DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2011/49

Low- and intermediate level radioactive waste from Risø, Denmark. Location studies for potential disposal areas. Report no. 9

Characterization and description of areas Limfjorden

Peter Gravesen, Bertel Nilsson,
Stig A. Schack Pedersen
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GEOLOGICAL SURVEY OF DENMARK AND GREENLAND
MINISTRY OF CLIMATE AND ENERGY

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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, 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 earth surface down to 300 m depth. Therefore, the possible geological situations include sediments and rocks of different composition and age and these are also geographical distributed over large areas of Denmark. These sediments and rocks are shortly described based on existing information in Report no. 2 (Gravesen et al., 2010) where four different types are included. 1: Crystalline granites and gneisses of Bornholm because in many other countries these rocks types are host for waste disposals. 2, Sandstones and shales from Bornholm as these sediments has fracture permeability, 3. Chalk and limestone because these sediments both act as groundwater reservoirs but in areas are low permeable seals. 4. Tertiary fine- grained clay deposits which are widely distributed, low permeable and can reach large thickness, 5. Quaternary clays of glacial, interglacial and Holocene age can also be important.

All the Danish sand and gravel deposits are excluded from the description because of their potential as ground water reservoir, high permeability, low sorption possibilities and low protection conditions. The sand and gravel deposits often occur below or above the described low permeable and fractured deposits and sand layers can be intercalated in them. Therefore in certain situations sand and gravel sediments are included in the final descriptions.

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 in southern part of Limfjorden, between southern Thy and Viborg, is focused on the occurrence of Late Elsterian meltwater clay and silt and Oligocene/Miocene clay and silt which can fulfil the criteria and answer the questions described and put forwards in Gravesen et al., (2010, Report no. 1).

The Elsterian clay area is large and therefore subdivided into three subareas. Towards the west one area is situated at Handbjerg, Struer. At Vorde, north of Viborg another subarea is located. The third subarea Lynderup is found north of Vorde.

In five areas, the preliminary studies have focused on Oligocene (Miocene) clays from the Vejle Fjord Formation, Branden Clay Formation and Viborg Formation. Towards the west, one area is located on Thyholm. Another area is found at Harre Vig, Salling and two other areas are located on Salling: Branden and Thise. West of Skive, the last area occurs. The areas are both similar and different on the same time but it is relevant to investigate and analyse these geological situations in relation to potential disposal areas.

5. Area 16. Limfjorden - south

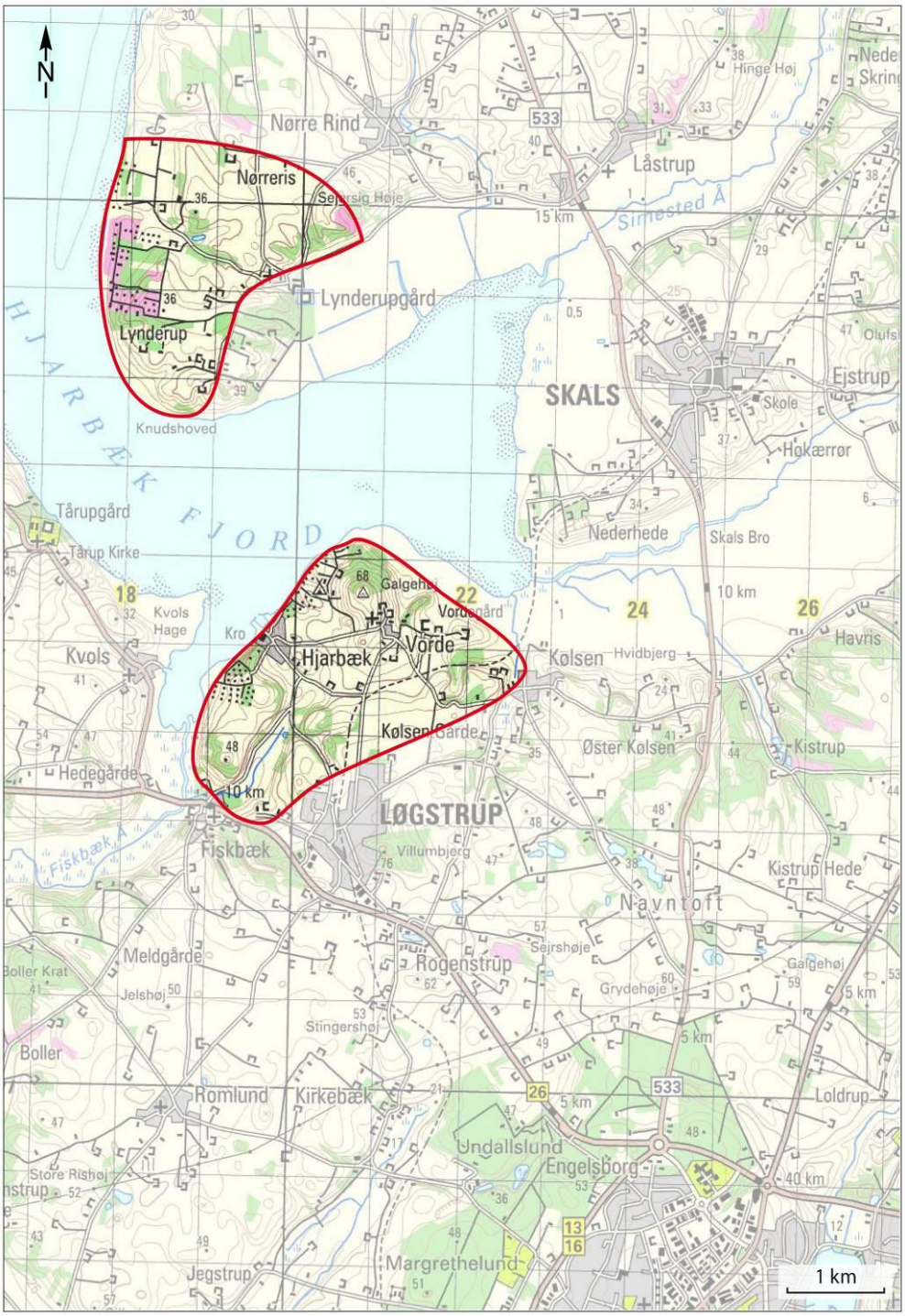
5.1 The location of the area

The area is located south of Limfjorden, between Struer and Viborg and consists of three subareas: Handbjerg just east of Struer, Vorde at Løgstrup and Lynderup north-west of Skals. The areas can be seen on figs. 1 and 2.

Figure 1. Location of the area. Limfjorden south is located in the middle part of Jylland.


N
Feriekoloni
Nørskov
Hærup Strand
Hostrup Strand
Nørby
Venø Tap
Kro
Skole
Pumpestation
Venø By
VENØ
Lejrskole
SUND
Stodbjerg
VENØ BUGT
Nygård Hage
Geddal
Elbrønd
Ejsingholm
Ultang
Kleppen
Venø Odde
Struer Bugt
Vrald Odde
Råst
Landting
Landting Mark
Skolehjem
STRUER
Handbjerg
Hummelmose Å
513
Hellegårde
Nørre Bjert
5 km
Volstrup
Nørrehede
Snødder
Skole
Kvistrup
Handbjerg Hovgård
Sønder Bjert
Telling
Dalby Gårde
Volstrupby
Kragelund
Hjerm Østre Kirke
Handbjerg Kirke
Rydhave
Hjerm Hede
Skole
HJERM
Skelsgårde
Tindskov
1 km
68
66
64
62
60
58
76
78
80
82
84

a.



b.

Figure 2. Detailed map of the subareas. (a) The subareas Handbjerg at Struer and (b) the subareas Vorde and Lynderup north of Viborg.

5.2 Terrain, topography and surface processes

Handbjerg

The area is located along the coast in the southern part of Venø Bugt in the south-western Limfjord area and east of the city Struer. The size of the area is c. 6.7 km^2. The Handbjerg area is situated on the northern slope of an end moraine. Along the southern delimitation of the area, the terrain is located up to 30 meters above sea level (m.a.s.). From here, the landscape slopes gently toward the coast in the northern direction and toward the Hellegård Å river valley (1 - 3 m.a.s.) in the eastern direction. The distal c. 0.5 km^2 of the valley has developed into a marine foreland with beach ridges and small overgrown lagoons. The longshore drift has forced the mouth of the stream Hellegård Å in a western direction. Apparently, the stream is now fixed by a channel. The coast seems to be suffering from a negative sediment budget (coastal erosion), as many groins are found along most of the coastal section west of the marine foreland.

The area is transacted W – E by a railway and a main road. The area north of the railway, next to the coast, is marked by two larger clusters of summer cottages and a small village, Handbjerg, west of the Hellegård Å. The area south of the railway is open land with few smaller roads and scattered houses. This part of the area is used for agriculture.

Vorde

The area is located at the south coast of Hjarbæk Fjord in the south-eastern part of the Limfjord area and SW of the city Skals. The size of the area is c. 6.1 km^2.

The terrain is undulating and marked by few great hills; the highest and dome-shaped, Galgehøj (68 m.a.s.) toward north-west, an elongated plateau-like (48 m.a.s.) toward south-west and a smaller, at Vorsegård (c. 20 m.a.s.) toward north-east. The area in the south-eastern part of the area is also high-lying (c. 40 m.a.s.) and plateau-like but not as well-defined and it is incised by steeper slopes several places. A stream is running in the valley between the two high-lying areas toward south-west. The area includes no lakes. The delimitation toward north-west follows the coast. A narrow marine foreland is found in front of the inactive, overgrown and locally very step and high coastal cliff. The coast appears stable or even prograding. Toward north-east, the delimitation is situated at the foot of the inactive and overgrown coastal cliff, at the passage to a c. 300 m wide marine foreland (1 m.a.s.).

