DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2011/45

Low- and intermediate level radioactive waste from Risø, Denmark. Location studies for potential disposal areas. Report no. 5

Characterization and description of areas Falster and Lolland

Peter Gravesen, Bertel Nilsson,
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GEOLOGICAL SURVEY OF DENMARK AND GREENLAND
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GEUS

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G E U S

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, strong 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 potentially useful for a waste disposal. 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 ground surface down to 300 meters depth. Therefore, the possible geological situations include sediments and rocks of different composition and age. These situations are 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: Sandstone and shale 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 they 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: Quaternary glacial, interglacial and Holocene clay deposits. These sediments are distributed all over Denmark.

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 al. (2010, Report no. 1) briefly describes the existing data collections including databases, maps and models, which have been used during the work on selection 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 Falster and Lolland has to fulfil the criteria and aims described and put forward in Gravesen et al., (2010, Reports 1 and 2).

The areas chosen on Falster and Lolland, on the southern parts of the islands, only include Quaternary and Paleogene deposits. On the southern part of Falster and on the southern part of Lolland near Rødbyhavn, a thick sequence of fine-grained Paleogene clays occurs.

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

5. Area 3. Gedesby Nyby – Gedser, South Falster

5.1 The location of the area

Falster is situated south of Sjælland in the Baltic Sea. The area is located in the southern part of Falster, between Gedesby Nyby and Gedser.

Figure 1. Location of Area 3. Falster is located in the Baltic Sea south of Sjælland.

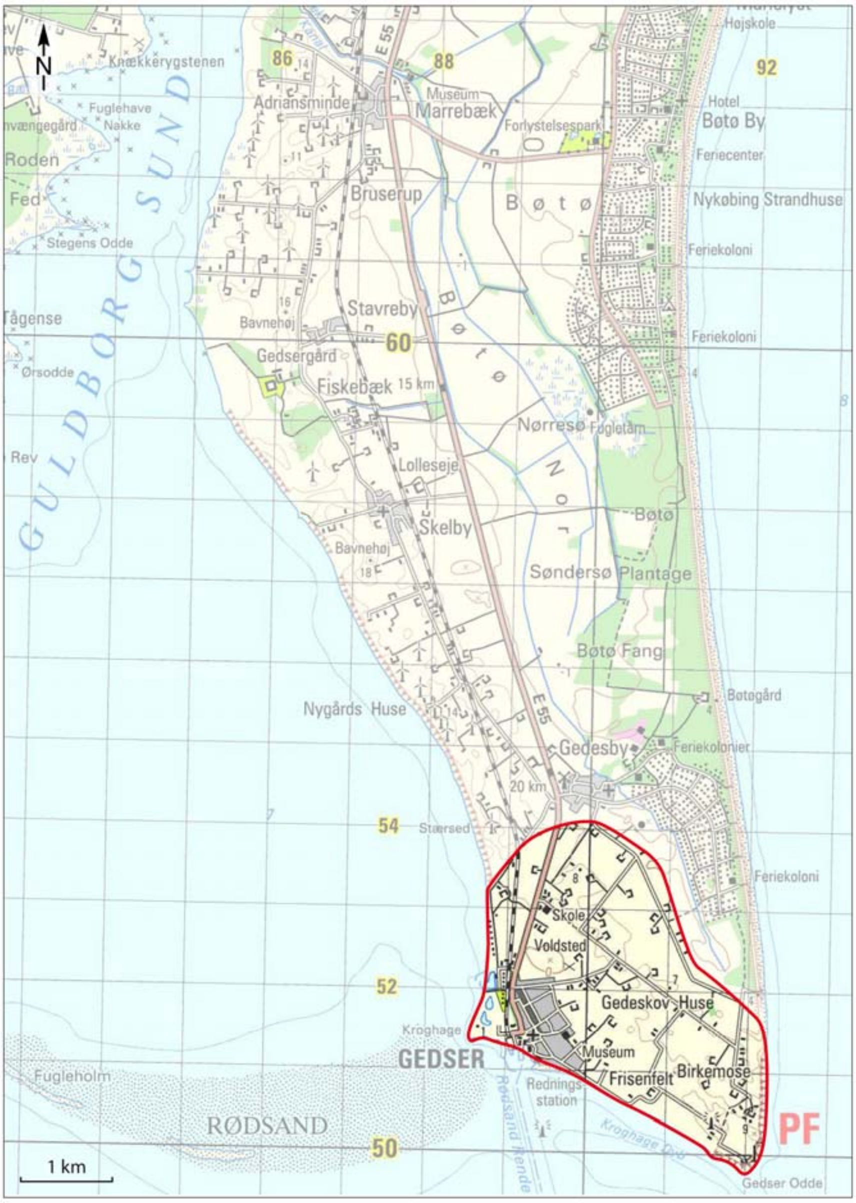


Figure 2. A detailed map of Area 3. Area 3 is located on the southernmost part of Falster.

5.2 Terrain, topography and surface processes

The area is located on a young end moraine at the southernmost part of Falster. The size of the area is c. 9 km^2. The overall impression of the landscape is a very flat terrain, almost without undulations. Most of the area is very low-lying, located between only 1 and 5 meters above present sea level (m.a.s.). The highest points are 8 and 9 m.a.s. found in the northern and south-eastern part of the area, respectively. Towards the east, south and west, the delineation of the area follows the coastline. The east and south-eastern section of the coastline is under erosion and protected by groynes. Gedser Lighthouse is located in the south-eastern corner of the area. The southwest facing coast has a narrow sandy/gravelly beach in front of a low, locally erosive escarpment. Gedser harbour is located in the western part of this coastal section. The harbour is protected against coastal erosion. Toward the west, the coast is characterised by a marine foreland with small lagoons and – toward north – a marina is found.

The south-western part of the area is dominated by the town Gedser, the harbour, a main road and a railway. The remaining and predominant part of the area is used for agriculture with scattered houses and crossed by several smaller roads. Except from the lagoons, the area holds no lakes or streams.

Owing to the low relief and the relatively intensive cultivation, the surface processes (soil creep, frost – thaw processes, soil development etc.) proceed slowly and undramatic. The by far most dynamic processes are found in the coastal zone: about half of the coastline of the area is marked by erosion.

Figure 3. The area seen from the east. Several buildings are recognized.

Figure 4. The area seen from the west.

Figure 5. The area seen from the south.

5.3 Surface geology and profiles

The surface geology consists mainly of clayey till but just outside the area, the tills are bordered by marine Holocene deposits towards east and southwest. Shallow cliff sections occur at Gedser Odde and Skelby and they are mainly build up of glacial deposits (Fig.6).

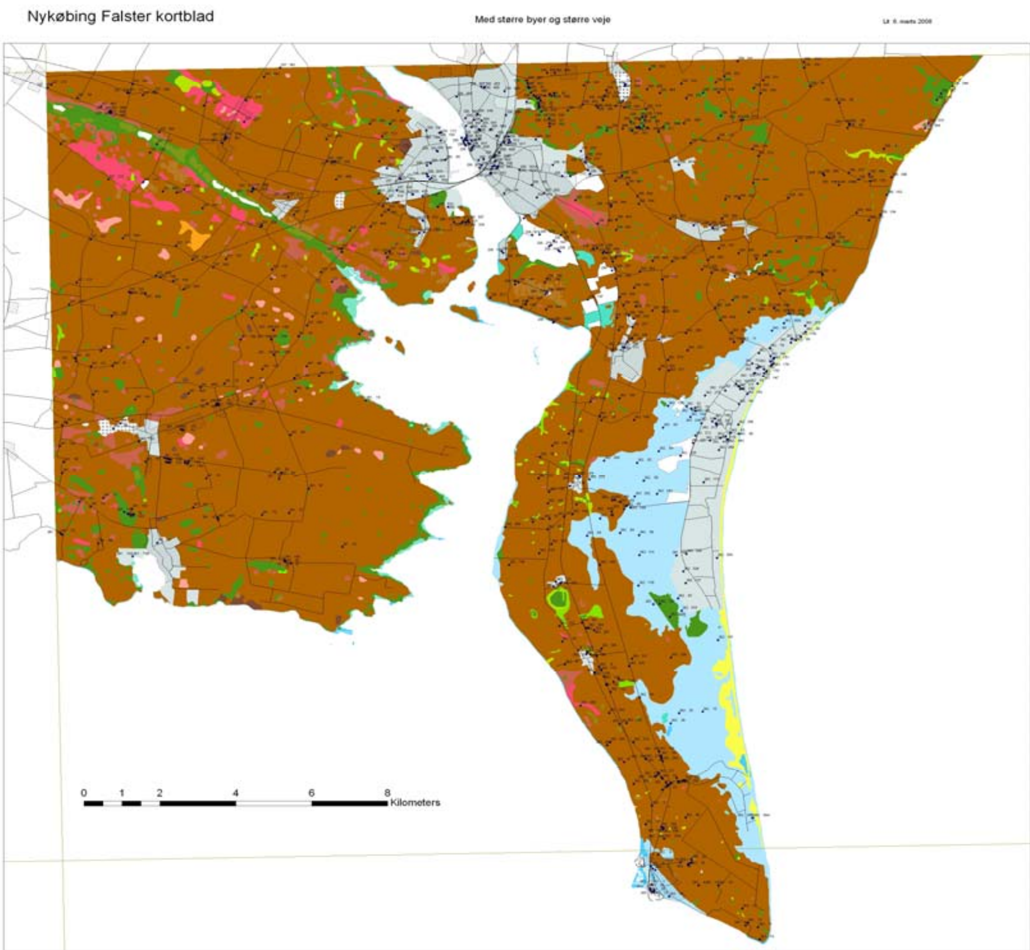


Figure 6. Map of the Quaternary surface deposits. Original scale 1:50.000. Legend: Brown: Clayey till, Red: Meltwater sand and gravel, Blue: Holocene marine deposits, Green: Holocene freshwater deposits, Yellow: Holocene Aeolian deposits (After Klint & Rasmussen, in press.).

5.4 Boreholes and geophysical surveys

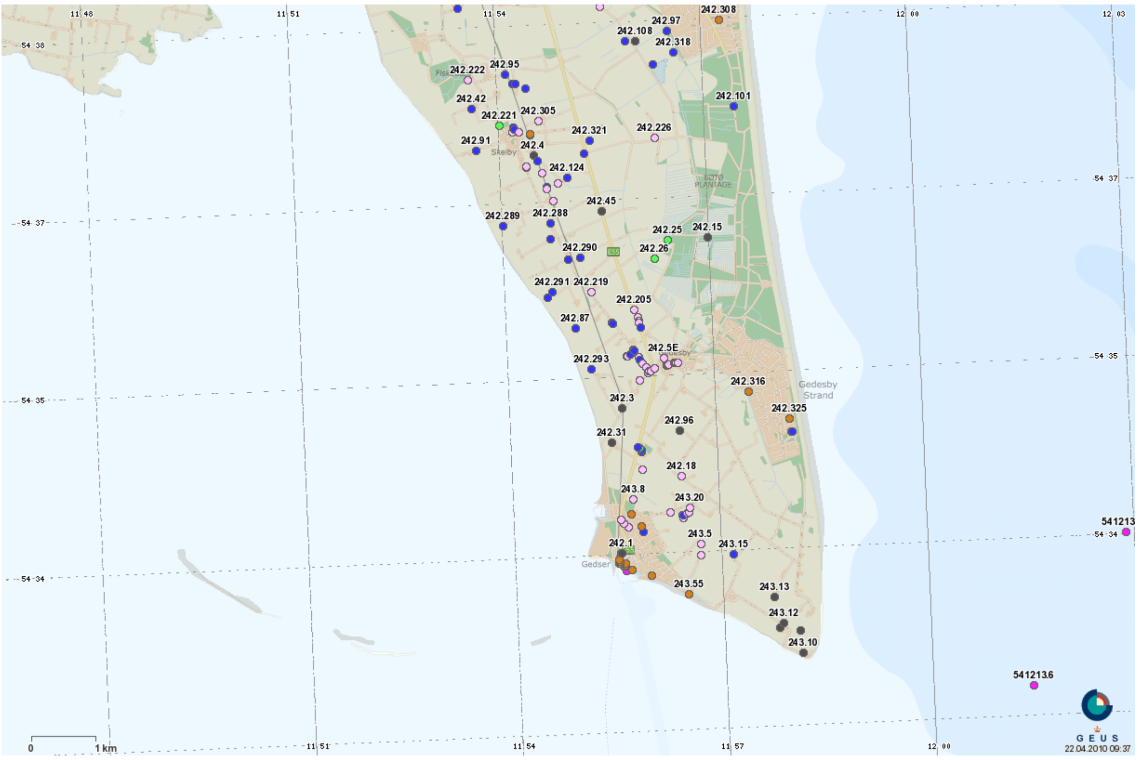


Figure 7. Map of the locations of boreholes from the Jupiter Database at GEUS. Legend: 242. 31: DGU no., Blue dot: Water supply well, Red dot: Geotechnical borehole, Pink dot: Raw material borehole, Green dot: Other borehole, Light red dot: Abandoned borehole, Black dot: Unknown purpose.

Relatively few boreholes are known from the area but these will be used to describe the geological build up of the area (Figs. 7, 8, 9). The main target is Paleogene plastic clays but only five boreholes reach the Paleogene clays in the area. Outside the area, three more boreholes reach the plastic clay.

Geophysical surveys immediately north of the area have been performed for the County of Storstrøm. The methods used were seismic and geoelectrical surveys. Also regional seismic surveys have been performed for the County (see Fig. 20).

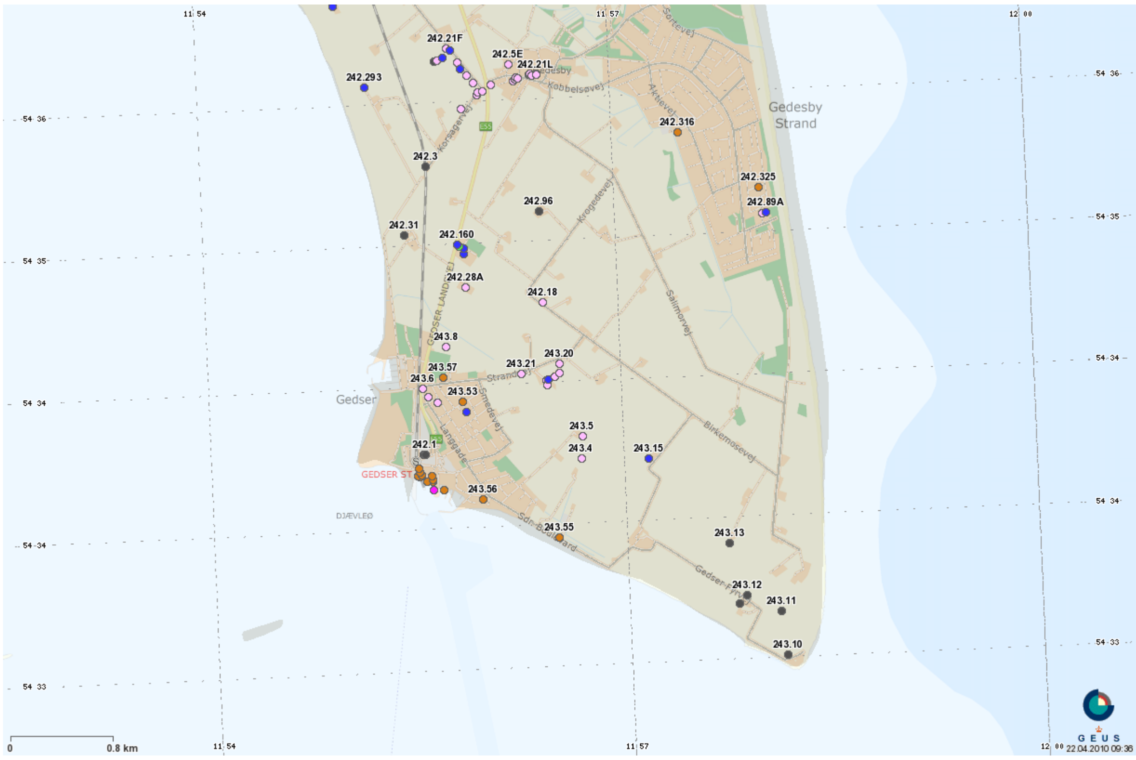
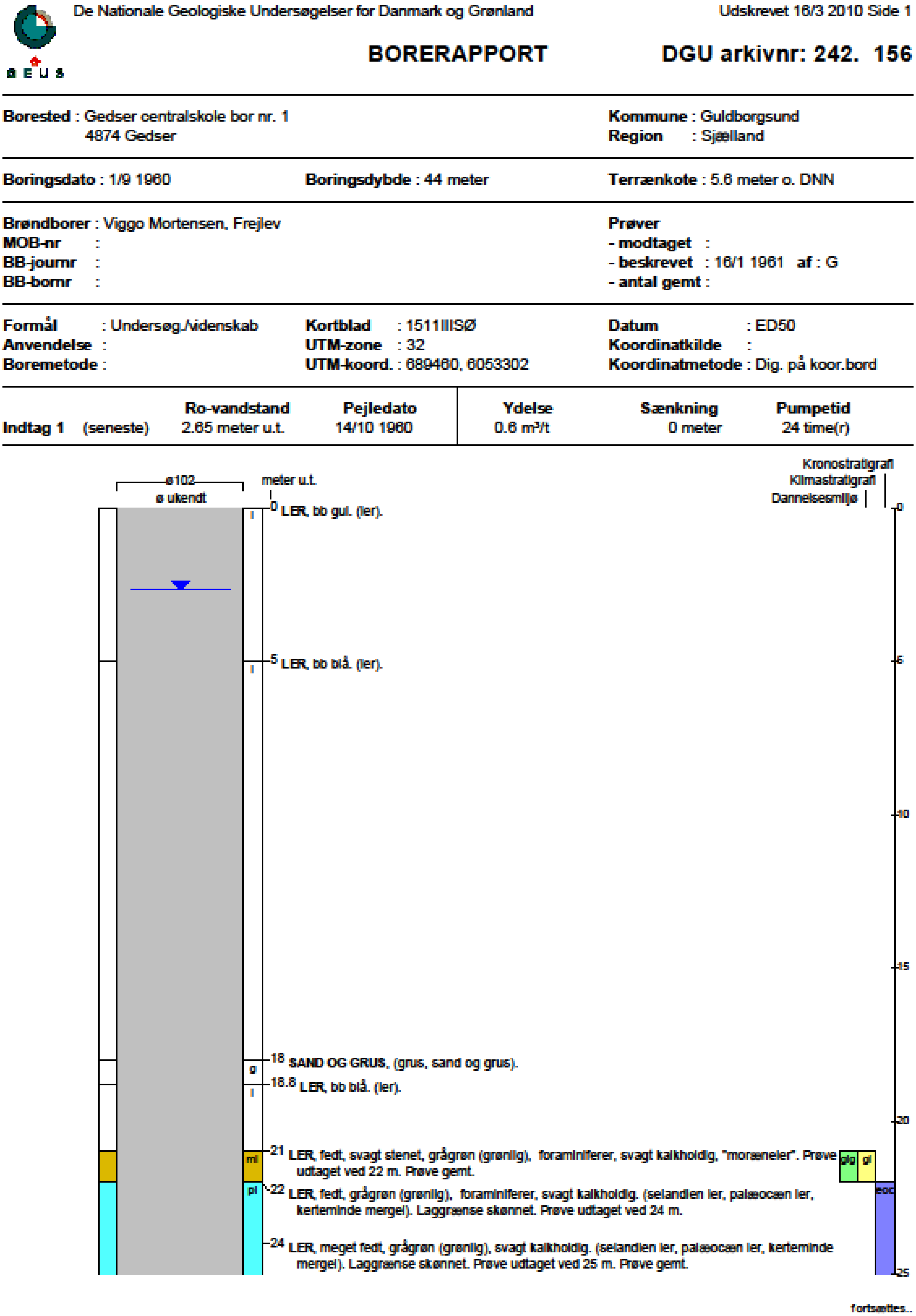


Figure 8. Location of boreholes in the area. (From GEUS Jupiter Well Database). Legend: See Fig. 7.



De Nationale Geologiske Undersøgelser for Danmark og Grønland

Udskrevet 16/3 2010 Side 1

BORERAPPORT

DGU arkivnr: 242. 156

Borested : Gedser centralskole bor nr. 1
4874 Gedser

Kommune : Guldborgsund
Region : Sjælland

Boringsdato : 1/9 1960
Boringsdybde : 44 meter
Terrænkote : 5.6 meter o. DNN

Brøndborer : Viggo Mortensen, Frejlev
MOB-nr :
BB-journr :
BB-bornr :

Prøver
- modtaget :
- beskrevet : 16/1 1961 **af** : G
- antal gemt :

Formål : Undersøg./videnskab
Anvendelse :
Boremetode :

Kortblad : 1511IIISØ
UTM-zone : 32
UTM-koord. : 689460, 6053302

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

	Ro-vandstand	Pejledato	Ydelse	Sænkning	Pumpetid
Indtag 1 (seneste)	2.65 meter u.t.	14/10 1960	0.6 m³/t	0 meter	24 time(r)

Figure 9. Geological borehole log of DGU No. 242.156. Upper part of the 44 m deep borehole. Legend: Brown: clayey till, Blue: Paleocene Clay.

5.5 Sediment and rock characteristics, mineralogy and chemistry

5.5.1 Pre-Quaternary deposits

Information about the pre-Quaternary deposits is gained from a few boreholes but basic data are found in the map of the pre-Quaternary deposits (Fig. 10).

The pre-Quaternary sediments just below the Quaternary in the area consist of very fine-grained plastic grey green clay probably belonging to the Late Paleocene Holmehus Formation (Fig. 11). Several samples from boreholes, which are lithological described, can be related to the formation but only two samples from borehole DGU No. 242.156 have been dated. The clay is non-calcareous to slightly calcareous and a minor content of pyrite and glauconite occur. The thickness is approximately 28 m.

Below this formation, grey, non-calcareous clay, which is fine-grained to sandy occur with a high content of glauconite and minor content of pyrite. Silicified glauconitic layers are found in the clay. Occasionally, black clay layers are found and sandy dark olive grey claystone beds occur. It is assumed that these approximately 40 m thick layers belong to the Æbelø Formation. Below the clay formations, Maastrichtian limestone/chalk deposits are found.

Towards the south, the thickness seems to increase to c. 120 m (Fig. 12). The clay deposits are reached 15 - 40 m below ground surface (Fig. 13). They are covered by Quaternary deposits (Fig. 14). Geophysical surveys point to a level of the pre-Quaternary surface in approx. – 20 m.

