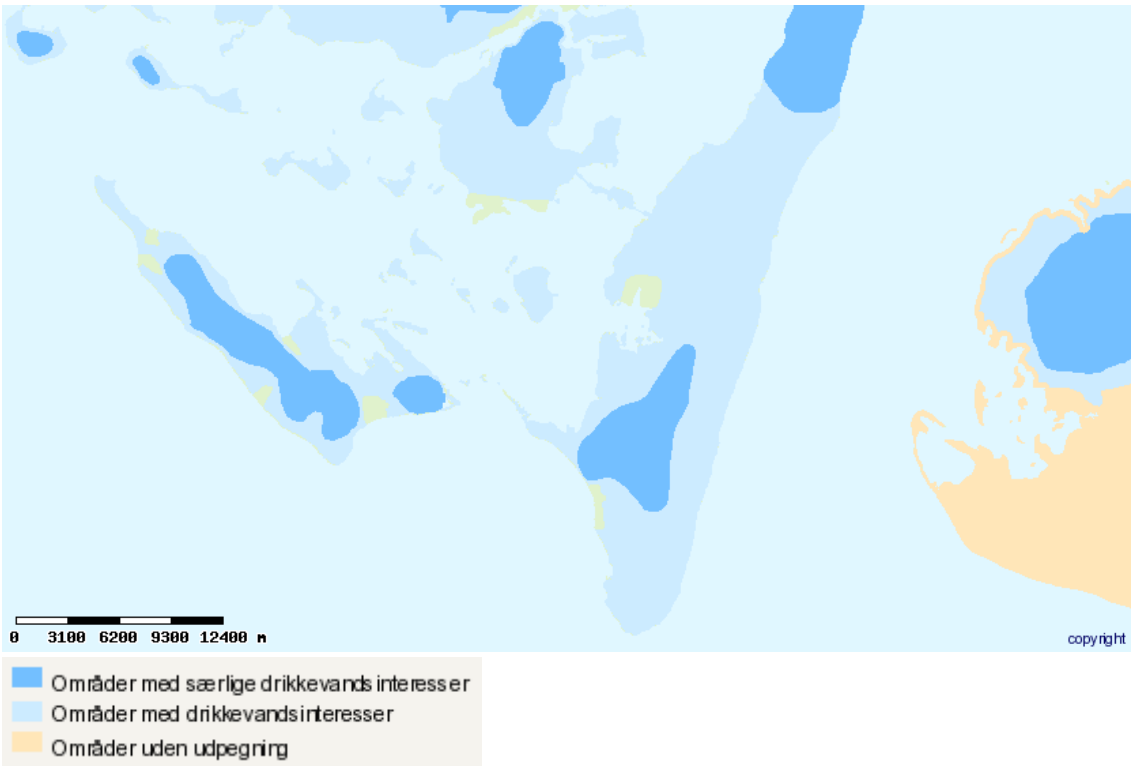


Figure 42. Various drinking water areas situated in the Langeland-Tåsinge region. Dark Blue: Areas of special drinking water interests (OSD); Light blue: Areas of some drinking water interests (OD); Yellow: Areas with limited or none drinking water interests.(http://kort.arealinfo.dk/).

6.9 Groundwater chemistry

The overall groundwater quality aiming for drinking water purpose has been assessed by the former Fyns Amt and Environmental Centre Odense for each groundwater body and reported in the catchment management plans “Hovedvandopland 1.15, Det Sydfynske Øhav” and “Hovedvandopland 1.14, Storebælt“. The groundwater bodies have been assessed to have a poor status. Saltwater intrusion has not been reported at the two islands; however, it is likely that the saltwater-freshwater boundary appears underneath both islands.

However, as long no significant groundwater abstraction appears at Siø and Strynø, then a sea level rise driven by climate change do not necessarily affect the position of the salt/freshwater transition. Groundwater abstraction wells within the Langeland Mid area do in accordance to the JUPITER Database contain around 50 mg/L of chloride. No significant effects of sea water intrusion in the Langeland Mid area is expected due to climate change driven sea level rise.

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).

Mid Langeland

The expected increase in precipitation and a sea level rise may cause flooding problems to the minor, low-lying marine foreland in the eastern part of the area during this century. Moreover, the sea level rise may increase the ongoing erosion of the coast at Gammel Spodsbjerg at the eastern delimitation of the area. The major part of the area is not expected to meet serious problems from the climate changes during this century.

Strynø and Siø

According to the very low-lying terrain of Siø and a major part of Strynø as well, both islands are expected to be affected by a sea level rise.

6.11 Restrictions and limitations

Strynø and Siø are both situated within NATURA2000 habitat areas (Fig. 43). In addition, the western margin of Langeland Mid is protected as a NATURA2000 habitat regulation and sporadic locations of areas protected in accordance to Naturbeskyttelsesloven (law for nature protection) are found. Sea water intrusion is not considered as a significant problem, either at the two islands, Siø and Strynø, or in Langeland Mid.

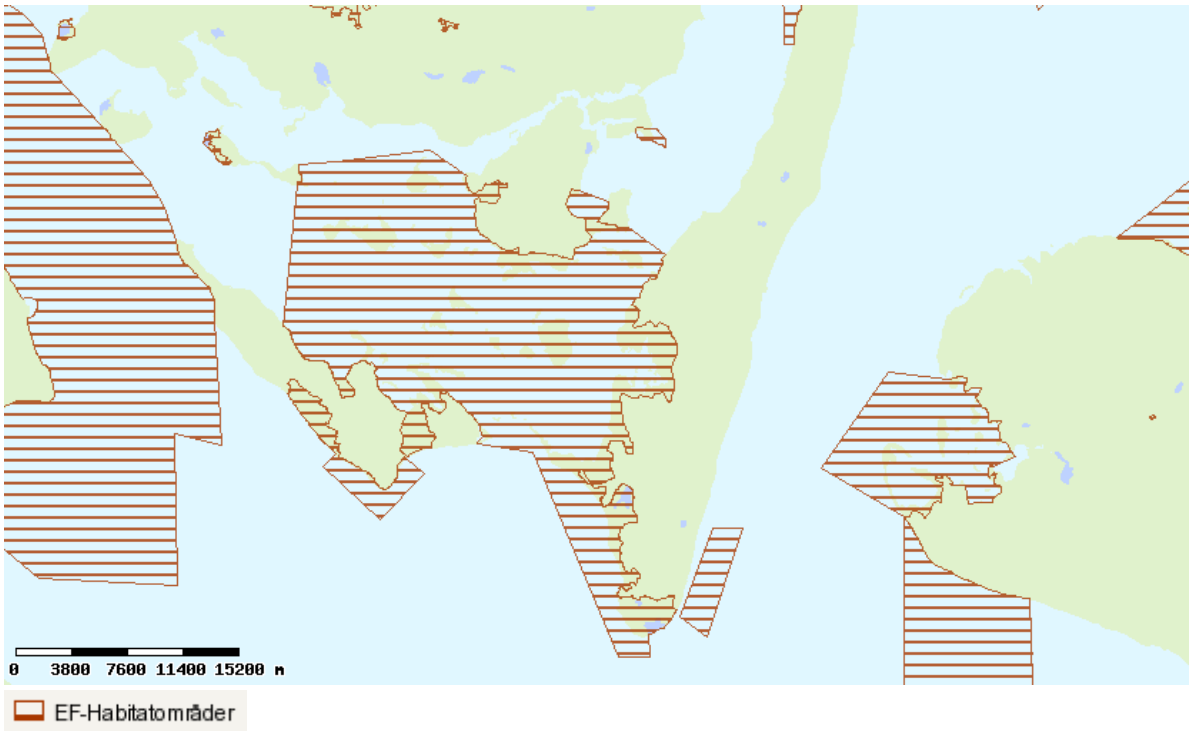


Figure 43. NATURA2000 Habitat areas in the Langeland-Tåsinge region (After Ministry of Environment, 2010).

6.12 Summary of the area conditions

Amount of data:
Sparse but in some parts of the area several boreholes are found.

Homogeneous conditions and isolation of the waste by low, permeability layers:
Perhaps perfect at depth of 50 to 100 m because of abundant clay deposits but the framework of the fractures is unknown. Probable fracture problem have to be considered in relation to other sites.

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

Seismic activity and tectonic movements
No seismic and tectonic movements and problems are expected. The area is probably also fault bounded towards the north.

Groundwater 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 as an OD area.

Groundwater chemistry, non- aggressive components
The groundwater contains apparently no aggressive components but saltwater problems can possibly occur on the islands.

Ground surface conditions
Processes on the ground surface should not give problems on a disposal. The low elevation of the landscape on the islands has to be considered in relation to future sea level rise.

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

Other restrictions
Apparent no other restrictions in most of the area will give problems but Siø and Drejø are covered by a NATURA2000 area.

6.13 Final remarks

Area 8 on mid Langeland is divided into three subareas of which two are small islands. Comprehensive thick deposits of Paleogene clays occur in the area, although only few details are known. The cover deposits are mainly clayey tills with few sand layers. The structural conditions within the area are poorly documented.

7. Area 9. Vemmenæs, Tåsinge

7.1 The location of the area

Tåsinge is situated south of Fyn and west of Langeland (Fig. 44). The area is a peninsula situated on east Tåsinge north of the Sundbrovej (Fig. 45).

Figure 44. Location of the area 9. Tåsinge is located south of Fyn and east of Langeland.

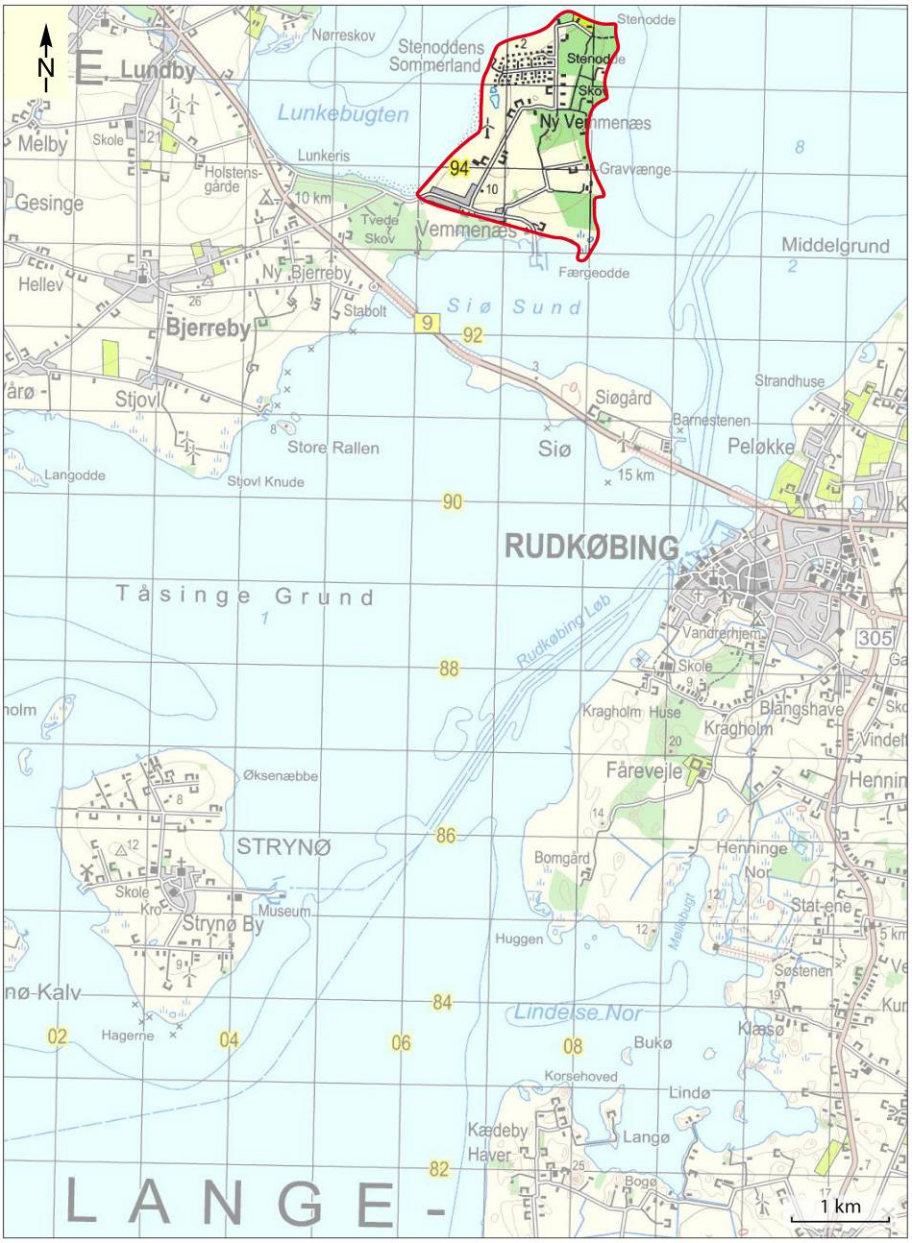


Figure 45. A detailed map of Area 9. Area 9 is located on the Vemmenæs peninsula on eastern part of Tåsinge.

7.2 Terrain, topography and processes

Area 9 is a peninsula of c. 3.6 km^2. The landscape is relatively level and low-lying as the central part, about half of the area, is situated between 5 and 10 meters above sea level (m.a.s.) and the other half part, the area along the coast is situated between sea level and 5 m.a.s. The highest point of the area is 10 m.a.s., found toward south, outside the village Vemmenæs. The land is sloping very gently toward the coast all the way around the peninsula and no cliffs have developed along this low-energy coastline, as the peninsula is situated in very calm waters, between Tåsinge, Fyn and Langeland. Some very small lakes

(lagoons in a beach meadow?) are found close to the west coast. Streams are not found in the area. Toward southeast, a small cuspate foreland is located.

Most of the area is used for agriculture. Some c. 20 % of the area is wood. Towards southwest, the small village Vemmenæs is found and a larger number of weekend cottages/summerhouses are located toward northwest. The area is crossed by few smaller roads along which scattered houses are located. A windmill is found in the western part of the area.

Owing to the low relief and intensive cultivation, the surface processes (soil creep, frost – thaw processes, soil development etc.) proceed slowly and undramatic. The peninsula is situated in low-energy waters and the coastal development proceeds slowly.

7.3 Surface geology and profiles

The area is mainly covered by clayey till with a few occurrences of sandy till. No surface exposures are available (Fig. 46).

Figure 46. Map of the Quaternary surface deposits (From GEUS´s Homepage. After Pedersen, 1989). Legend: Brown: Clayey till, Red brown: Sandy till, Red and orange: Meltwater sand and gravel, Green: Holocene freshwater deposits, Blue: Holocene marine deposits. Legend for boreholes: See fig. 47.

7.4 Boreholes and geophysical surveys

The target is Eocene/Paleocene clays but only 3 boreholes within the area reach these clays (Figs. 47 and 48). Very few samples have been collected and described lithological. No sample has been dated on microfossils. A map with borehole locations from the adjacent Bjerreby area is on fig. 49 as the deposits have been used as reference. An example of a borehole log is found in fig. 50.

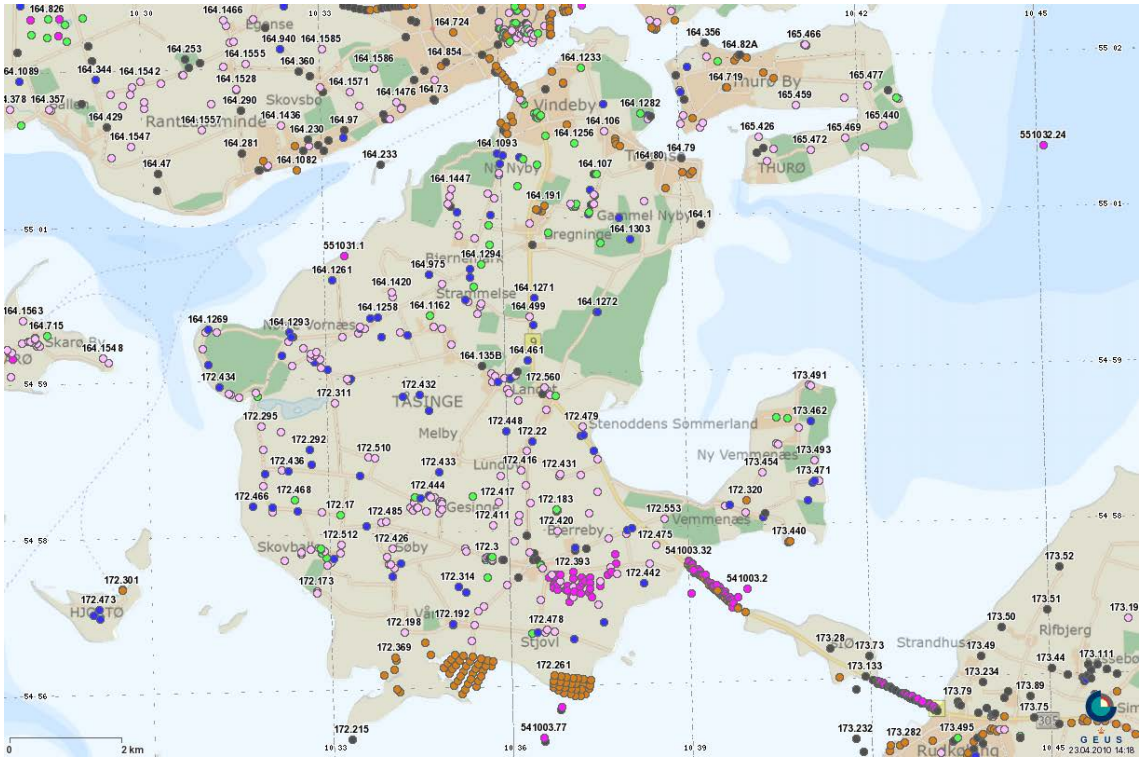


Figure 47. Map of the locations of boreholes from the Jupiter Database at GEUS. Legend: 173.455: DGU No., Blue dot: Water supply well, Red dot: Geotechnical borehole, Pink dot: Raw material borehole, Green dot: Other borehole, Light red dot: Abandoned borehole, Black dot: Unknown purpose.

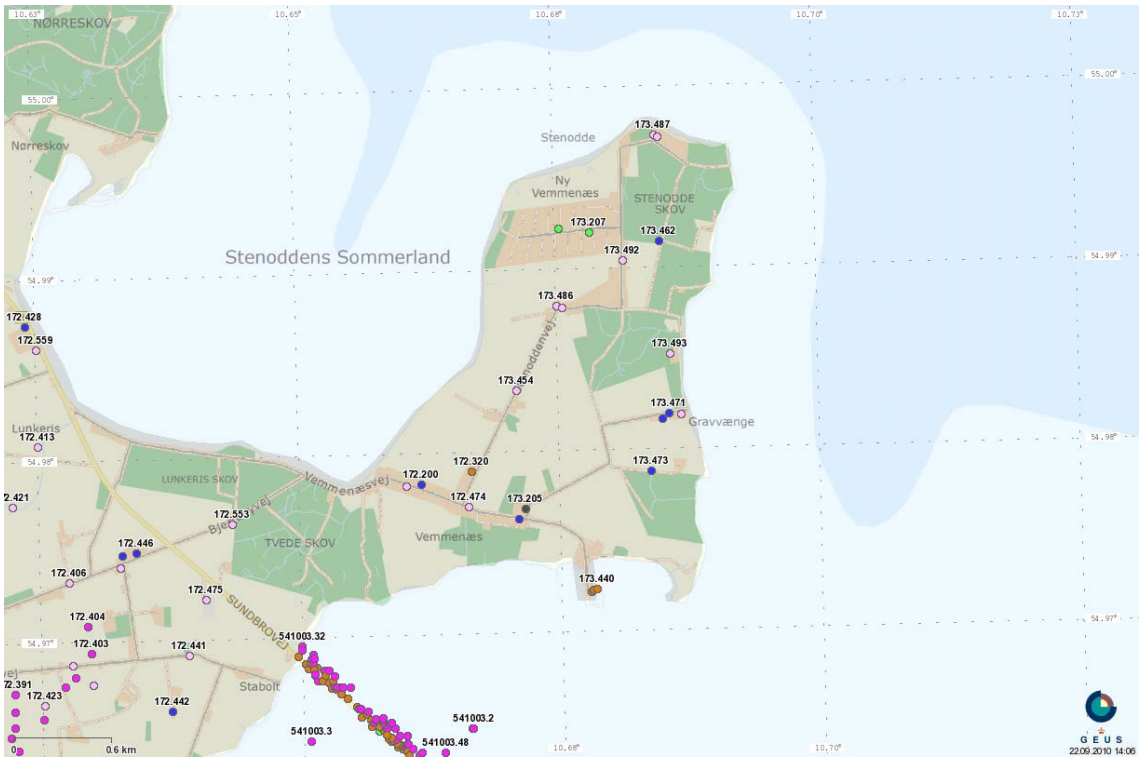


Figure 48. Detailed map with borehole locations on Vemmenæs. Legend see fig. 47.