Most of the area is used for agriculture. About 10 - 15 % of the area is covered by small woods. Several minor roads cross the area. The small village Hjarbæk is located in the central western part (including a harbour) and the even smaller village Vorde is found toward north-east. The area outside these villages only includes very few scattered houses, but many summer cottages and a camping place are found along the coast.

Lynderup

The area is located at the north coast of Hjarbæk Fjord in the south-eastern part of the Limfjord area and WNW of the city Skals. The size of the area is c. 5.6 km^2. The terrain is high-lying; c. 2/3 of the area is situated more than 25 meters above sea level (m.a.s.) with top level of 36 m.a.s. The landscape is undulating, but plateau-like in the highest areas. The remaining 1/3 part of the area is marked by relatively steep slopes toward the coast in the western and southern direction and toward the marine foreland in the south-east facing section, north of the farm Lynderupgård. A narrow marine foreland is situated at the foot of the slope along almost the entire coastal section of this area, and the coastline appears stable. There are no streams in the area but a small lake is located in the central part.

Most of the area is used for agriculture. About 15 - 20 % of the area is covered by woods and heath, which holds many summer cottages. Several minor roads cross the area. Scattered houses are located along some of the roads. A gulf course is found in the north-western part of the area.

The surface processes of the three sub-areas (soil creep, frost – thaw processes, soil development etc.) are proceeding slowly and undramatic owing to the cultivation and relatively low relief of large parts of the areas. The most dynamic processes are found locally, in the streams and in the coastal zone; the coastal zone of Handbjerg appears to be the most dynamic of the three subareas.

5.3 Surface geology and profiles

The surface geology is dominated by Quaternary deposits.

Handbjerg

At Handbjerg, clayey till dominates the subarea while meltwater sand and gravel besides Holocene marine and freshwater deposits occur towards the east (Fig. 3). No exposures exist in the subarea.

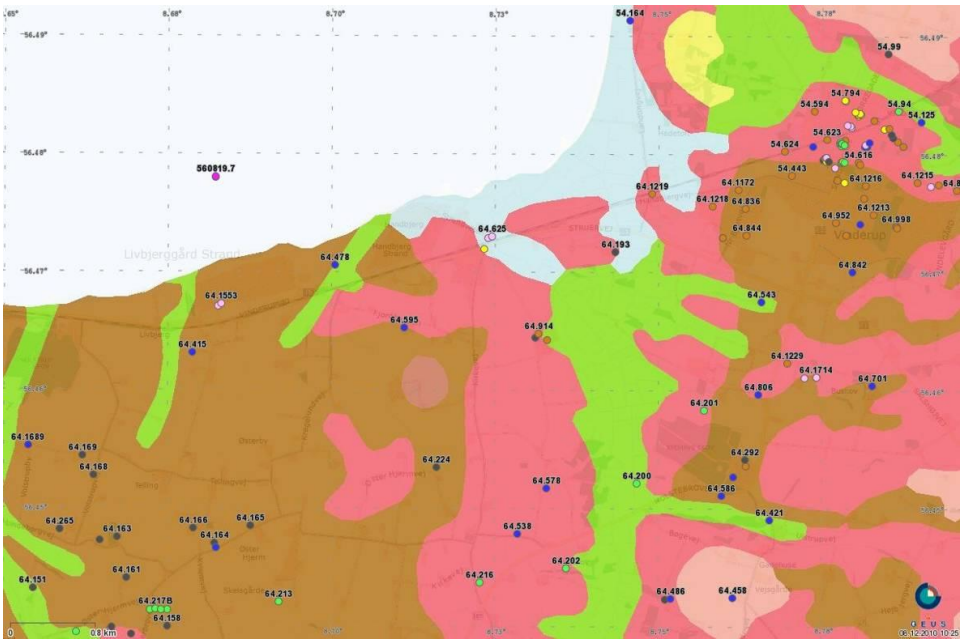


Figure 3. Map of the Quaternary surface deposits at Handbjerg (GEUS´s Homepage, after Pedersen, 1989). Legend: Brown: Clayey till; Light brown: Meltwater clay; Red: Meltwater sand and gravel; Green: Holocene freshwater deposits; Light blue: Holocene marine deposits; Yellow: Aeolian sand. Legend for the boreholes: See fig.6.

Vorde

The Vorde subarea is bordered by Holocene marine deposits towards the Limfjorden while otherwise clayey till dominate the area. Some areas of meltwater sand and gravel occur (Fig. 4).

No outcrops are found in the subarea.

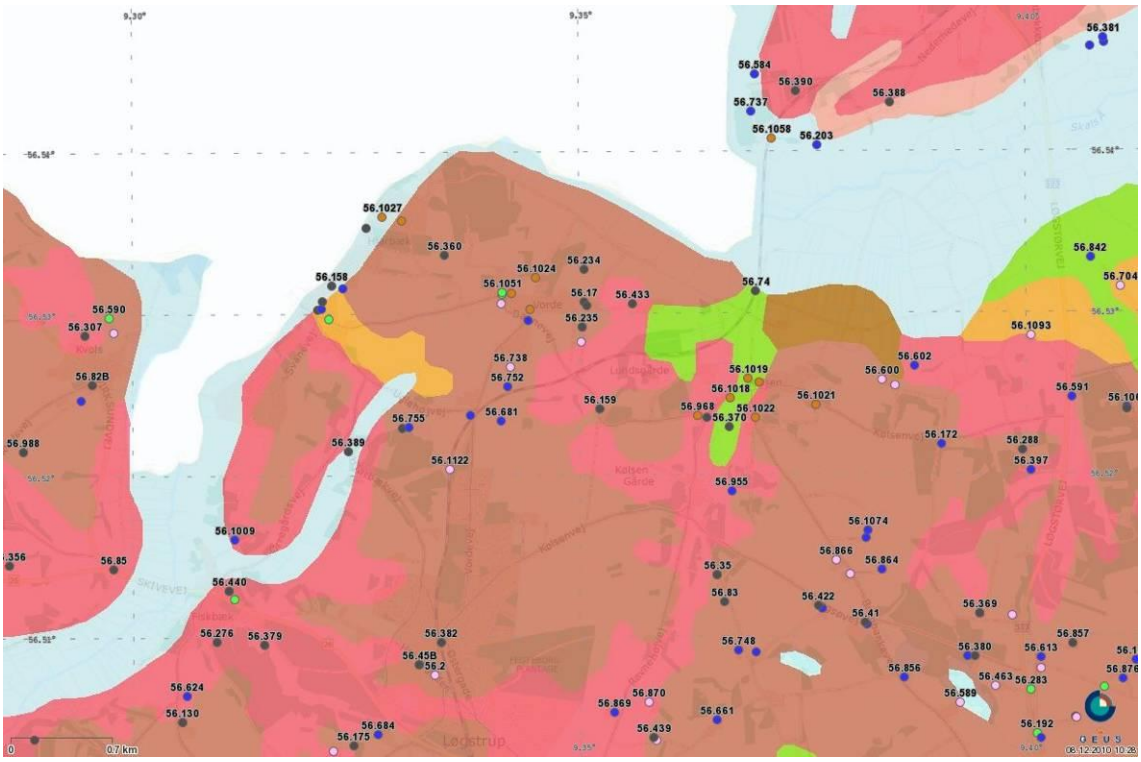


Figure 4. Map of the Quaternary surface deposits at Vorde. (From GEUS Homepage, after Pedersen, 1989). Legend: See fig. 4.

Lynderup

The peninsula has Holocene marine deposits towards the Limfjorden. Meltwater sand, gravel and clay form most of the area while clayey till is the core of the peninsula (Fig. 5). No exposures of the sediments occur in the subarea.