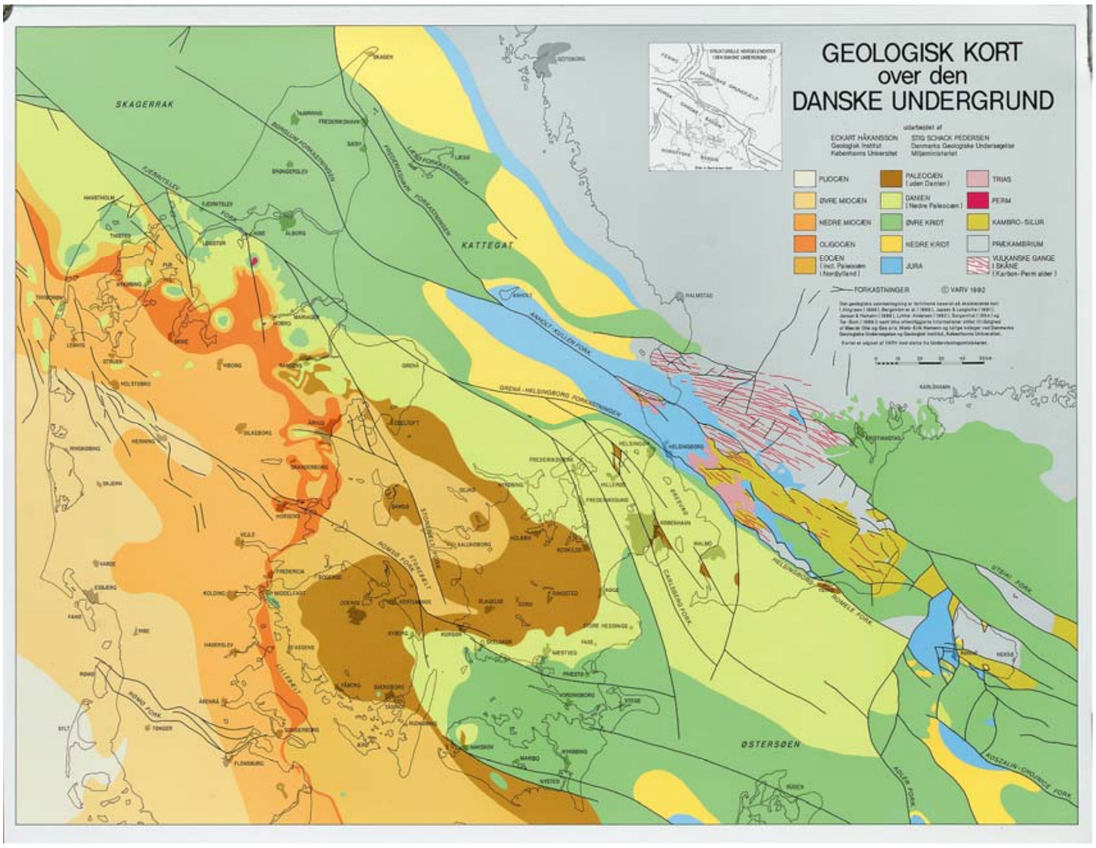


Figure 10. Map of the pre-Quaternary surface: Time units. Original scale: 1:50.000. Legend: Red lines: Precambrian intrusions, grey: Precambrian, olive: Cambrian-Silurian, red: Permian, light red: Triassic, blue: Jurassic, yellow: Lower Cretaceous, green: Upper Cretaceous, light green: Danian, brown: Paleocene, yellow olive: Eocene, red brown: Oligocene, light yellow brown: Lower Miocene, very light yellow brown: Upper Miocene, white: Pliocene (Håkansson & Pedersen, 1992).

Figure 11. Green plastic clay, probably the Eocene Lillebælt Clay Formation from Albæk Hoved Cliff, Jylland. The plastic clay is lithological comparable to the plastic clays from the Holmehus Formation.

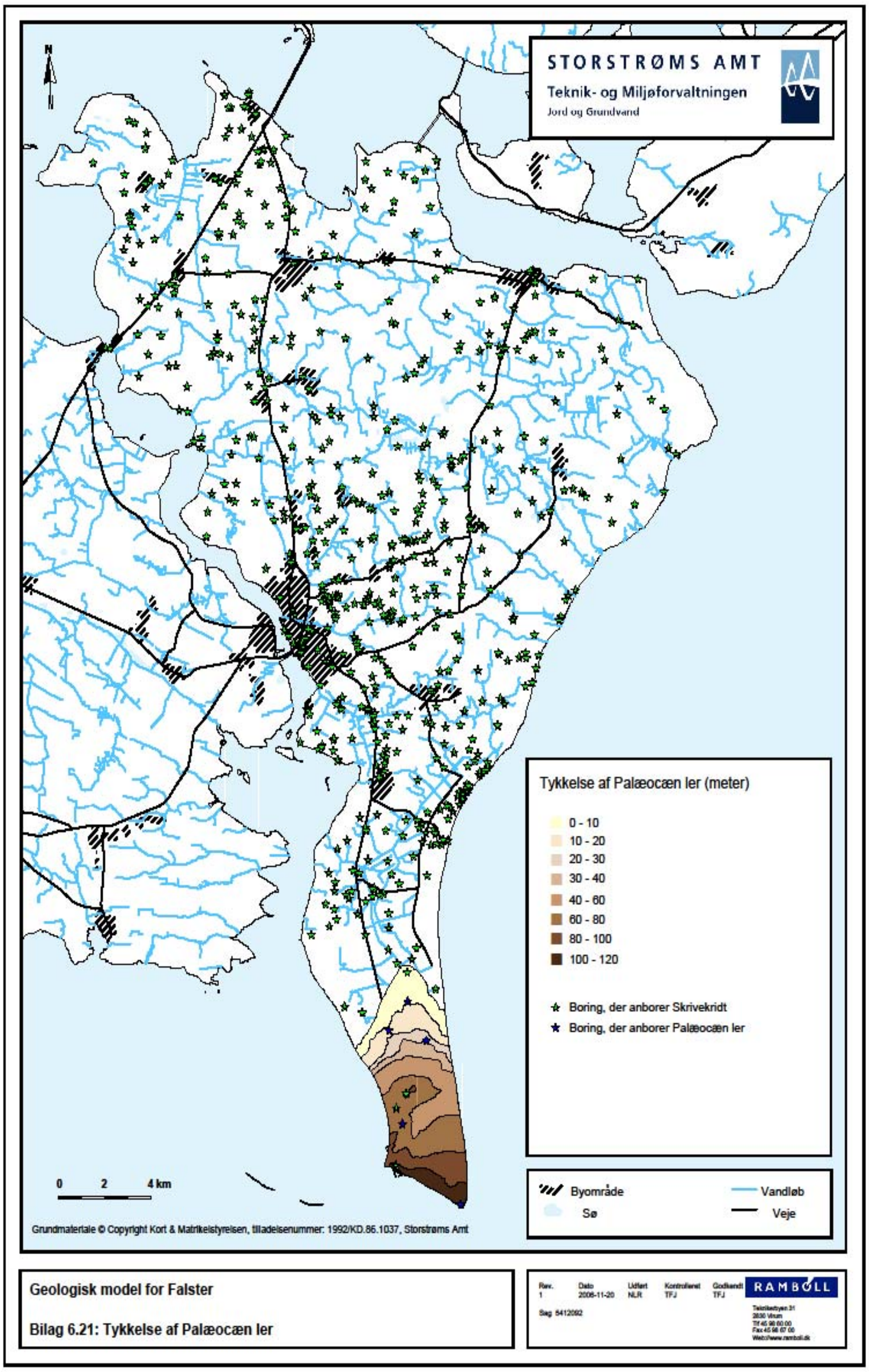


Figure 12. Map of the thickness of the Paleocene deposits. Legend: Green asterisk: Borehole in Chalk, Blue asterisk: Borehole in Paleocene clay. Contours: Yellow: Smallest thickness, dark brown: Largest thickness (From Rambøll, 2006).

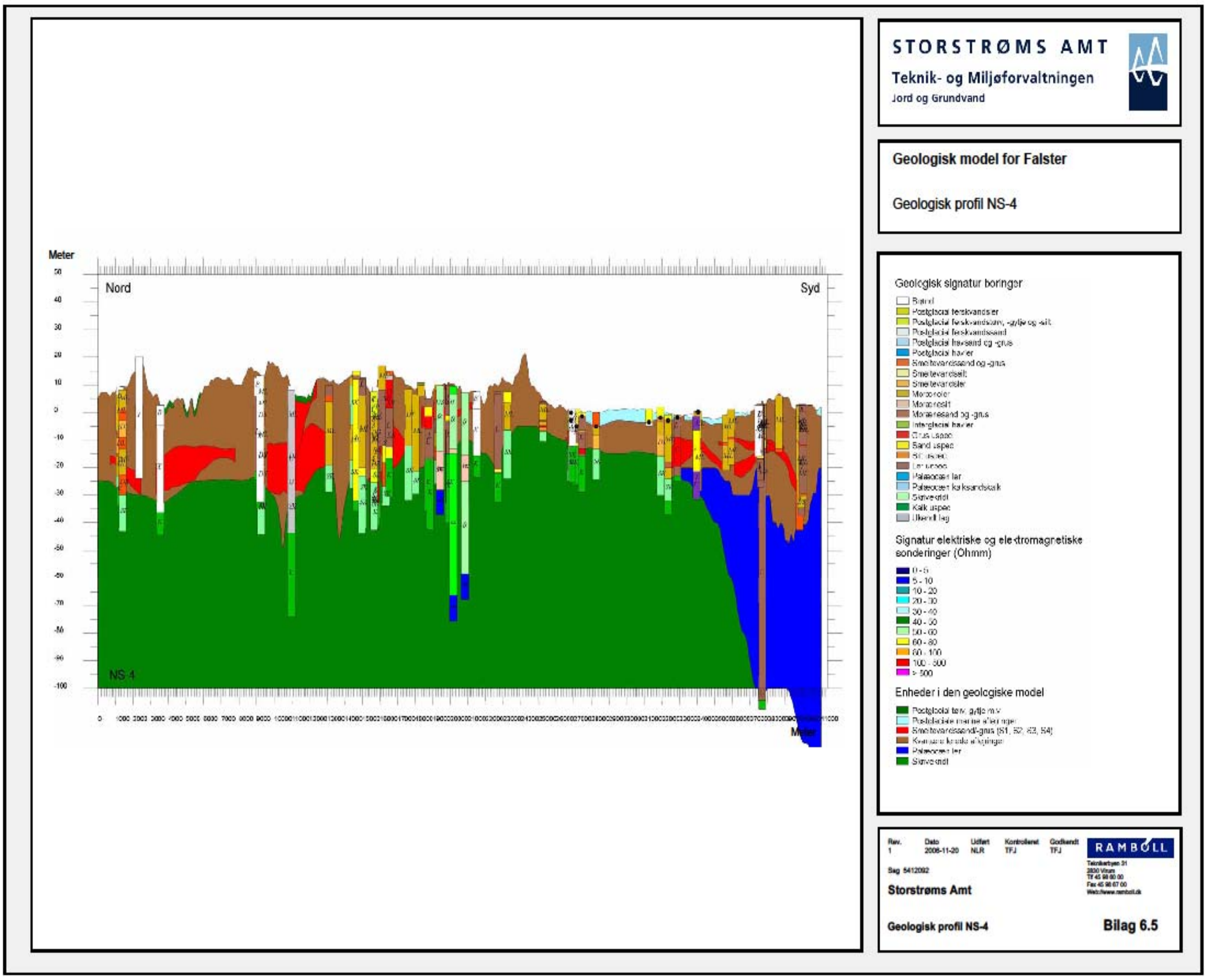


Figure 13. Geological section through the boreholes based on borehole data and some geophysical information. Legend: Green: Chalk, Blue: Paleocene clay, Brown: Clayey till, Red: Meltwater sand and gravel (From Rambøll, 2006).

5.5.2 Quaternary deposits

The Quaternary deposits are dominated by clayey till in the boreholes and the nearby shallow cliff sections (Gedser, Skelby)(Figs. 6 and 14). The clayey till is silty and sandy with scattered gravels and few stones. The thickness is between a few meters and 20 m (Fig. 15). Thin layers of meltwater sand with gravel (1-2 m) are intercalated in the clayey till. The marine Holocene deposits are relatively thin, but in the city of Gedser, approx. 5 m of marine sand is deposited.

The distribution of the sediments is guided by the geomorphologic units in the area (Fig. 16) with the Væggerløse Buen, the large north-south oriented ice border line with a concave bow towards the east where the marine Holocene sediments are deposited on a flat moraine plain. Marine sedimentation has also occurred on the southern west side of the border line.

Observations from field work in the area demonstrate till deposits from three glacier advances during the Weichselian and Saalian (?).

Weathering

The clayey till is suffering from redox processes within the upper 2-3 m. In the upper part, the colour of the till has changed from olive grey and grey to yellow brown due to oxidising of the iron minerals. Normally, the content of calcium carbonate is also lower in upper part than the lower part (Fig. 17).

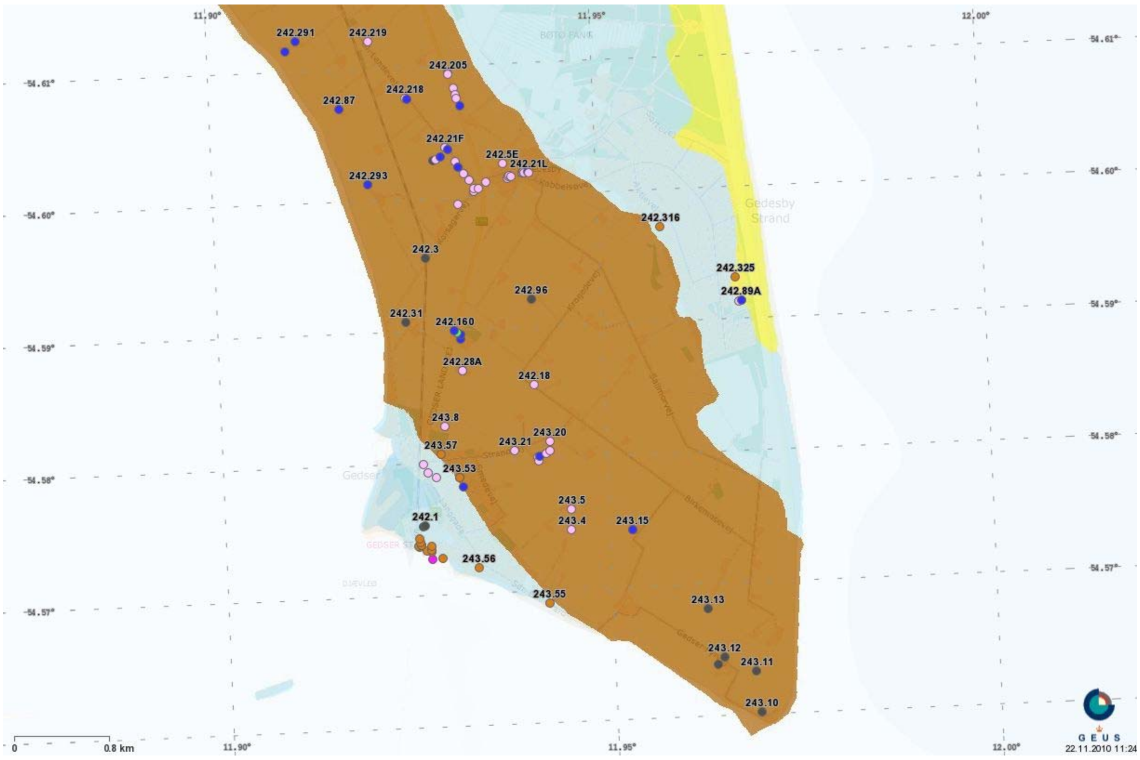


Figure 14. Map of the Quaternary deposits (From GEUS Homepage, after Pedersen, 1989). Legend: See fig. 6.

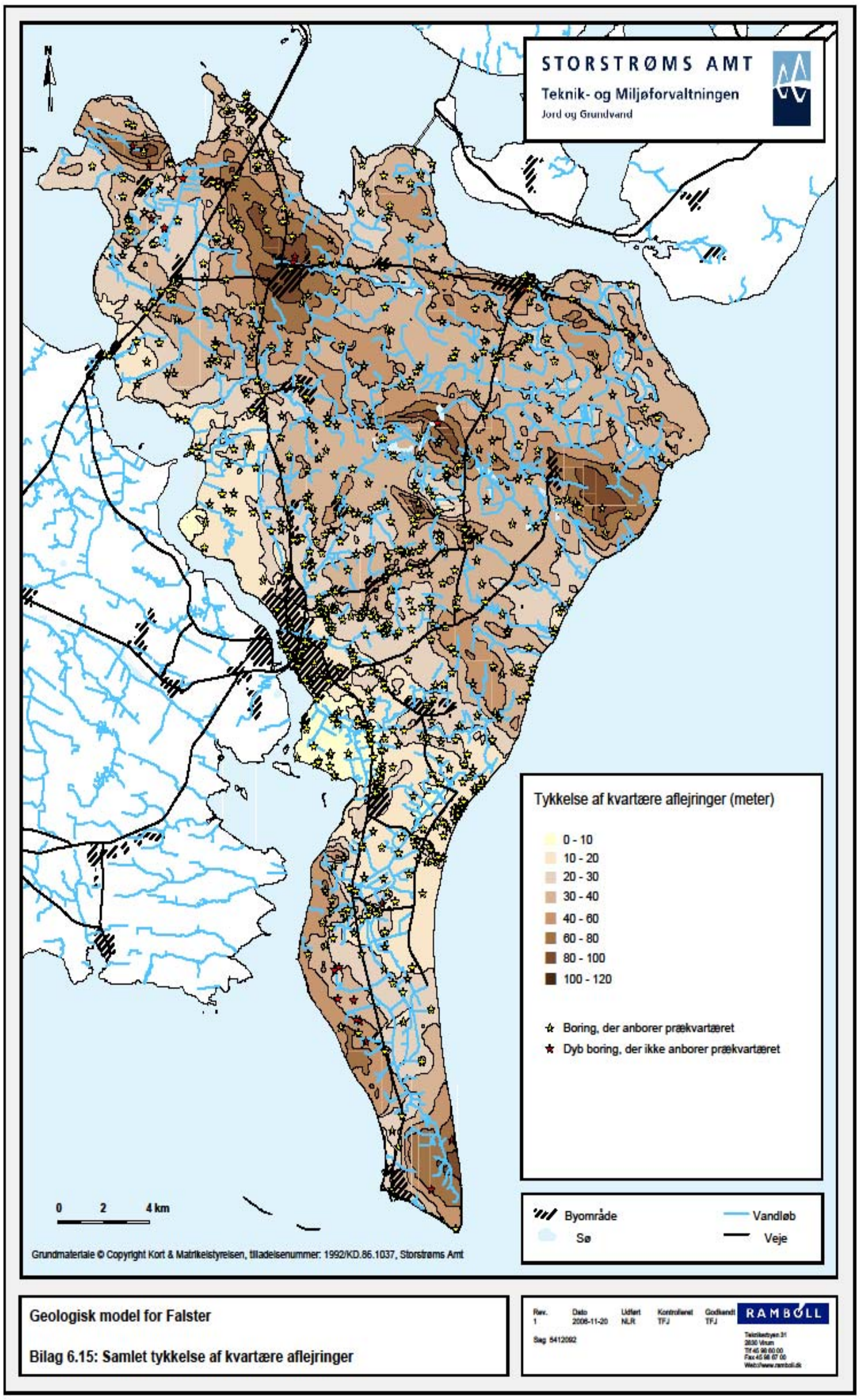


Figure 15. Thickness of the Quaternary deposits. Legend: Contours: Yellow: Smallest thickness, Dark Brown: Largest thickness (From Rambøll, 2006).

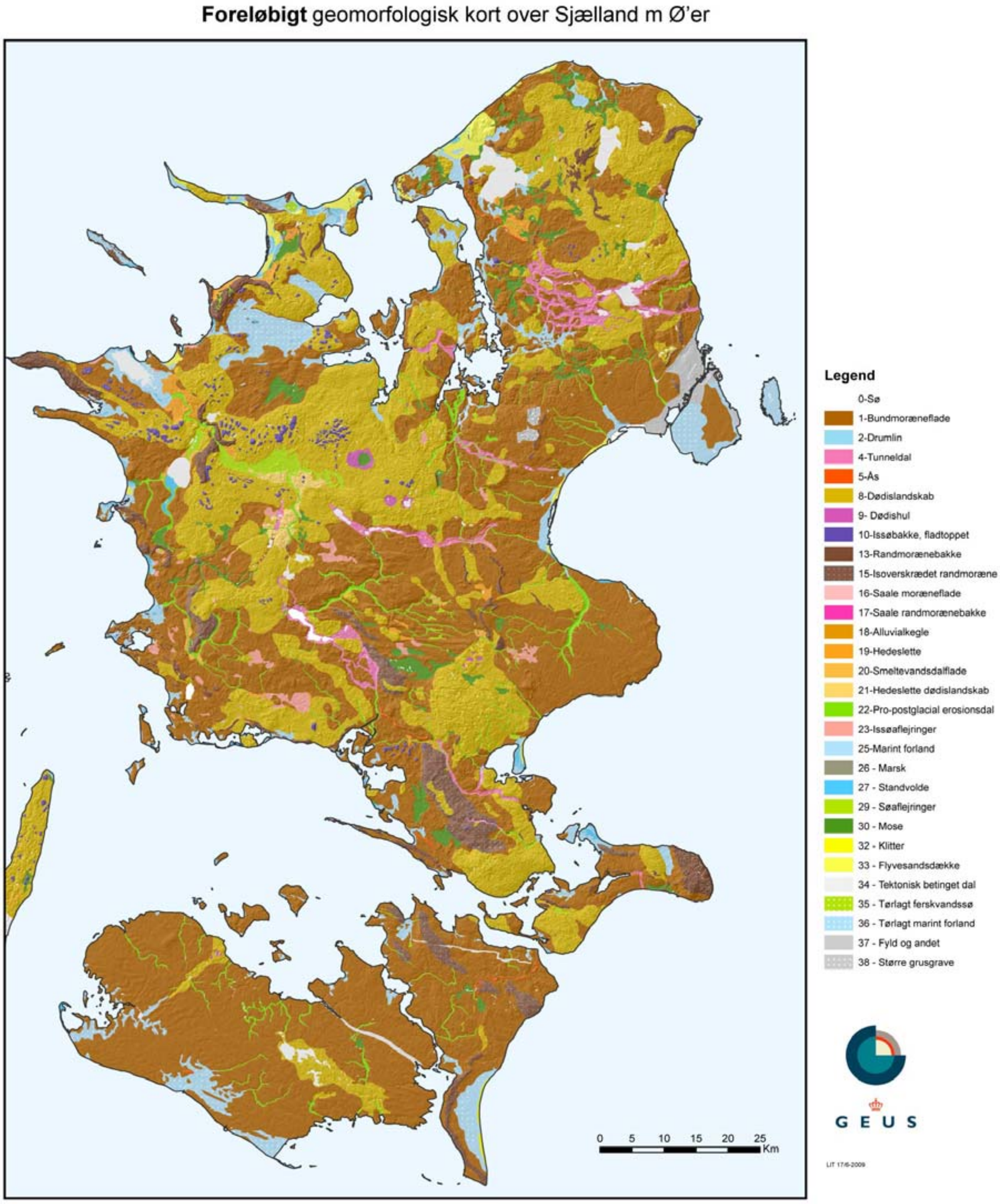
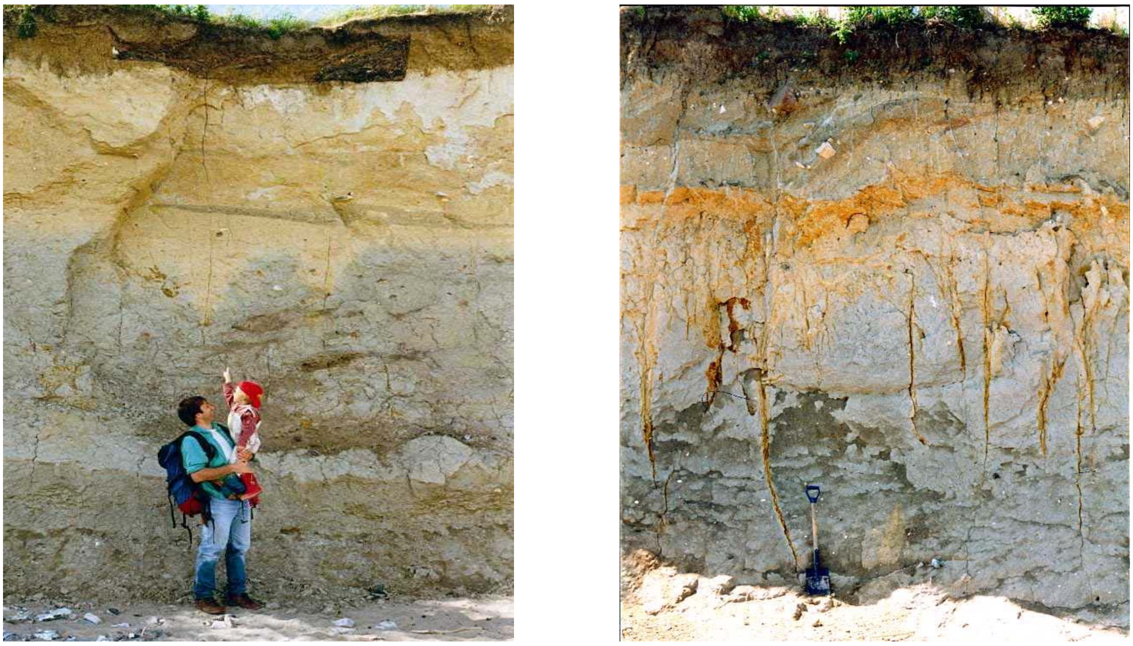


Figure 16. Geomorphologic map of eastern Denmark. Legend of main units: Brown: Lodgement till plains, Olive brown: Dead-ice landscape, Dark brown: Ice border landscape, Light blue: Marine landscape, Yellow: Dunes (Jakobsen, in Press).