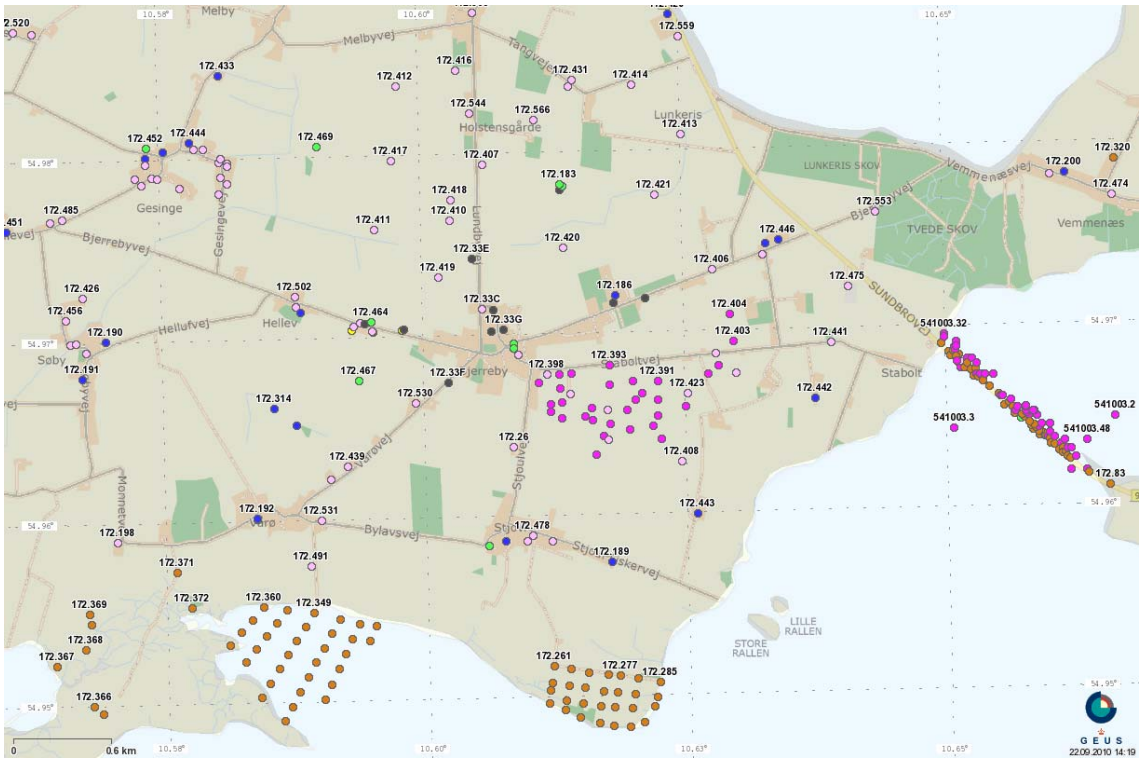


Figure 49. Borehole locations from the Bjerreby area. Legend: See fig. 47.

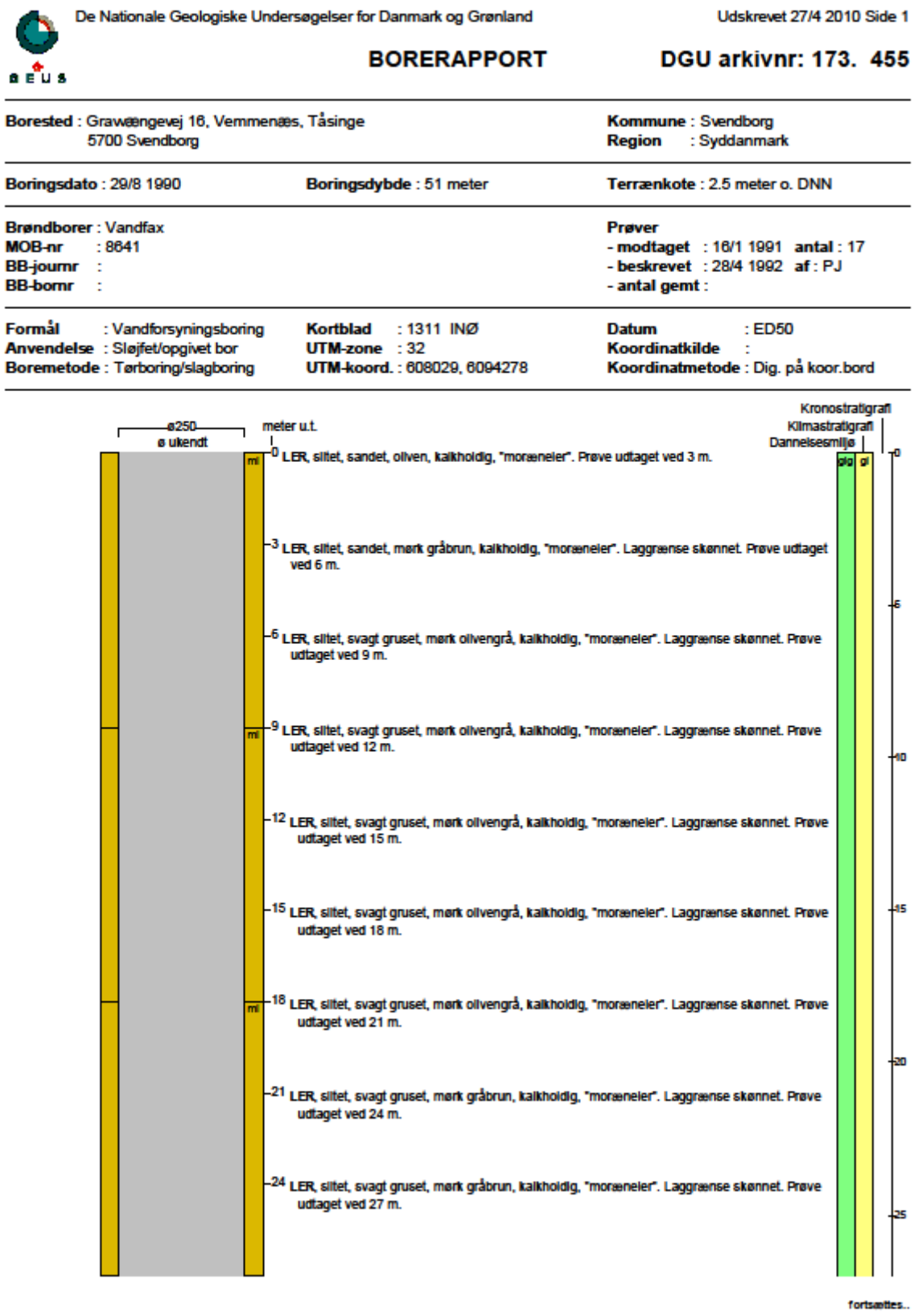
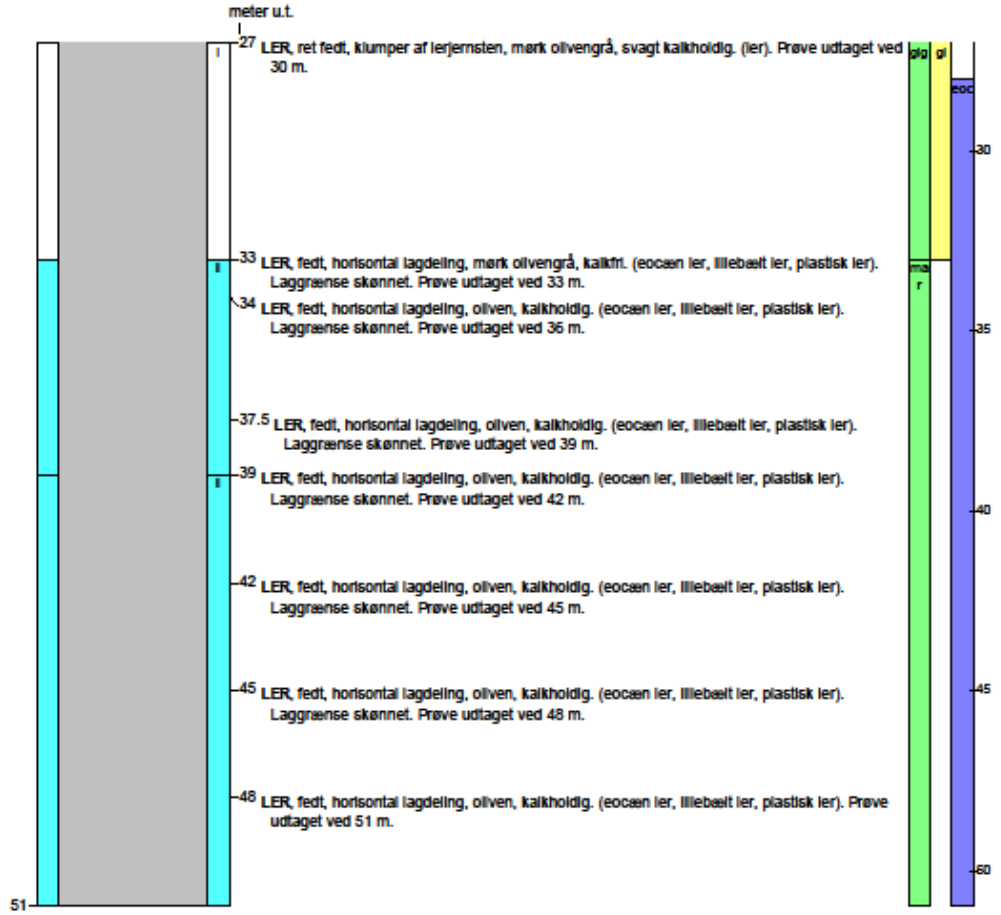


Figure 50. Geological log from the borehole DGU no. 173.455. Upper parts of the 51 m deep borehole. Legend: ml: Clayey till, l Marine Eocene.

BORERAPPORT **DGU arkivnr: 173. 455**



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

meter u.t.			
0	-	28	glacigen - glacial
28	-	33	glacigen/marin - glacial - eocæn
33	-	51	marin - eocæn

Fig. 50. Continued.

Geophysical investigations: geoelectric and electromagnetic surveys are carried out on selected parts of Tåsinge.

7.5 Sediment and rock characteristics, mineralogy and chemistry

7.5.1 Pre-Quaternary deposits

According to the map of the pre-Quaternary surface, Eocene clays should be reached below the Quaternary, but this can be discussed (Fig. 51). The county of Fyn has mapped Paleogene clays close to the ground surface at Bjerreby, just east of Bjerreby and on Vemmenæs.

Paleogene clays occur between 2 and 25 m below ground surface at Vemmenæs. Towards the south, the layers consists of fine-grained to silty olive grey and olive green clays containing volcanic ash layers. The clays are non-calcareous and are at least 17 m thick. Towards the east, the clay is fine-grained, green and olive green calcareous or non-calcareous. A faint lamination seems to occur and here the thickness is at least 18 m. It is difficult to include the deposits into formal units but the clays could belong to the Paleocene Holmehus Formation (Fig. 52).

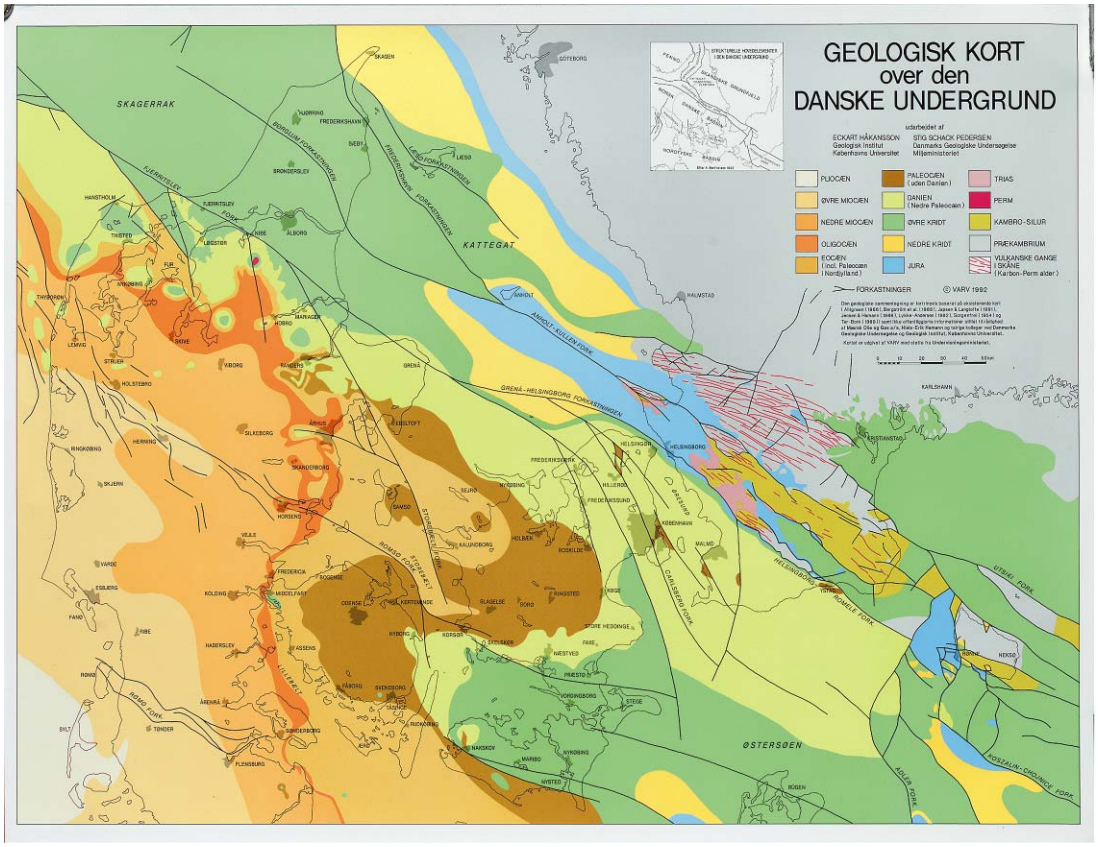


Figure 51. Map of the pre-Quaternary surface: Time units. Original scale: 1:50.000. Legend: Red lines: Precambrian intrusions, grey: Precambrian, olive: Cambrian-Silurian, red: Permian, light red: Triassic, blue: Jurassic, yellow: Lower Cretaceous, green: Upper Cretaceous, light green: Danian, brown: Paleocene, yellow olive: Eocene, red brown: Oligocene, light yellow brown: Lower Miocene, very light yellow brown: Upper Miocene, white: Pliocene (Håkansson & Pedersen, 1992).

Figure 52. Section from the Albæk Hoved cliff, Juelsminde, Jylland. Red and green plastic clays comparable to the plastic clays Holmehus Formation.

As a support for the conditions in the Vemmenæs area, detailed descriptions and dating of clay samples from a 48 m deep borehole at Bjerreby exist. Very fine-grained plastic olive green, black and olive grey clays covered by 2 m clayey till are found in the borehole.

The Paleogene clays have been dated and the clays belong to the Paleocene Holmehus Formation and the Eocene Ølst Formation. The deposits have been deformed by Weichselian glaciers and the formations are repeated and pushed up into several floes along thrust faults with meltwater sand on the thrust planes. The clay (bentonite) has been mapped by geoelectric methods showing that probably the glaciotectonic and deformed deposits have a distribution north, south and northeast of Bjerreby.

7.5.2 Quaternary deposits

The Quaternary deposits in the surface layers in the area mainly consist of clayey tills (Figs. 46 and 53). Towards the east, the clayey tills are silty, sandy, olive grey and calcareous from the ground surface and down to 30 m below. Towards the west, the clayey tills have the same characters but are only few m thick. Towards the north, clayey tills are slightly silty, sandy, yellow brown and non-calcareous down to 2 m. Toward the north and northeast, coarse-grained meltwater sand and gravel are found above olive grey calcareous clayey till down to 28 below ground surface.

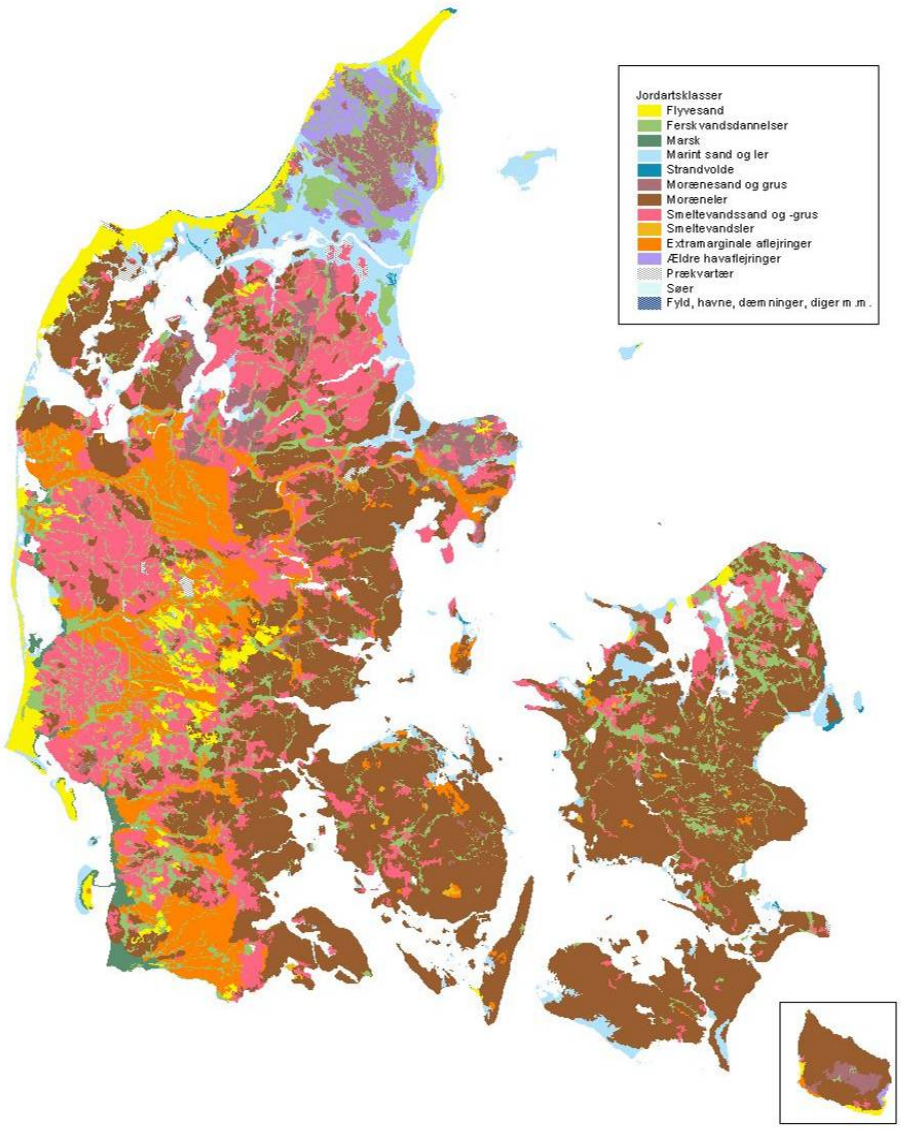


Figure 53. The map of the Quaternary surface deposits. Original scale: 1:200.000. Legend: Brown: Clayey till, light brown: Sandy till, red: Meltwater sand and gravel, orange: Sandur sand and gravel, purple: Late glacial marine deposits, light blue: Holocene marine deposits. Green: Holocene freshwater deposits, yellow: Aeolian sand (From Pedersen, 1989).