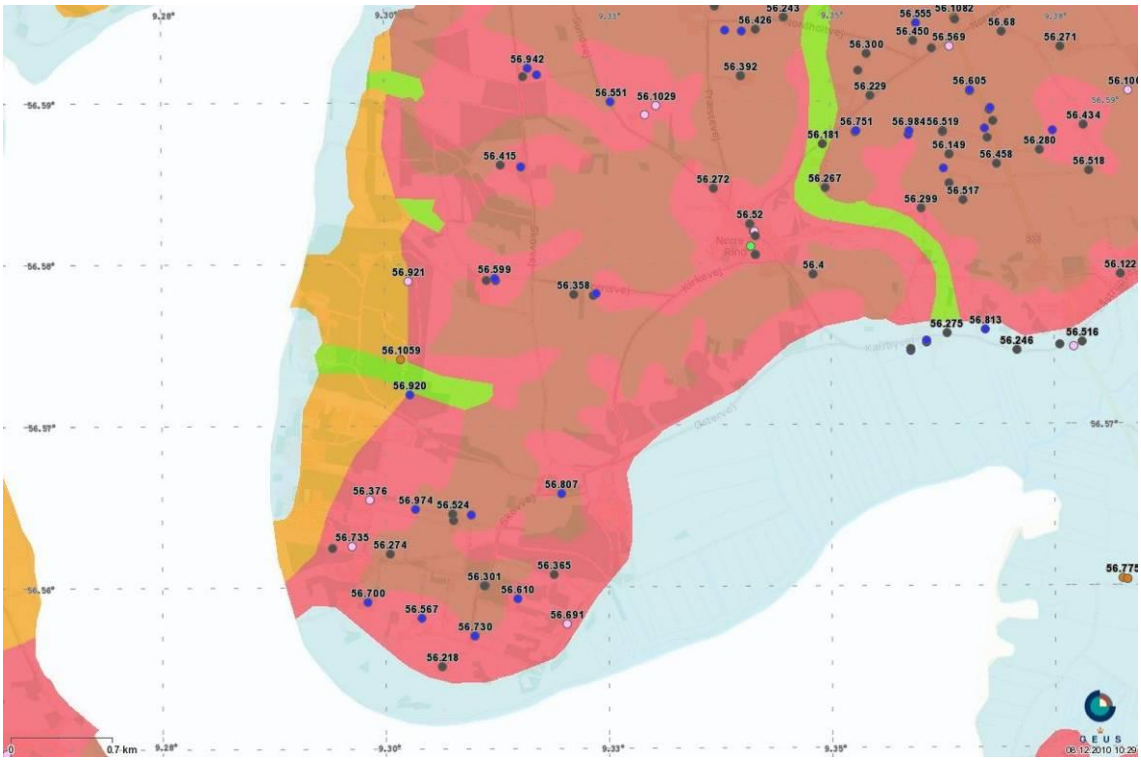


Figure 5. Map of the Quaternary surface deposits at Lynderup on the Skals peninsula (From GEUS's Homepage, after Pedersen, 1989). Legend: See fig.3.

5.4 Boreholes

The area south of the Limfjorden is penetrated by many hundred boreholes and many reach the target deposits: Elsterian meltwater clay. The drillings method normally produces fair samples of the Quaternary sediments. The distribution of boreholes at the three subareas is illustrated in figs. 6, 7 and 8.

Most of the boreholes are wells that supply households, smaller farms and other local needs. Many wells are shallow, some are dug, but because of the need for the optimal water supply, the wells have to reach groundwater reservoirs in more than 100 m depth.

Handbjerg

Relatively few boreholes are found at Handbjerg (Fig. 6). No geophysical investigations have been carried out.

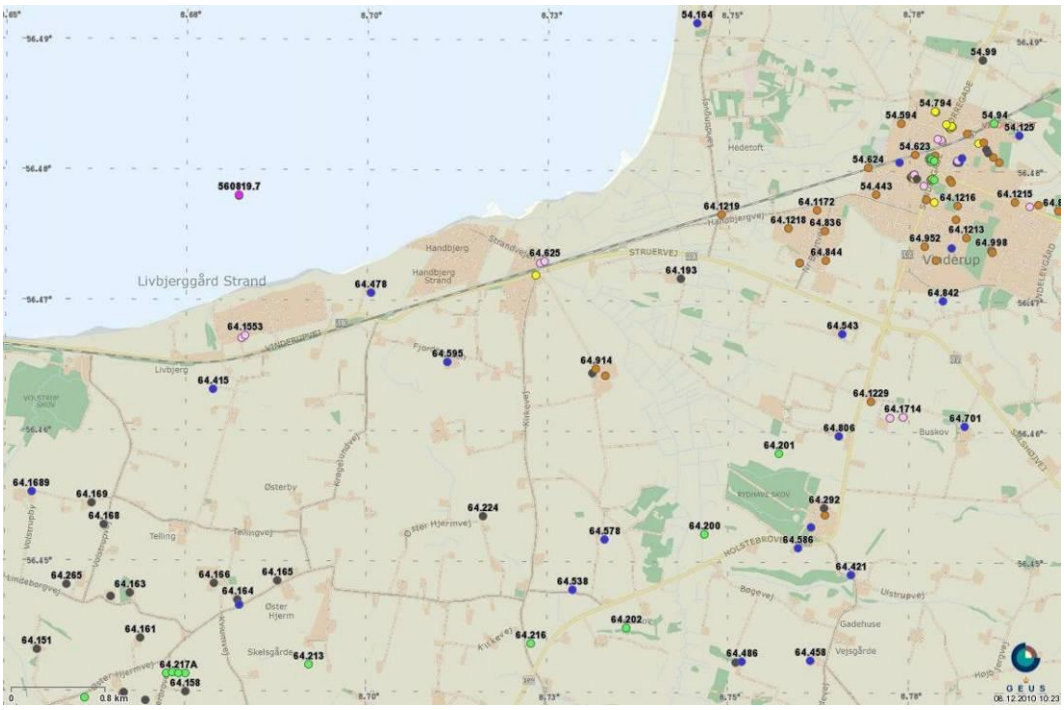


Figure 6. Map of the locations of boreholes from the Jupiter database at GEUS. Legend: 64. 415: DGU no., Blue dot: Water supply well; Red dot: Geotechnical borehole; Pink dot: Raw material borehole; Green dot: Other borehole; Light red dot: Abandoned borehole; Black dot: Unknown purpose.

Vorde

Some boreholes occur on a small area at Vorde (Fig.7). No geophysical surveys are known form the area but some surveys have been performed east of the area.

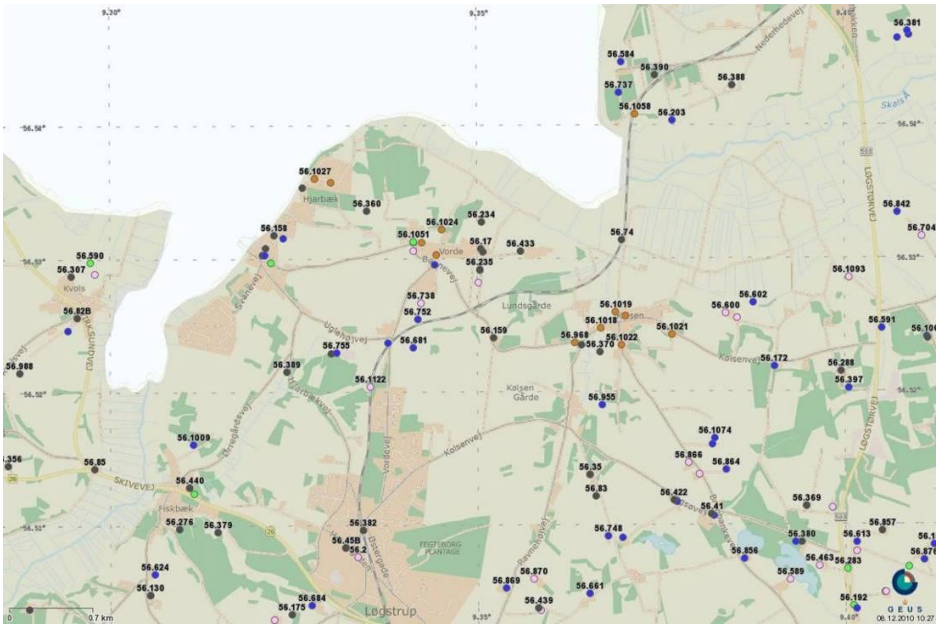


Figure 7. Location of the boreholes in the Vorde subarea. Legend see fig. 8.

Lynderup

Some boreholes are located in the Lynderup area (Fig. 8). The area is covered by some geophysical surveys.

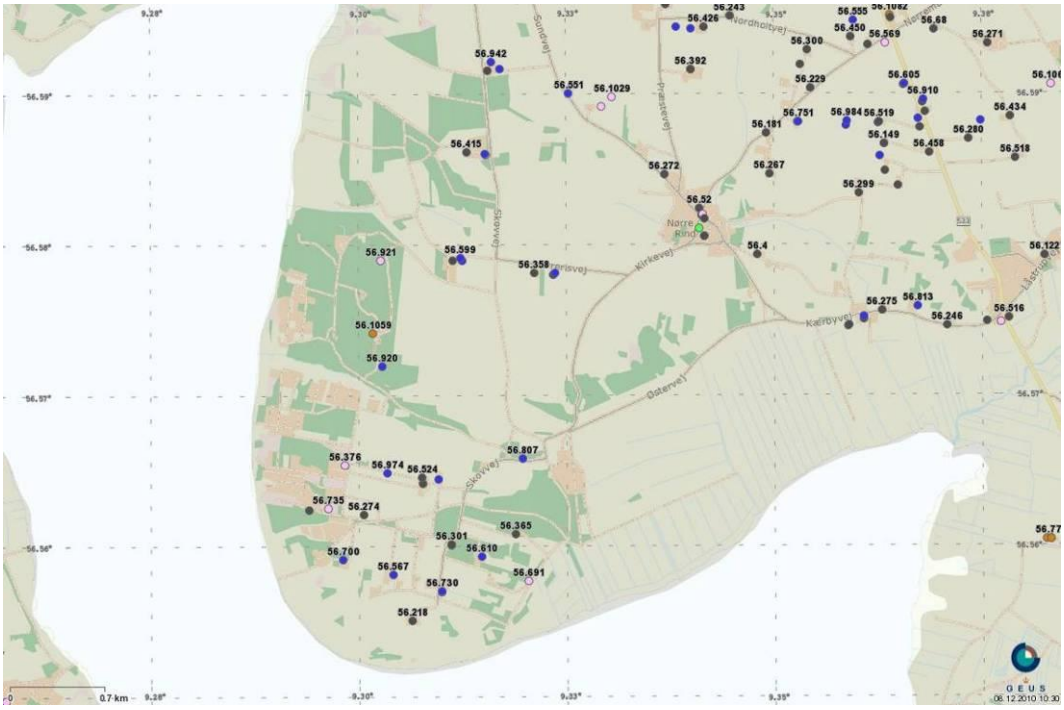


Figure 8. Locations of boreholes in the Lynderup subarea. Legend: See fig.6.