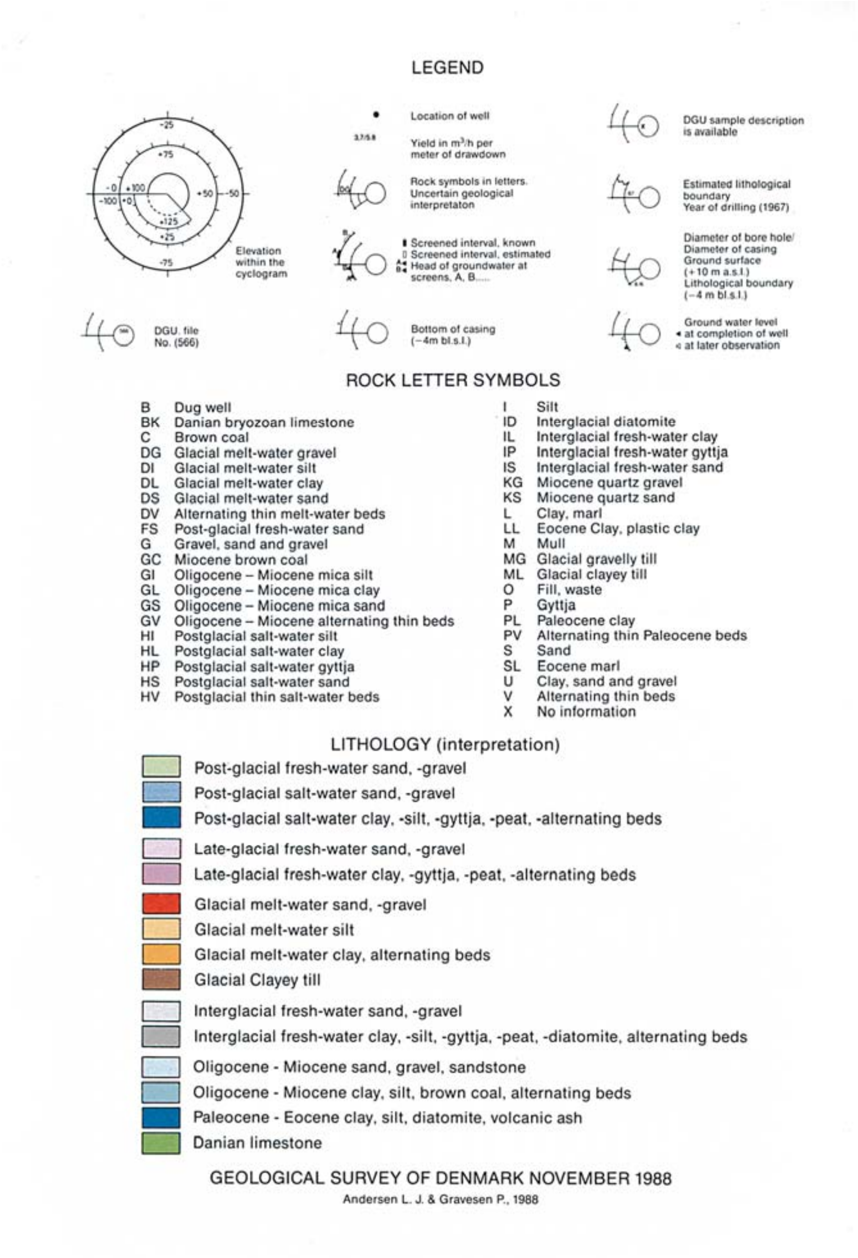
a b

Figure 17. Clayey till deposits from Gedser Odde Cliff. a. Variation in the redox boundary between the yellow brown oxidised upper till and the olive grey reduced lower till. b. Section with many fractures in the till. The redox boundary follows the fractures into the lower till (Photos: K.E.S. Klint).

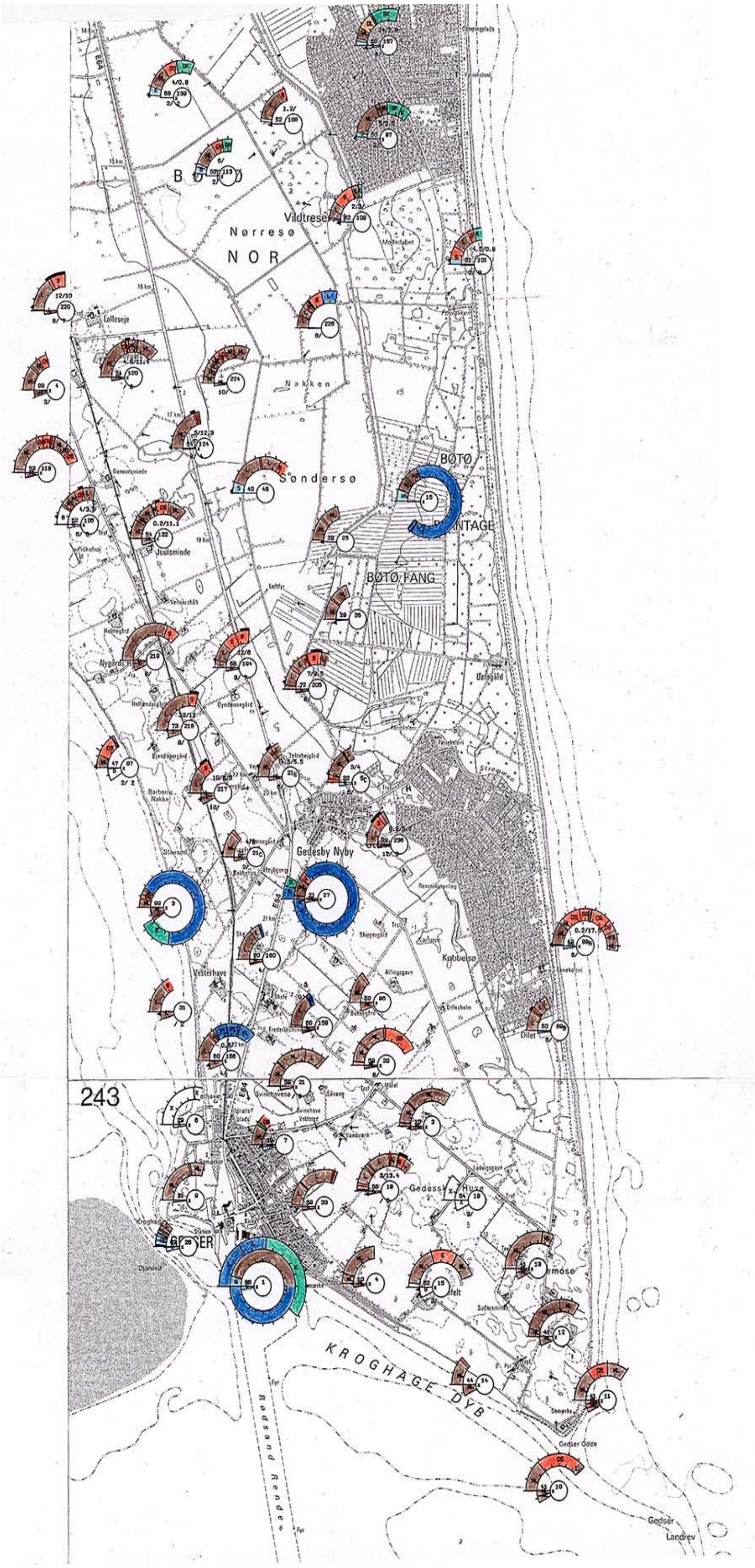
5.6 Tectonics, structures and seismic activity

5.6.1 Major tectonic structures

The pre-Quaternary deposits outside the area indicate that at Nørresø Nor, limestone deposits interpreted as Cretaceous chalk are met in 20 m depth. At Bøtø Plantage and Nakken, fine-grained Paleocene Holmehus Formation clays are found in approx. 20 m depths, at Gedesby Nyby 15-20 m and at Gedser Odde in approx. 50 m depth. The Cretaceous and Paleogene deposits are separated by a fault (Fig. 10, 19) documented indirectly by the missing Danian and Early Selandian deposits (Fig. 18). The map (Fig. 19) shows many mapped faults crossing the subsurface. Most of the faults are mapped in relation to top Cretaceous. In relation to southern Falster, apparently fault lines occur between Gedser and Gedser Nyby with a direction WNW-ESE, a line which also is indicated by the borehole data. Other fault lines are situated at the Cretaceous-Paleogene boundary or close to this boundary. The area has been uplifted and the Danian limestone and Selandian Greensand and calcareous clay sediments have either been eroded during early Paleocene before deposition of the Æbelø and Holmehus Formations or the area has been land without any sedimentation. The variation in elevation of the pre-Quaternary surface is probably erosional and that the deposits are found in situ as also indicated by shallow geophysical surveys. The thickness is increasing towards the south, either because of basin conditions or fault activities. The salt diapirs at Rødby and Søllested are so far away that movements in these have not affected the deposits (Fig. 19). Deeper fault lines have crossed southern Falster as e.g. at the base of the Cretaceous (Fig. 20).



a.



b.

Figure 18. Geological Basic Data Map with borehole data and indication of the pre-Quaternary geology. a. Legend to the map b. Map of the southern part of Falster.

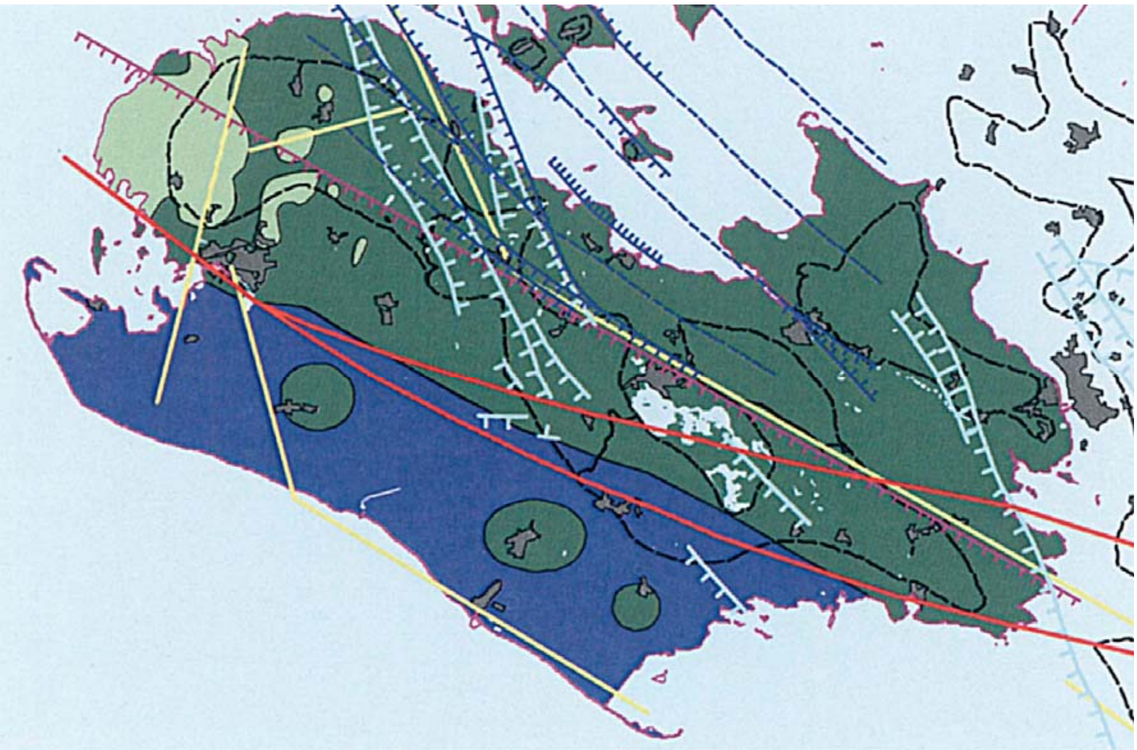


Figure 19. Structural map of Lolland. The map shows the continuation of the fault lines from Lolland to Falster although the orientations of the faults seems different in fig. 20. Legend: Dark Green: Chalk, Light Green: Danian Limestone, Blue: Paleogene clay, Yellow, red and blue lines: faults (From Rambøll, 2006).

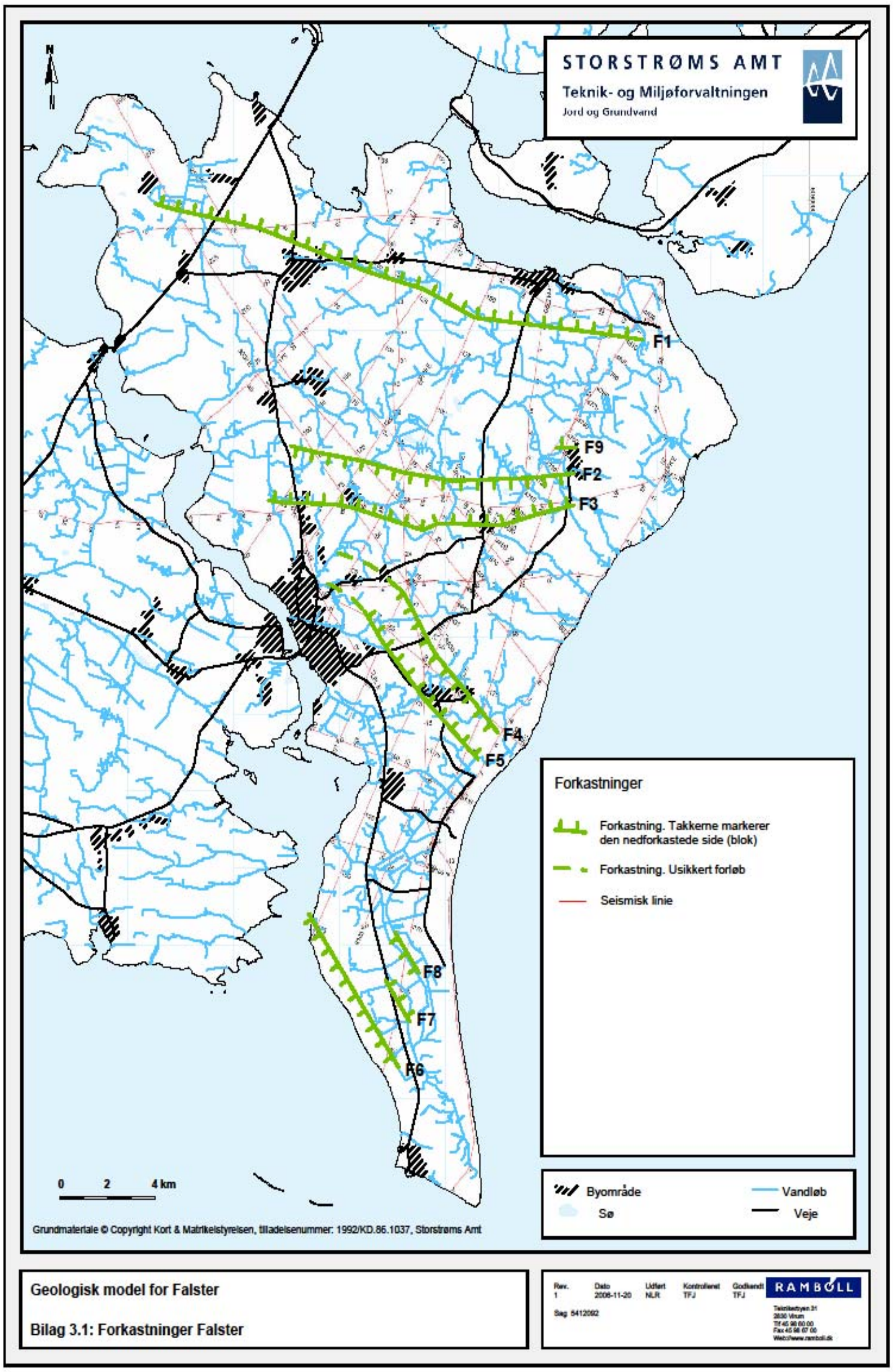


Figure 20. Map showing the location of deep seated fault lines. Legend: Green lines: Faults, Thin red lines: Seismic lines (From Rambøll, 2006).

Field investigations at Gedser Odde and Skelby have shown that at 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 border line “Væggerløse Buen”, which can be followed from north to south on Falster. The Poly-morphological map of Falster demonstrates the relationship between superimposed Quaternary landscapes (Fig. 21). Two types occur in the area: Moraine plain above ice border line deposits and moraine plain above meltwater sand and gravel.

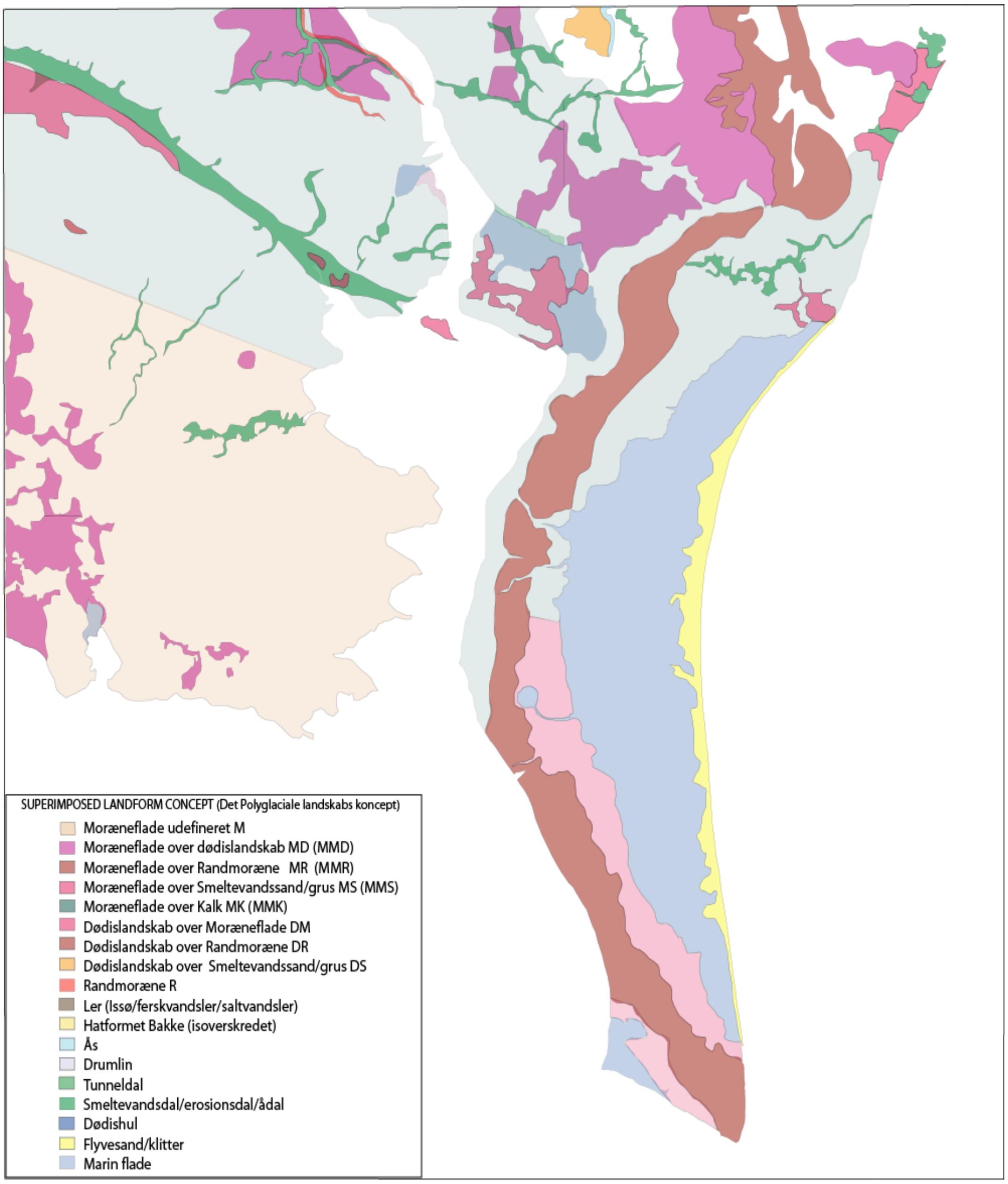


Figure 21. Poly-geomorphologic map of Falster. Legend for area 3: Brown: Moraine plain above ice border deposits, Light red: Moraine plain above meltwater sand and gravel (From Klint & Rasmussen, in press.).

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.
Fractures in the fine-grained Tertiary clays are expected.

5.6.3 Geological model

The geological and structural model of the area is rather simple in relation to lithology but complex in relation to the structural conditions.
Model of the area is as follows:

A. Quaternary Clayey till 2-20 m thick. The tillmay be glaciotectonic displaced.

B. Paleocene sticky clay from the Holmehus Formation, up to 28 m thick.

C. Paleocene fine-grained and sandy grey clay from the Æbelø Formation, up to 60 m thick.

D. Limestone/chalk probably from the Maastrichtian.

The schematic model is shown in Fig. 22.

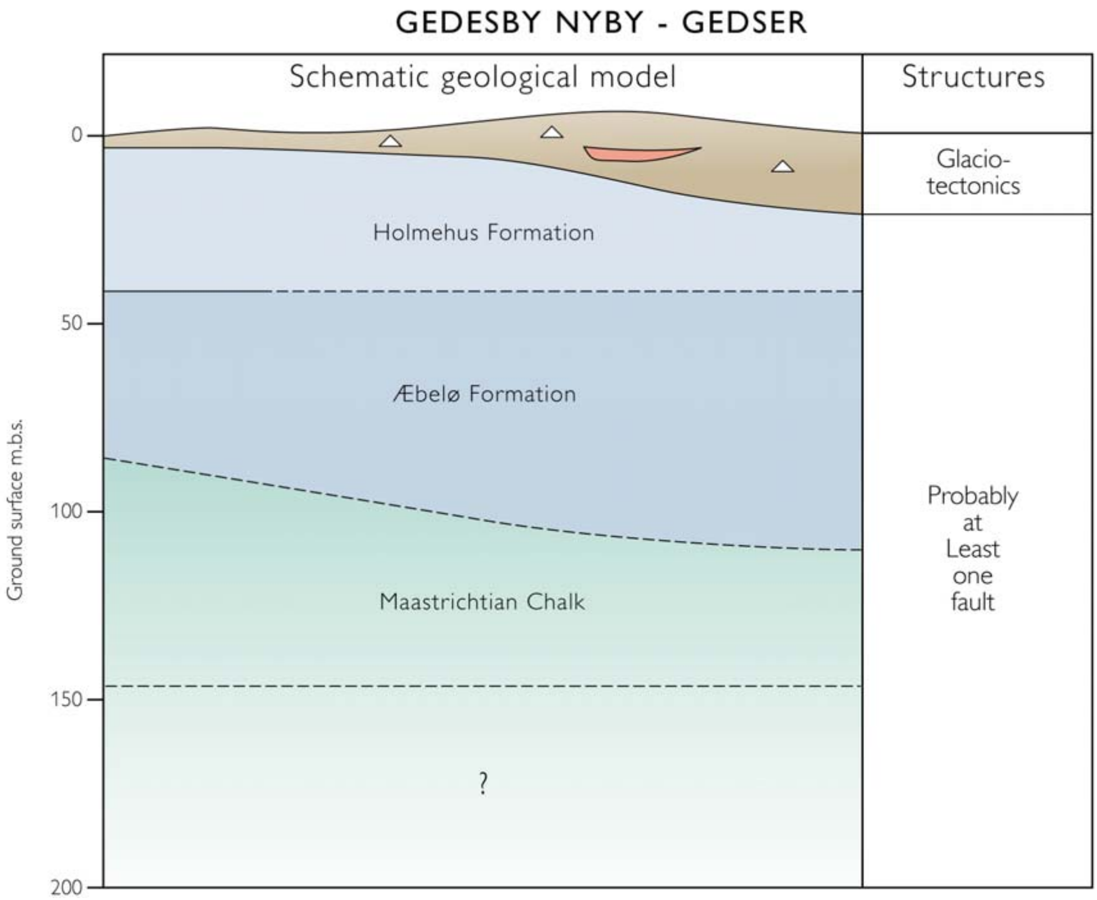


Figure 22. Schematic model of the geological conditions of Area 4.