7.6 Tectonics, structures and seismic activity

7.6.1 Major tectonic structures

No major fault lines have been registered and mapped on Tåsinge but as faults apparently cut the pre-Quaternary surface at Langeland between Rudkøbing and Tullebølle, it would be logical to expect faults on Tåsinge as a continuation of these structures. The map of the pre-Quaternary deposits (Fig. 51) shows Eocene in the area but the deposits could be of Paleocene age. This could be open for discussion, as it is difficult to relation samples to formations.

Many of the Quaternary deposits have been glaciotectonic disturbed and also the Paleogene deposits have often been pushed up and occur as floes in the clayey tills (Fig. 54).

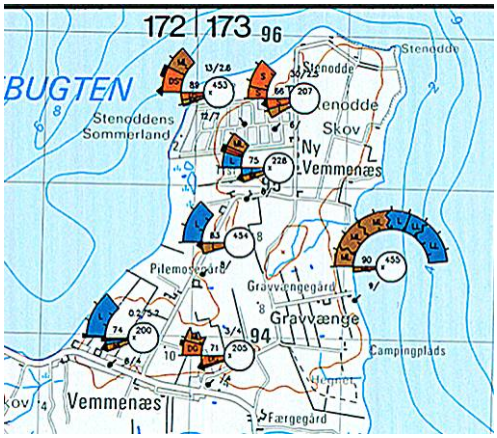


Figure 54. Part of the Geological Basic Data map 1311 I Rudkøbing, showing borehole data from Vemmenæs, Tåsinge. Original Scale 1:50.000. Legend: See fig. 10 (From Gravesen, 1993).

7.6.2 Fractures

The plastic clays often contain fractures and some small faults or fractures. The clayey tills are always cut by fractures but the conditions on Tåsinge are not investigated because of lack of field localities.

7.6.3 Geological model

The geological model of the area is fairly simple with three units (Fig. 55).

A. Quaternary till 2 to 30 m thick: Sandy, gravelly clayey till.

B. Meltwater sand and gravel (partly). Up to 8 m thick.

C. Tentatively Holmehus Formation, at least 25 m thick. Sticky, fine-grained plastic clay, green or brown.

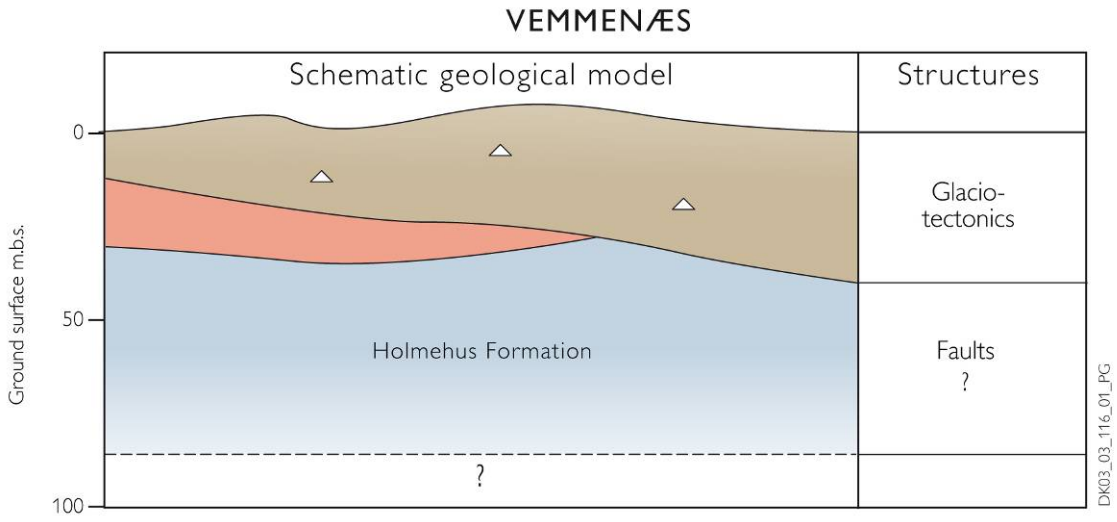


Figure 55. Schematic geological model of the area.

7.6.4 Earthquake activity

The seismic activity in Tåsinge and the near surrounding sea is very low (Fig. 56). 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.

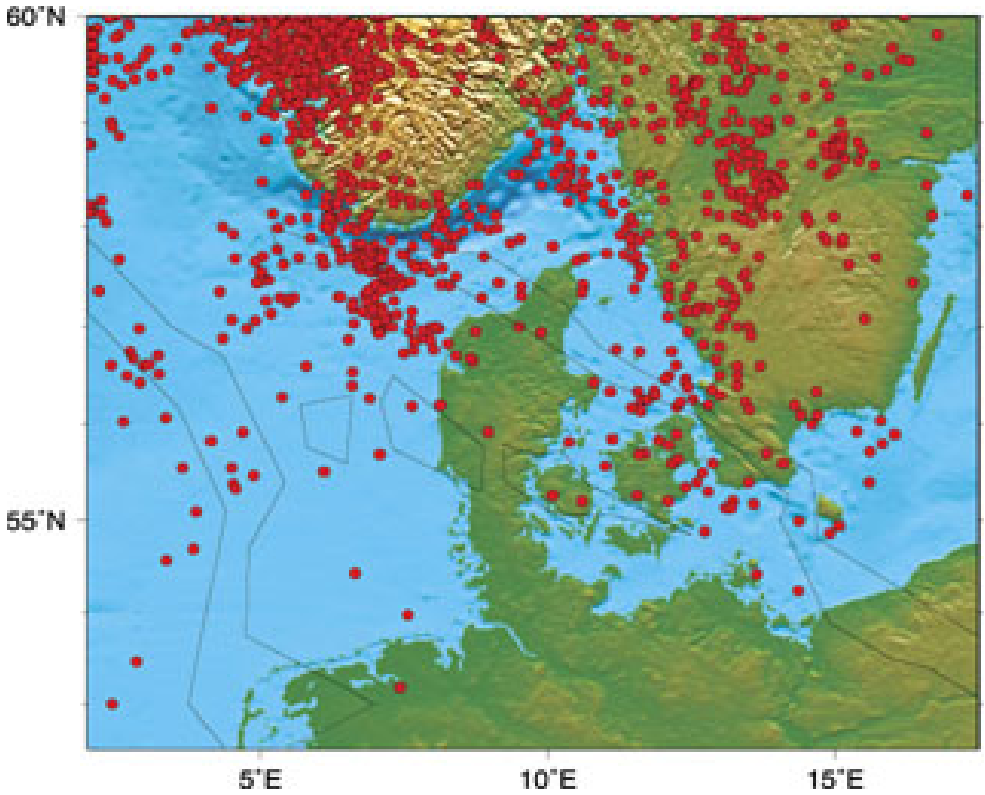


Figure 56. Map of epicentres from earthquakes in the Danish and surrounding area. (From GEUS´s Home page).

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. These are caused by fractures in the clays and because of large changes in volume at drying and water filling.

7.8 Groundwater hydrogeology

7.8.1 Groundwater characteristics

The Quaternary and Paleogene sediments include approximately 65 m of clays without groundwater reservoir characteristics. The area is close to a drinking water area on the northernmost part of Vemmenæs.

The Vemmenæs location include a shallow (DK1.15.1.4) and a regional groundwater body (DK1.15.2.5) (Figs. 57 and 58). Both groundwater bodies consist of meltwater sand deposits. Deep groundwater bodies have not been identified in or near Area 9 in the catchment management plan. The subdivision into groundwater bodies is described as part of the basis analysis carried out by the former Fyns Amt (www.ode.mim.dk).

The overall assessment of the chemical and quantitative status of the shallow and regional groundwater bodies is poor, due to a poor qualitative status in the shallow groundwater body and a poor quantitative status in the regional groundwater body (see Section 7.9).

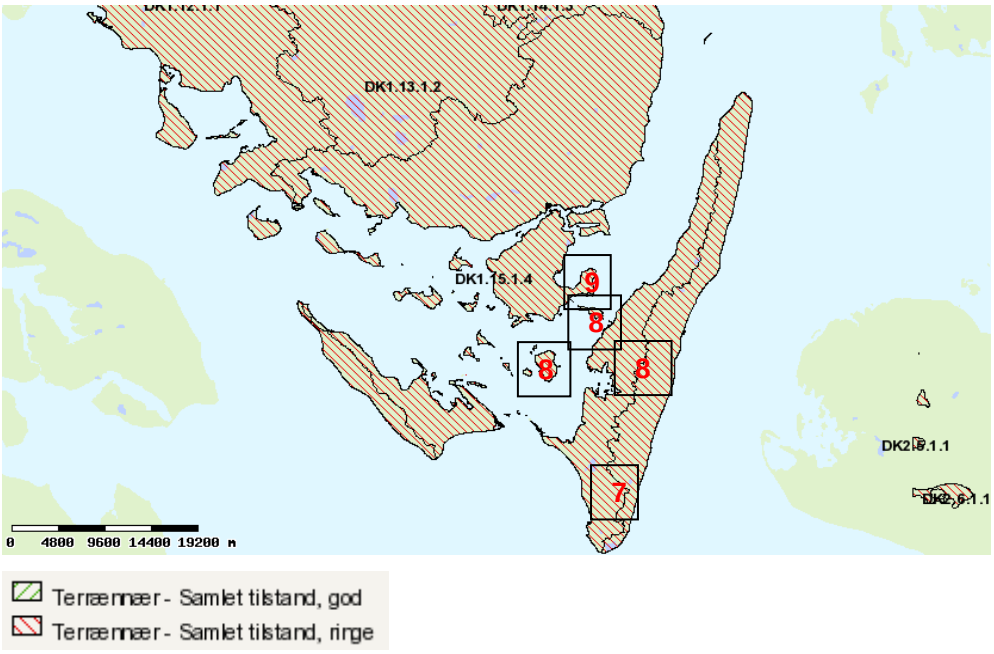


Figure 57. Shallow (or terrain near) groundwater bodies DK1.14.1.3 and DK1.15.1.4 at the areas Langeland South (Area 7), Langeland Mid, Siø & Strynø (Area 8), and Vemmenæs (Area 9). The overall assessment of chemical and quantitative status of all three areas: poor status (Red shaded area)(After Ministry og Environment, 2010).

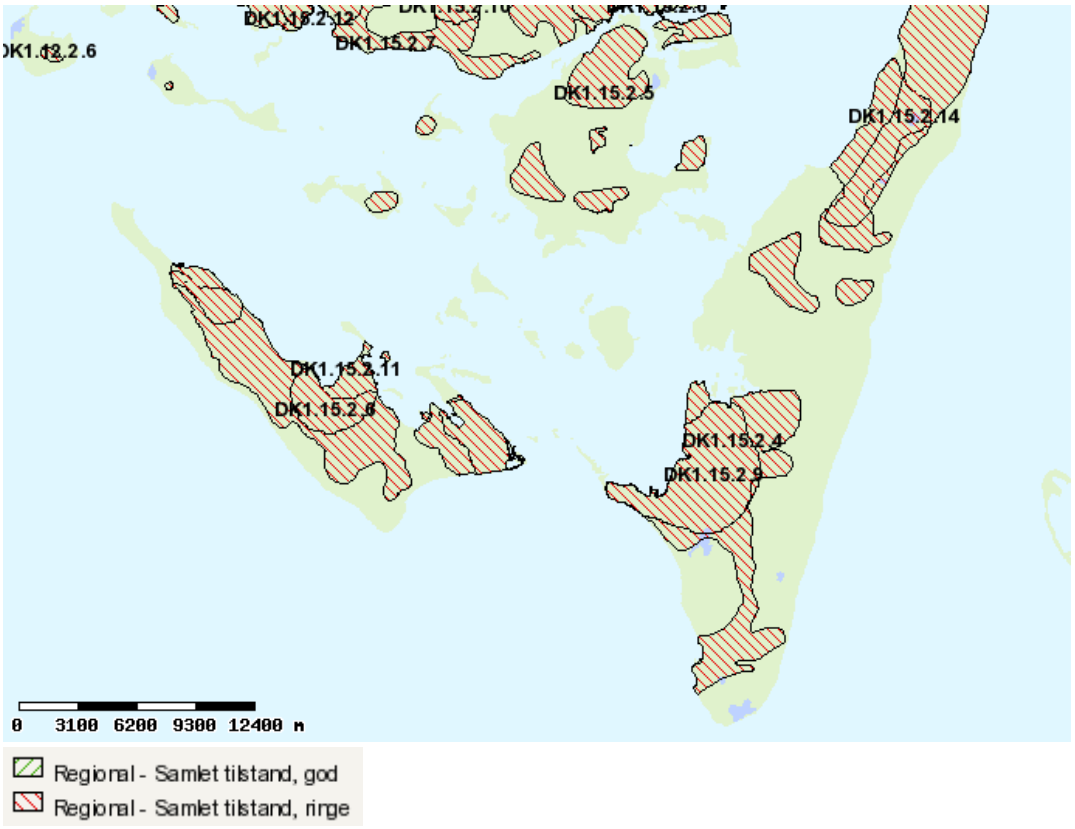


Figure 58. Regional groundwater bodies in the Langeland-Tåsinge region. Near Langeland South area (Area 7): DK1.15.2.4; Near Langeland Mid Area 8): DK1.15.2.9; At Vemmenæs (Area 9): DK1.15.2.5. The overall assessment of chemical and quantitative status for all three areas: poor status (Red shaded area)(After 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. 59).

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.

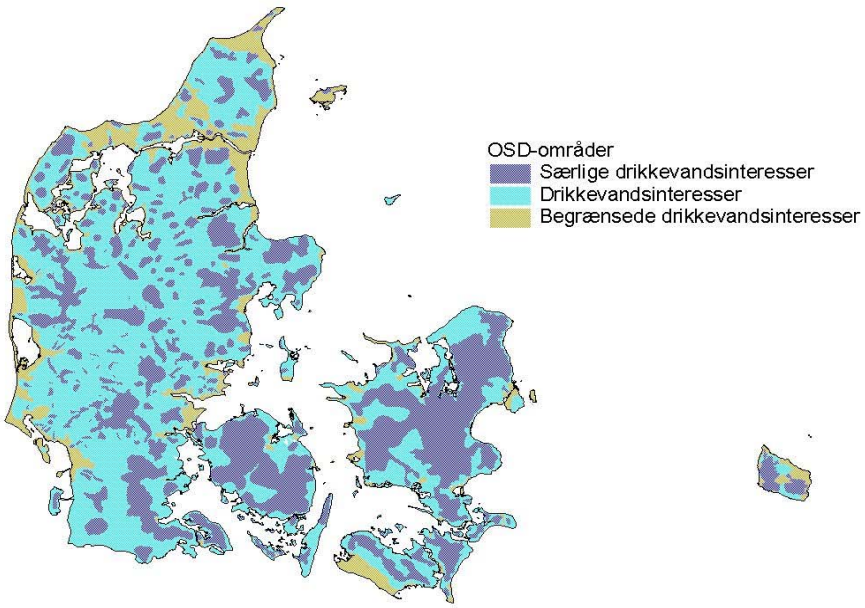


Figure 59. Areas of special drinking water interests (OSD): Dark blue and areas of drinking water interest (OD): Light blue. Areas with limited drinking water interests are olive brown. (http:/kort.arealinfo.dk/).

The Vemmenæs area is located in an area with drinking water interests (OD) with the Stenodden waterwork placed in the northern part (Fig. 60). The waterwork belongs to Svendborg Vand and has permission to abstract up to 20.000 m^3 of groundwater per year.

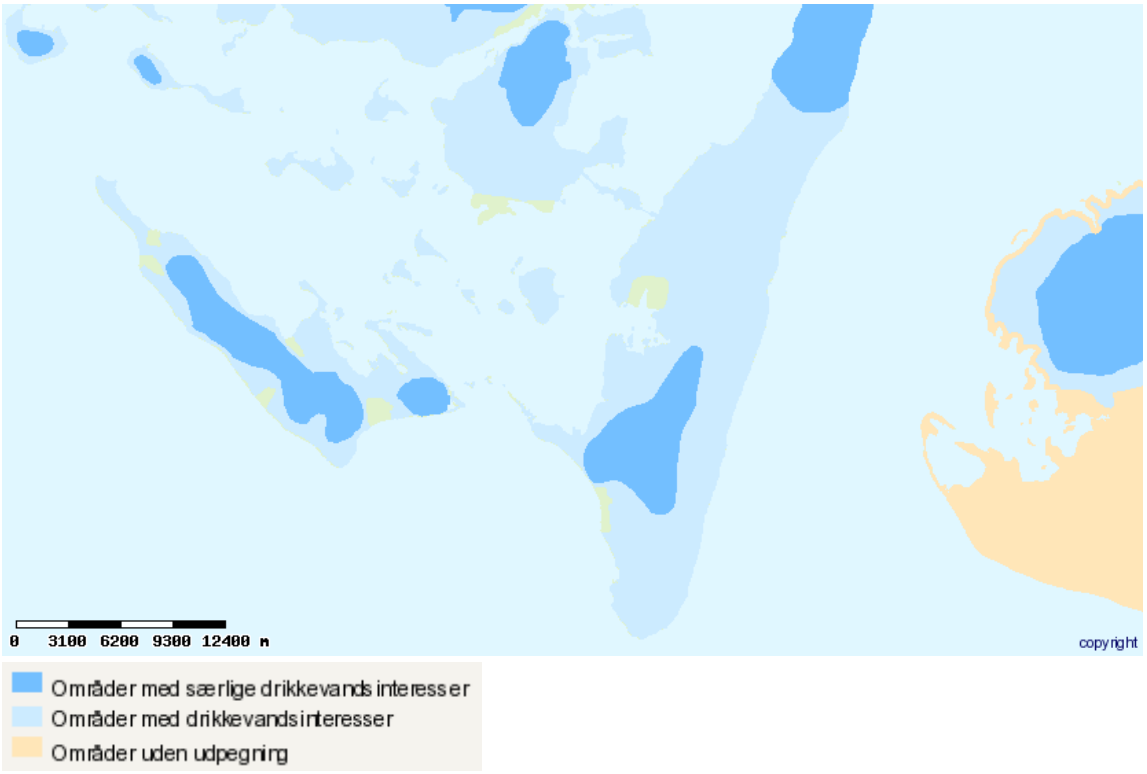


Figure 60. Various drinking water areas situated in the Langeland-Tåsinge region. Dark Blue: Areas of special drinking water interests (OSD); Light blue: Areas of some drinking water interests (OD); Yellow: Areas with limited or none drinking water interests. (http:/kort.arealinfo.dk/).