An example of a borehole from the Vorde subarea are seen in fig. 9.

De Nationale Geologiske Undersøgelser for Danmark og Grønland — Udskrevet 16/9 2010 Side 1

BORERAPPORT — **DGU arkivnr: 56. 940**

Borested : Bavnevej 45 A, Vorde
8831 Løgstrup
Bor.nr.1, boringen negativ

Kommune : Viborg
Region : Midtjylland

Boringsdato : 5/4 1993 — **Boringsdybde** : 85 meter — **Terrænkote** : 22.5 meter o. DNN

Brøndborer : Poul Christiansen,Højslev
MOB-nr : 17925
BB-journr : 48/93
BB-bornr :

Prøver
- **modtaget** : 15/7 1993 **antal** : 9
- **beskrevet** : 29/1 1996 **af** : AGR
- **antal gemt** :

Formål : Vandforsyningsboring
Anvendelse : Sløjfet/opgivet bor
Boremetode : Lufthæve

Kortblad : 1215 IVNØ
UTM-zone : 32
UTM-koord. : 521624, 6265135

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

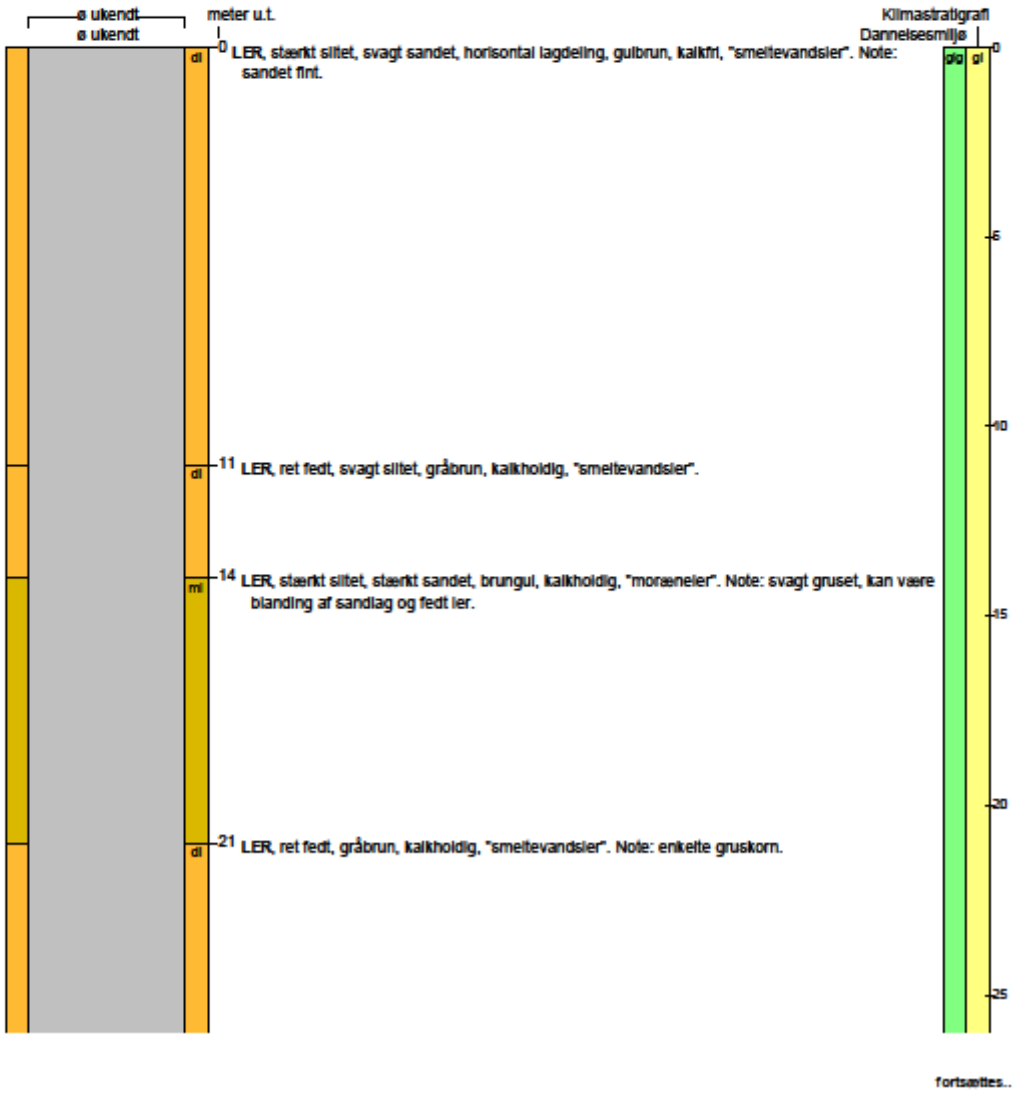


Figure 9. Borehole log for DGU no. 56.940. The upper part of the 85 m deep borehole. Legend: DL: Meltwater Clay; ML: Clayey Till.

5.5 Sediment and rock characteristics, mineralogy and chemistry

5.5.1 Pre-Quaternary rocks

The distributions of the pre-Quaternary sediments in the three subareas can be seen in fig. 10. The clays and sands are from the Oligocene and Miocene.

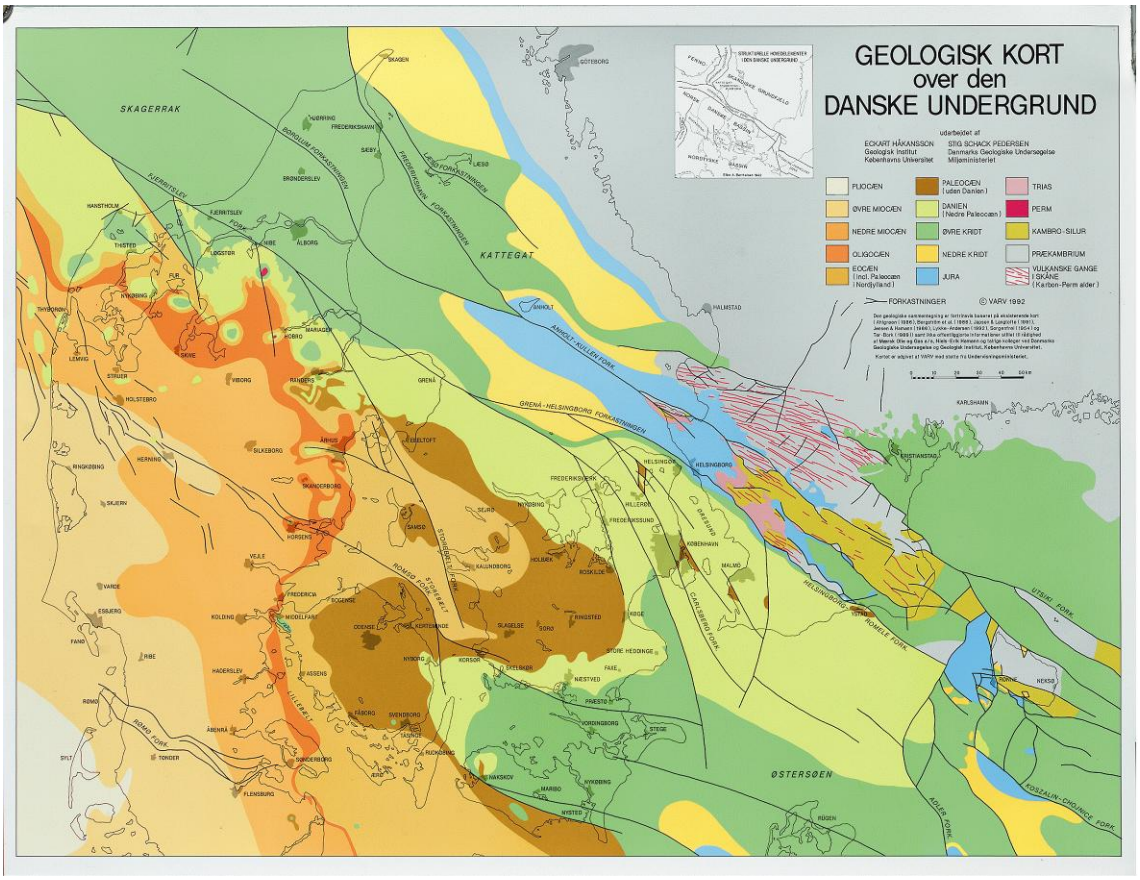


Figure 10. Map of the pre-Quaternary surface: Time units. Original scale: 1:50.000. Legend: Red lines: Precambrian intrusions; Grey: Precambrian; Olive: Cambrian-Silurian; Red: Permian; Light red: Triassic; Blue: Jurassic; Yellow: Lower Cretaceous; Green: Upper Cretaceous; Light green: Danian; Brown: Paleocene; Yellow; Olive: Eocene; Red brown: Oligocene; Light yellow brown: Lower Miocene; Very light yellow brown: Upper Miocene; White: Pliocene (Håkansson & Pedersen, 1992).