5.6.4 Earthquake activity

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

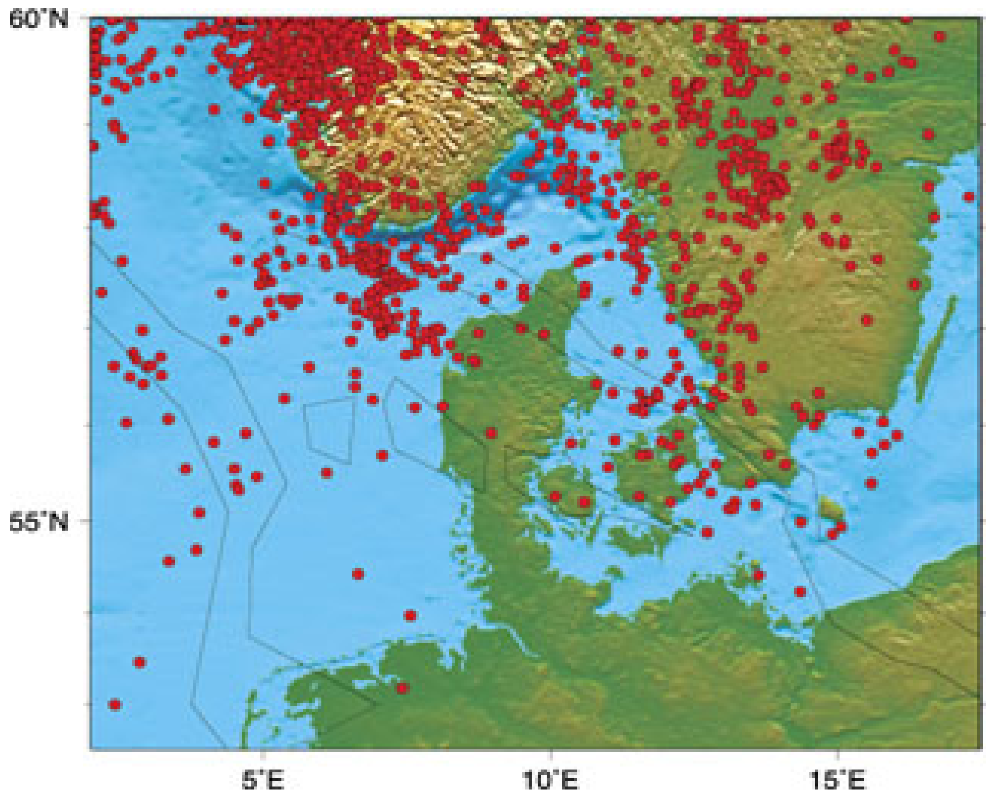


Figure 23. Map of the seismic activities in Denmark and the surroundings. Red dots show earthquake epicentres (From www.geus.dk).

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

Subdivision of the Lolland-Falster region in shallow, regional and deep groundwater bodies are shown Figs. 24, 25 and 26. The subdivision is described as part of the basis analysis carried out by the former Storstrøms County. The Gedesby Nyby – Gedser area (Area 3) is shown in red circle in Fig. 24. No shallow groundwater body is situated inside the circled area. However, both regional and deep groundwater bodies are found close to that area. The overall assessment of the chemical and quantitative status of the regional groundwater body (DK2.5.2.17) is poor, due to a poor quantitative status. In other words, it is not possible to abstract enough amounts of groundwater from the regional groundwater aquifers in Area 3. The deep groundwater body DK2.5.3.4 is divided in minor groundwater aquifers within the circled area and all aquifers have a good status in terms of both chemical and quantitative conditions.

A hydrogeological investigation has been carried in the area north of Area 3 (Fig. 28). An interpreted geological section through the southern part of the investigation area demonstrates that clayey till and plastic clay are dominating (Fig. 28). Special attention should be given to the Gedesby Nyby water work that is situated north of Gedesby. The hydrogeological investigations recommend that the abstraction wells of Gedesby water work ought to be moved in northern direction, due to scarcity of groundwater.

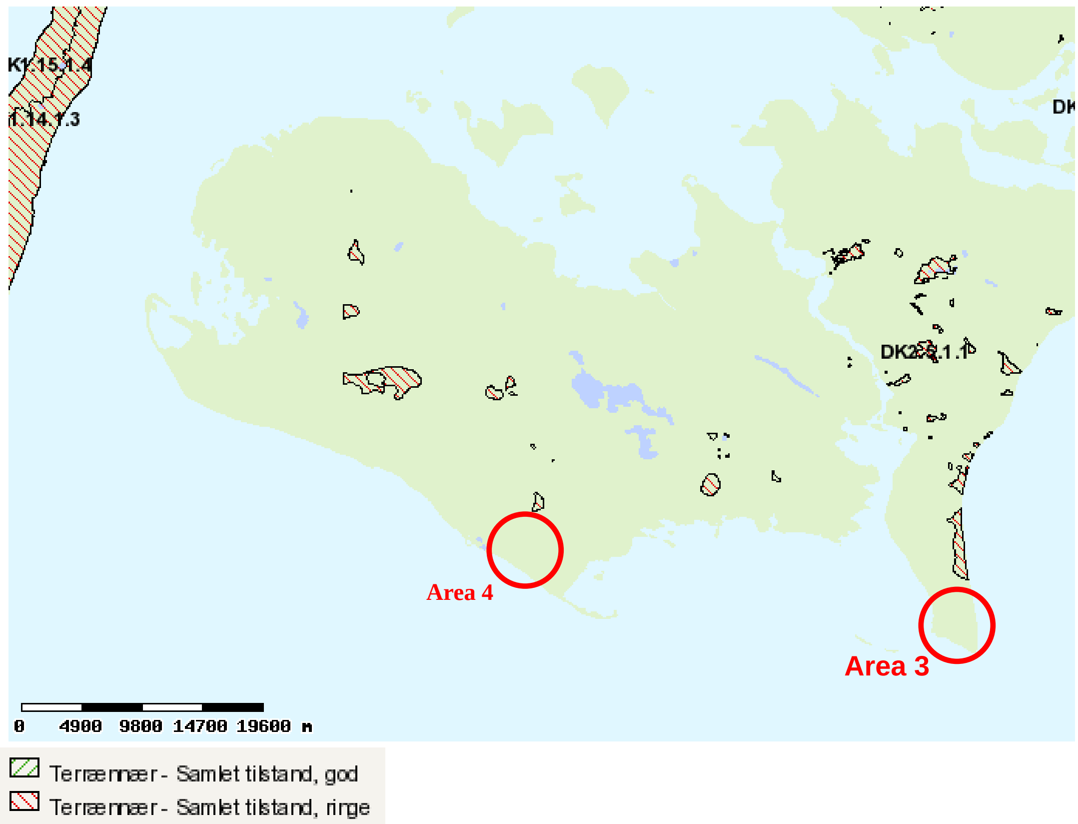


Figure 24. Shallow (or terrain near) groundwater bodies at Falster (Area 3) and Lolland (Area 4, see section 6.8). The overall assessment of chemical and quantitative status: poor status (Yellow shaded area). It has been assessed by the Environmental Centre that there are no drinking water interests in the shallow groundwater bodies (From Miljøstyrelsen, 2010a).

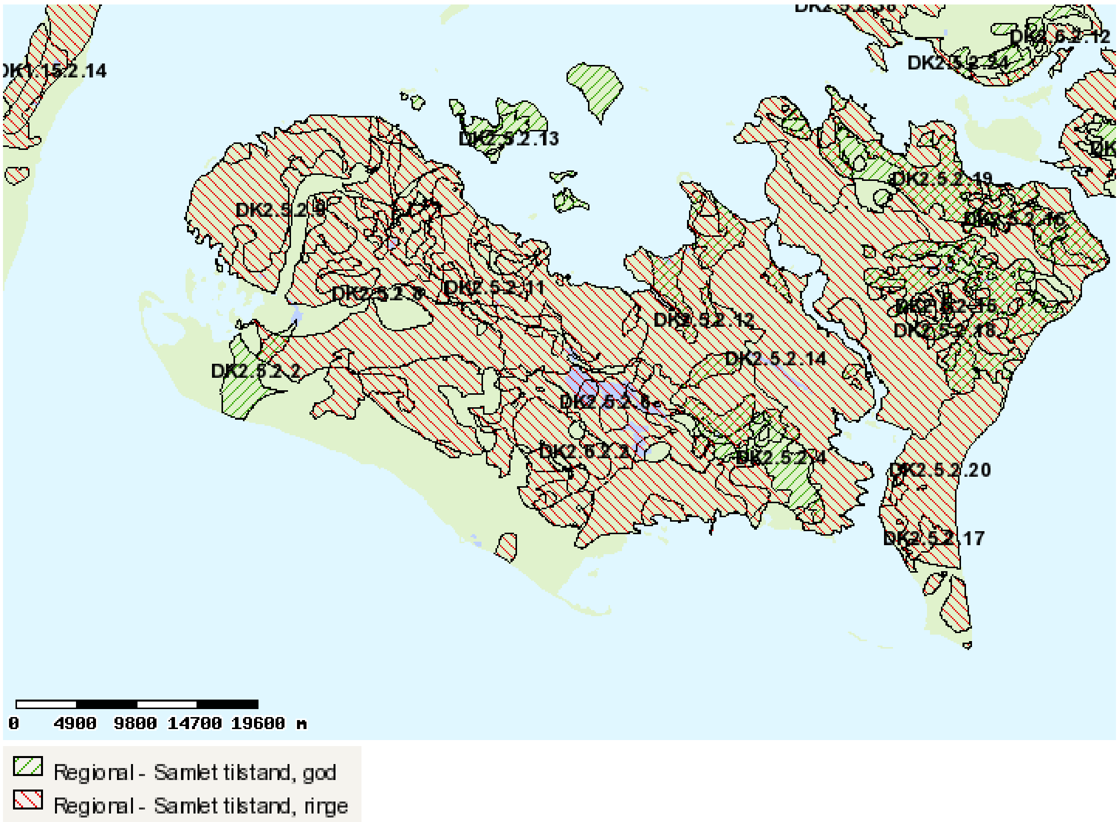


Figure 25. Regional groundwater bodies at Lolland-Falster. The overall assessment of chemical and quantitative status: poor status (Red shaded area) and good status (green shaded area)(From Miljøstyrelsen, 2010a).

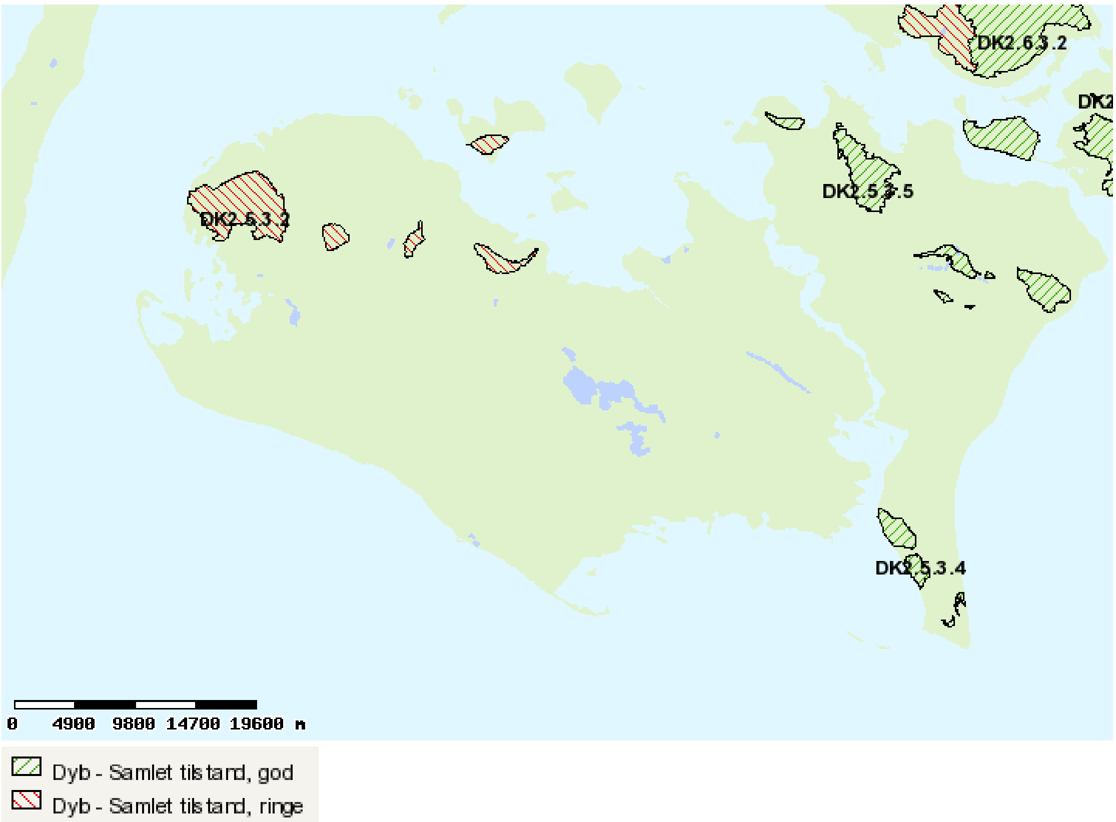


Figure 26. Deep groundwater bodies at Lolland-Falster (blue shaded areas). The overall assessment of the chemical and quantitative status: poor status (Red shaded area) and good status (green shaded area). (From Miljøstyrelsen, 2010a).

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

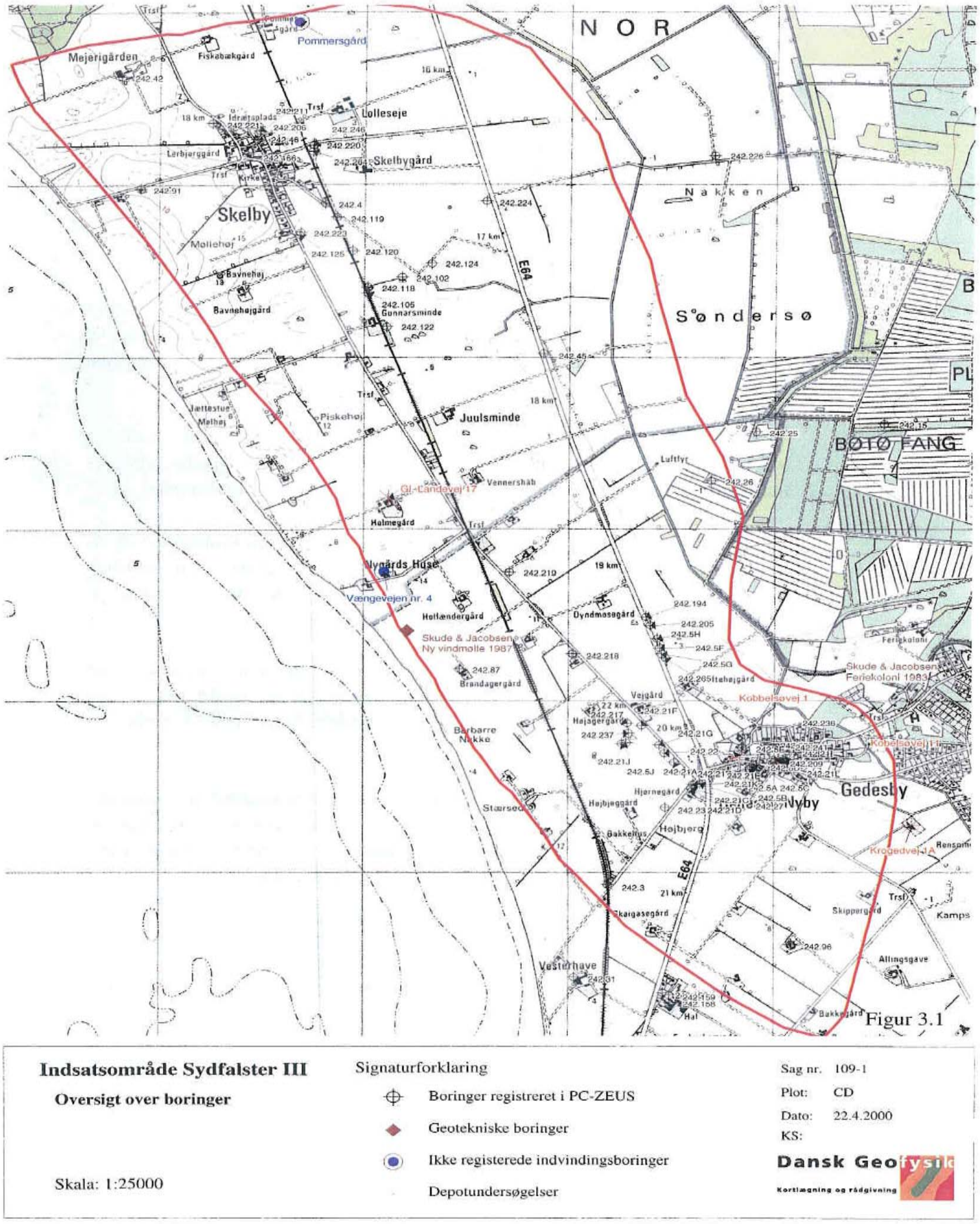


Figure 27. Hydrogeological investigation area on southern Falster. Legend: Red line: Investigation area, Dots: boreholes (From Dansk Geofysik, 2002).

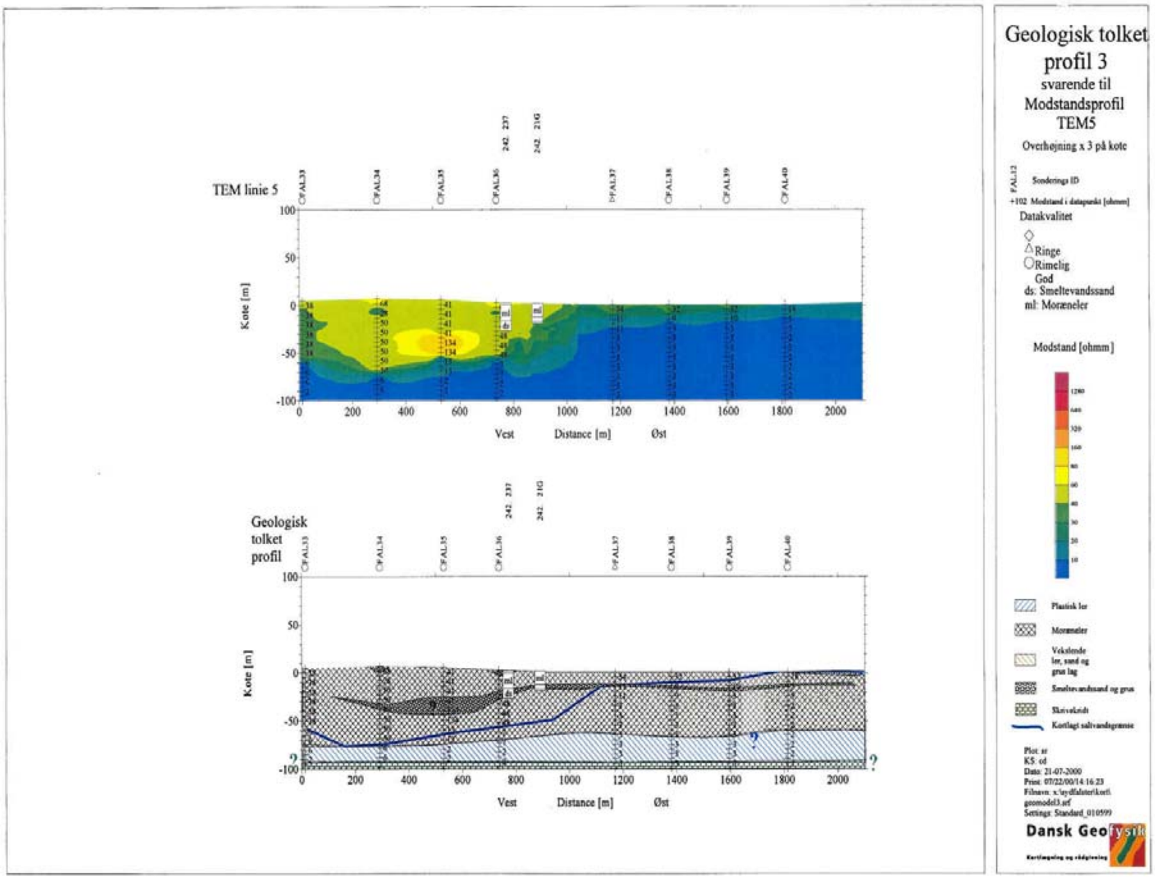


Figure 28. Section trough the recharge area to Gedesby Nyby Water Work based on borehole data and TEM. Legend upper section: Colour scale for resistivity, blue: lowest value. Legend for lower section: Grey: Quaternary clays, Blue: Paleocene clays, Blue line: saltwater boundary (From Dansk Geofysik, 2002).

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 present 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. 29).

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.

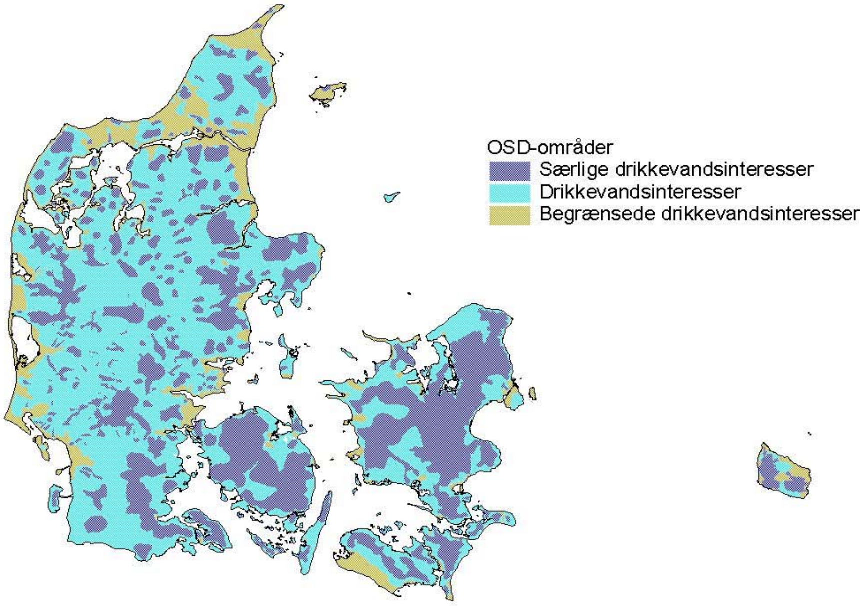


Figure 29. Map of three categories of drinking water interests in Denmark. The areas of special recharge groundwater and drinking water interests (OSD areas protected by law) are in dark blue colour. The areas shown with light blue colour are areas of some interest for drinking water purposes. The areas in brown colour are areas of limited (or none) drinking water interests (http://kort.arealinfo.dk/).

The drinking water areas categorised by the Environmental Centre Nykøbing for the Lolland-Falster region are given in Fig. 30 and South Falster in Fig. 31. On the southern tip of Falster is Area 3 (Gedesby Nyby – Gedser) situated mostly in the category of limited or no drinking water interest. However, it should be noted that the northern limit of the suggested Area 3 may reach into an area with some drinking water interests.