7.9 Groundwater chemistry

The overall groundwater quality aiming for drinking water purpose has been assessed by the former Fyns Amt and Environmental Centre Odense for each groundwater body and reported in the catchment management plans “Hovedvandopland 1.15, Det Sydfynske Øhav”. Generally, the shallow groundwater body has been assessed to have a poor chemical status.

No seawater intrusion problem has been reported from the Vemmenæs area and is not considered to be a significant problem.

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). The expected increase in precipitation and a sea level rise may cause flooding problems to the low-lying parts of the area along the coast, especially the marine forelands toward west and southeast, during this century.

7.11 Restrictions and limitations

No raw material restrictions exist on Vemmenæs but an area at Bjerreby, southeast of the town, is digging area for bentonite (Holmehus Formation).

The southern and western margin of Area 9 is protected by NATURA2000 regulation; however, no habitat interests are located within Area 9 (Fig. 61).

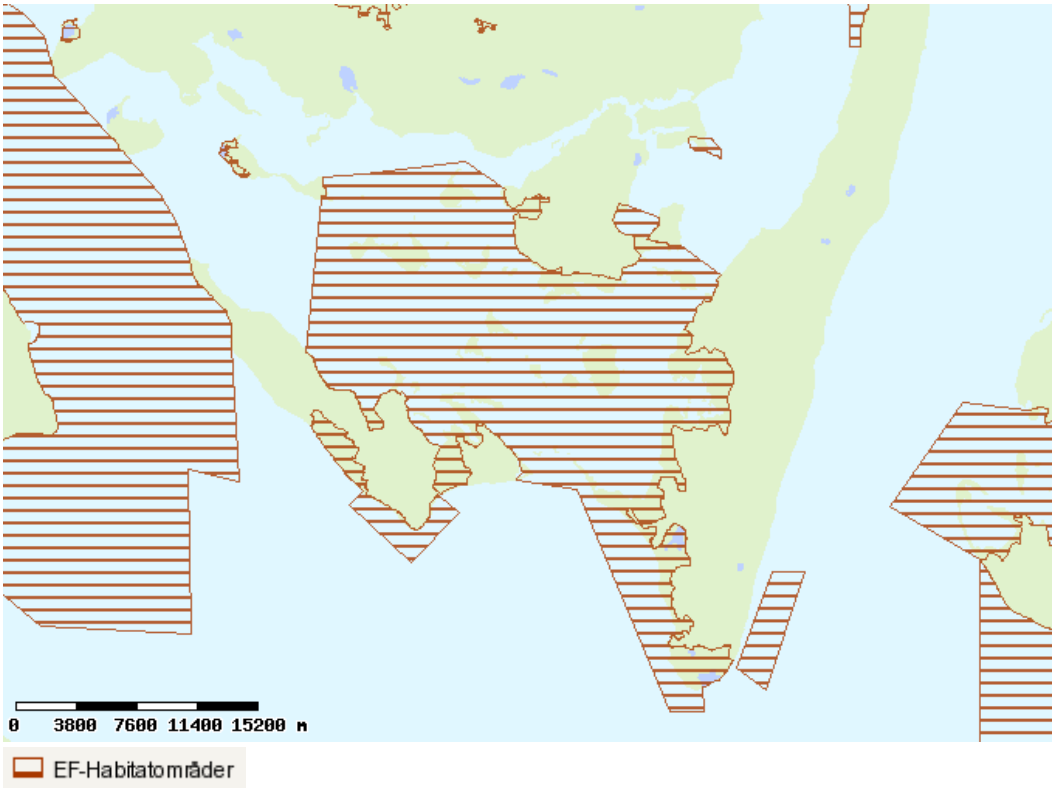


Figure 61. NATURA2000 Habitat areas in the Langeland-Tåsinge region.

7.12 Summary of the area 10 conditions

Amount of data:
Sparse. Very few boreholes but some geophysical surveys exist.

Homogeneous conditions and isolation of the waste by low, permeability layers:
Perhaps perfect on depths below 30 m but the framework of the fractures below 20 m is unknown. Probable fracture problem have to be considered in relation to other sites.

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

Seismic activity and tectonic movements

No seismic and tectonic movements and problems, although the area is situated along the margin of a salt diaper. The area is probably also fault bounded towards the south.

Groundwater 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

No OSD area within the Area 9 but the area is an OD 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. The low elevation of the landscape has to be considered in relation to future sea level rise but dikes are already established along the coast.

Climate extreme conditions

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

Other restrictions

Apparently no other restrictions will give problems.

7.13 Final remarks

Area 9 on Vemmenæs, Tåsinge is a possible waste disposal area. The area is not a well documented area, but geophysical investigations (indirect data) indicate that relatively thick Paleogene clay deposits can be found on Vemmenæs. At Bjerreby, the Paleogene deposits are found in several floes and at Ny Søby toward east, some indication of comprehensive clay deposits based on TEM and a few boreholes occur. These two last areas are not included in the potential waste disposal areas.

8. Area 10. Kertinge Mark, East Fyn

8.1 The location of the area

The area is situated on north-eastern Fyn (Fig. 62). It is a peninsula situated west of Kerteminde at Kerteminde Fjord and Kertinge Nor (Figs. 62 and 63).

Figure 62. Location of the area 10. Kertinge Mark is located on north-east Fyn, west of Kerteminde.

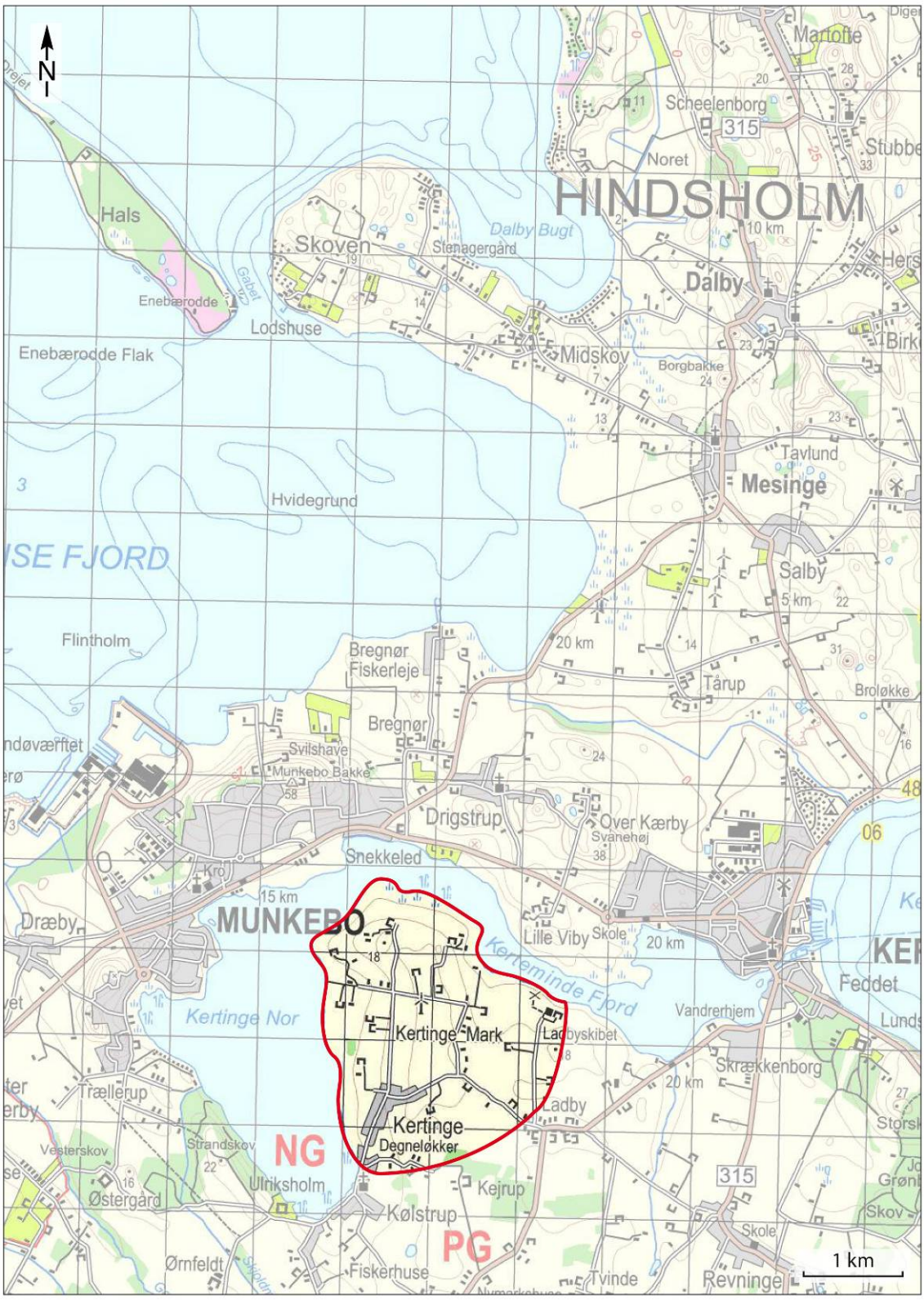


Figure 63. A detailed map of Area 10, which is located on a peninsula in eastern part of Fyn, west of Kerteminde.

8.2 Terrain, topography and processes

The area is located next to Kertinge Nor and Kerteminde Fjord. The size of the area is c. 7 km^2. The area is marked by a central, N-S oriented, elongated hill that reaches a level between 15 and 20 meters above sea level (m.a.s.). The top of the hill has character of a plateau and from this central part of the area, the landscape slopes gently toward the periphery of the area. Toward west, north and northeast, the area is delimitated by Kertinge Nor and Kerteminde Fjord (Fig. 64 & 65). There are no cliffs along this low-energy coastline. Towards southeast and south, the plateau slopes gently to levels around 5 m.a.s. Neither lakes nor streams are found in the area.

The predominant part of the area is used for agriculture. Towards southwest, the small village Kertinge is found. The area is crossed by some smaller roads along which scattered houses are located. A windmill is found in the middle of the area. The museum Ladbyskibet, holding the only Danish burial in a viking ship, is situated in the north-eastern periphery of the area, next to Kerteminde Fjord.

Owing to the low relief and intensive cultivation, the surface processes (soil creep, frost – thaw processes, soil development etc.) proceed slowly and undramatic. Kertinge Nor and Kerteminde Fjord are low-energy waters and the coastal development proceeds slowly.

8.3 Surface geology and profiles

The area is mainly covered by clayey till with a few occurrences of sandy till. No surface exposures are available (Fig. 66).

Figure 64. Photo of Area 10 towards South.

Figure 65. Panorama photo of Area 10 taken towards Kertinge Nor and Kerteminde Fjord.

Figure 66. Map of the Quaternary surface deposits (From GEUS´s Homepage. After Pedersen, 1989). Legend: Brown: Clayey till, red brown: Sandy till, red and orange: Melt-water sand and gravel, green: Holocene freshwater deposits, blue: Holocene marine de-posits. Legend for boreholes: See fig. 67.

8.4 Boreholes and geophysical surveys

The target is Eocene/Paleocene clays, but only 5 boreholes within the area reach these clays (Fig. 67). Very few samples have been collected and described lithological. No sam-ple has been dated on microfossils. An example of a borehole log is found in fig. 68.

Figure 67. Map of the locations of boreholes from the Jupiter Database at GEUS. Legend: 137.384: 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 1/10 2010 Side 1

BORERAPPORT

DGU arkivnr: 137. 384

Borested : Kertinge, Kertinge Bygade 6
5300 Kerteminde
Kerteminde

Kommune : Kerteminde
Region : Syddanmark

Boringsdato : 1/3 1965

Boringsdybde : 40.5 meter

Terrænkote : 10 meter o. DNN

Brøndborer : Neptun, Nyborg
MOB-nr :
BB-journr :
BB-bornr :

Prøver
- modtaget :
- beskrevet : 7/12 1967 **af** : G
- antal gemt :

Formål : Vandforsyningsboring
Anvendelse : Sløjfet/opgivet bor
Boremetode : Tørboring/slagboring

Kortblad : 1313 IISV
UTM-zone : 32
UTM-koord. : 600525, 6144538

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

Notater : intet vand - bor. opgivet og trukket op boret i gammel 5m dyb brønd - vsp. ved lok. 2/9-75 var 4.0m.u.t.

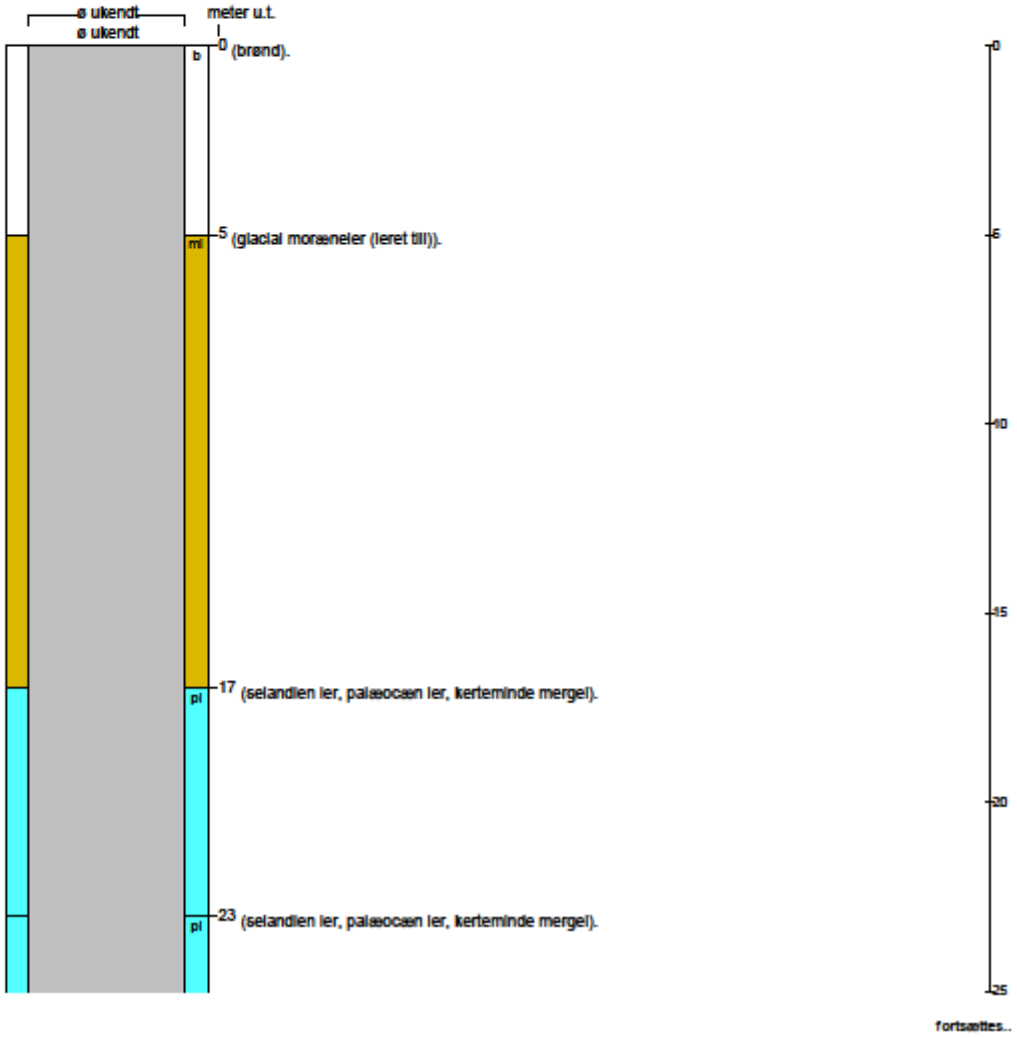


Figure 68. Geological log from the borehole DGU no. 137.384. Upper parts of the 40.5 m deep borehole.

Geophysical investigations: geoelectric and electromagnetic surveys are carried out on selected parts of the area.

8.5 Sediment and rock characteristics, mineralogy and chemistry

8.5.1 Pre-Quaternary deposits

According to the map of the pre-Quaternary surface, Paleocene clays should be reached below the Quaternary (Fig. 69). Paleogene clays occur between 16 and 28 m below ground surface at Kertinge Mark but the boreholes are mainly located in the south-eastern part of the area.

The clays are silty and fine-grained, light olive grey and grey, strongly calcareous and cemented or silicified layers occur occasionally. The calcareous content range between 40 and 70 %. A few samples are dated to Selandian and the clays belong to the Kerteminde Marl Formation. The formation is at least 40 m thick but a borehole just outside the area includes 60 m Selandian above interpreted Danian limestone. But the limestone layer could be greensand deposits and several cemented layers occur above the limestone.

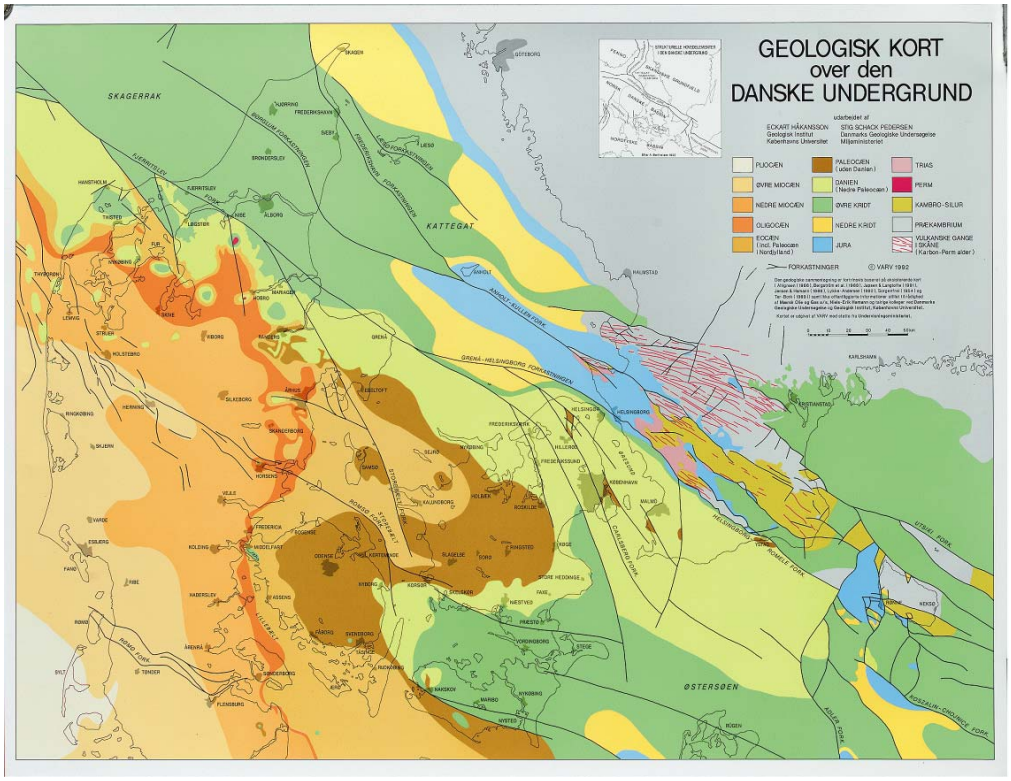


Figure 69. Map of the pre-Quaternary surface: Time units. Original scale: 1:50.000. Legend: Red lines: Precambrian intrusions, grey: Precambrian, olive: Cambrian-Silurian, red: Permian, light red: Triassic, blue: Jurassic, yellow: Lower Cretaceous, green: Upper Cretaceous, light green: Danian, brown: Paleocene, yellow olive: Eocene, red brown: Oligocene, light yellow brown: Lower Miocene, very light yellow brown: Upper Miocene, white: Pliocene (Håkansson & Pedersen, 1992).