Pre-Quaternary deposits are not reached in boreholes in the three subareas. At Handbjerg, the pre-Quaternary deposits (probably from the Early Miocene) are at least covered by 100 m of Quaternary sediments. Towards the southwest, at the Vejrum salt diaper, the Quaternary cover above Paleogene and Neogene deposits is only of 5 - 50 m thick..

At Vorde, Oligocene micaceous clays occur below at least 150 m Quaternary deposits and at Lynderup, the Quaternary sediments are more than 110 m thick.

The uppermost formation is probably the Oligocene-Miocene Vejle Fjord Formation including the Brejning Formation of clay, silt and sand. Below this, clays from the Branden Formation (Late Oligocene) and the Viborg Formation (Early Oligocene) are expected.

5.5.2 Quaternary deposits

The boreholes from the three subareas show thick layers of Late Elsterian clay. They are normally covered by clayey till or meltwater sand and gravel, probably from the Saalian or the Weichselian. The clay is olive grey or grey, calcareous and without gravel or stones. The clay shows horizontal lamination and is often interlayered by thin silt and fine-grained sand. The Elsterian clay has a very comprehensive distribution south of the Limfjorden, from the west coast to Viborg and thicknesses of more than 120 m are present. The clay is described from many coastal cliffs and clay pits (e.g. at Majgård and Stoholm) often together with marine deposits from the Holsteinian.

Grain-size analyses show an amount of 45 % in the clay fraction and the rest is mainly silt. Analyses of the clay mineralogy show the following:

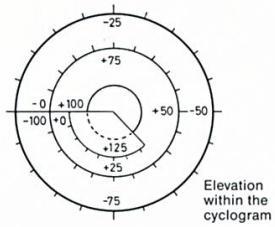
At Majgård clay pit, northeast of Højslev, the composition is: 36 % smectite, 42 % illite, 18 % kaolinite. At Stoholm clay pit, Stoholm city west of Viborg: Oxidized clay: 42 % smectite, 27 % illite, 31 % kaolinite and reduced clay: 62 % smectite, 17 % illite, 21 % kaolinite.

Handbjerg
At Handbjerg, the fine-grained and silty Elsterian clay and silt are up to 75 m thick and is almost exposed at the ground surface. Thin layers of clayey till can be found on the top. Below the Elsterian clay, meltwater sand and gravel in up to 15 m thick layers occur.

Vorde
At Vorde, the fine-grained and silty green grey or olive grey, calcareous Elsterian clay and silt can be approx. 120 m thick but is sometimes intercalated with clayey till. Above the clays, meltwater sand and gravel dominate in up to 20 m thick layers.

Lynderup
In the Lynderup subarea, thick layers of fine-grained olive grey, calcareous Elsterian clay and silty, olive grey calcareous clayey till occur and are more than 100 m thick with thin intercalated layers of fine to medium-grained meltwater sand. Borehole data and interpretations are shown in figs. 13 and 14.

LEGEND



Elevation within the cyclogram

Location of well

3,7/5.8 Yield in m^3/h per meter of drawdown

DG Rock symbols in letters. Uncertain geological interpretaton

Screened interval, known

Screened interval, estimated

Head of groundwater at screens, A, B.....

DGU sample description is available

67 Estimated lithological boundary Year of drilling (1967)

6.6 Diameter of bore hole/ Diameter of casing Ground surface (+10 m a.s.l.) Lithological boundary (−4 m bl.s.l.)

566 DGU. file No. (566)

Bottom of casing (−4m bl.s.l.)

Ground water level at completion of well

at later observation

ROCK LETTER SYMBOLS

B	Dug well	I	Silt
BK	Danian bryozoan limestone	ID	Interglacial diatomite
C	Brown coal	IL	Interglacial fresh-water clay
DG	Glacial melt-water gravel	IP	Interglacial fresh-water gyttja
DI	Glacial melt-water silt	IS	Interglacial fresh-water sand
DL	Glacial melt-water clay	KG	Miocene quartz gravel
DS	Glacial melt-water sand	KS	Miocene quartz sand
DV	Alternating thin melt-water beds	L	Clay, marl
FS	Post-glacial fresh-water sand	LL	Eocene Clay, plastic clay
G	Gravel, sand and gravel	M	Mull
GC	Miocene brown coal	MG	Glacial gravelly till
GI	Oligocene – Miocene mica silt	ML	Glacial clayey till
GL	Oligocene – Miocene mica clay	O	Fill, waste
GS	Oligocene – Miocene mica sand	P	Gyttja
GV	Oligocene – Miocene alternating thin beds	PL	Paleocene clay
HI	Postglacial salt-water silt	PV	Alternating thin Paleocene beds
HL	Postglacial salt-water clay	S	Sand
HP	Postglacial salt-water gyttja	SL	Eocene marl
HS	Postglacial salt-water sand	U	Clay, sand and gravel
HV	Postglacial thin salt-water beds	V	Alternating thin beds
		X	No information

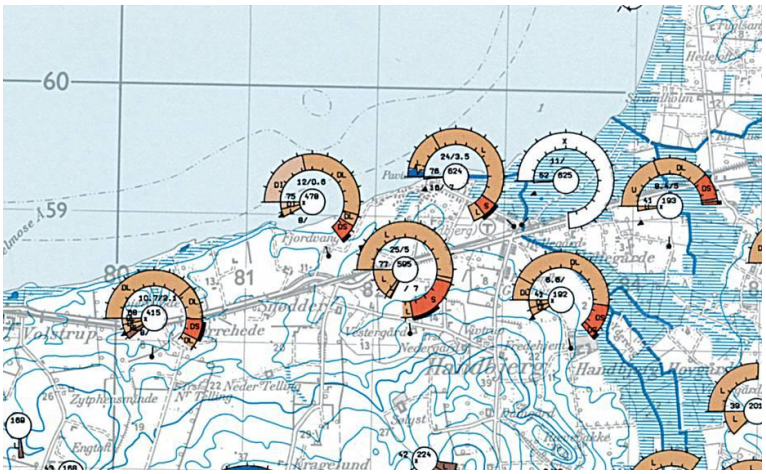
LITHOLOGY (interpretation)

- 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 11. Geological Basic Data map. a. Legend to the map (After Andersen & Gravesen, 1989, b. part of 1115 I Struer showing subarea Handbjerg. Original scale 1:50.000. (From Gravesen, 1989).

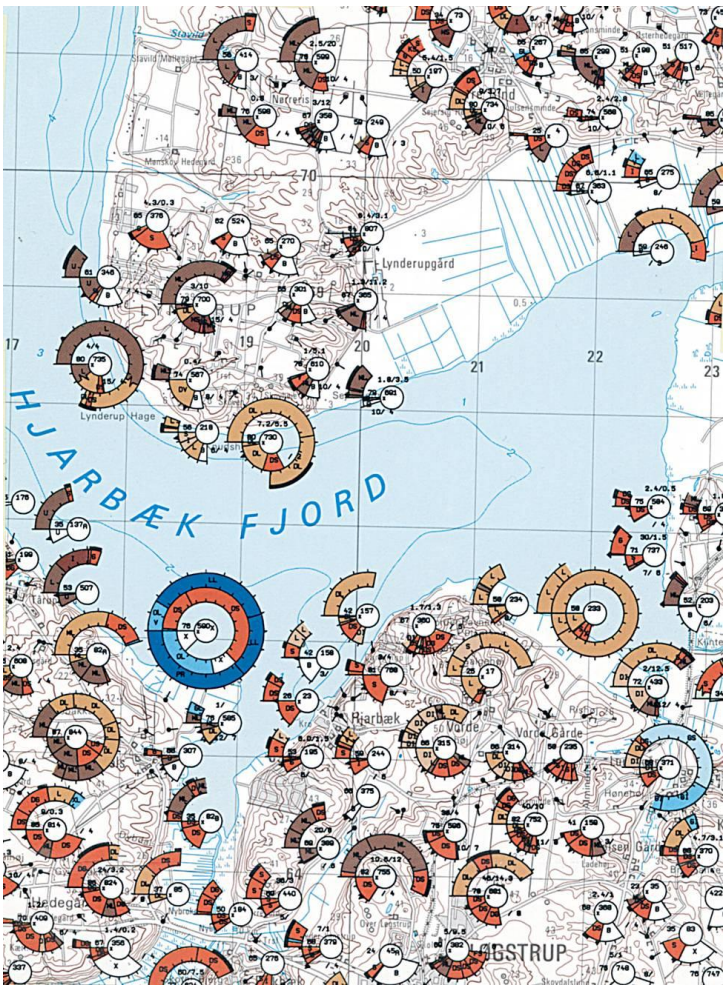


Figure 12. Geological Basic Data Map 1215 IV Viborg showing subareas Vorde and Lynderup. Original Scale 1:50.000. Legend: See fig.11 (From Gravesen, 1990).

The map of the Quaternary surface deposits is seen in fig. 13.