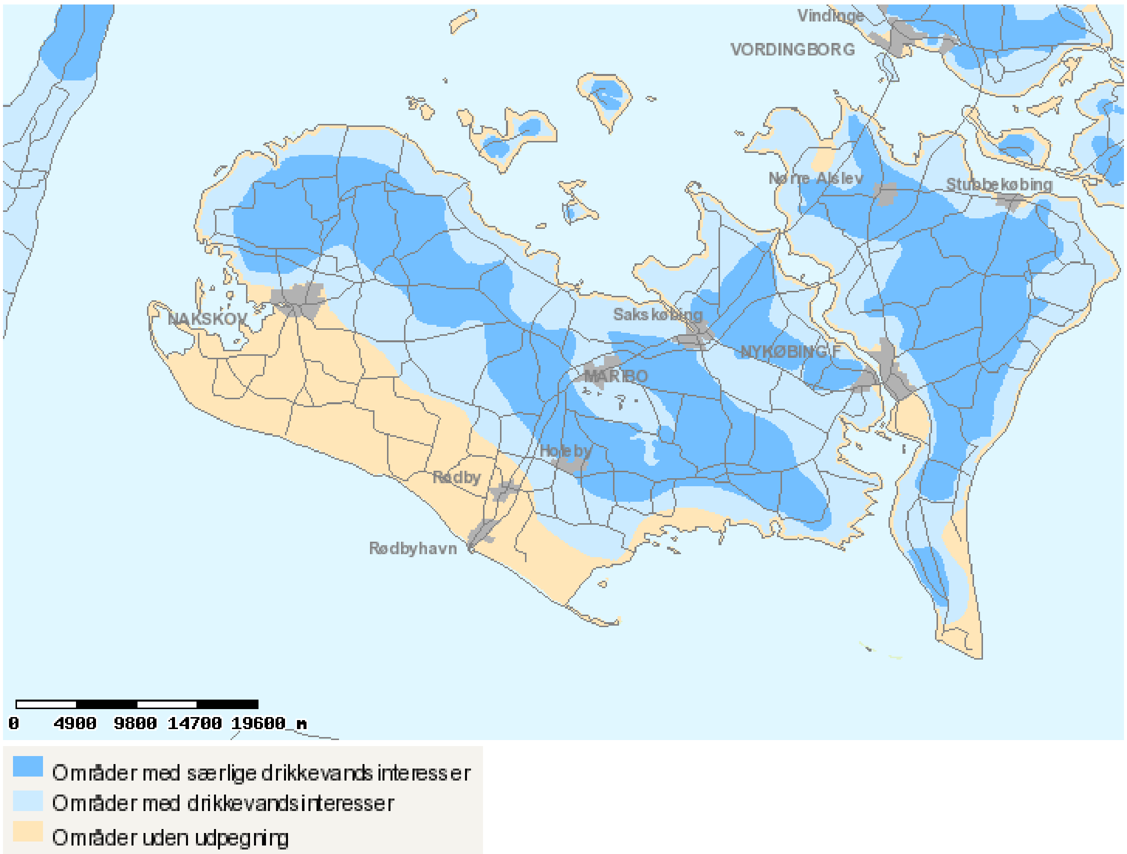


Figure 30. Drinking water areas at Lolland-Falster. Dark Blue: Areas of special drinking water interests; Light blue: Areas of some drinking water interests; Yellow: Areas with limited or none drinking water interests (http://kort.arealinfo.dk/).

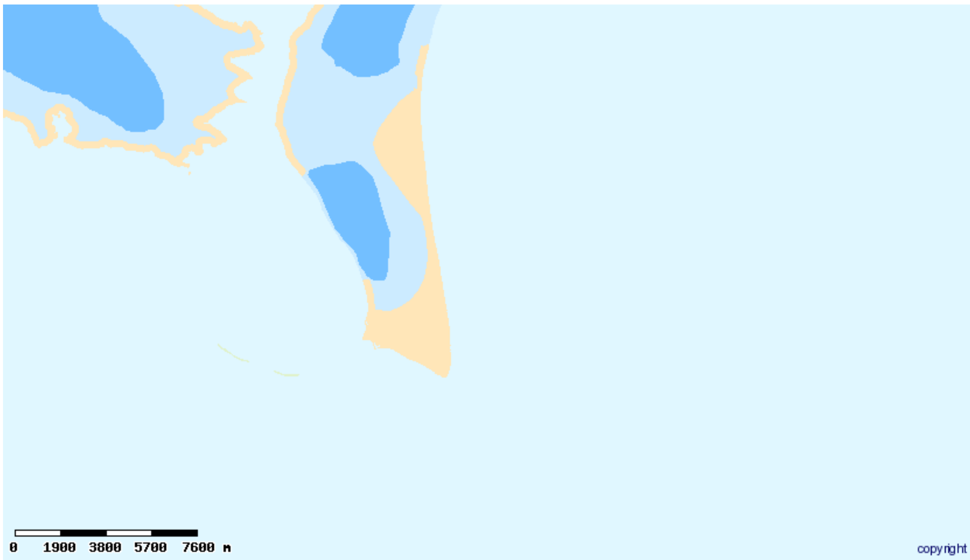


Figure 31. Drinking water areas at Falster and east Lolland. Dark Blue: Areas of special drinking water interests; Light blue: Areas of some drinking water interests; Yellow: Areas with limited or none drinking water interests (http://kort.arealinfo.dk/).

5.9 Groundwater chemistry

The overall groundwater quality aiming for drinking water purpose has been assessed by Environmental Centre Nykøbing for each groundwater body and reported in the river basin management plan (Hovedopland 2.6, Østersøen) (Miljøministeriet, 2010). The regional and deep groundwater bodies within the Gedesby Nyby – Gedser (Area 3) are both assessed to have a good chemical status.

There is no water chemistry data available in JUPITER from abstraction wells within Area 3. Thus, it is not possible to assess the risk for saltwater intrusion based on existing data. However, the Gedesby Nyby area (maximum elevation 8-9 m above sea level) has a hydrogeological setting at the tip of a narrow island/peninsula with a maximum distance of 3 km from east to west coast that have to be viewed in perspective of future sea level rise. Seawater intrusion in perspective of climate change with rising sea level is studied at the middle part of Falster in the European INTERREG project BaltCICA (http://www.baltcica.org/casestudies.html).

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). It is not expected that a rise in net precipitation will influence on (deep) groundwater formation and level. It is obvious, that a higher sea level and any raise in storm activity may increase the ongoing coastal erosion and enlarge the length of the coastline, which is marked by erosion. Furthermore, the risks for flooding of parts of the low-lying area will most probably be higher in the future.

5.11 Restrictions and limitations

There are no restrictions regarding NATURA2000 or protected areas in accordance to Naturbeskyttelsesloven (the law for nature protection) directly in Area 3 (Fig. 32). Due to the hydrological setting of Area 3 at the tip of Falster, a future sea level rise will very likely have significant influence on a rise of the salt/freshwater transition underneath Area 3.

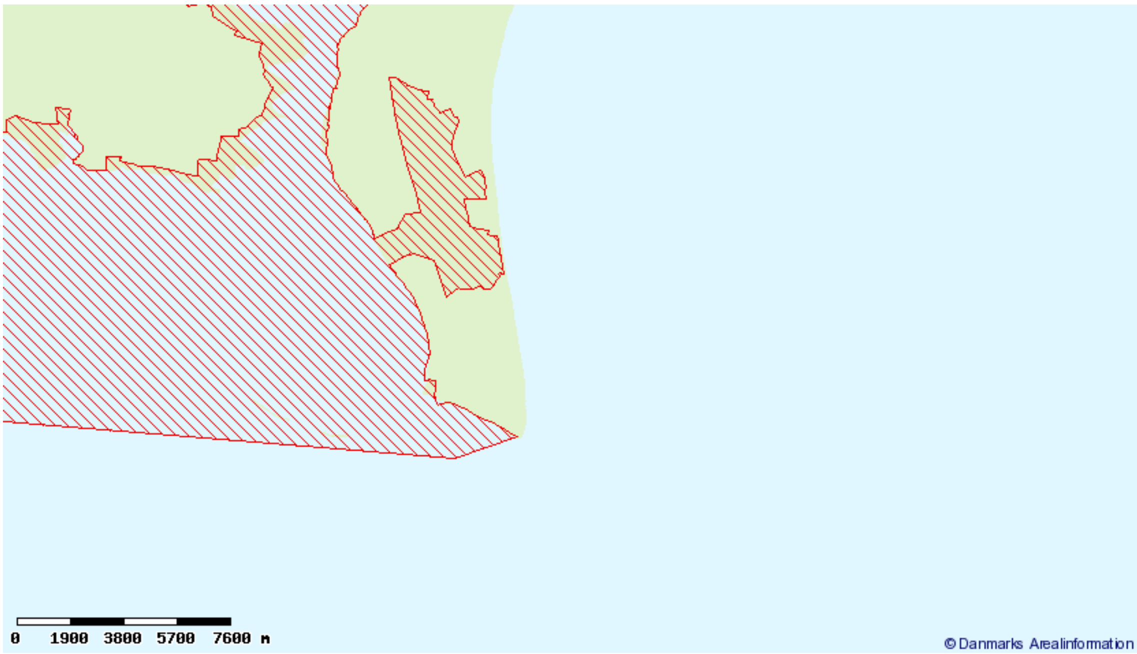


Figure 32. NATURA2000 areas at south Falster (*http://kort.arealinfo.dk/).*).

5.12 Summary of the area conditions

Amount of data:
Sparse amount of borehole data. Some geophysical surveys.

Homogeneous conditions and isolation of the waste by low, permeability clay layers:
Perhaps perfect on depth below 20 m in the Holmehus Formation. The spatial 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 Paleocene clays and overlaying tills and meltwater deposits are expected to be favourable for storage of radioactive waste under water saturated conditions, but a thoroughly investigation of the site specific groundwater conditions are required.

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

Drinking water interests
No OSD area within Area 3. However, the Northern part of Area 3 lies next to an OD area. Local well supplies to Gedesby Nyby are located north of the area. Further investigations needed to identify the delineation of the catchment zone for the abstraction wells of Gedesby Nyby water work.

Groundwater chemistry, non- aggressive components
The groundwater contains apparently no aggressive components but the area is located near the shore and the level of the area is between 2 m and 9 m above sea level.

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 e.g. in relation to the risk of saltwater intrusion, coastal erosion and flooding. Climate changes and extremes as heavy precipitation and storms will probably not have influence on a disposal below ground surface.

Other restrictions
No other restrictions will give problems.

5.13 Final remarks

Area 3 is a relatively small and restricted area. The geological set up with clayey till and the plastic clays could be a promising situation. The structural conditions have to be evaluated.

Area 3 on Falster is the only area where it will be possible to place a waste disposal on the island.

6. Area 4. Rødbyhavn, South Lolland

6.1 The location of the area

Lolland is situated south of Sjælland and west of Falster (Fig. 33). The area is situated east of the city of Rødbyhavn and the motorway (Fig. 34).

Figure 33. Location of the Area 4. Lolland is located in the Baltic Sea south of Sjælland.

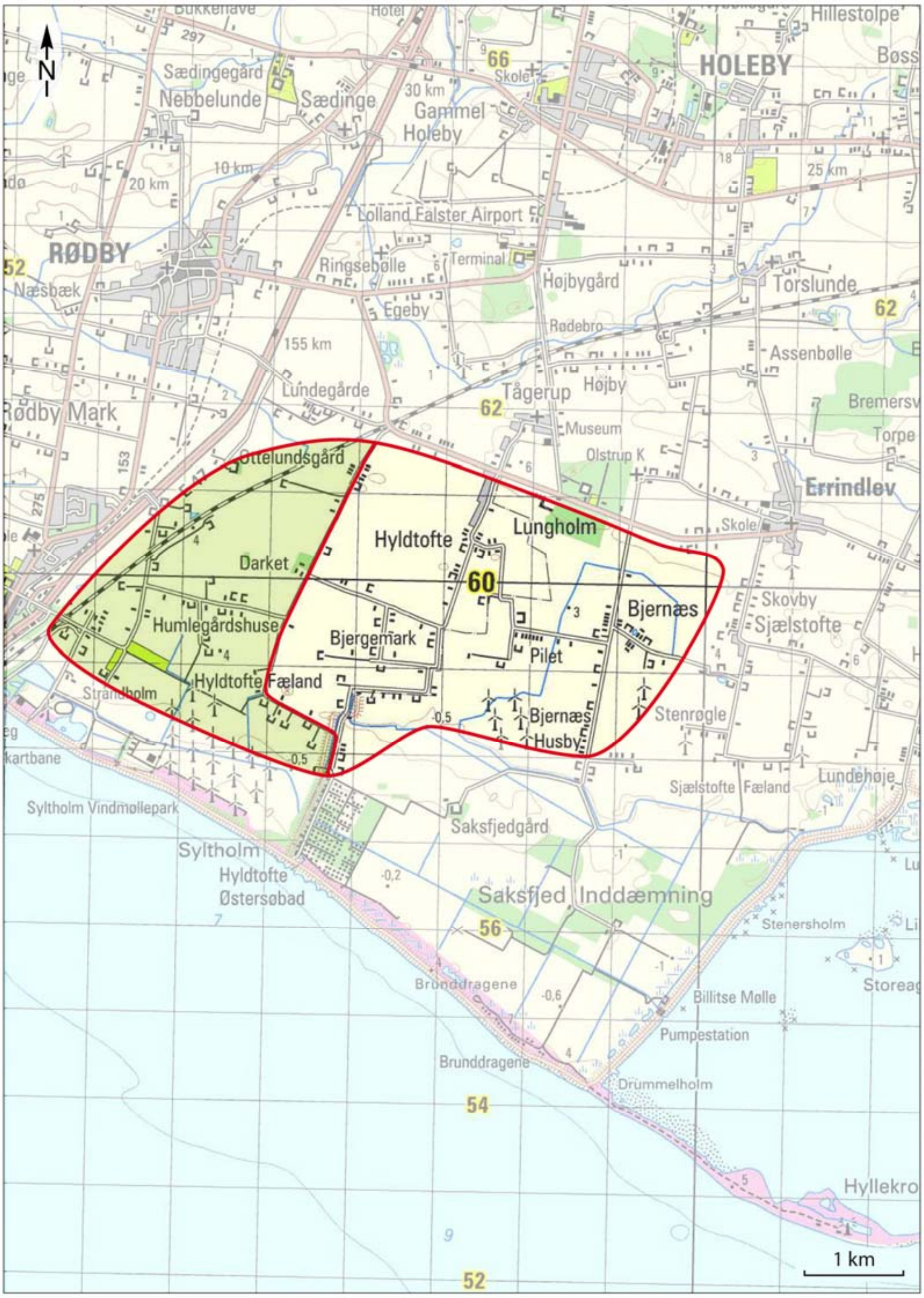


Figure 34. A detailed map of Area 4. Area 4 is located on the southern part of Lolland east of Rødbyhavn. The area is separated in two areas as the westernmost part is reserved for the Femern Belt Fixed Link.

6.2 Terrain, topography and processes

Most of the area is located on a flat ground moraine. A smaller part toward southwest is reclaimed land. The size of the area is almost 20 km^2. The overall impression of the landscape is a very flat terrain, almost without undulations. Most of the area is very low-lying, located between 0 and 4 meters above sea level (m.a.s.), locally to 0.5m below present sea level.

The western part of the area is crossed by a railway. The remaining and predominant part of the area is used for agriculture. Most of the houses are located along the roads. Large fields are found between the roads. Some windmills are located in the eastern part of the area, west of Bjernæs Husby and south of Bjernæs, respectively. There are no lakes or streams in the area but drainage ditches are found in the eastern and south-western part of the area.

Owing to the low relief and the relatively intense cultivation, the surface processes (soil creep, frost – thaw processes, soil development etc.) proceed slowly and undramatic. The by far most dynamic processes are found in the coastal zone outside the area. A four m high dike along the coast protects the land area from flooding by the sea.

6.3 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. 35). Towards the south, Holocene marine deposits covers the glacial sediments.

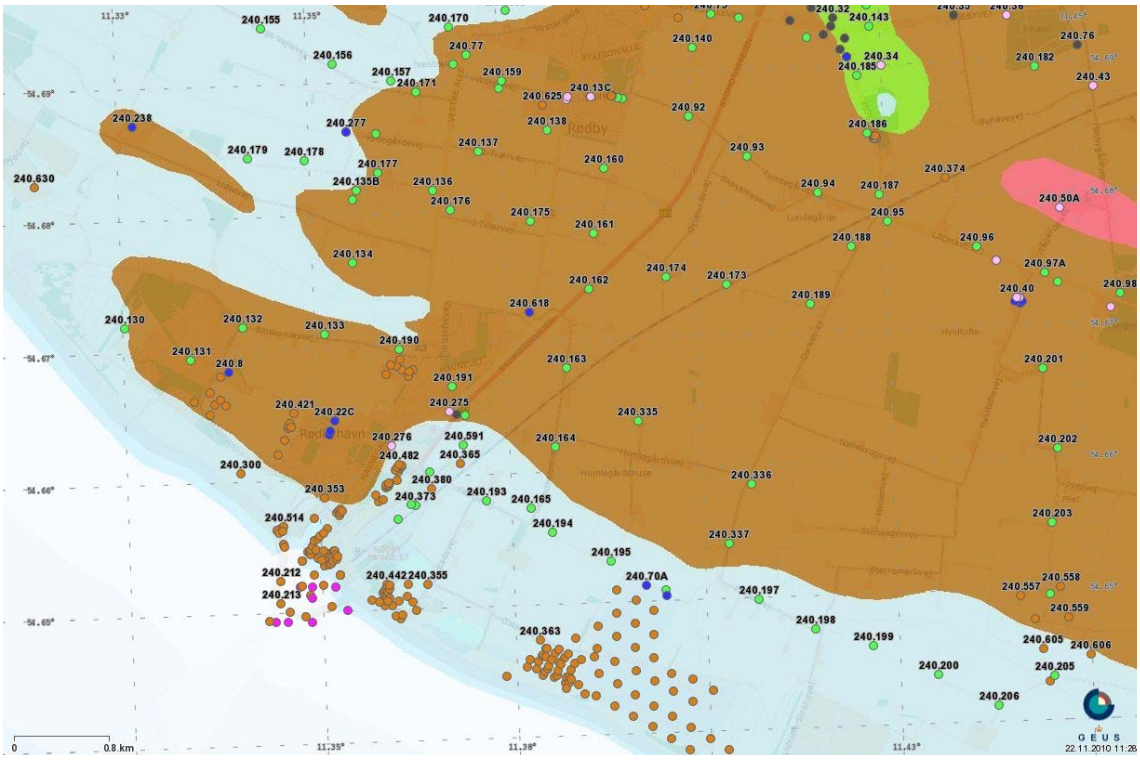


Figure 35. Map of the Quaternary deposits (From GEUS Homepage, after Pedersen, 1989). Legend: Brown: Clayey till, Red: Meltwater sand and gravel, Green: Holocene freshwater deposits, Light blue: Holocene marine deposits. Borehole data, see legend Fig. 34.

6.4 Boreholes and geophysical surveys

The target is Paleocene clays but only eleven boreholes within an area around Rødbyhavn reach these clays. Very few samples have been collected, described lithological and dated and the information is mainly based on borehole DGU No. 240.334 (Raw material borehole B1) and three other raw material boreholes drilled for bentonite exploration (Figs. 36, 37, 38).

Most of the boreholes are for minor supplies as households and local water works as groundwater reservoirs in the area are very limited.

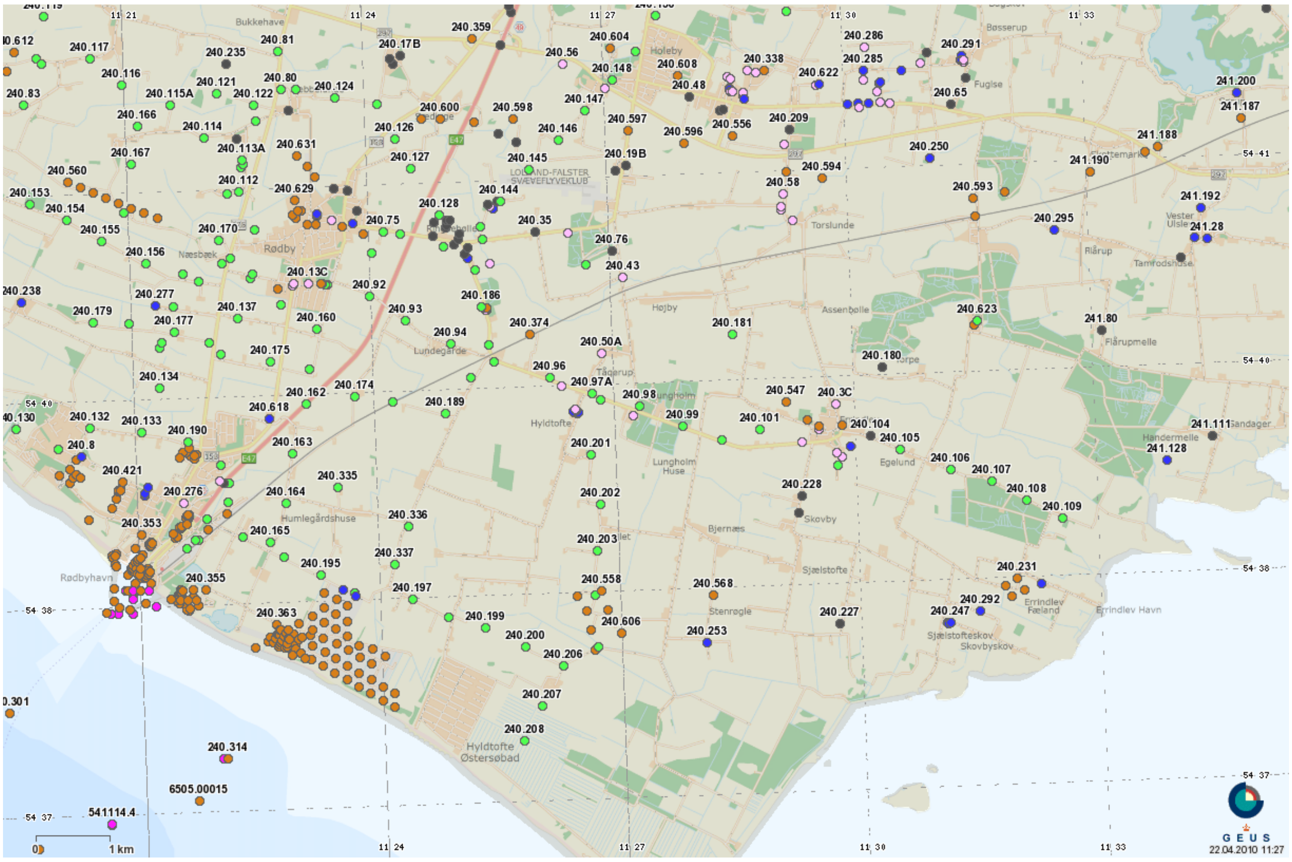


Figure 36. Map of the locations of boreholes from the Jupiter database at GEUS. Legend: 240.338: DGU No., Blue dot: Water supply well, Red dot: Geotechnical borehole, Pink dot: Raw material borehole, Green dot: Other borehole, Light red dot: Abandoned borehole, Black dot: Unknown purpose.