8.5.2 Quaternary deposits

The Quaternary deposits in surface layers in the area mainly consist of clayey tills (Figs. 66 and 70). The boreholes contain up to 28 m thick layers of clayey tills which are sandy, silty, olive grey and calcareous.

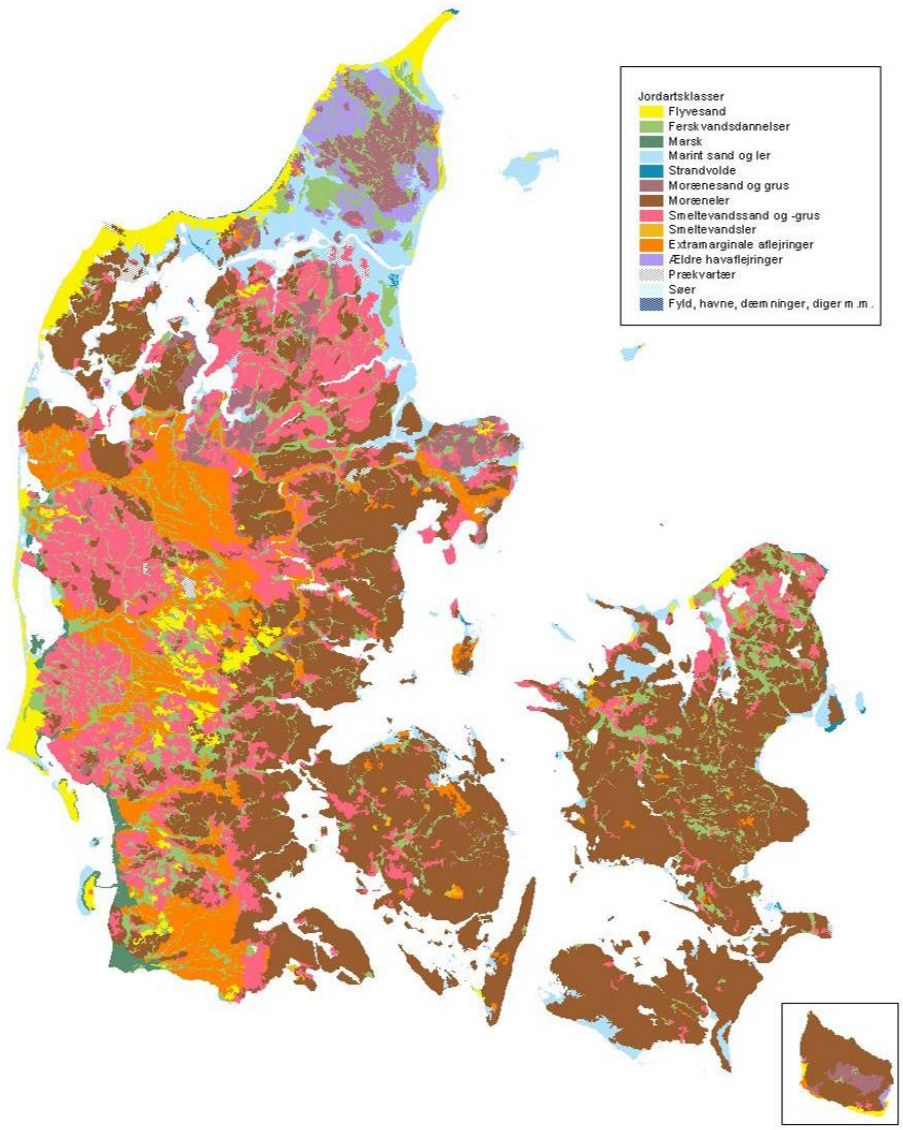


Figure 70. The map of the Quaternary surface deposits. Original scale: 1:200.000. Legend: Brown: Clayey till, light brown: Sandy till, red: Meltwater sand and gravel, orange: Sandur sand and gravel, purple: Late glacial marine deposits, light blue: Holocene marine deposits. Green: Holocene freshwater deposits, yellow: Aeolian sand (From Pedersen, 1989).

8.6 Tectonics, structures and seismic activity

8.6.1 Major tectonic structures

No major fault line have been registered and mapped in the Kertinge Mark area or the surroundings. The map of the pre-Quaternary deposits (Fig. 69) shows Paleocene in the area.

Many of the Quaternary deposits on the peninsula Hindsholm north of the area have been glaciotectonic disturbed and also the Kerteminde Marl deposits are found as a large floe in the cliff Lundsgård Klint south of Kerteminde. Moreover, floes are demonstrated in several boreholes at Munkebo and Kerteminde. The few boreholes are shown in fig. 71.

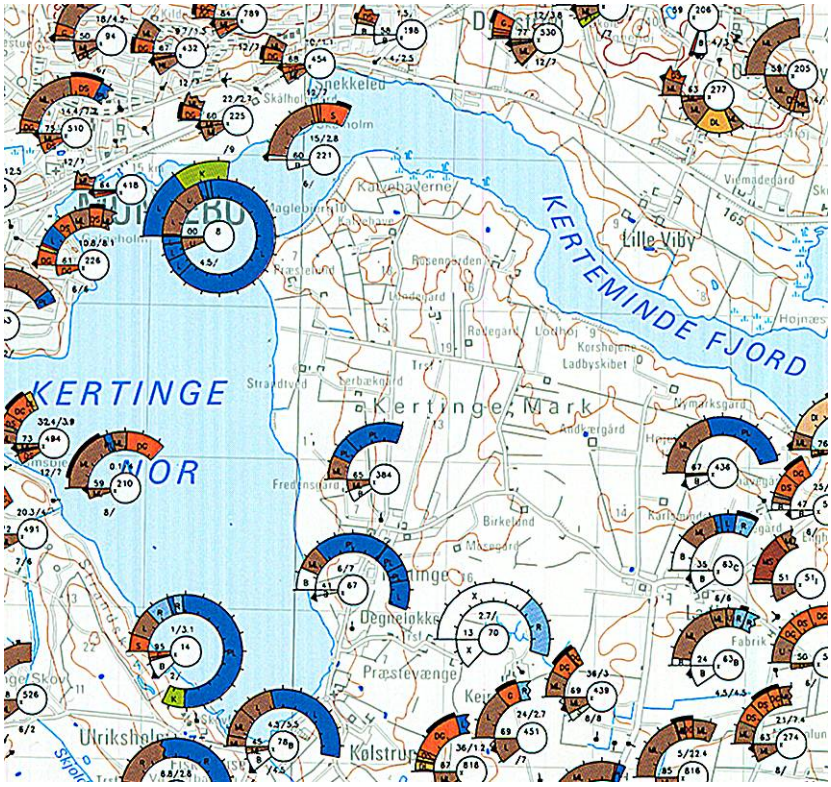


Figure 71. Part of the Geological Basic Data map 1313 II Kerteminde showing borehole data from Kertinge Mark, Fyn. Original Scale 1:50.000. Legend: See fig. 10 (From Jakobsen, 1993).

8.6.2 Fractures

The Paleocene clays often contain fractures and some small faults or fractures. The clayey tills are always cut by fractures but the conditions on Kertinge Mark are not investigated because of lack of field localities.

8.6.3 Geological model

The geological model of the area is fairly simple with two units (Fig. 72).

A. Quaternary till up to 30 m thick: Sandy, gravelly clayey till.

D. Kerteminde Marl Formation, at least 40 m thick. Silty and fine-grained plastic clay, olive grey.

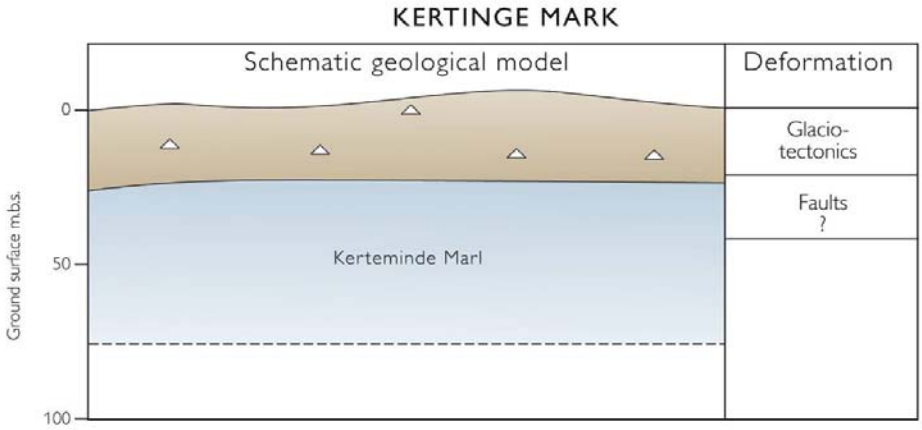


Figure. 72. Schematic geological model of the area.

8.6.4 Earthquake activity

The seismic activity in the Kertinge Mark area and the near surrounding sea is very low (Fig. 73). 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.

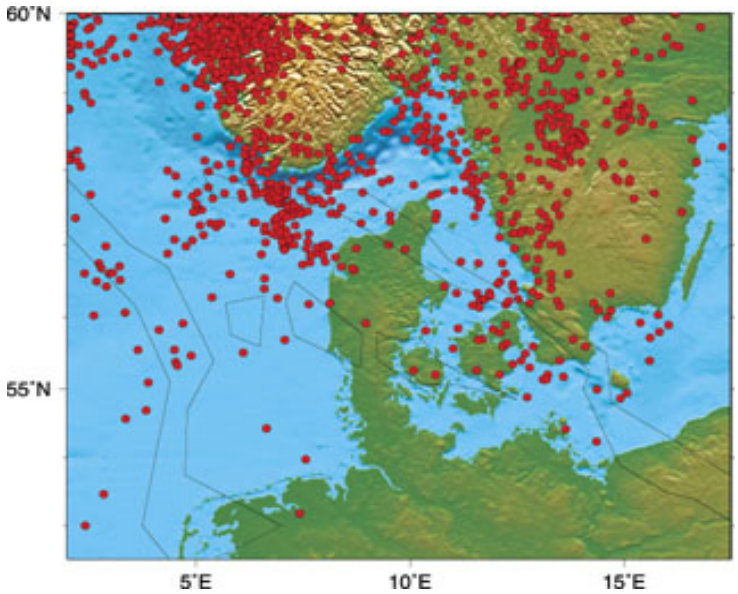


Figure 73. Map of epicentres from earthquakes in the Danish and surrounding area. (From GEUS´s Home page).

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 fine-grained clays can give problems. This is caused by fractures in the clays.

8.8 Groundwater hydrogeology

8.8.1 Groundwater characteristics

The Quaternary and Palaeogene sediments include approximately 70 m of clays without groundwater reservoir characteristics.

Kertinge Mark (Area 10) is positioned in an area that is characterized by the presence of a shallow (DK1.14.1.3) and a regional groundwater body (DK1.15.2.4) (Figs. 74 and 75). Both groundwater bodies consist of meltwater sand deposits. Regional groundwater bodies are not situated within Area 10 but a regional groundwater body (DK1.14.2.2.) exists along the southern margin of Area 10 (Fig. 75). Deep groundwater bodies have not been identified in or near Area 10 in the catchment management plan. The subdivision into groundwater bodies is described as part of the basis analysis carried out by the former Fyns Amt (www.ode.mim.dk). The overall assessment of the chemical and quantitative status of the shallow and marginal laying regional groundwater bodies is poor, due to a poor qualitative status (see Section 8.9).

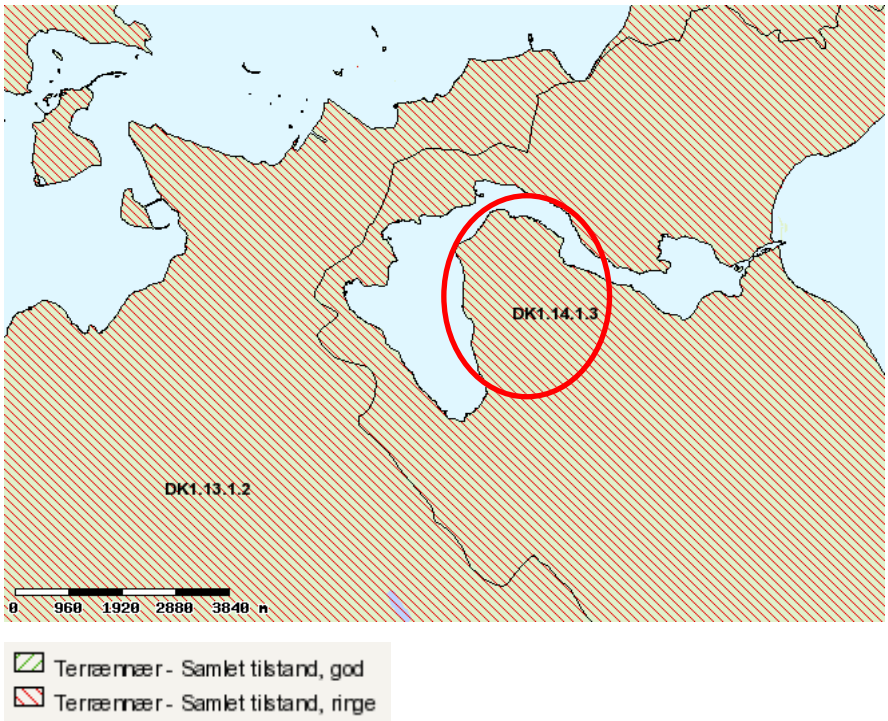


Figure 74. Shallow (or terrain near) groundwater body DK1.14.1.3 at the Kerteminde Mark area (Area 10). The overall assessment of chemical and quantitative status of shallow groundwater body: poor status (Red shaded area). (After Ministry of Environment, 2010).

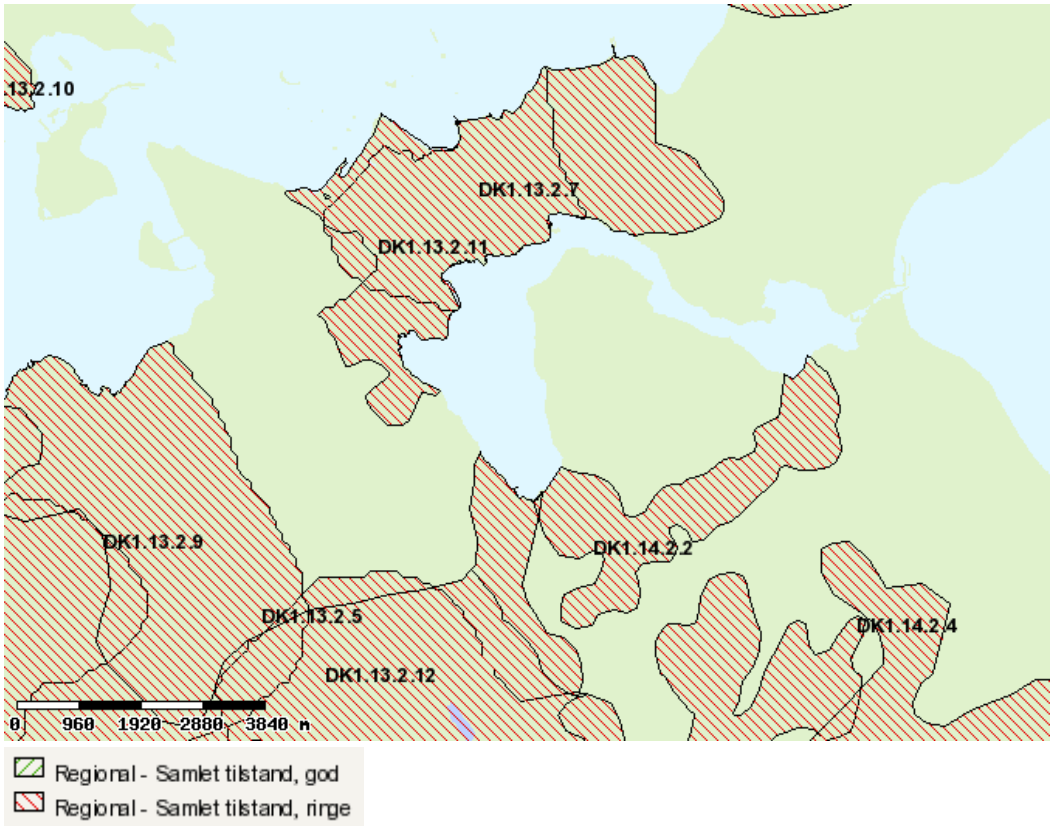


Figure 75. Regional groundwater bodies in the Kerteminde region. South of Kertinge Mark: DK1.14.2.2. The overall assessment of chemical and quantitative status for DK1.14.2.2: poor status (Red shaded area). (After Ministry of Environment, 2010).

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. 76).

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.

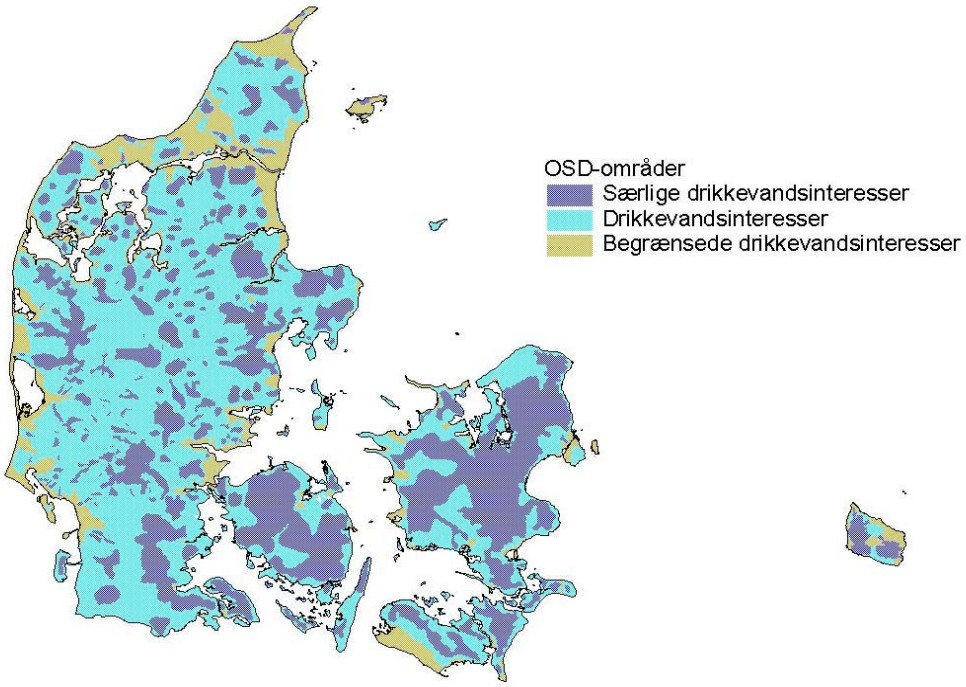


Figure 76. Areas of special drinking water interests (OSD): Dark blue and areas of drinking water interest (OD): Light blue. Areas with limited drinking interests are olive brown. (http://kort.arealinfo.dk/).

The drinking water areas categorised by the Environmental Centre Odense for the Kerteminde region is shown in fig. 77. Kertinge Mark (Area 10) is located in an area with drinking water interests (OD). Just south of Area 10, an important groundwater abstraction area exists with special water interests (OSD). There are no registered private abstraction wells or waterworks right in the Kertinge Mark area. Along the southern margin, few private abstraction wells for household purposes exists.