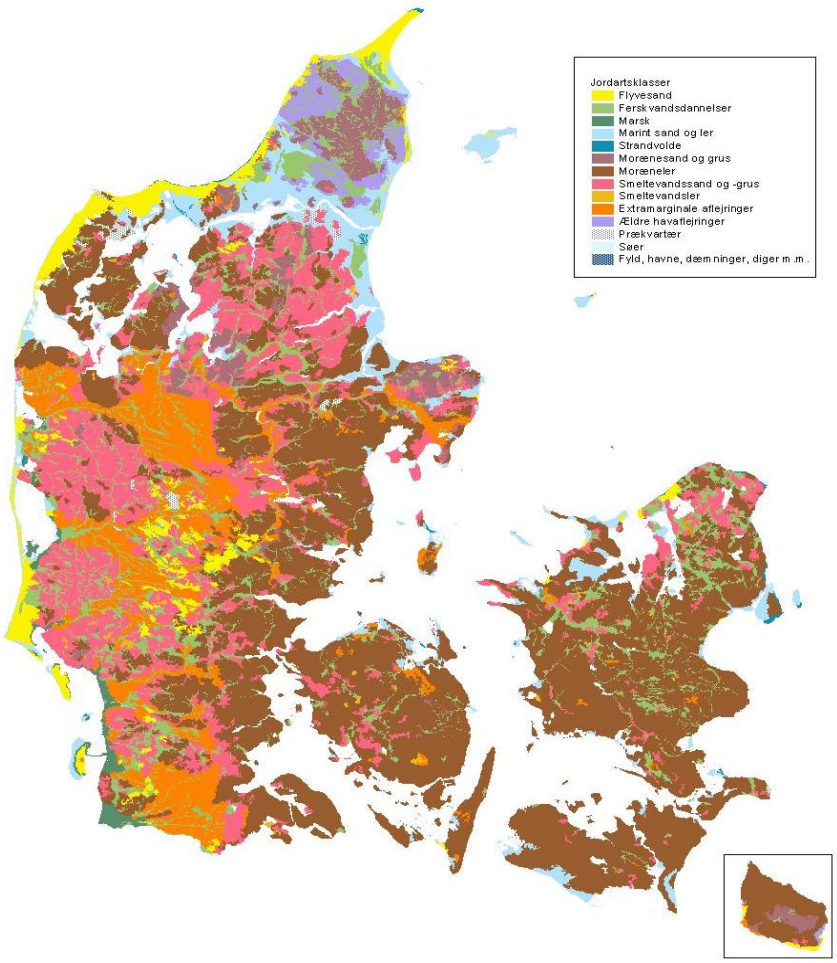


Figure 13. The map of the Quaternary surface deposits. Original scale: 1:200.000. Legend: Brown: Clayey till; Light brown: Sandy till; Red: Meltwater sand and gravel; Orange: Sandur sand and gravel; Purple: Late glacial marine deposits; Light blue: Holocene marine deposits; Green: Holocene freshwater deposits; Yellow: Aeolian sand (From Pedersen, 1989).

Examples of the Elsterian meltwater clay are seen in figs. 14 and 15.

Figure 14. Cliff section at Karby Klint, Mors showing the Elsterian fine-grained grey meltwater clay with distributed sand and silt lenses.

Figure 15. Horizontal laminated fine-grained Elsterian clay. Karby Klint, Mors.

5.6 Tectonics, structures and seismic activity

5.6.1 Major tectonic structures

The subareas are situated between the positions of several Zechstein salt diapers: Hvidbjerg (Uglev), Mors, Batum, Tostrup, Mønsted, Sevel and Vejrum (Fig. 16). The remarkable large occurrence of continuous Elsterian clay and silt layers up to 100 m in thickness between the salt diapers points to a formation of a large ice lake in Late Elsterian of meltwater from the melting Elsterian glaciers. It is possible, that movements in the salt diapers concurrently with the disappearance of the glaciers have contributed to the formation and subsidence of the lake basin.

Also glaciotectonic disturbances occur in the areas as known from e.g. the cliffs and sand-gravel and clay pits. In Majgårde clay pit, the layers are disturbed by glaciers coming from NNW.

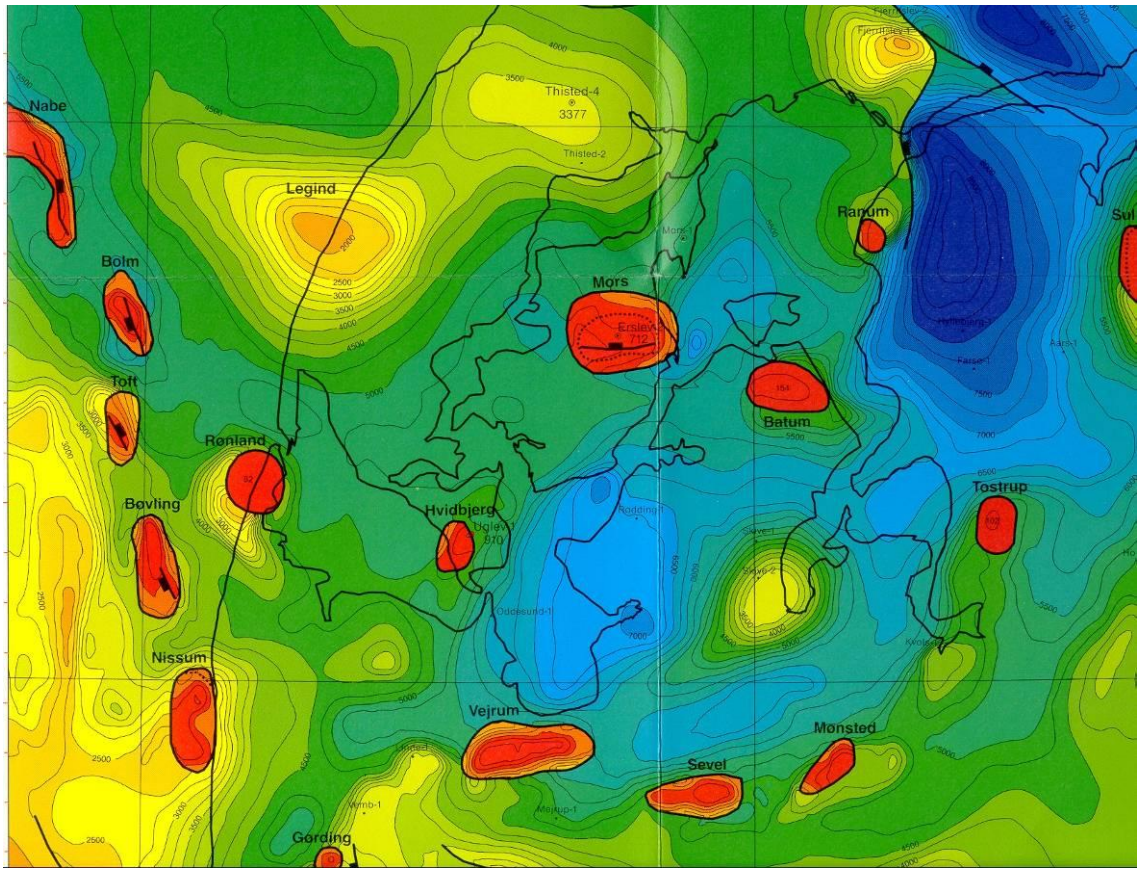


Figure 16. Map of the depth to base Cretaceous. The contours are in m; the blue is the deepest areas, the green and yellow the intermediate and the red are the shallowest areas. The salt diapirs in northern Denmark are shown with black lining. Also high laying structures (possible salt structures) can be seen as circular yellow areas. (From Japsen & Langtofte, 1991).

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. Small fractures in the fine-grained meltwater clays are also recognized.

Fractures in the fine-grained Tertiary clays are expected.

5.6.3 Geological model

The geological model of the area is rather simple concerning lithology but complex in relation to the structural conditions of the salt diapirs.

Model of the area is as follows (Fig. 17):

A. Quaternary clayey tills and meltwater sand and gravel, up to 20 m thick.

B. Elsterian meltwater clay, occasionally covered by marine Holsteinian clays, silt and sand. From 75 m to 120 m thick. The meltwater clay can be intercalated with clayey till.

C. Neogene and Paleogene silt and clay deposits, mainly Oligocene and Miocene.

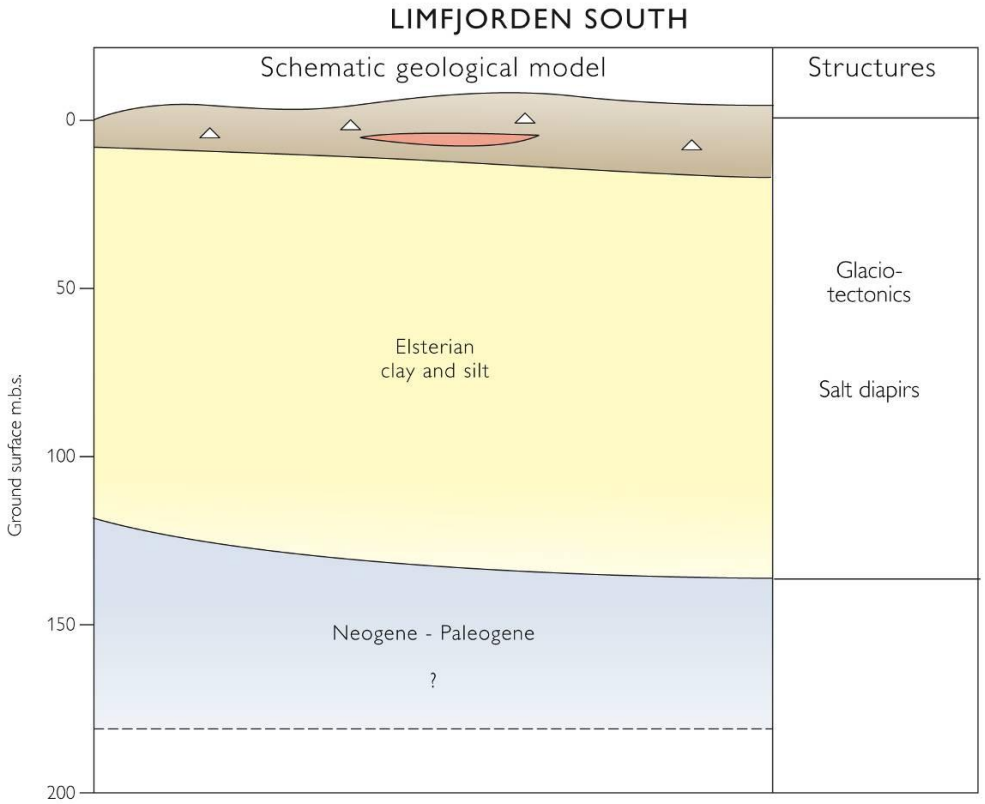


Figure 17. Schematic geological model of the Area 16.