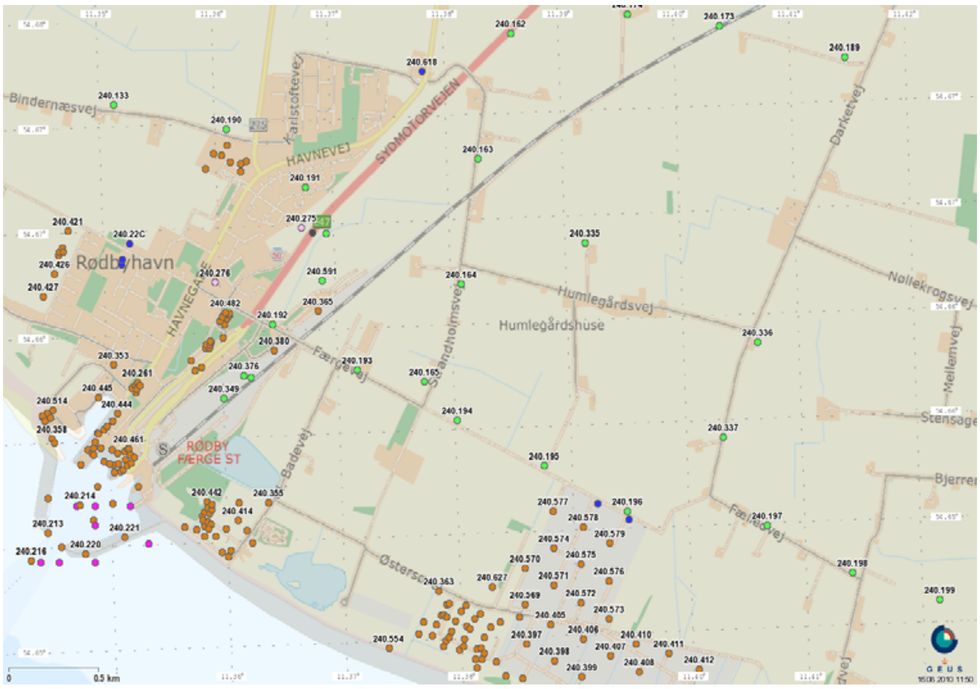


Figure 37. Details of borehole locations. Legend: See Fig. 34.

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BORERAPPORT — **DGU arkivnr: 240. 334**

Borested : Rødbyhavn
4970 Rødby
Boring nr.1

Kommune : Lolland
Region : Sjælland

Boringsdato : 15/11 1991 — **Boringsdybde** : 122 meter — **Terrænkote** : 2.5 meter o. DNN

Brøndborer : Poul Christiansen,Højslev
MOB-nr :
BB-journr : B 246/245
BB-bornr : 105/91

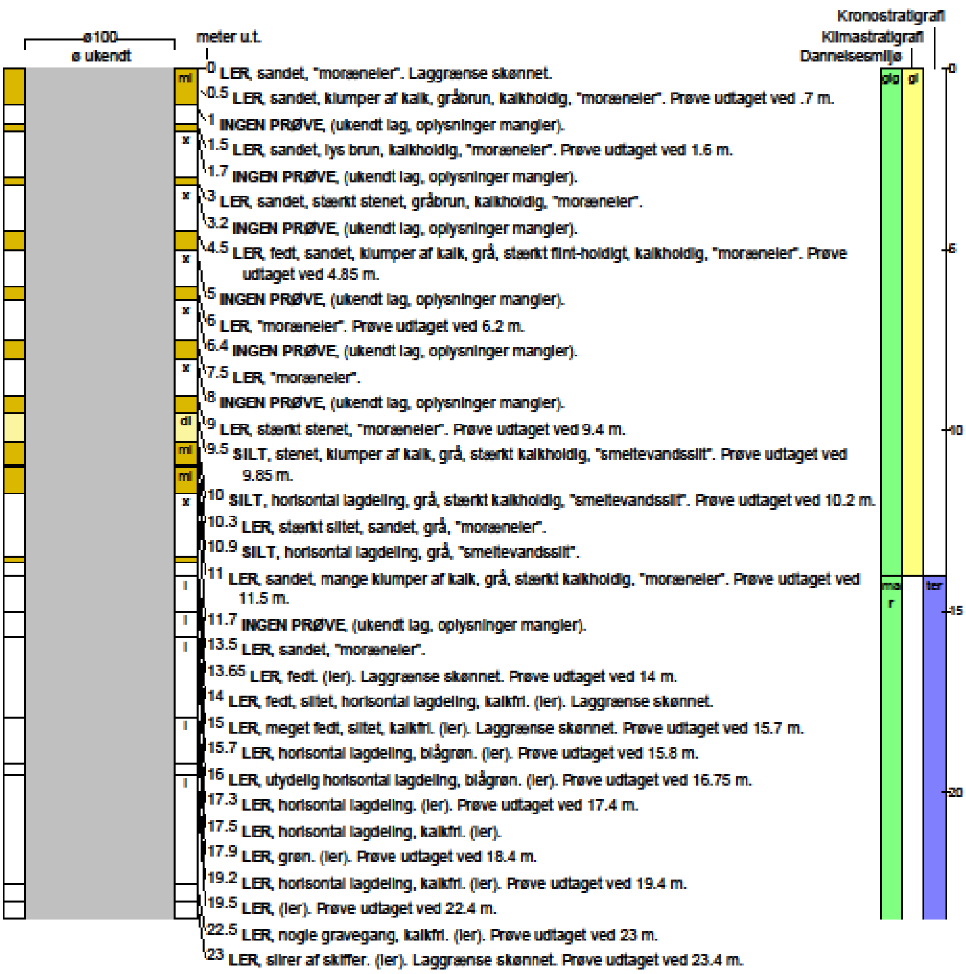
Prøver
- **modtaget** :
- **beskrevet** : 1/11 1991 **af** : A
- **antal gemt** :

Formål : Råstofboring
Anvendelse : Monitering/kontrol
Boremetode : Kerneboring

Kortblad : 1411 IISV
UTM-zone : 32
UTM-koord. : 652891, 6080248

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

Notater : kernebor. for bentonitundersøgelse



fortsættes..

Figure 38. Geological log from borehole DGU no. 240.334 from the Jupiter Database. Upper parts of the 122 m deep borehole drilled for bentonite exploration.

Geophysical investigations: seismic, geoelectric, electromagnetic and SkyTEM surveys are carried out on most of Lolland. Seismic and geoelectric surveys west and east of Rødbyhavn point out where three areas with shallow Paleogene clay deposits probably can be found.

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. 39), the formations on the southern part of Lolland should be of Paleocene Age. Very few borehole samples have been identified as Paleocene/Eocene from lithological descriptions and almost no have been dated (Fig. 38).

The Paleocene deposits are known from a series of few boreholes in the Rødbyhavn area (10-20 m below ground surface) and together with relatively few boreholes at Errindlev, Lundehøje, Tillidse, Græshave, Rudbjerg and Sædingskov and probably also at Holeby (but apparently as a thick glacial floe) they characterize the pre-Quaternary surface.

Two boreholes situated in Area 4 are drilled in connection with the pre-investigations for the Femern Belt Fixed Link and they do reach the Holmehus Formation. Two boreholes close to the southern shore of Lolland show that Eocene deposits from the Røsnæs and Ølst Formations rest on Holmehus Formation.

Sediment sample description and biostratigraphical analysis information from the borehole in the area east of Rødbyhavn confirm that the sequence consists of Late Paleogene clays, which include two formations.

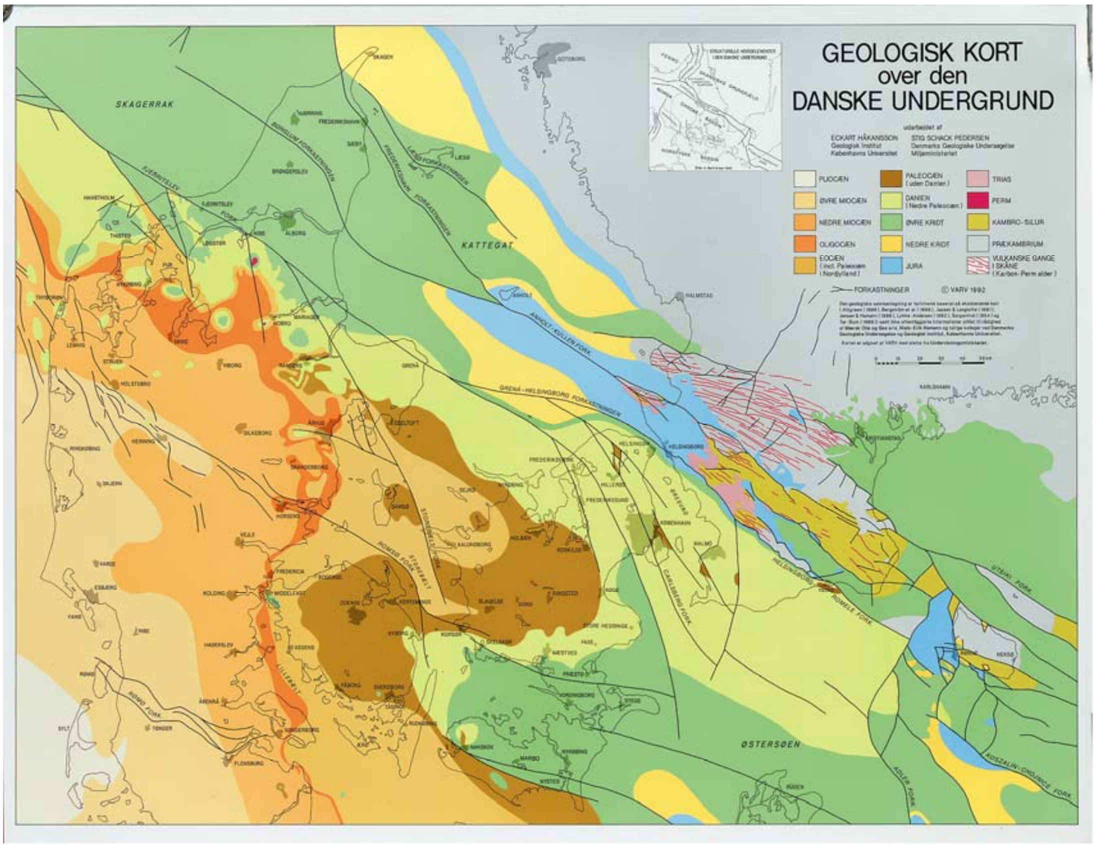


Figure 39. Map of the pre-Quaternary surface: Time units. Original scale: 1:50.000. Legend: Red lines: Precambrian intrusions, grey: Precambrian, olive: Cambrian-Silurian, red: Permian, light red: Triassic, blue: Jurassic, yellow: Lower Cretaceous, green: Upper Cretaceous, light green: Danian, brown: Paleocene, yellow olive: Eocene, red brown: Oligocene, light yellow brown: Lower Miocene, very light yellow brown: Upper Miocene, white: Pliocene (Håkansson & Pedersen, 1992).

Just above the Maastichtian chalk follow 35-40 m dark grey or grey, silty and fine-grained homogeneous clay from the Æbelø Formation. The clay deposits can be silicified and often contain pyrite concretions. The formation is only recognized in borehole DGU No. 240.334. Above the Æbelø Formation follow 35-40 m fine-grained plastic green grey, green or brown clay from the Holmehus Formation. The clay is laminated to faintly horizontally laminated but the lamination is often disturbed because of bioturbation. The clay content varies between 50 and 70 % and the rest is quartz and feldspar. Most of the clay is non-calcareous but thin layers of calcareous clay occur. Very few macrofossils are present. The formation is found in ten boreholes near Area 4. A section through the raw material boreholes is seen in Fig. 41. An excavation demonstrates the green plastic clay from the Holmehus formation below clayey till (Fig. 42a).

Figure 40. Section from the Albæk Hoved cliff, Juelsminde, Jylland. Red and green plastic clay which are comparable to clays from the Holmehus Formation.

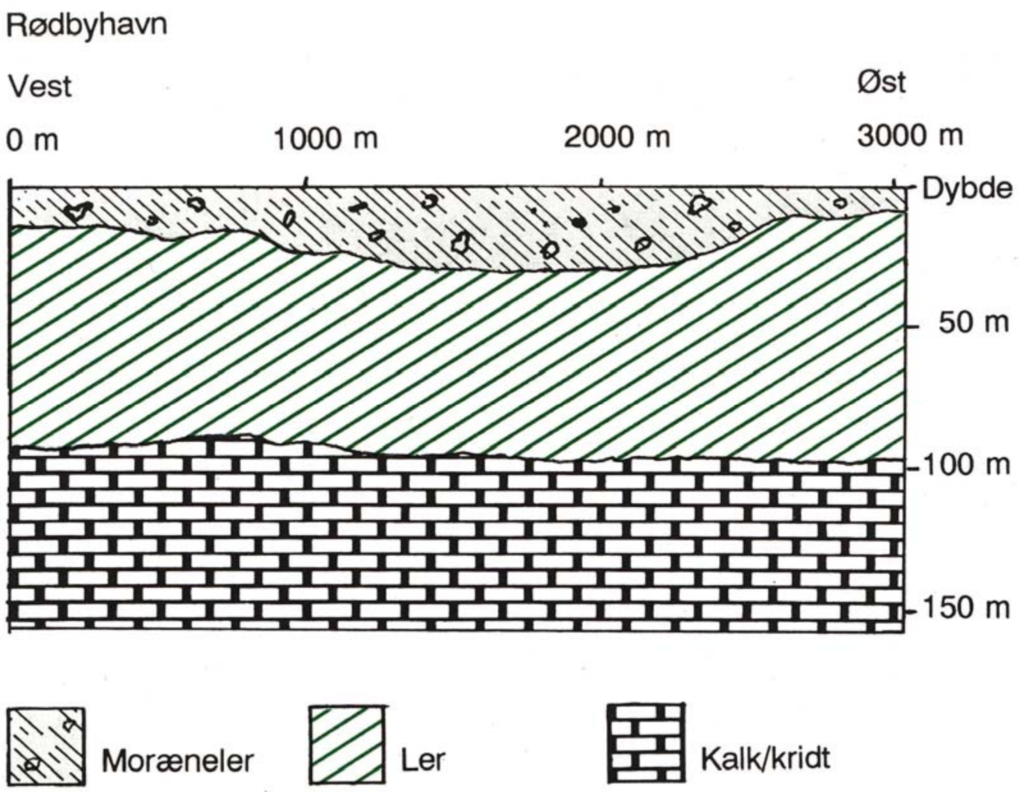


Figure 41. Geological section through the raw material exploration boreholes east of Rødbyhavn. The interpretation is based on seismic surveys and information from four boreholes. Legend: Bricks: Limestone/chalk, Green hatched: Paleogene clay, Upper layer: Clayey till (From Pedersen, 1992).

Mineralogy
The clay consists of 70-80 % smectite, 20-25 % illite and 2-4 % kaolinite and very little chlorite. Chemical analysis demonstrates that the clay is a combination of Na and Ca bentonites.

a.

b.

Figure 42. a. A small amount of the plastic clay/bentonite has been dug in the western part of the area. b. The exaction is now filled with water.

6.5.2 Quaternary deposits

The Quaternary deposits in the area consist mainly of clayey tills. Excavations in relation to raw material mapping have exposed the till layers and borehole samples demonstrate these sediments as well (Fig. 42a). The thickness is 14-36 m. Towards the south, the area is bordered by Holocene marine deposits (Figs. 35 and 43).

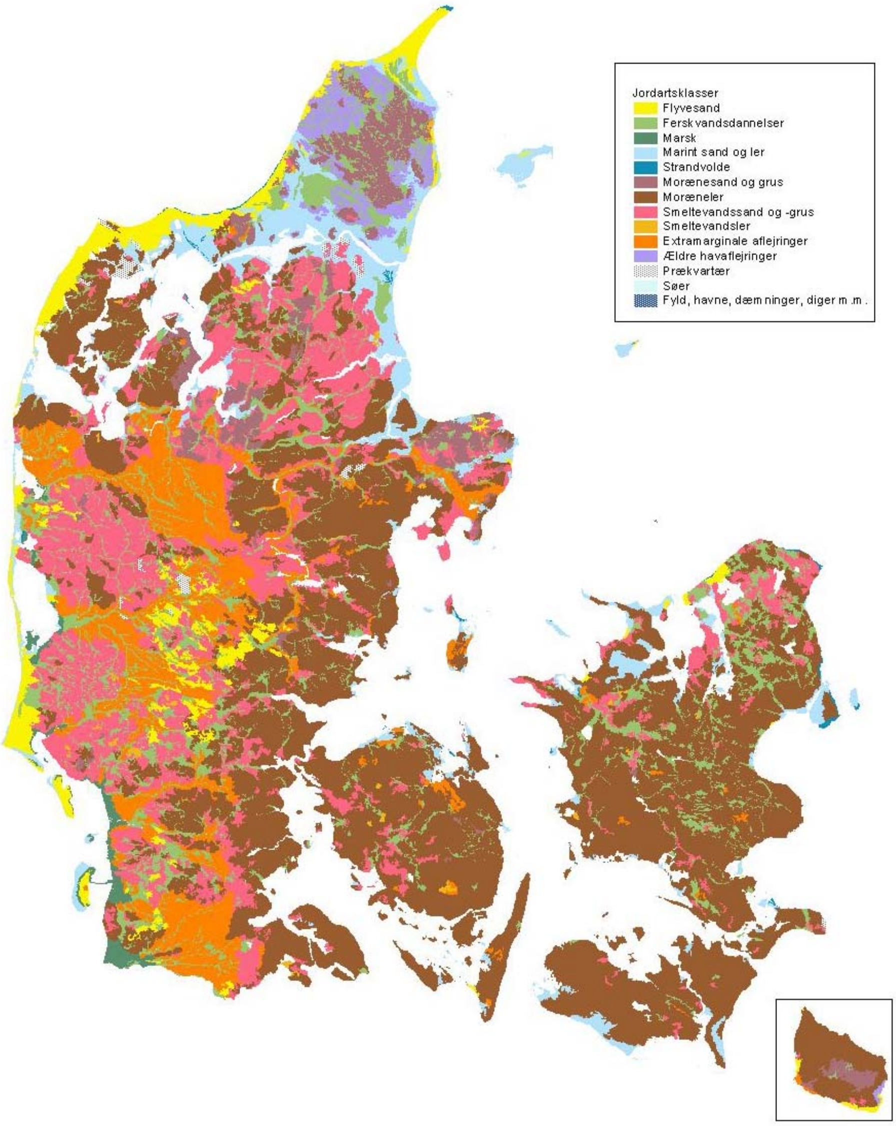


Figure 43. Map of the Quaternary surface deposits. Original scale: 1:200.000. Legend: Brown: Clayey till, light brown: Sandy till, red: meltwater sand and gravel, orange: sandur sand and gravel, purple: Late glacial marine deposits, light blue: Holocene marine deposits. Green: Holocene freshwater deposits, yellow: Aeolian sand (From Pedersen, 1989).

The upper 5 m is mainly yellow brown or grey brown clayey till with content of limestone clasts and a matrix with a calcareous content. Below this till a light green or grey, dry and very firm is found. This sandy, stony till is partly cemented by $CaCO_3$ and contain limestone and flint clasts. The local name of the till is “Knald-ler”. The clay content is from 10 to 20 % in the clay fraction but the till includes layers of strongly calcareous laminated gravelly silt. The clay fraction contain 2% smectite. The $CaCO_3$ content is of 50-60 % in the clay fraction. The clay has high density of 2.4 g/cm^3. Up to 6 m thick layers of coarse-grained, gravelly meltwater sand with bryozoans are found in the eastern part of the area. The clayey till rests on the Paleocene clays. Often, the upper 1-2 m of these clays have been disturbed (brecciated and mixed with glacial material) by the glacier advances over the area during the Weichselian or Saalian.

6.6 Tectonics, structures and seismic activity

6.6.1 Major tectonic structures

A major hiatus occur between the Maastrichtian chalk and the Paleogene plastic clays as deposits from the Danian and Paleocene Selandian greensand and calcareous clay deposits are missing. The character of the boundary is not known but it is probably a major fault (Fig.44). The elevation of the chalk area on northern Lolland is higher than of the Paleocene area on southern Lolland but a tectonic? valley seems to occur just south of the Maastrichtian-Paleocene boundary. Towards the south, the elevation of the pre-Quaternary surface increases again. In the area around Rødby and Søllested (at Dannemare), the Maastrichtian chalk cuts the Paleogene deposits and occur just below the Quaternary deposits. This is caused by the occurrence and movements of at least two deeper laying salt structures (Fig. 45, 46 and 47).

The thickness of the Paleogene deposits is known from two to three boreholes but seismic surveys indicate thin thickness close to the salt diapirs Rødby and Søllested. In the tectonic valley south of Nakskov at Hillested, Holeby and Erridlev, the thickness can be more than 100 m but the Quaternary cover is rather thick (up to 100 m). Towards the west, the thickness increases again according to the seismic information but no boreholes documentation exists (Fig.48).

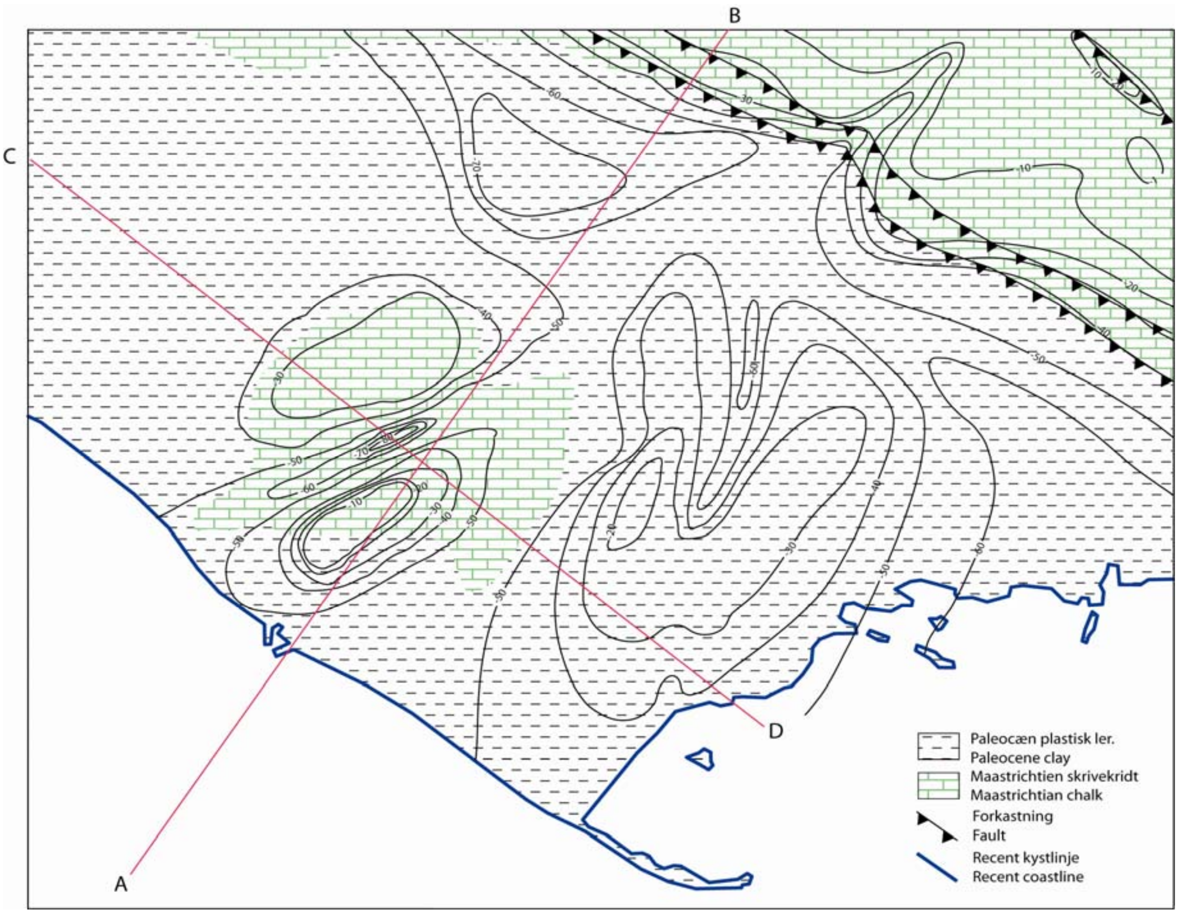


Figure 44. Map of the pre-Quaternary deposits and structural features. The contours show the thickness of the Quaternary deposits (From Klint & Rasmussen, 2006).