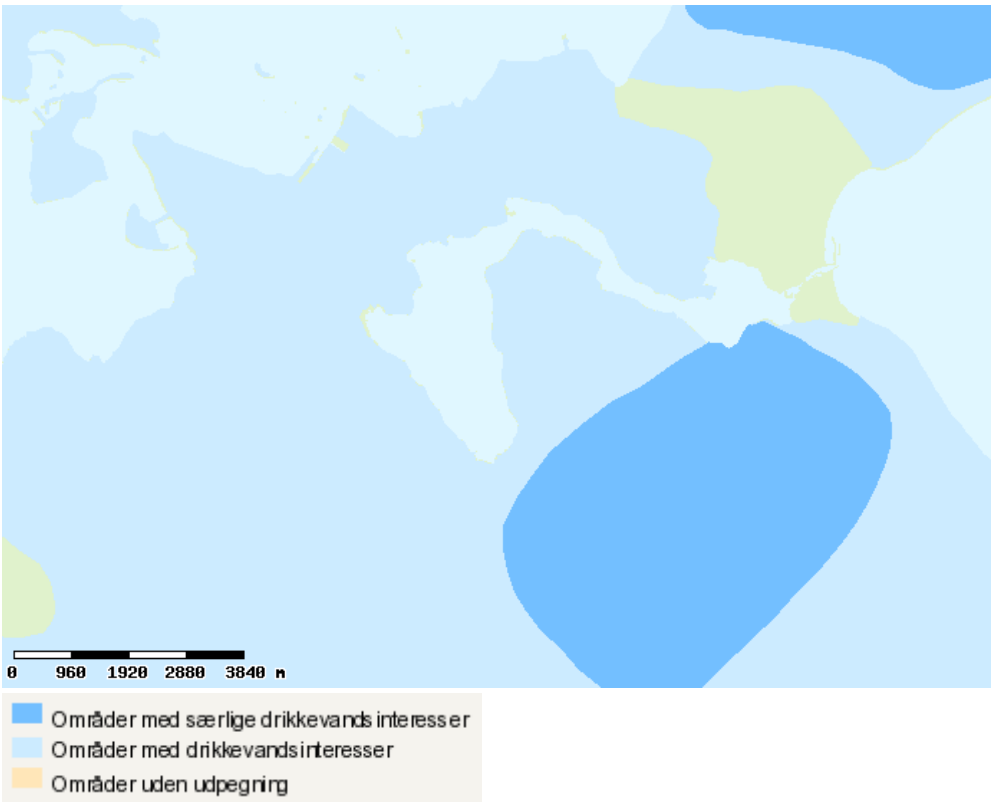


Figure 77. Various drinking water areas situated in the Kerteminde region. Dark Blue: Areas of special drinking water interests (OSD); Light blue: Areas of some drinking water interests (OD); Yellow: Areas with limited or none drinking water interests. (http://kort.arealinfo.dk/).

8.9 Groundwater chemistry

The overall groundwater quality aiming for drinking water purpose has been assessed by the former Fyns Amt and Environmental Centre Odense for each groundwater body and reported in the catchment management plans “Hovedvandopland 1.15, Det Sydfynske Øhav” and “Hovedvandopland 1.14, Storebælt“. The groundwater bodies have a poor status due to findings of total phosphorus and other contaminants in concentrations that exceed the acceptable limits in groundwater. Seawater intrusion is not considered to be a problem within Area 10, even at sea level rise caused by climate change, due to a general terrain level around 10 meters above present sea level.

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 this area seriously during this century, although a sea level rise may cause minor, local flooding problems to the low-lying parts of the area along Kertinge Nor and Kerteminde Fjord.

8.11 Restrictions and limitations

The Kerteminde Mark area and the nearby region has no restrictions in accordance to the NATURA2000 regulation, and land protected in relation to the naturbeskyttelsesloven (law for nature protection) is not found within area 10 (Fig. 78).

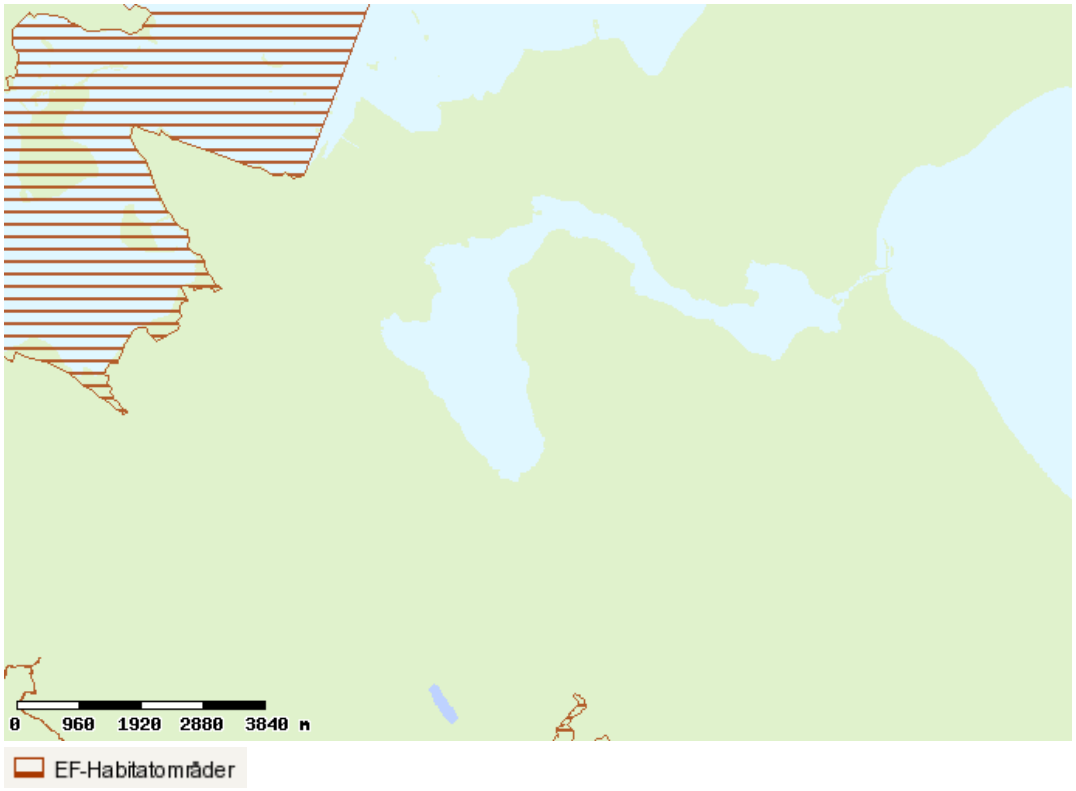


Figure 78. NATURA2000 habitat areas in the Kerteminde region (After Ministry of Environment, 2010).

The famous Ladby ship is located in the north-eastern part of the Area 10.

8.12 Summary of the area 10 conditions

Amount of data:
Very sparse. Only few boreholes, no geophysical data or outcrops exist.

Homogeneous conditions and isolation of the waste by low, permeability layers:
Perhaps perfect at depths below 30 m but the framework of the fractures below 20 m is unknown. Probable fracture problem have to be considered in relation to other sites.

Stability
Good stability on surface and depth but fine-grained clays can give problems.

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

Groundwater 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
No OSD area within the Area 10 but the area is an OD 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. The low elevation of the landscape has to be considered in relation to future sea level rise.

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

Other restrictions
Apparently no other restrictions will give problems.

8.13 Final remarks

Area 10 on Kertinge Mark is a possible area for a waste disposal.

The area is not a well documented area but borehole data indicate that relatively thick Paleogene clay deposits can be found on Kertinge Mark.

It has to be considered that around the area, the Paleocene Kerteminde Marl is found in glacial tills as floes in boreholes as well as in cliff outcrops at Kerteminde.

9. Area 11. Hindsgavl and Fænø, west Fyn

9.1 The location of the area

The area is situated on western Fyn (Fig.79). The area consists of the western tip of the Hindsgavl peninsula, situated south of Fredericia and east of Middelfart. The Island Fænø is located south of Hindsgavl (Fig. 80).

Figure 79. Location of the Area 12. Hindsgavl and Fænø are located on west Fyn.

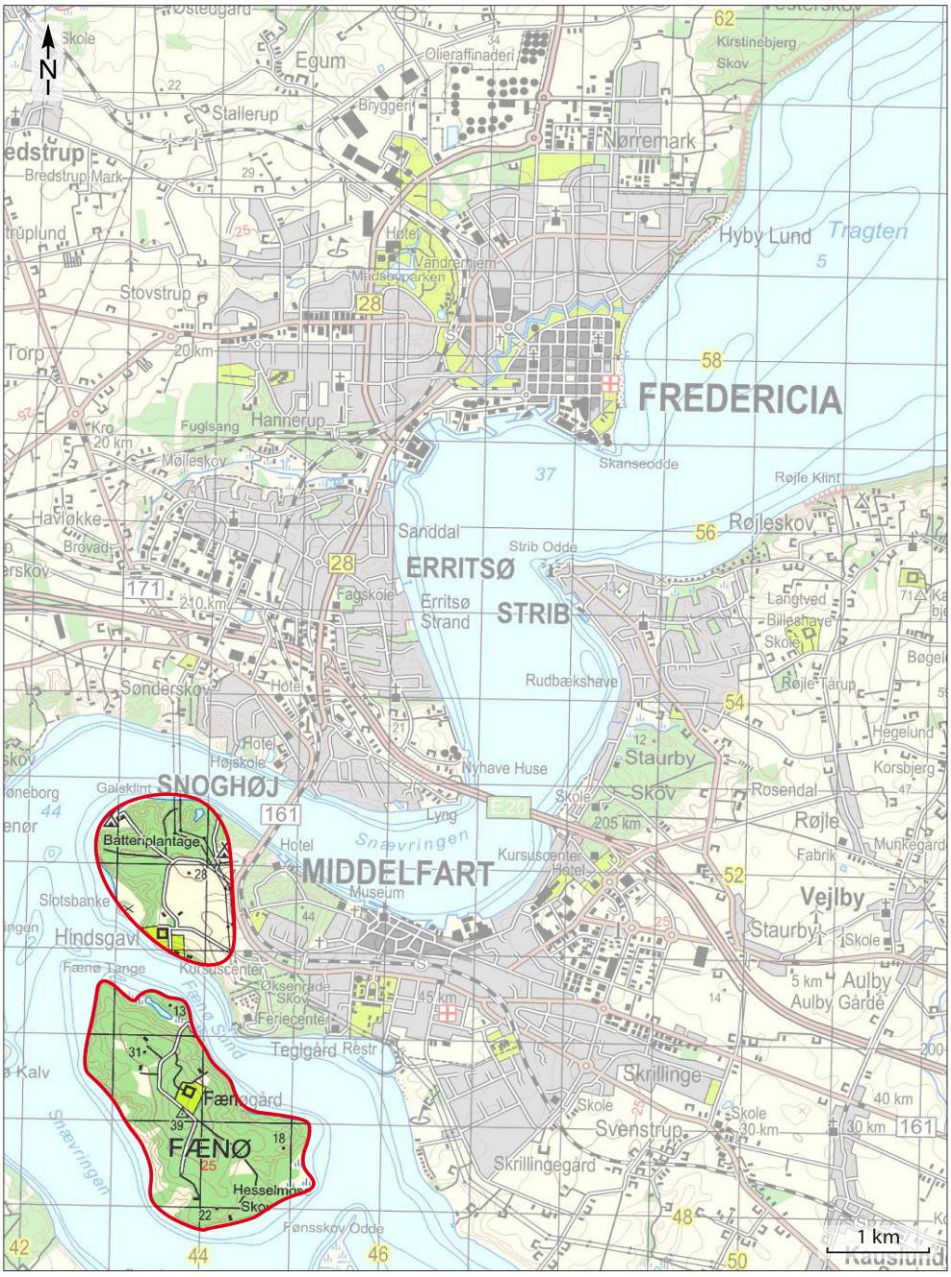


Figure 80. A detailed map of Area 11. Area 11 is located on the Hindsgavl peninsula and the island Fænø on western part of Fyn.

9.2 Terrain, topography and processes

Hindsgavl

The area is located on the distal part of a peninsula north-west of the town Middelfart and measures c. 2.2 km^2. Most of the area is marked by a central plateau 20 – 25 m above sea level. Centrally, a top level of 28 m is found. From the plateau, the landscape slopes rather steeply to the shore. The coastal cliffs seem to be inactive, and overgrown by trees and vegetation. A small lake is found toward the north and a marine foreland is sound in the

western part of the area, at Slotsbanke. No streams are found in the area. In front of the coast, the near shore zone slopes deeply into Lillebælt.

The area is crossed by several small roads. Two camping places are found, one toward NW and one in the eastern part of the area. The Hindsgavl manor house is situated in the south-western part of the area. Only very few houses are located in the area. Approximately 1/3 of the area is used for agriculture and 2/3 for plantation including many rare trees and bushes and a deer park. The eastern part of the area is crossed by some major (N-S running) supply cables for electricity.

Owing to the low relief and intensive cultivation, the surface processes (soil creep, frost – thaw processes, soil development etc.) proceed slowly and undramatic. Parts of the coastal cliffs are potentially erosive if the protecting vegetation cover is damage or if coastal erosion proceeds landward from the shore. Otherwise, the peninsula is situated in low-energy waters (concerning the waves but the current in Lillebælt is strong) and the coastal development proceeds slowly.

Fænø

Fænø is an island located in Lillebælt, southwest of the town Middelfart and measures c. 3.9 km^2. The part of the island is marked by an elongated, relatively narrow, high-lying plateau 30 – 40 m above sea level. From the plateau, the landscape slopes more or steeply steeply to the shore. The coastal cliffs seem to be inactive, and overgrown by trees and vegetation. A small lagoon is found in a beach meadow toward northeast; another small beach meadow/marine foreland is sound in the south-eastern part of the area. No streams are found in the area. In front of the coast, the near shore zone slopes deeply into Lillebælt.

The area is crossed by one small road. The modern and exclusive Fænø Estate is build on the central part of the island and more than 700.000 trees and bushes are planted all over the island. Today, all the islands 400 hectares are classified as forest reserve, holding an extraordinarily rich wild life.

Owing to the intensive cultivation, and in spite of the undulating landscape, the surface processes (soil creep, frost – thaw processes, soil development etc.) proceed slowly and undramatic. Parts of the coastal cliffs are potentially erosive if the protecting vegetation cover is damage or if coastal erosion proceeds landward from the shore. Otherwise, the peninsula is situated in low-energy waters (concerning the waves but the current in Lillebælt is strong) and the coastal development proceeds slowly.

9.3 Surface geology and profiles

The area is mainly covered by clayey till with a few occurrences of sandy till. Outcrops are known from the cliff area at the Lillebælt Bridge, at the Øxenrade cliff at Middelfart and from the opposite side of Lillebælt, at Hagenør and Børup (Fig. 81).

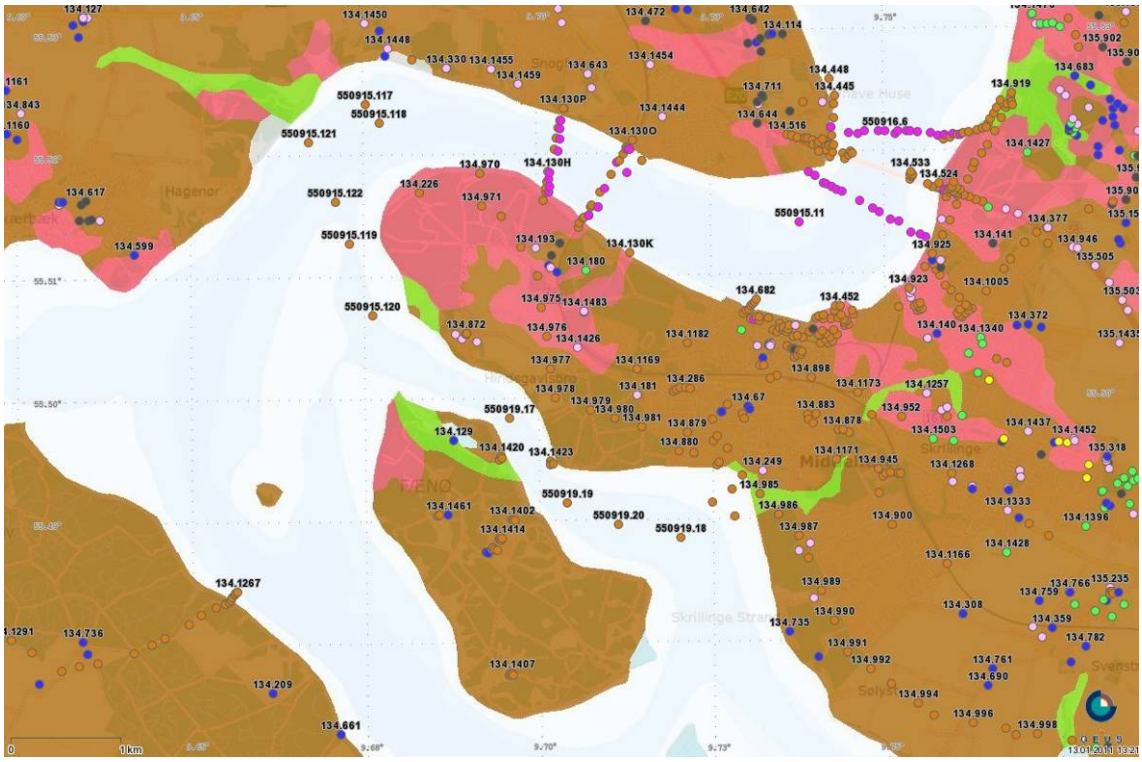


Figure 81. Map of the Quaternary surface deposits (From GEUS Homepage. After Pedersen, 1989). Legend: Brown: Clayey till, Red brown: Sandy till, Red and orange: Meltwater sand and gravel, Green: Holocene freshwater deposits, Blue. Holocene marine deposits, White: Pre-Quaternary deposits. Legend for boreholes: See fig. 82.

9.4 Boreholes and geophysical surveys

The target is Oligocene/Eocene/Paleocene clays but only few boreholes within the area reach these clays (Figs. 82 and 83). Very few samples have been collected and described lithological. No sample has been dated on microfossils. An example of a borehole log is found in fig. 84.

Figure 82. Map of the locations of boreholes on Hindsgavl from the Jupiter Database at GEUS. Legend: 134.226: 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 83. Map of the borehole locations on Fænø. Legend: See fig. 82.