5.6.4 Earthquake activity

The seismic station net in Denmark is operated by GEUS and comprises 5 stations of which three stations are located on Sjælland: Gilleleje museum, Vestvolden, København and Lille Linde, Stevns (GEUS´s homepage: www.geus.dk).

The earthquake activity is measured with respect to location, time and size. The activity in Denmark during the period 1929-2003 is very low compared to many other countries..

The seismic activity in the Limfjorden area is very low (Fig. 18). No seismic activity has been registered for the area although a seismic station is located at Mønsted.

It is impossible to relate recent seismic activity to the many faults and fractures in the bed-rocks. Other signs of recent movements along the faults and fractures have not been proven.

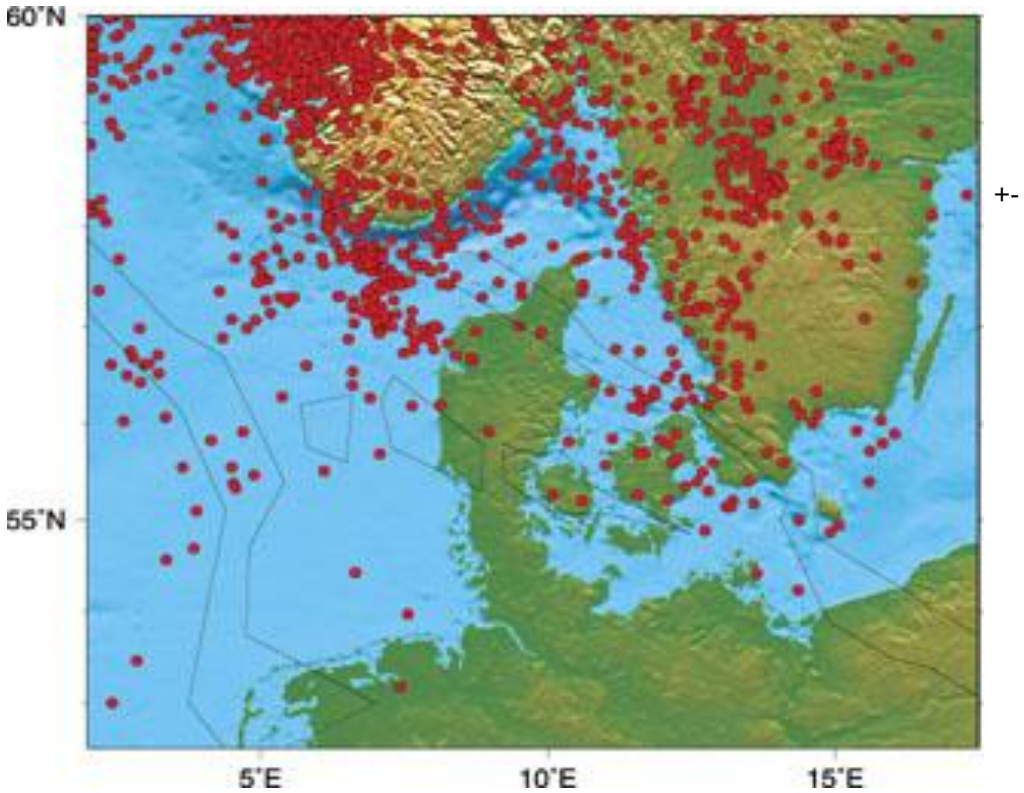


Figure 18. Map of the earthquake epicentres in Denmark and the surrounding areas. A red dot shows the location (From GEUS´s Home Page: www.geus.dk).

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 or fine-grained clays can give problems.

5.8 Groundwater hydrogeology

5.8.1 Groundwater characteristics

The Limfjorden south area is represented by the three subareas: Handbjerg, Lyndelse and Vorde. Area 16 is characterized by presence numerous groundwater bodies (GWB): two shallow groundwater bodies (DK 1.2.1.2; 1.2.1.10) (Fig. 19), four regional groundwater bodies (DK 1.2.2.14; 1.2.2.15; 1.2.2.17; 1.2.2.25 (Fig. 20) and two deep groundwater bodies (DK1.2.3.8; 1.2.3.19) (Fig. 21). The shallow and regional groundwater bodies all consist of meltwater sand deposits while the deep groundwater bodies consist of limestone (KS). The subdivision into groundwater aquifers/bodies are thoroughly described in the basisanalysis (Basisanalysis Part 1, 2004) in joint effort by the former counties in Ringkøbing, Nordjylland, Viborg and Århus. In addition, the Limfjorden catchment management plan (Hovedvandopland 1.2 Limfjorden) has been described by the Ministry of Environment. The overall assessment of the chemical and quantitative status: shallow GWB (all poor), regional GWB (three poor and one good), and deep (all good), see Section 5.9.

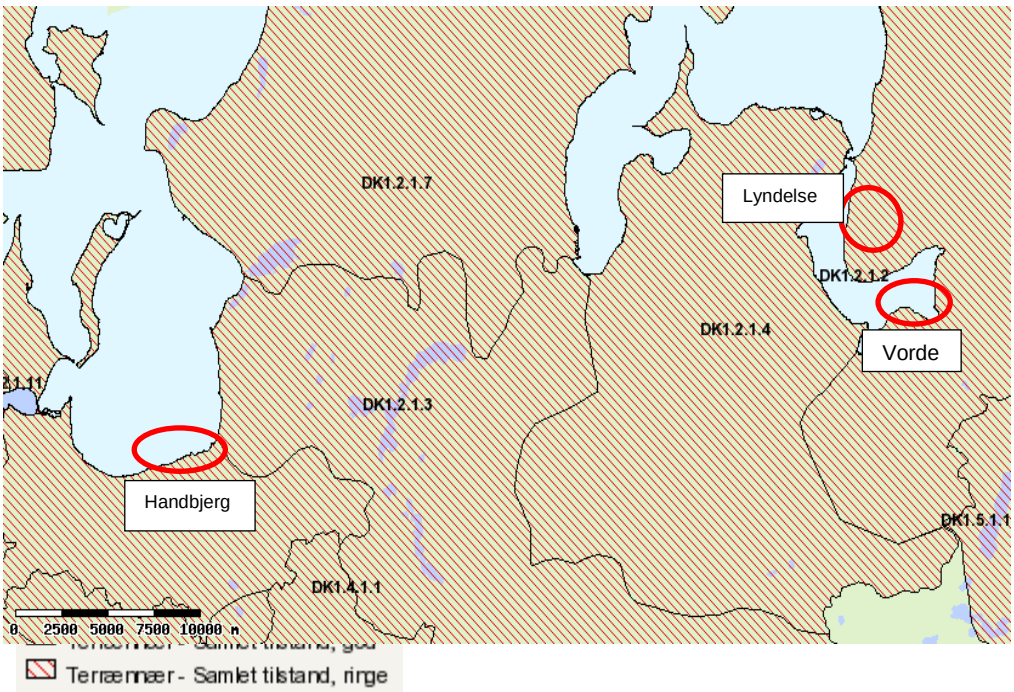


Figure 19. Limfjorden south – shallow groundwater bodies (After Ministry of Environment, 2010).

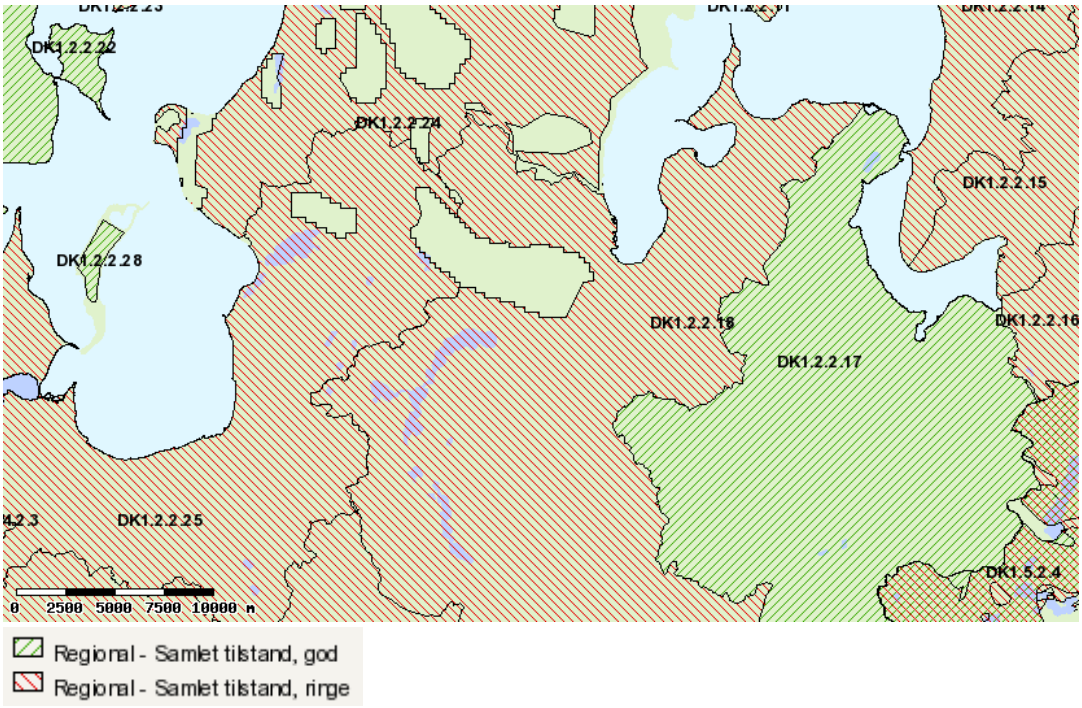


Figure 20. Limfjorden south – regional groundwater bodies (After Ministry of Environment, 2010).