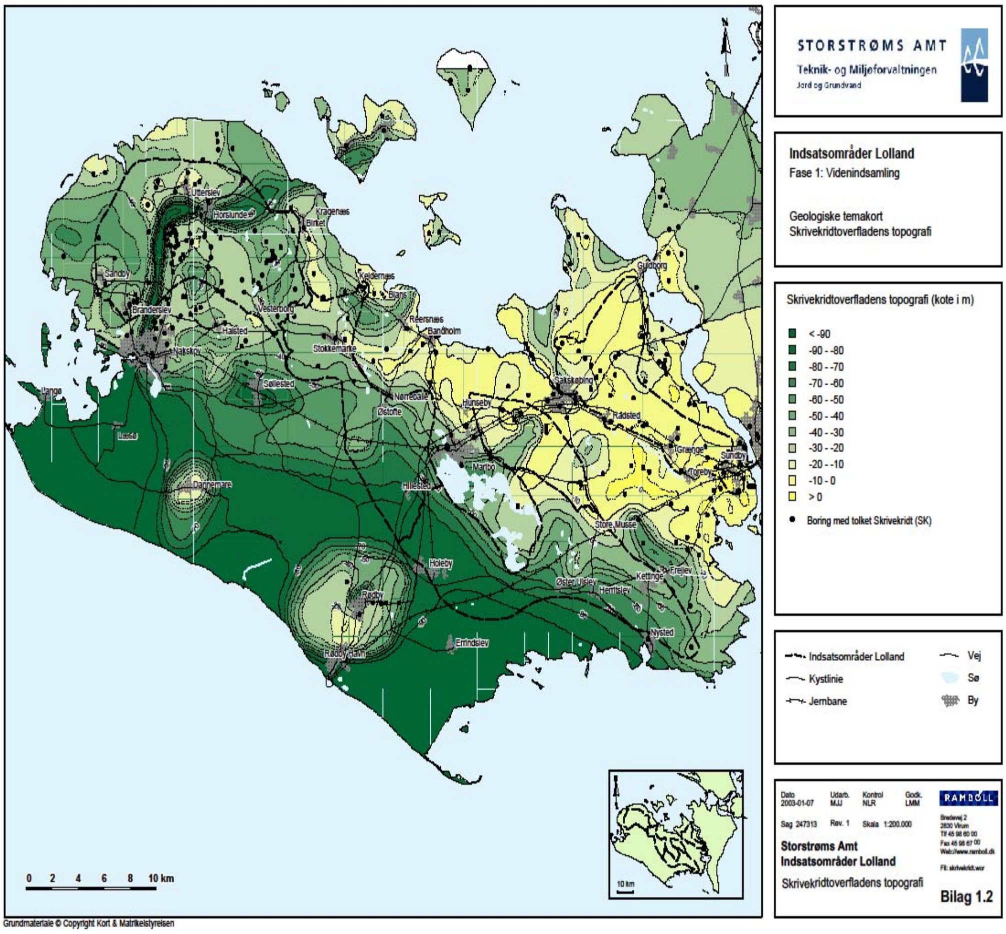


Figure 45. Map of the elevation of the Maastrictian chalk surface. Legend: Colour show the elevation in m: Yellow is highest elevation and dark green lowest. The highs at Rødby and Dannemare show the location of the two salt diapirs (From Rambøll, 2003).

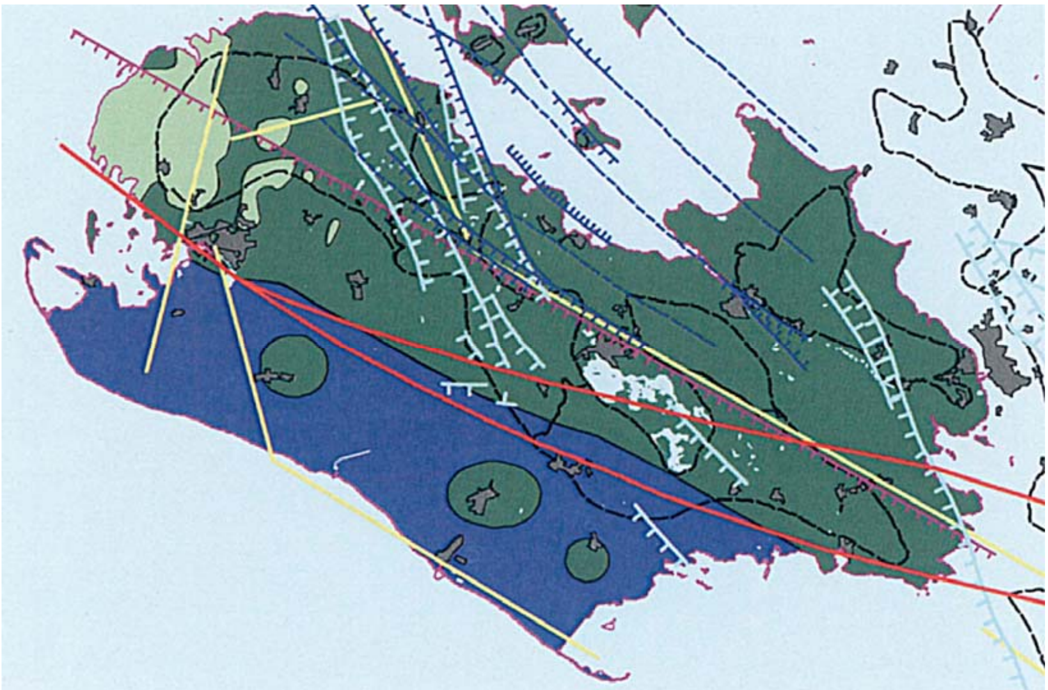


Figure 46. Structural map of Lolland. Legend: Dark Green: Chalk, Light Green: Danian Limestone, Blue: Paleogene clay, Yellow, red and blue lines: faults (From Rambøll, 2006).

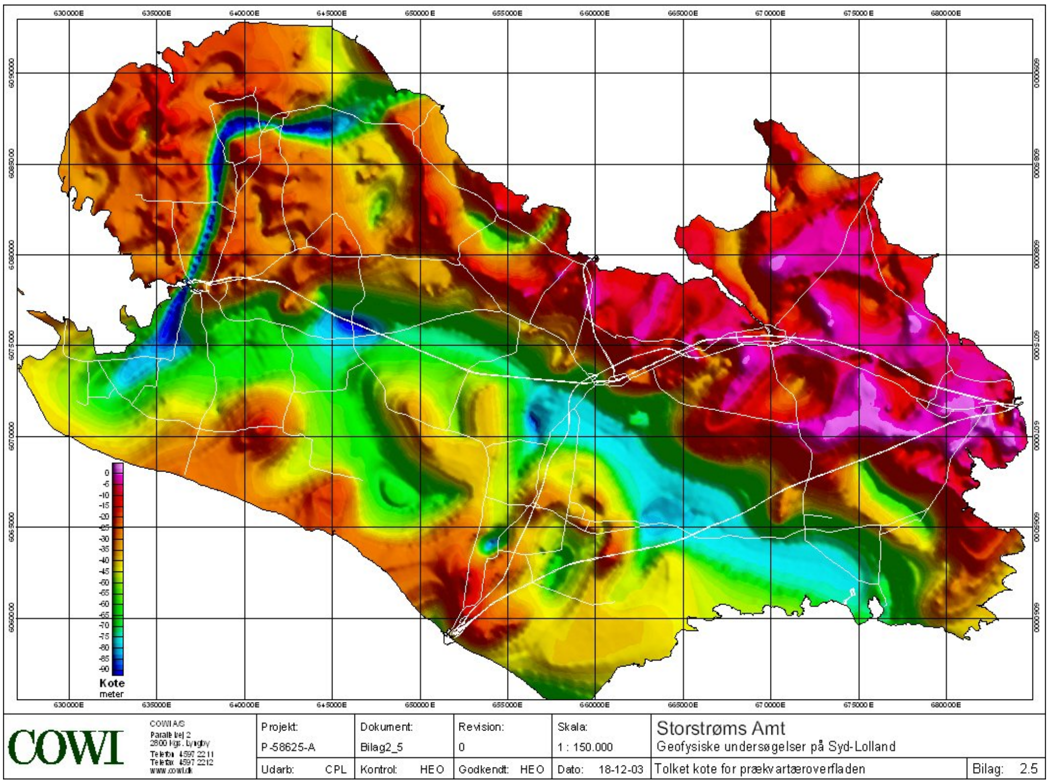


Figure 47. The elevation of the pre-Quaternary surface based on geophysical surveys (From COWI, 2003).

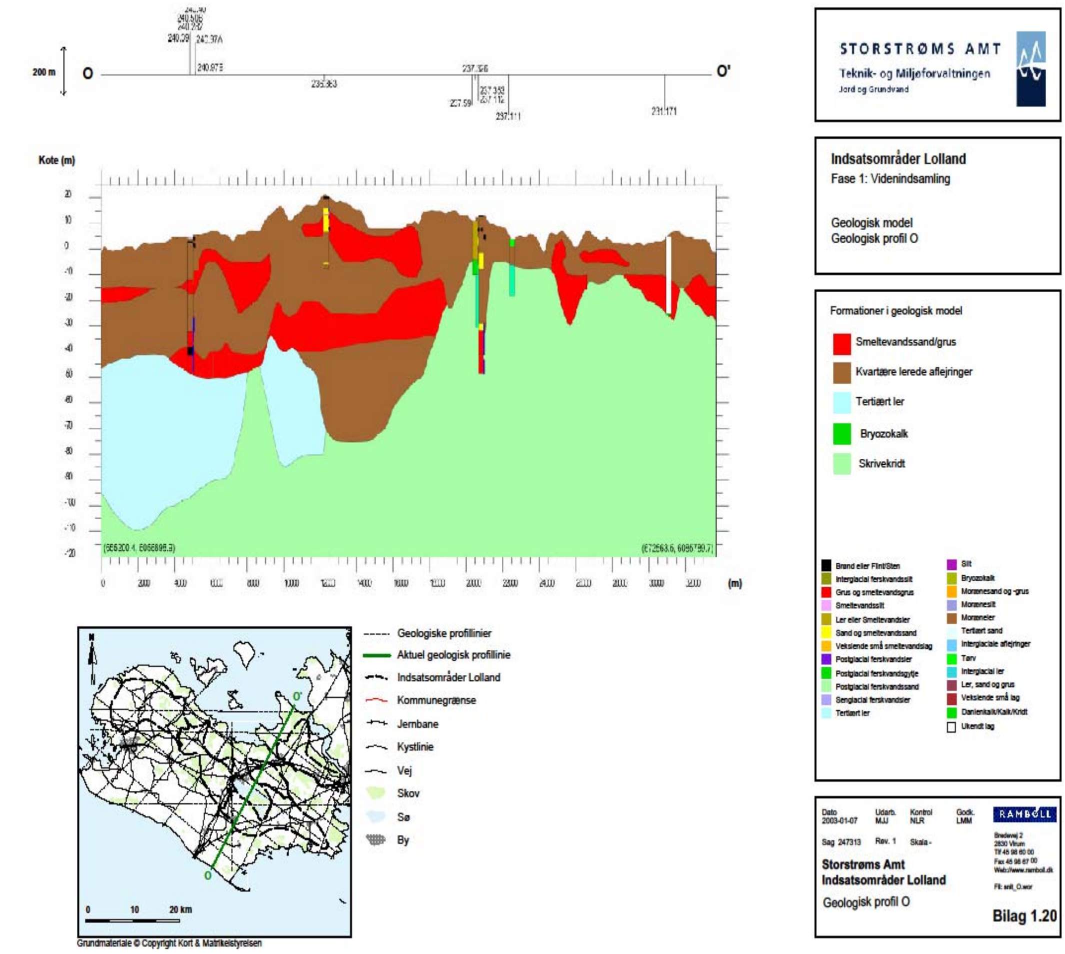


Figure 48. Geological section from Hildesvig (northeast) to Syltholm (southwest). The section crosses southern Lolland just east of Area 4. Paleocene clays are interpreted to occur apparently 45 m below ground surface but no boreholes reach these clays. Legend: Green: Chalk, Light blue: Paleogene clays, Brown: clayey till, Red: meltwater sand and gravel (From Rambøll, 2006).

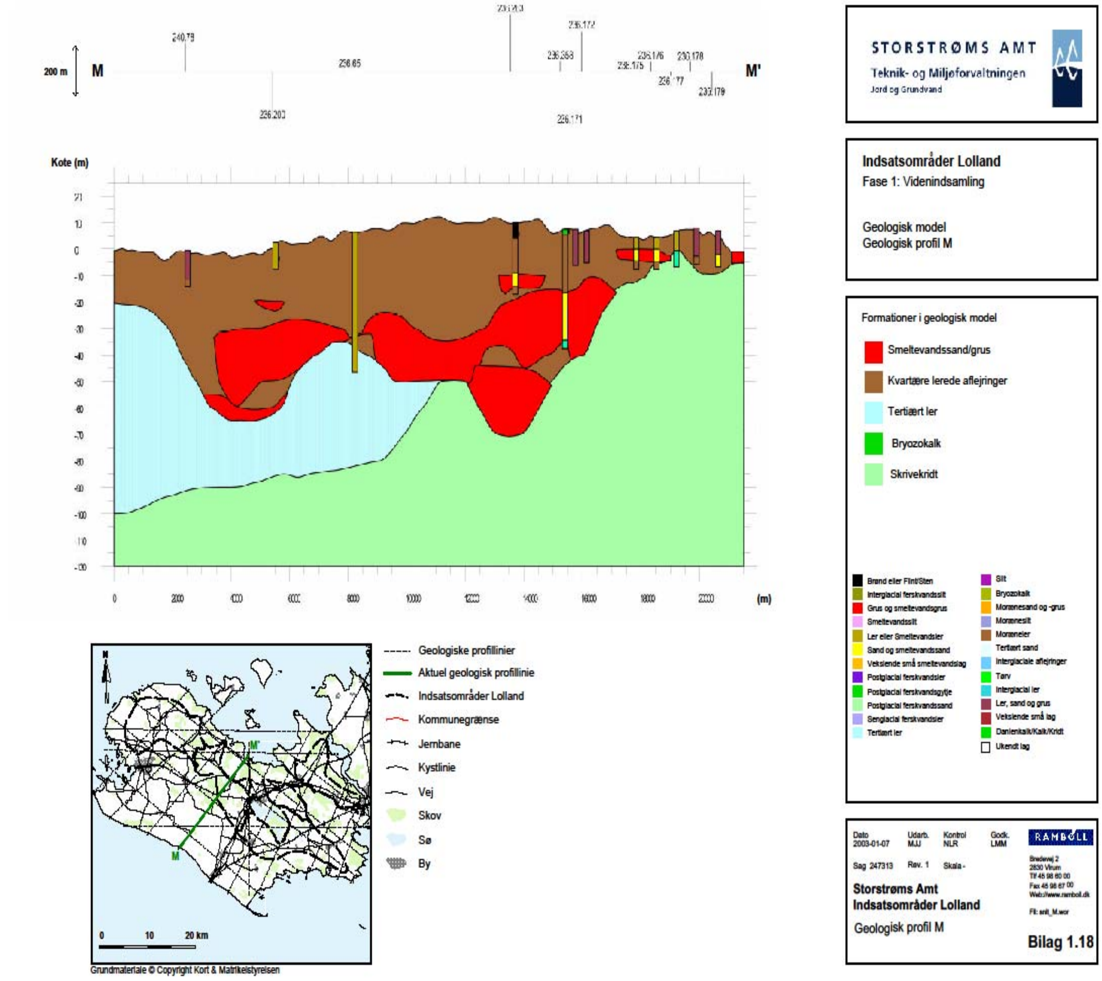


Figure 49. Geological section from Keldernæs Hage (northeast) to Maglehøj Strand (southwest). The section shows an interpretation of the occurrence of Paleocene clays on southern Lolland based on few boreholes (From Rambøll, 2006).

The locations of the high laying Paleocene clays are probably caused by movements in the Rødby and Søllested salt diaper as movements in diapirs have elevated the clays after deposition. According to geophysical surveys, no glaciotectonic floes occur in Area 4, the clay has a large horizontal distribution in the area and is relatively homogeneous (Fig. 48, 49). The surveys show that the clays are located close to the ground surface in three areas: North of Hyltofte Fæland, at Rødby Fæland and below Rødbyhavn and west of Rødbyhavn (Fig. 50).

In Femern Belt, another salt diaper is situated and Maastrichtian chalk forms a dome bordered by Paleogene clay deposits covered by Quaternary deposits. New boreholes with lithostratigraphical and biostratigraphical analyses confirm the occurrence of the Paleogene clay formations. Moreover, Paleocene clay floes in the Quaternary clayey till deposits indicate that the upper parts of Paleocene deposits are disturbed and eroded by the Quaternary glaciers. A fault line in top chalk is indicated along the southern coast of Lolland and movements along that could be responsible for the different levels of the Paleocene-Eocene deposits in the boreholes onshore-offshore (Fig. 46).

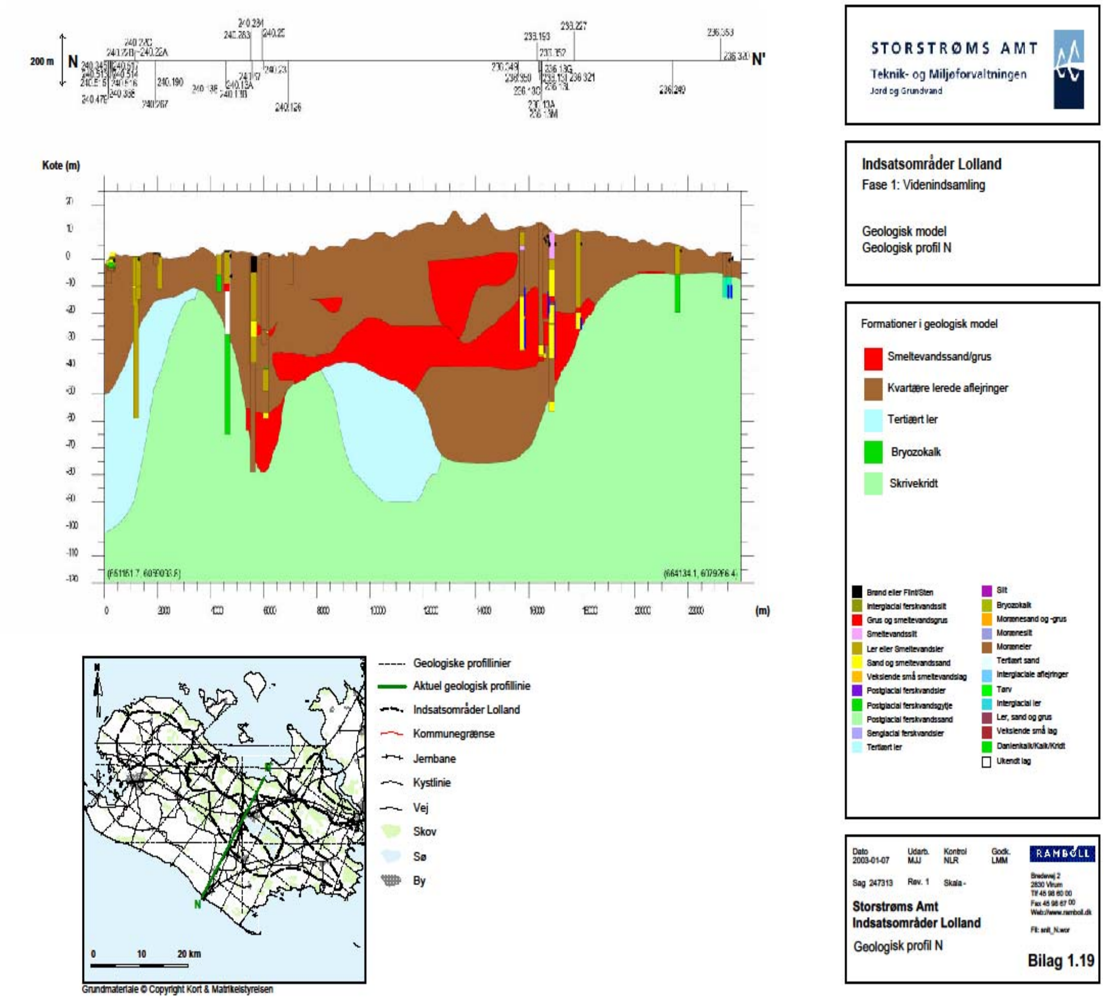


Figure 50. Geological section from Kragevig (northeast) to Rødbyhavn (southwest). The section crosses Rødbyhavn just west of Area 4. The section demonstrates the Rødby salt diapir with elevated Maastrictian chalk covered by Paleogene clays. (From Rambøll, 2006).

A Quaternary system of buried valleys on Lolland is crossing from Maribo towards south-west. South of Holeby, the valley turns towards the south and stops at Hyltofte. The main valley continuous below Rødby and reaches the coast at Rødbyhavn.

6.6.2 Fractures

The plastic clays often contain fractures and some small fault or fractures in the intact cores from boreholes at Rødbyhavn confirm this. The clayey tills are always cut by fractures but the conditions on southern Lolland are not investigated because of lack of field localities.

6.6.3 Geological and structural model

The geological and structural model of the area is fairly simple with four units.

A. Quaternary till 14 to 36 m thick: Sandy, gravelly clayey till, firm, $CaCO_3$ cemented.

B. Holmehus Formation 35-40 m thick. Sticky, fine-grained plastic clay, green or brown.

C. Æbelø Formation 35-40 m thick. Silty and fine-grained grey clay.

D. Maastrichtian chalk. Muddy chalk with flint nodules.

A schematic model is shown in Fig. 51.

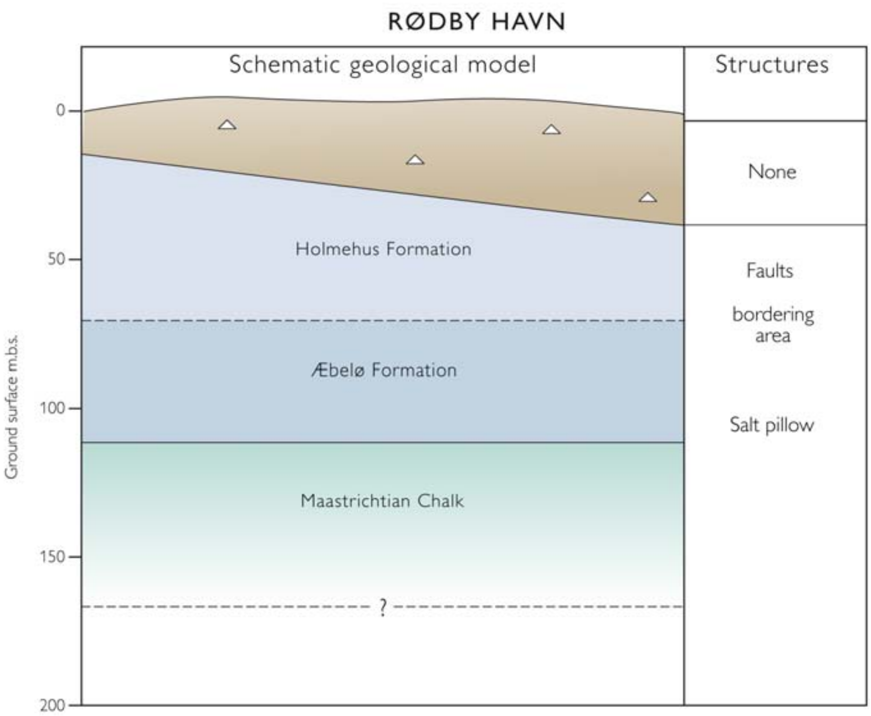


Figure 51. The geological model of the area.