De Nationale Geologiske Undersøgelser for Danmark og Grønland

Udskrevet 29/9 2010 Side 1

BORERAPPORT

DGU arkivnr: 134. 226

Borested : GAMBORG DAPCO NO 7
5500 Middelfart

Kommune : Middelfart
Region : Syddanmark

Boringsdato : 18/8 1950

Boringsdybde : 158,5 meter

Terrænkote : 2,1 meter o. DNN

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

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

Formål : Geoteknisk boring
Anvendelse :
Boremetode :

Kortblad : 1213 IINV
UTM-zone : 32
UTM-koord. : 543214, 6152731

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

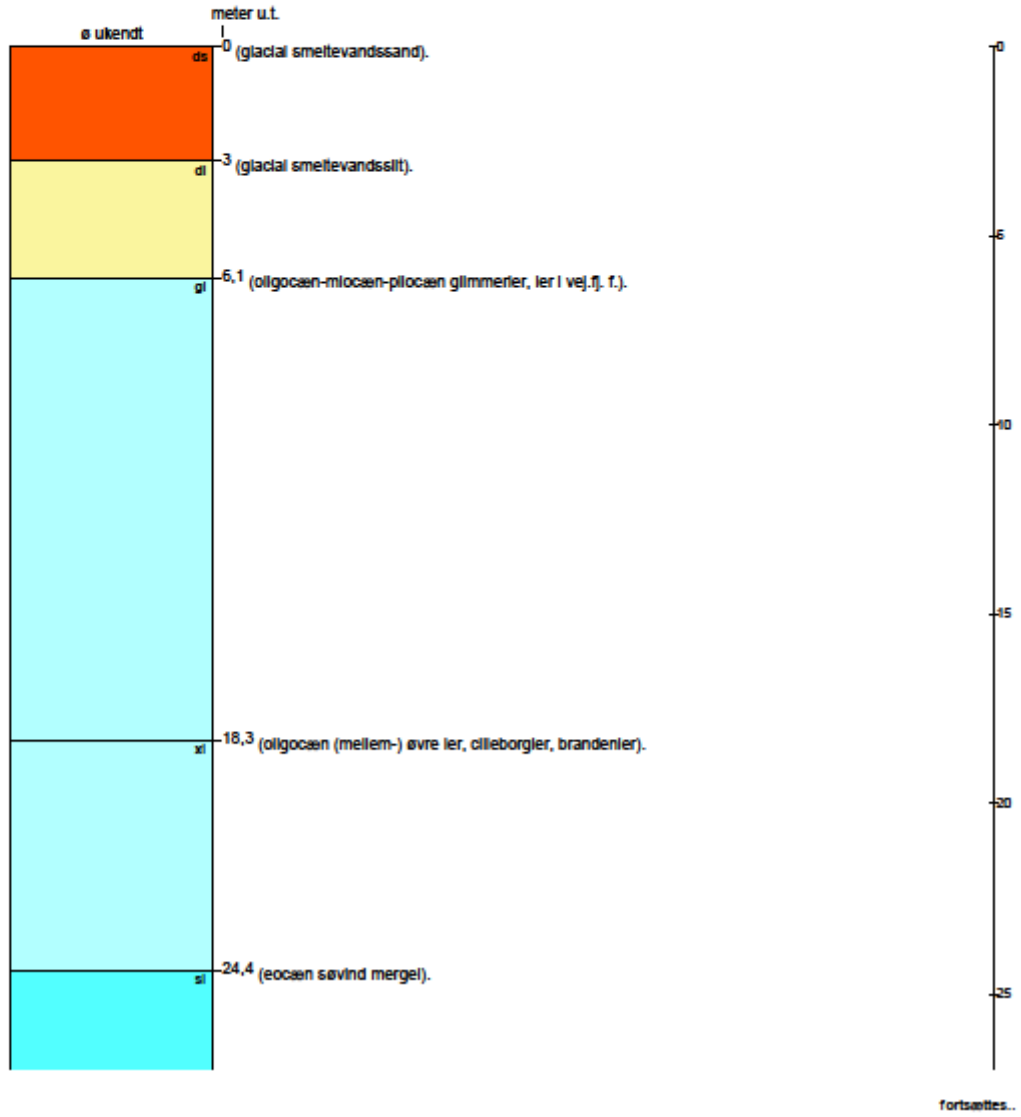


Figure 84. Geological log from the borehole DGU no. 134.226. Upper parts of the 158.5 m deep borehole.

Geophysical investigations: geoelectric and electromagnetic surveys are carried out on selected parts of the area.

9.5 Sediment and rock characteristics, mineralogy and chemistry

9.5.1 Pre-Quaternary deposits

According to the map of the pre-Quaternary surface, Paleocene, Eocene or Oligocene clays should be reached below the Quaternary (Fig. 85).

Hindsgavl

At the western tip of Hindsgavl, the boundary layers between Oligocene and Miocene occur as c. 18 m Vejle Fjord Formation of which 6 m is the Brejning clay Member (Formation). The Oligocene Brejning clay consists of brown black mica clay with glauconite and some sandstone layers while the Miocene Vejle Fjord clay consists of black micaceous clay.

The Late Oligocene deposits rest on 32 m Eocene Søvind Marl Formation of sticky calcareous clay, 35 m grey plastic clay from the Eocene Lillebælt Clay Formation, 14 m red plastic clay from the Eocene Røsnæs Clay Formation, 10 m clay with volcanic ash from the Eocene Ølst Formation, 37 m fine-grained clay with glauconite from the Paleocene Kerteminde Marl, and at last 6 m Bryozoan limestone with flint from the Danian (see DGU no. 134.226). Some of the sediment types can be seen in fig. 86.

Yellow brown and red brown sandstone layers are also known from the outcrop at Øksenrade on the south coast of Hindsgavl just east of Middelfart. The sandstone is cemented by iron minerals and contains glauconite. In the shallow cliff, the sandstone is resting on dark brown Brejning clay.

On the northern side of Hindsgavl, at the Lillebælt Bridge, the Late Oligocene deposits are approx. 25 m thick. Below these follows the Eocene Lillebælt Clay Formation. The alternating thin layers of brown and grey micaceous Oligocene sand and clays are found in the cliff west and east of the old bridge. Towards the northwest, at Galsklint, it is possible that younger sand and clay deposits from the Miocene occur.

Towards the south-east part of Hindsgavl, Eocene clays are found approx. 1 m below ground surface.

Fænø

On Fænø, Oligocene clays are reached approx. 36 m below ground surface. The clays are rather fine-grained black brown non-calcareous and contain mica and glauconite. Some of these marine Oligocene clays contain so much glauconite that the colour changes to green gray and they are calcareous. The deposits seem to belong to the Brejning
Clay Member and are at least 24 m thick.

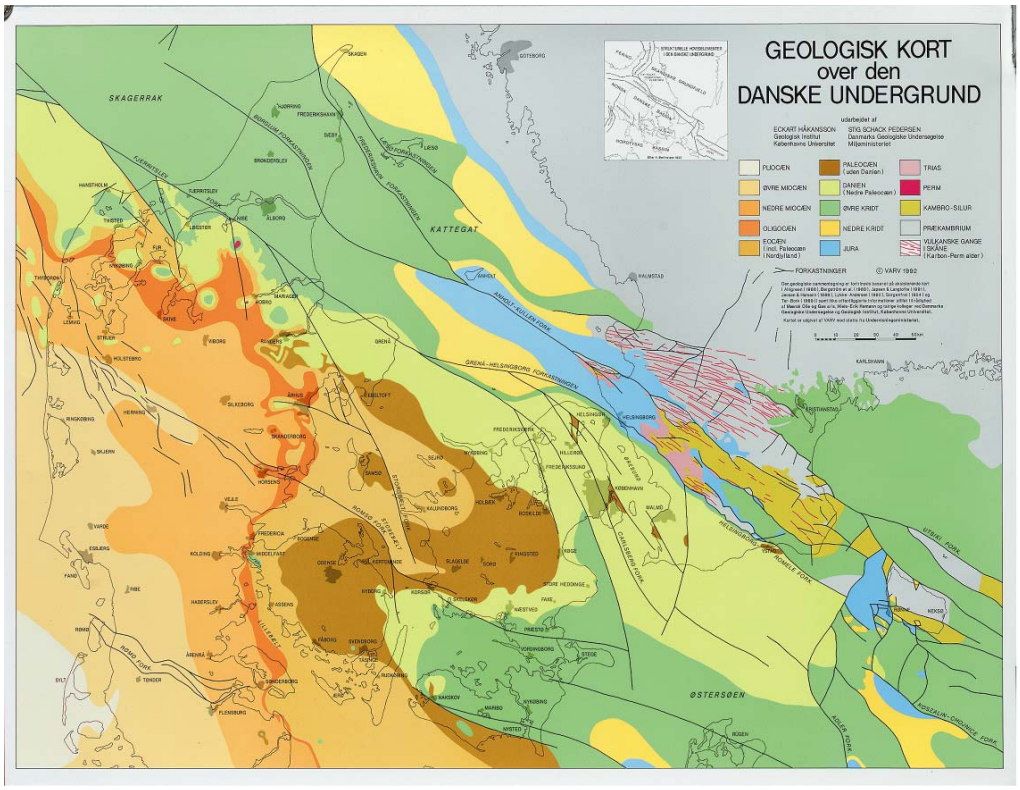


Figure 85. Map of the pre-Quaternary surface: Time units. Original scale: 1:50.000. Legend: Red lines: Precambrian intrusions, grey: Precambrian, olive: Cambrian-Silurian, red: Permian, light red: Triassic, blue: Jurassic, yellow: Lower Cretaceous, green: Upper Cretaceous, light green: Danian, brown: Paleocene, yellow olive: Eocene, red brown: Oligocene, light yellow brown: Lower Miocene, very light yellow brown: Upper Miocene, white: Pliocene (Håkansson & Pedersen, 1992).

Figure 86. Section from the Albæk Hoved cliff, Juelsminde, Jylland. Red and green plastic clay from the Lillebælt Clay Formation and the Røsnæs Clay Formation.

9.5.2 Quaternary deposits

The Quaternary deposits in surface layers in the area mainly consist of sandy deposits (Figs. 81 and 87).

Hindsgavl

On Hindsgavl, the Quaternary deposits consist of sandy till and meltwater sand. The thickness is between 1 m and 6 m but at the northern part up to 18 m.

Fænø

On Fænø, the Quaternary deposits are thicker, and range from 30 m to 40 m. The upper 20-30 m consists of sandy and silty gravelly grey and light olive brown calcareous clayey till which contain many clasts of limestone/chalk. Medium-grained gravelly meltwater sand often follows below.

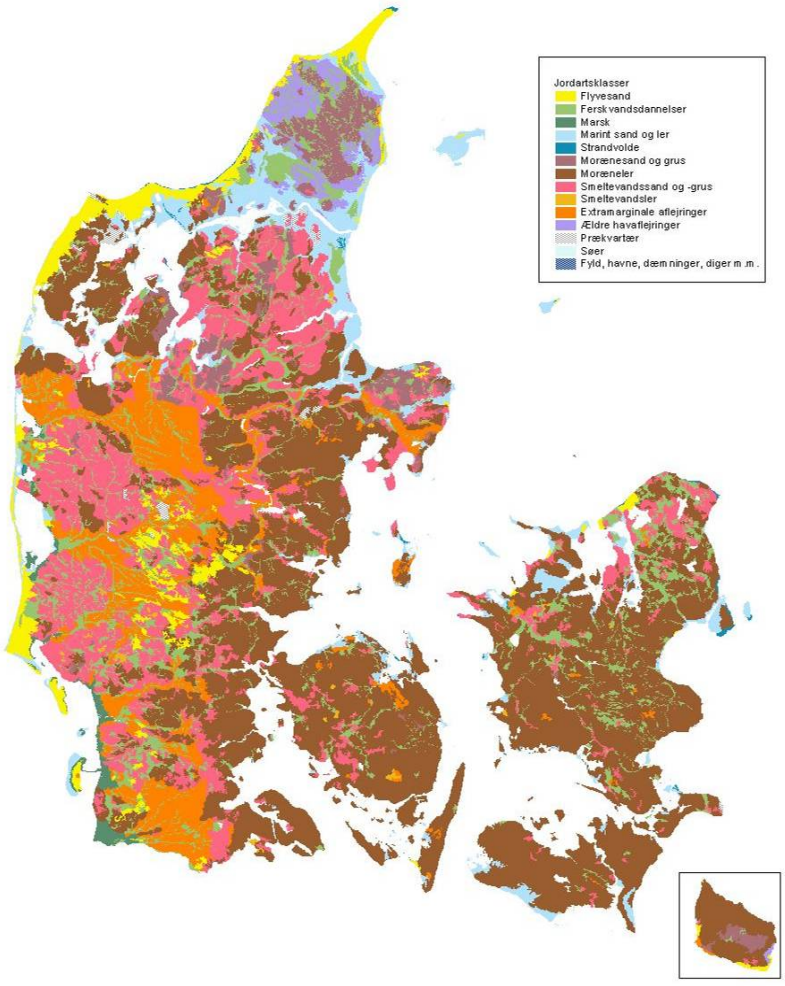


Figure 87. The map of the Quaternary surface deposits. Original scale: 1:200.000. Legend: Brown: Clayey till, light brown: Sandy till, red: Meltwater sand and gravel, orange: Sandur sand and gravel, purple: Late glacial marine deposits, light blue: Holocene marine deposits. Green: Holocene freshwater deposits, yellow: Aeolian sand (From Pedersen, 1989).

9.6 Tectonics, structures and seismic activity

9.6.1 Major tectonic structures

No major fault line have been registered and mapped in the Hindsgavl-Fænø area. The Geological basic data map of the area demonstrates the positions of the Oligocene and Eocene deposits (Fig. 88). Further towards the southeast, outside the area, a 175 m deep valley in the pre-Quaternary deposits exists around Gamborg Fjord. It has been suggested that a local doming in the area has exposed Late Oligocene deposits.

The area is now sinking approx. 1 mm pr. year according to deep tectonic movements.

Figure 88. Part of the Geological Basic Data map 1213 II Fredericia showing borehole data from Hindsgavl, Fyn. Original Scale 1:50.000. Only data from one borehole were available on Fænø when the map was produced. Legend: See fig. 10 (From Grambo-Rasmussen, 1995).

9.6.2 Fractures

The Paleocene and Eocene clays often contain fractures and some small faults or fractures. The clayey tills are always cut by fractures but the conditions on Hindsgavl and Fænø are not investigated because of lack of field localities.

9.6.3 Geological and structural model

The geological and structural model of the area is fairly simple with five major units (Fig. 89).

A. Quaternary tills and meltwater deposits, up to 18 m thick, but often thinner: Sandy, gravelly clayey till dominates.
B. Oligocene clay and sand from the Vejle Fjord Formation, Brejning Member, 18 m thick.
C. Eocene plastic clays from the Søvind Marl, Lillebælt Clay, Røsnæs Clay and Ølst Formations. Together at least 90 m thick.
D. Kerteminde Marl Formation, at least 40 m thick. Silty and fine-grained olive grey plastic clay.
E. Danian bryozoan limestone, at least 6 m thick.

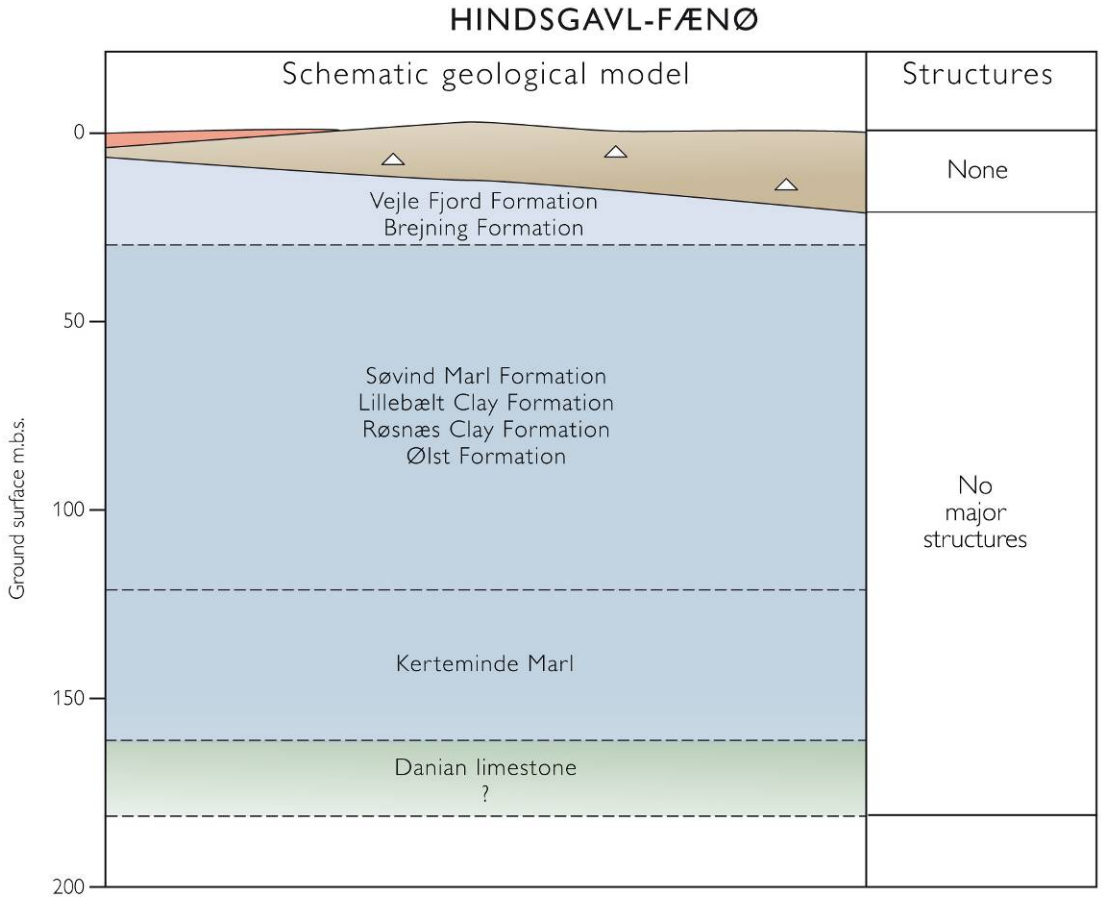


Figure 89. Schematic geological model of the area.

9.6.4 Earthquake activity

The seismic activity in the Hindsgavl-Fænø area and the near surrounding areas is very low (Fig. 90). 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.

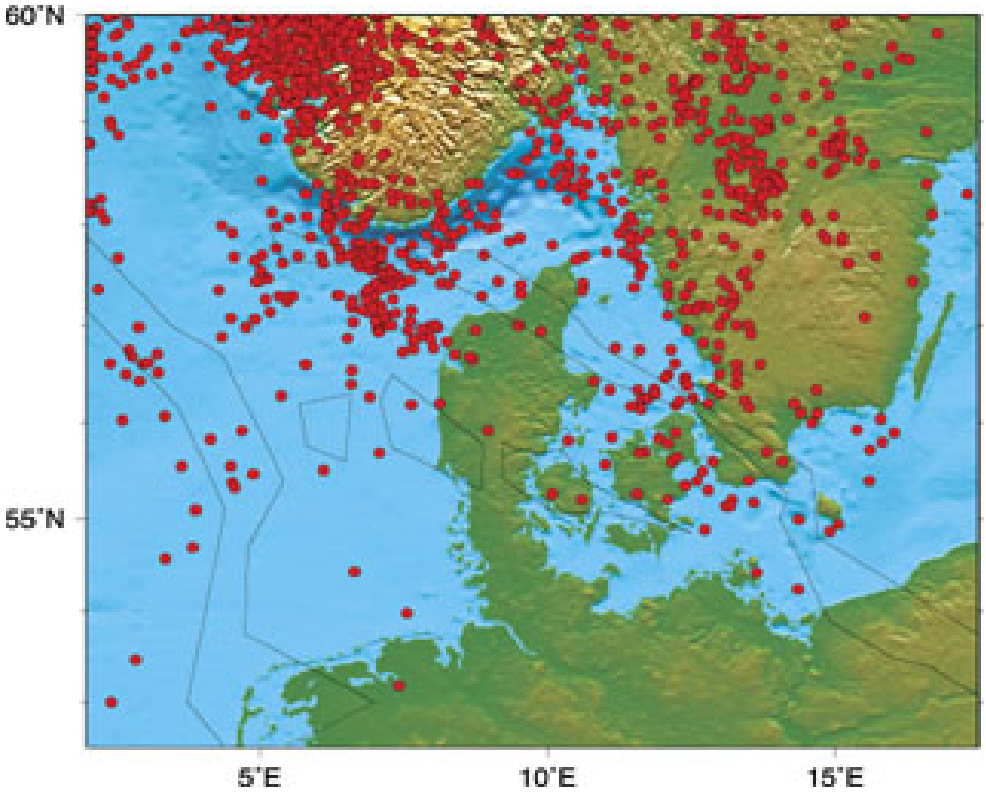


Figure 90. Map of epicentres from earthquakes in the Danish and surrounding area. (From GEUS´s Home page).

9.7 Ground stability

The area is expected to have good ground stability. Nevertheless, it is always important to remember that constructions established on and in fine-grained and plastic clays can give problems. This is caused by fractures in the clays.

9.8 Groundwater hydrogeology

9.8.1 Groundwater characteristics

The Quaternary and Palaeogene sediments include approx. 150 m of clays without groundwater reservoir characteristics.

The island Fænø in Lillebælt and the peninsula Hindsgavl nearby Middelfart (Area 11) is positioned in an area that is characterized by the presence of the shallow groundwater body (DK1.12.1.1) (Fig. 91), that consists of meltwater sand deposits. Regional or deep groundwater bodies have not been identified in or near Area 11 in the catchment management plan (Figs. 92 and 93). The subdivision into groundwater bodies is described as part of the basis analysis carried out by the former Fyns Amt (www.ode.mim.dk). The overall assessment of the chemical and quantitative status of the shallow groundwater body is poor, due to a poor qualitative status (see Section 9.9).

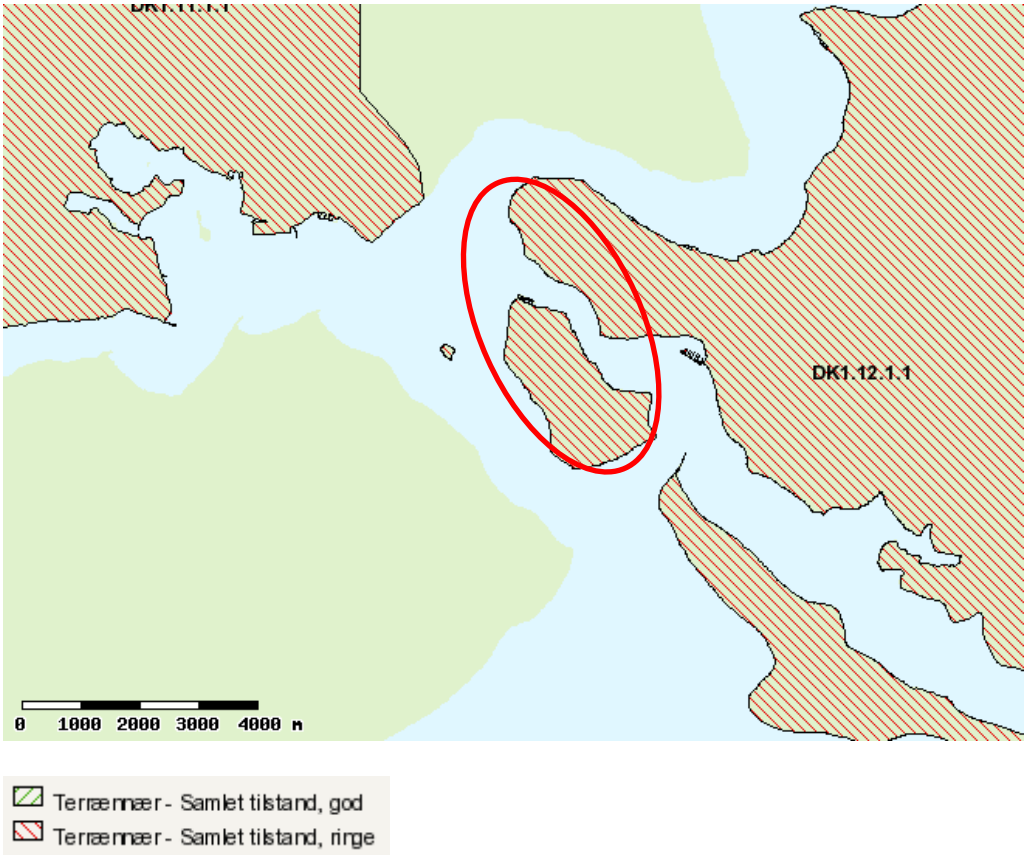


Figure 91. Shallow (or terrain near) groundwater body DK1.12.1.1 in the Fænø-Hindgavl area (Area 11). The overall assessment of chemical and quantitative status of shallow groundwater body: poor status (Red shaded area). (After the Ministry of Environment, 2010).

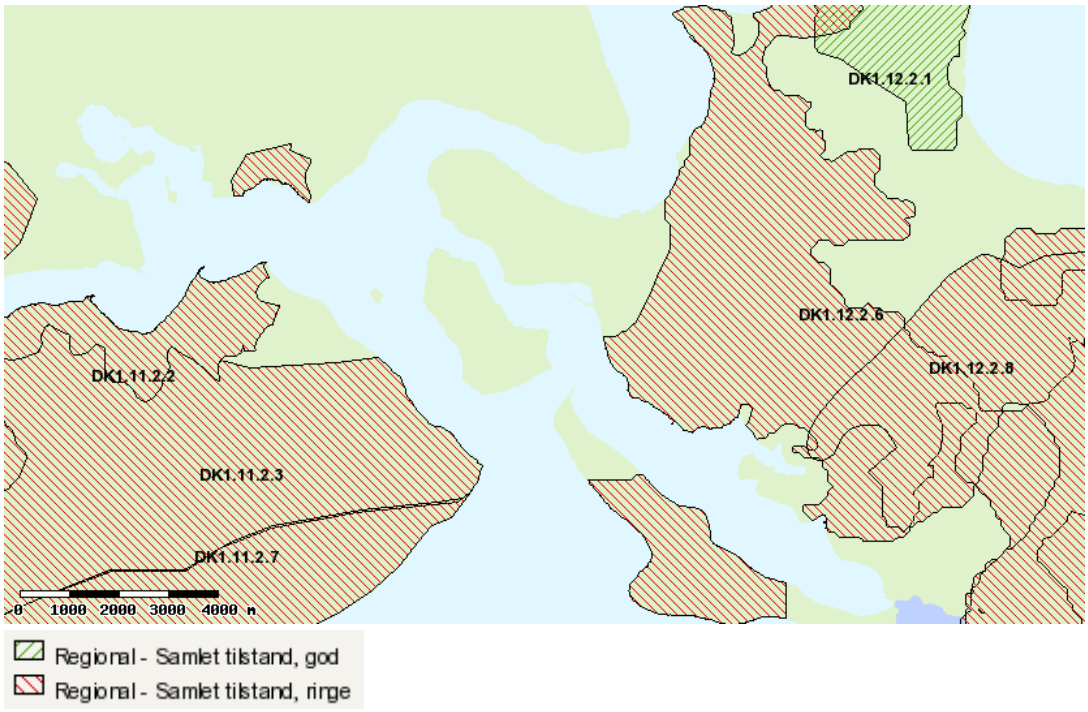


Figure 92. Regional groundwater bodies in the Lillebælt region, including the Fænø-Hindsgavl area (Area 11). (After Ministry of Environment, 2010).

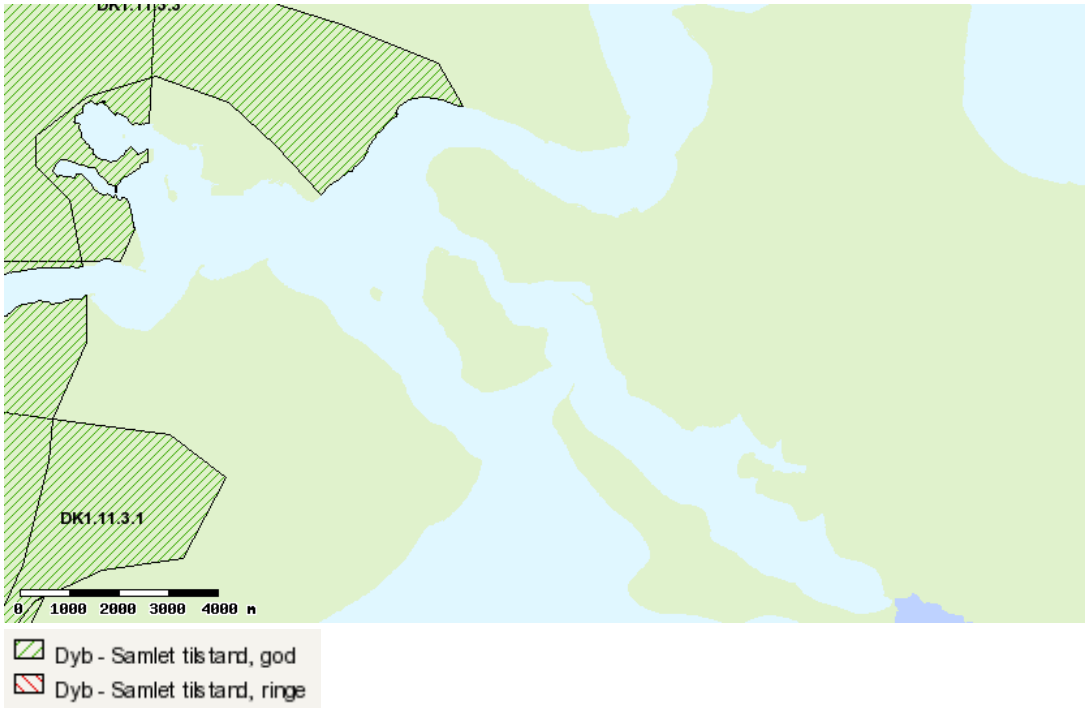


Figure 93. Deep groundwater bodies in Jylland west of Lillebælt (After Ministry of Environment, 2010).

9.8.2 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. 94).

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.

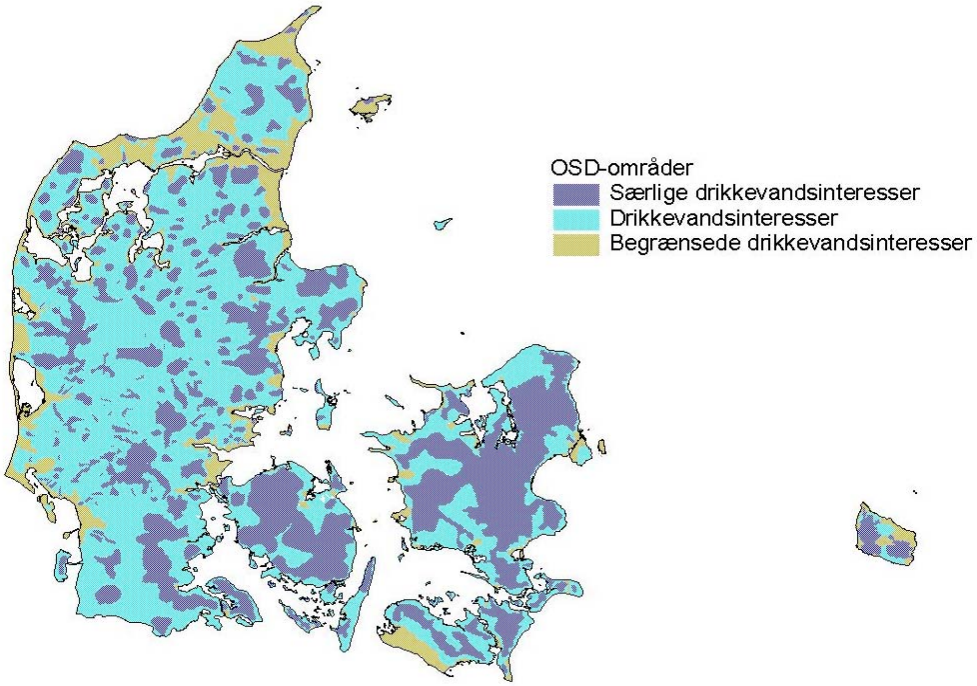


Figure 94. Areas of special drinking water interests (OSD): Dark blue and areas of drinking water interest (OD): Light blue. Areas with limited drinking interests are olive brown (http://kort.arealinfo.dk/)..

The drinking water areas categorised by the Environmental Centre Odense for the Fænø-Hindsgavl area is shown in Fig. 95. The island Fænø is located in an area with drinking water interests (OD). Fænø Gods (estate) has its own water supply, which is abstracting groundwater from few meter thick local sand layers at 20 to 30 meters depth. At the

Hindsgavl peninsula, the Environmental Centre Odense has assessed the drinking water interests to be limited or ignorable. The assessment is supported by the fact that no water supply wells are registered in the JUPITER database west of the Middelfart main road crossing the old Lillebælt Bridge.

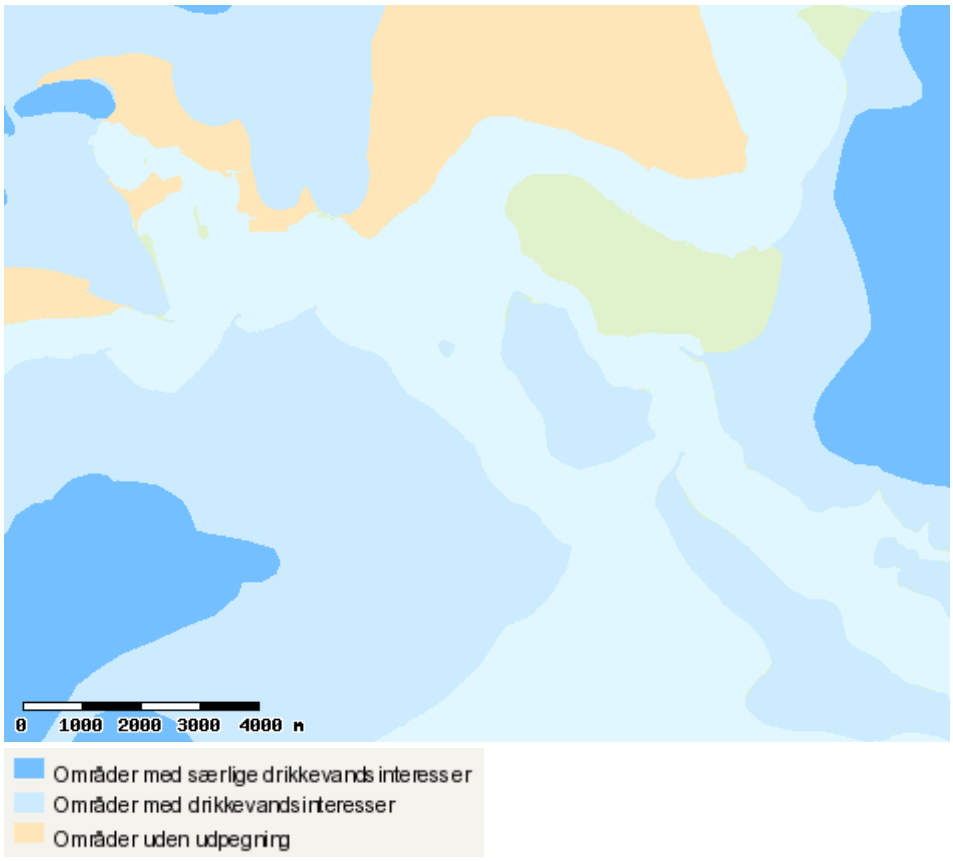


Figure 95. Various drinking water areas situated in the Kerteminde region. Dark Blue: Areas of special drinking water interests (OSD); Light blue: Areas of some drinking water interests (OD); Yellow/green: Areas with limited or none drinking water interests (http://kort.arealinfo.dk/).

9.9 Groundwater chemistry

The overall groundwater quality aiming for drinking water purpose has been assessed by the former Fyns Amt and Environmental Centre Odense for the shallow groundwater body (DK1.12.1.1) and reported in the catchment management plan “Hovedvandopland 1.14, Lillebælt/Fyn“ . Relevant groundwater chemistry in the abstraction wells belonging to Fænø Gods does not show indication of problems with salt water intrusion. Groundwater chemistry at the Hindsgavl peninsula is unknown.

9.10 Climate and climate changes

Hindsgavl and Fænø

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 this area seriously during this century. A sea level rise may cause minor, local flooding problems to the low-lying parts of the areas (the marine forelands) and some sections of the coasts will most probably be affected by erosion.

9.11 Restrictions and limitations

On Hindsgavl two sites with Areas of National Geological Interest are located at the Øksenrade Klint and at Hindsgavl Klint. The Fænø-Hindsgavl area has no restriction in accordance to the NATURA2000 regulation. An adjacent NATURA2000 habitat area is located southeast of Fænø (Fig. 96).

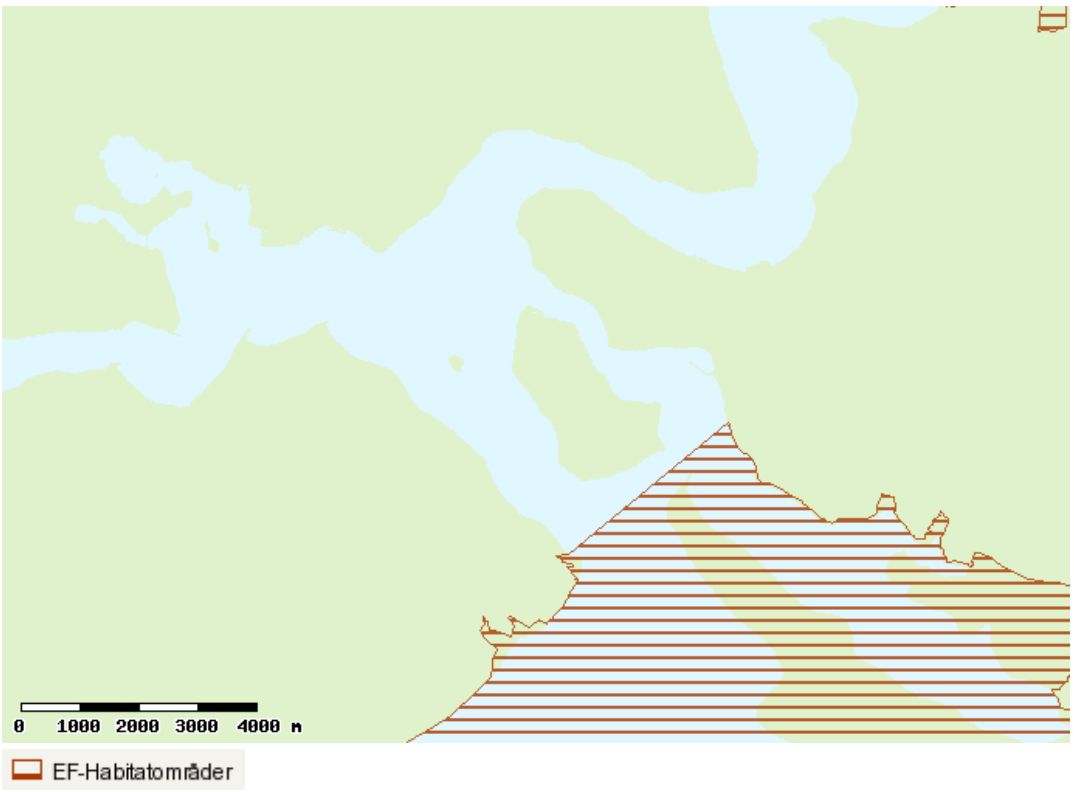


Figure 96. NATURA2000 habitat areas in the Lillebælt region (After Ministry of Environment, 2010).

9.12 Summary of the area 11 conditions

Amount of data:
Sparse. Few boreholes and no geophysical surveys

Homogeneous conditions and isolation of the waste by low, permeability layers:
Perhaps perfect at depth of 10-20 m but the framework of the fractures below 20 m is unknown. Probable fracture problem have to be considered in relation to other sites.

Stability
Good stability on surface and depth but plastic and fine-grained clays can give problems.

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

Groundwater 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
No OSD or OD areas within the Area 11, as the area is of limited 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. The low elevation of the landscape has to be considered in relation to future sea level rise.

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

Other restrictions
Apparently no other restrictions will give problems

9.13 Final remarks

Area 11 on Hindsgavl and Fænø is a possible area for a waste disposal. The area is not well documented. Boreholes indicate that relatively thick Paleogene clay deposits can be found on both Hindsgavl and Fænø.

10. 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.

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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.

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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.