6.6.4 Earthquake activity

The seismic activity in southern Lolland and the near surrounding sea is very low (Fig. 52). 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

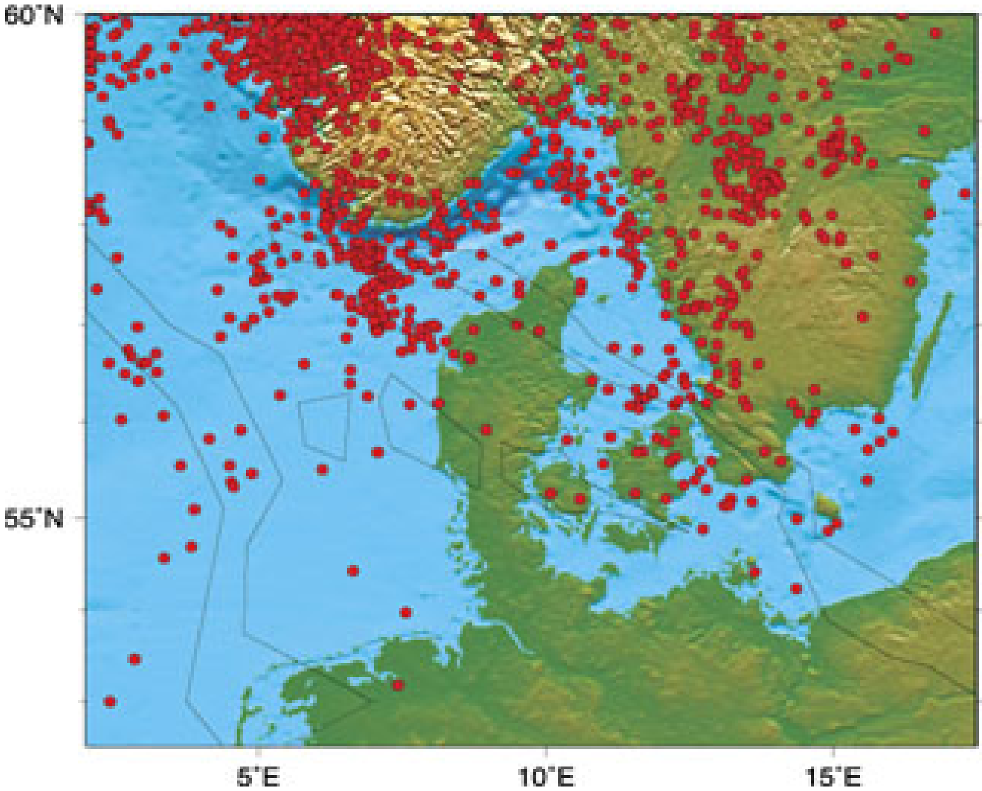


Figure 52. Map of epicentres from earth quakes in the Danish area and the surroundings. (From GEUS Home page).

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 because of the 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 Paleocene sediments within Area 4 (Rødbyhavn), include approximately 100 m of clays with very limited groundwater interests. Location of Area 4 is given in Fig. 53. In the Rødbyhavn area (Area 4) no shallow or deep type groundwater bodies has been mapped by the Environmental Centre (Fig. 53 and 55). However, a minor regional groundwater body (DK2.6.2.1) is situated just east of Rødbyhavn (Fig. 54). This water body has been assessed as groundwater aquifer with a good status of the groundwater chemistry, but a poor status of the quantity. No water abstraction for public water supply takes place in the area. Three permissions for abstraction of surface water occur on Southern Lolland around Rødbyhavn. Only one, immediately east of Rødbyhavn and close to the shore, is important in relation to surface runoff from a potential disposal site placed in Area 4. The groundwater flow direction in the clays and surface water is predicted to be towards the Baltic Sea/Femern Belt.

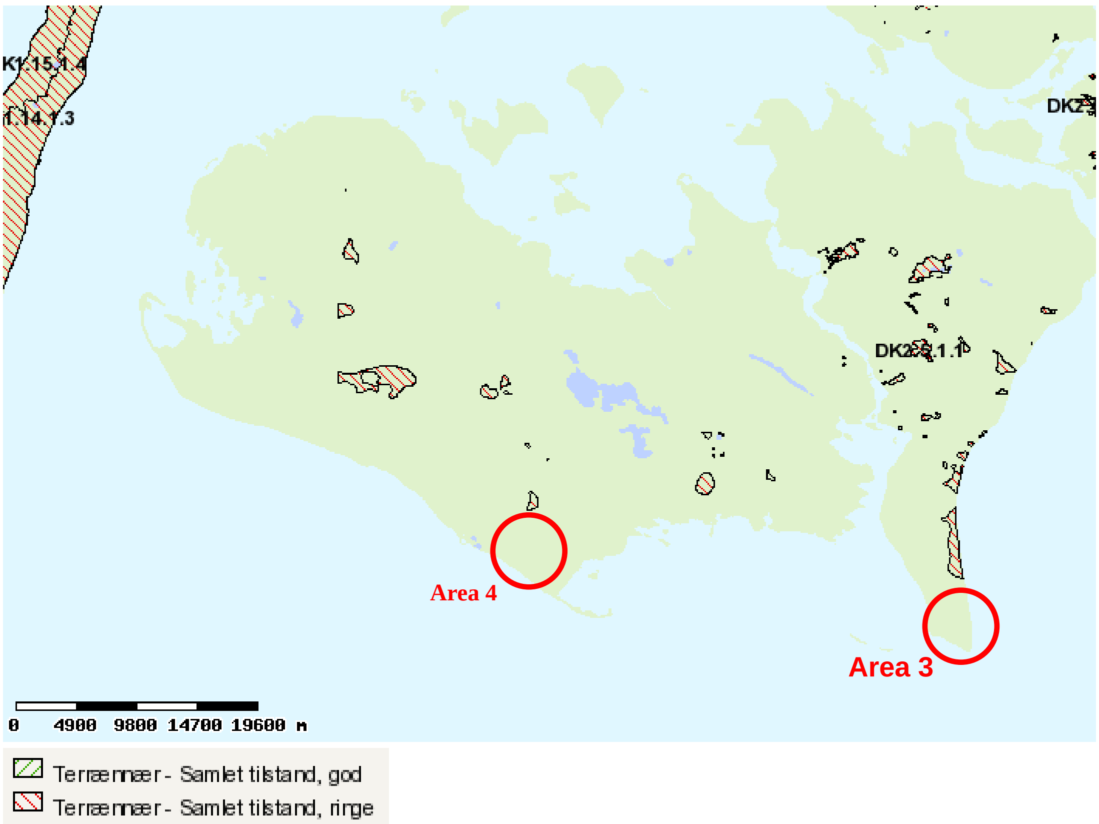


Figure 53. Shallow (or terrain near) groundwater bodies at Falster (Area 3) and Lolland (Area 4, see section 6.8). The overall assessment of chemical and quantitative status: poor status (Yellow shaded area). It has been assessed by the Environmental Centre that there are no drinking water interests in the shallow groundwater bodies (from the Miljøstyrelsen, 2010b).

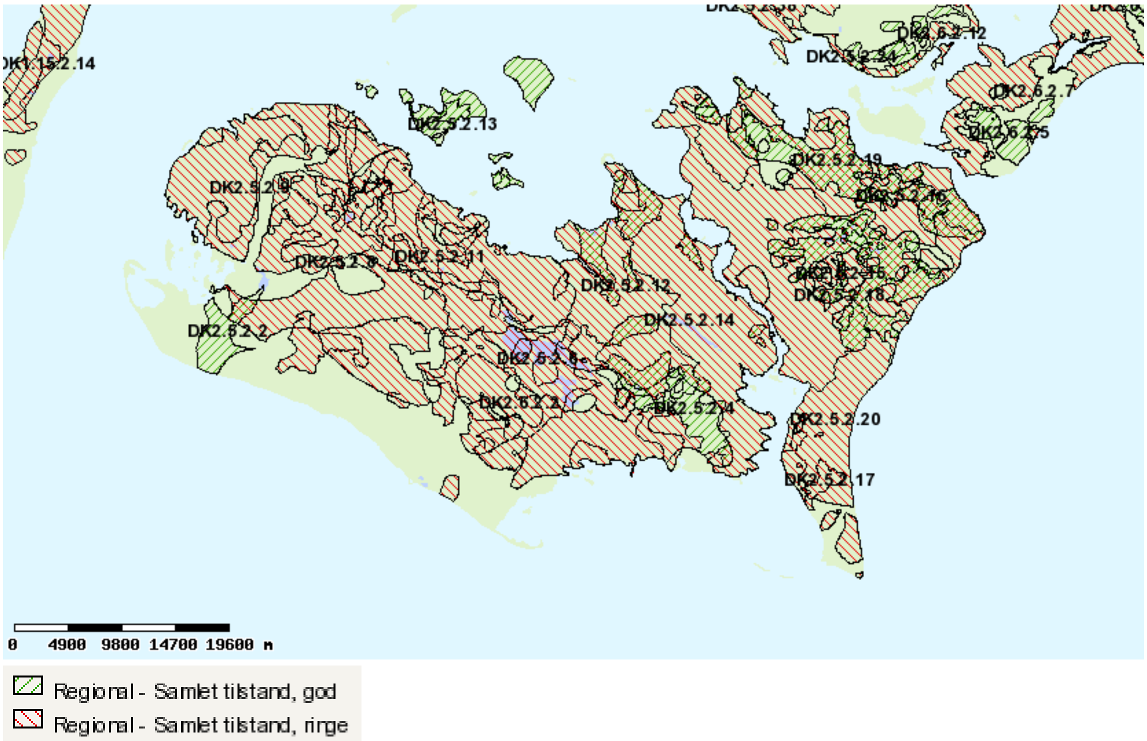


Figure 54. Regional groundwater bodies at Lolland-Falster. The overall assessment of chemical and quantitative status: poor status (Red shaded area) and good status (green shaded area) (From the Miljøstyrelsen, 2010b).

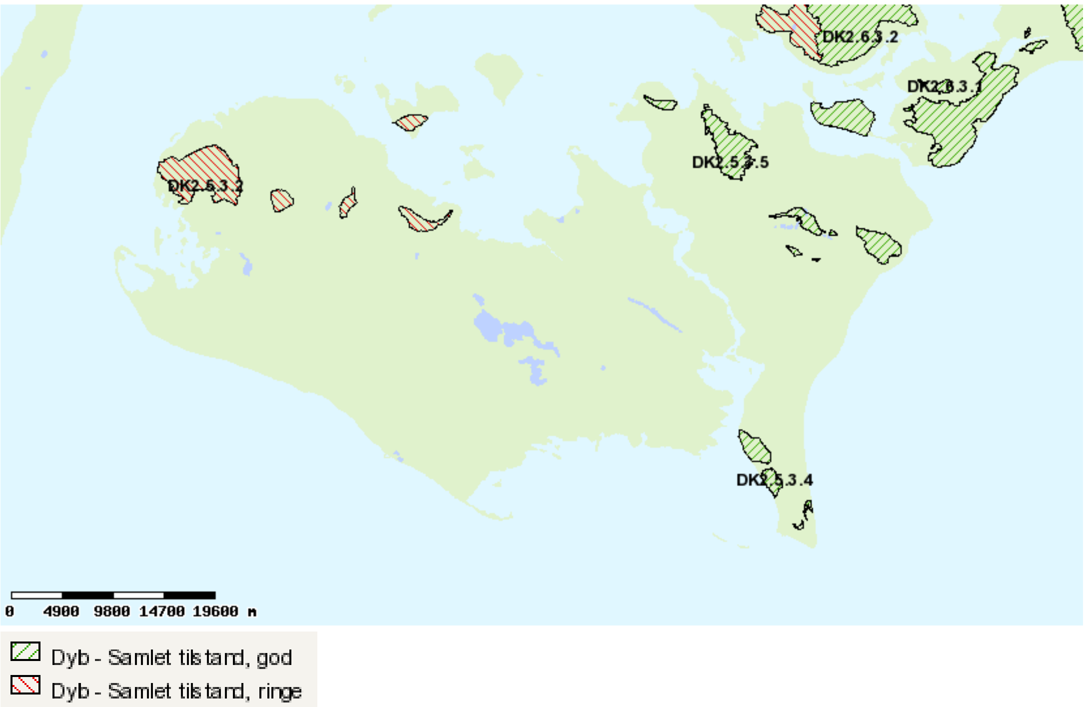


Figure 55. Deep groundwater bodies at Lolland-Falster (blue shaded areas). The overall assessment of the chemical and quantitative status: poor status (Red shaded area) and good status (green shaded area)(From the Miljøstyrelsen, 2010b).

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.56).

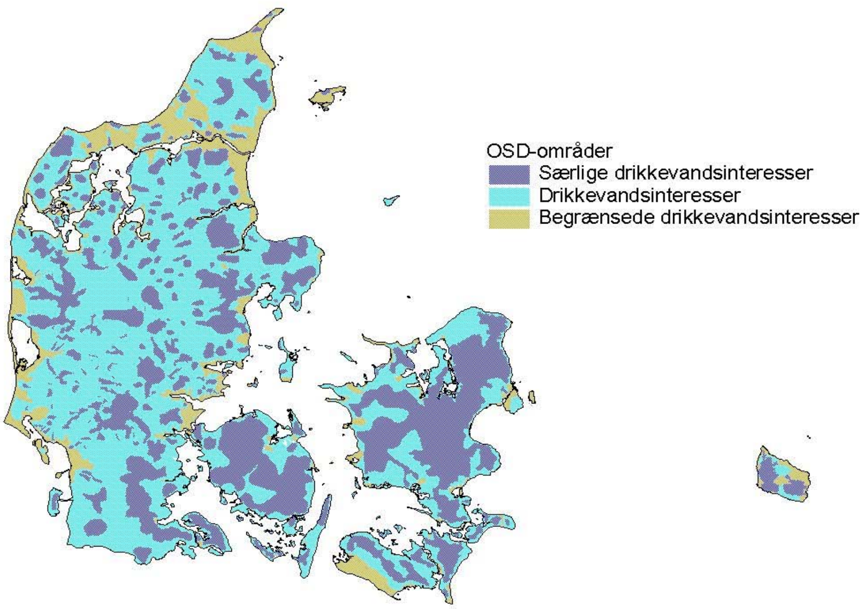


Figure 56. Map of three categories of drinking water interests in Denmark. The areas of special recharge groundwater and drinking water interests (OSD areas protected by law) are in dark blue colour. The areas shown with light blue colour are areas of some interest for drinking water purposes. The areas in brown colour are areas of limited (or none) drinking water interests (http://kort.arealinfo.dk/).

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

The drinking water areas categorised by the Environmental Centre Nykøbing for the Lolland-Falster region are given in Fig. 57. Area 4 placed just East of Rødbyhavn on the Southern part of Lolland, is situated in the category of limited or no drinking water interest.

There is a distance of 3-5 km to area of some drinking water interests just north of Area 4. However, it is important to notice that the groundwater direction in Area 4 is predicted to be toward south. It is very likely that a disposal site not will impact the important groundwater aquifers at the central parts of Lolland. However, it is of course required to confirm the flow direction with a detailed hydrogeological investigation.

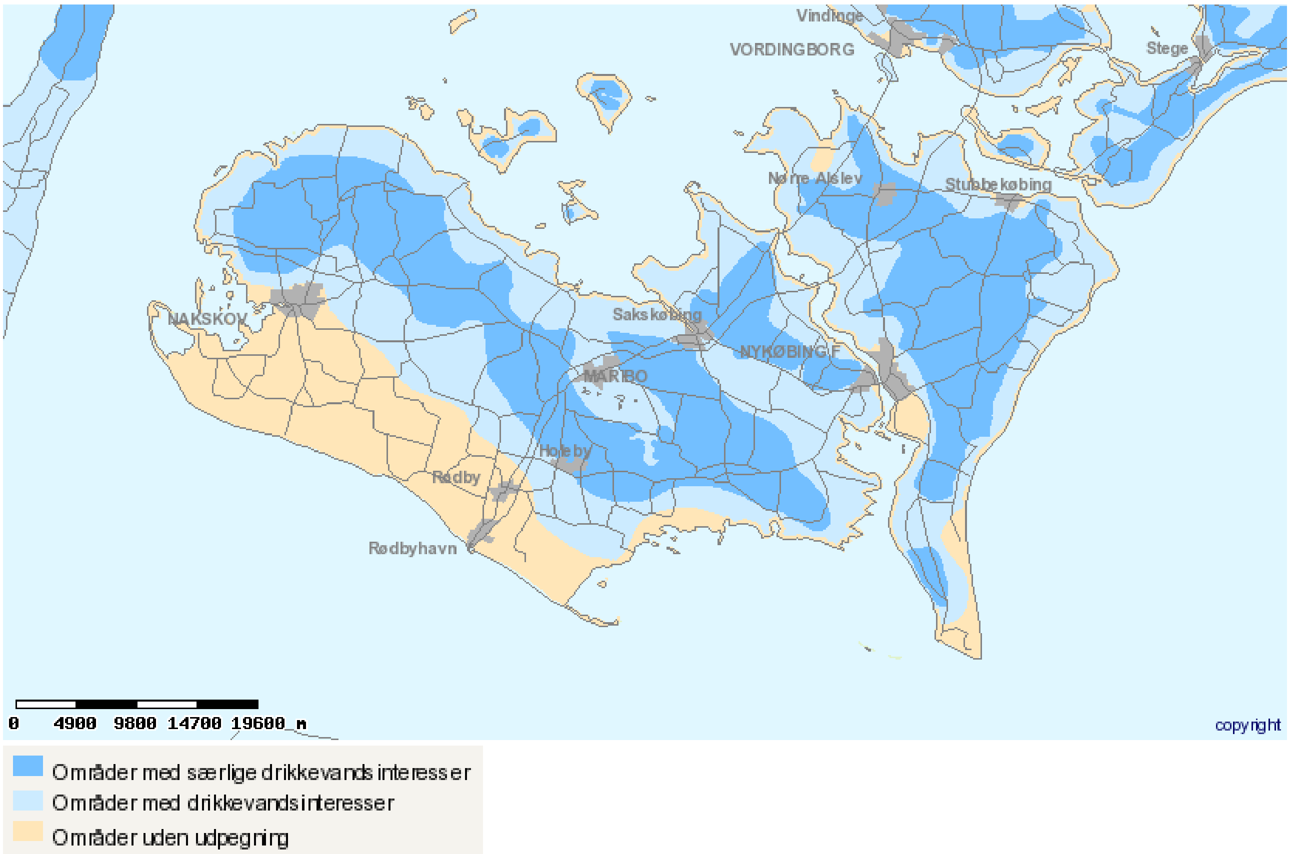


Figure 57. Drinking water areas at Lolland-Falster. Dark Blue: Areas of special drinking water interests; Light blue: Areas of some drinking water interests; Yellow: Areas with limited or none drinking water interests (http://kort.arealinfo.dk/).

6.9 Groundwater chemistry

The overall groundwater quality aiming for drinking water purpose has been assessed by Environmental Centre Nykøbing and reported in the river basin management plan (Hovedopland 2.6, Østersøen). The only groundwater body of regional type situated in Area 4 has been assessed to have a good chemical status.

Twenty-five years old analysis of chloride at Errindlev water work, situated 3 km from the coast at the northern margin of Area 4, indicate raised levels of chloride to the range of 250-500 mg Cl/L. Only very few abstraction wells exist in the area between Errindlev water work and the coast and no chemical analysis are available from these wells in JUPITER

Database. The coastline at Rødbyhavn contains 4 meter high dikes to avoid flooding of sea water into land. On the land side, an intense drainage system of ditches is established 1 to 3 meter below sea level to keep the land surface dry. The groundwater table in Area 4, closest to the coast, is positioned lower than the water table in the sea outside the dikes. This hydraulic scenario may potentially raise the saltwater/freshwater transition to less than 80 meters depth. Further site specific investigation of this topic is needed. Thus, it cannot be excluded that seawater (brackish water) intrusion can appear in the coast-near segments of Area 4.

6.10 Climate and climate changes

The actual climate and the expected future climate changes and sea level development is described in Gravesen et al. (2010, Rep. No. 2). It is not expected that a rise in net precipitation will influence on (deep) groundwater formation and level. But more and more intense rain may cause troubles to the lowest parts of the area if the ditches and the pumps cannot keep up with the surplus of water. It is obvious, that a higher sea level increases the risks for flooding of this low-lying area.

6.11 Restrictions and limitations

The area is a potential area for digging and exploitation of Paleocene clay (bentonite) and therefore regarded as a raw material interest area and special cautions should be taken in relation to the resource. The raw material resources interests will be changed in relation to area reservations for the Femern BeltFixed Link. No NATURA 2000 area or protected areas are found in Area 4 (Fig. 58).

A larger NATURA 2000 habitat area and a protected area in accordance to Naturbeskyttelsesloven (law for nature protection, see Chapter 6) is positioned just east of and maybe along the margin of Area 4. In addition, seawater intrusion can be a problem in the coast-near part of Area 4. A future sea level rise scenario will exacerbate the risk for further rise of the salt/freshwater interface and flooding of the area.

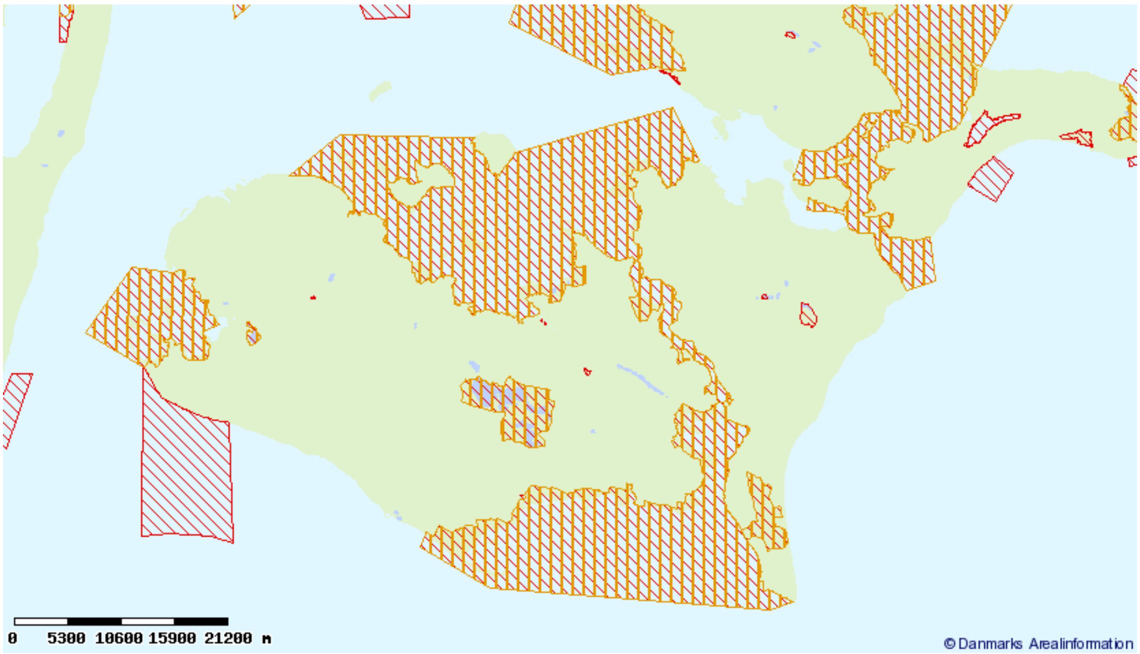


Figure 58. NATURA 2000 Areas at Falster and Lolland (From the Miljøstyrelsen, 2010b).

6.12 Summary of the area conditions

Amount of data:
Sparse, but some boreholes and several physical surveys.

Homogeneous conditions and isolation of the waste by low, permeability layers:
Perhaps perfect at depth of 30 to 100 m. A framework of fractures can be expected to less than 20 m depth. Potential fracture problem deeper than 20 meter have to be considered in relation to knowledge from other areas.

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

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

Groundwater conditions
Likely, the groundwater flow in the area is slow because of the comprehensive clay deposits. The level of the groundwater table is expected to be depth range from 1 to 5 meter below terrain but site specific investigations need to be carried out 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 retension of radionucleides in glacial till sediments.

Drinking water interests
No OSD within the Area 4. However, the northern margin of Area 4 slightly overlaps with 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 precipitation and storms will not have influence on a disposal.

Other restrictions
Clarification of the exact position with the tunnel construction for the Femern belt Fixed Link is required.

6.13 Final remarks

Based on existing data, Area 4 on Lolland is a well documented area in relation to location of a waste disposal but the area reservation for the Femern Fixed Link is problematic. Geophysical investigations (indirect data) indicate that thick Paleogene clay deposits can be found on the southern part of Lolland but documentation by borehole data are very rare.

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The specific maps and wells are cited in the reports describing the approx. 20 localities.