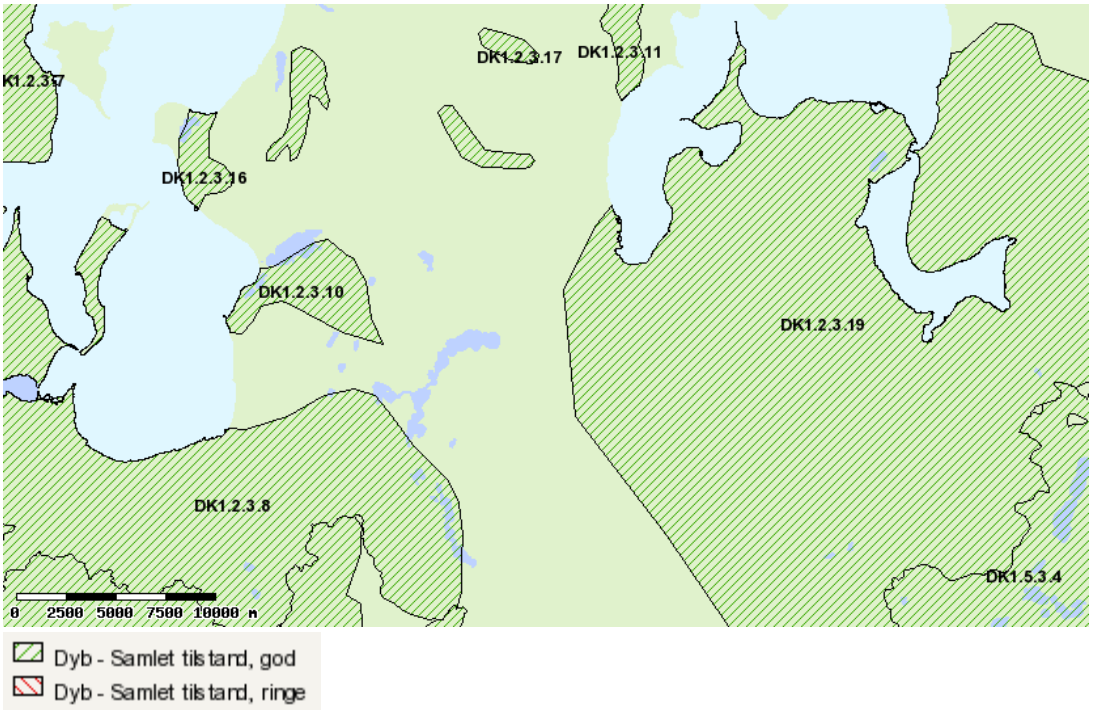


Figure 21. Limfjorden South – Deep groundwater bodies. (After Ministry of Environment, 2010).

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. 22).

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.

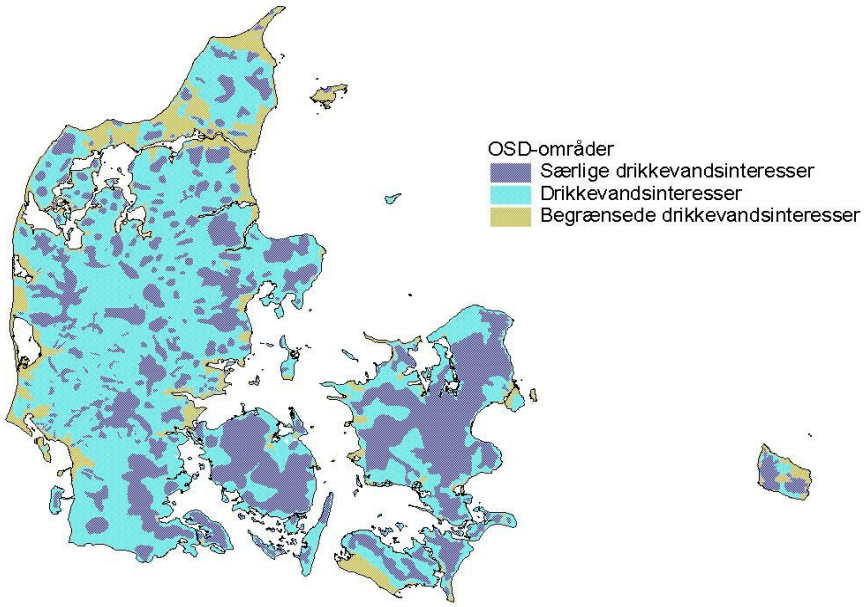


Figure 22. Map of three categories if drinking water interest in Denmark. The areas of special recharge groundwater and drinking water interests (OSD areas protected by law) are in dark blue colour. The areas shown with light blue colour are areas of some interest for drinking water purposes. The areas in brown colour are areas of limited (or none) drinking water interests (/kort.arealinfo.dk/).

The geographical distribution of the drinking water areas in the Limfjorden south area is given in fig. 23. All three locations are outside OSD classified areas but on the edge of OD or areas, with limited or no groundwater interests.

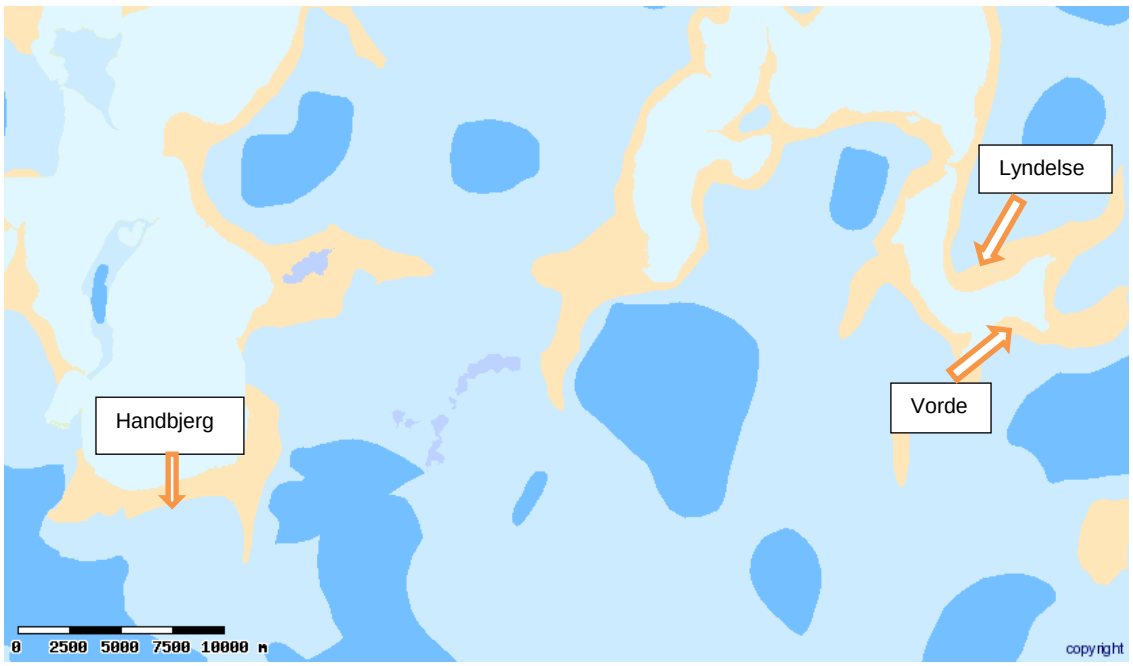


Figure 23. Distribution of the drinking water areas in the Limfjorden south area (Area 16). Dark Blue: Areas of special drinking water interests (OSD); Light blue: Areas of some drinking water interests (OD); Yellow: Areas with limited or none drinking water interests (/kort.arealinfo.dk/).

5.9 Groundwater chemistry

The overall groundwater quality aiming for drinking water purpose has been assessed by the Environmental Centre Ringkøbing in the catchment management plan “Hovedvandopland 1.2 Limfjorden“. The groundwater chemistry do not fulfil the EU criteria, thus the groundwater bodies (except for two GWBs) are classified as poor status. The shallow groundwater bodies and those of the regional groundwater bodies, that have water quality problems, the problems are due to impact from nutrients (nitrate). No saltwater intrusion problems have been reported in relation to the relevant groundwater bodies in Area 16.

No problematic seawater intrusion is expected to happen in the three specific subareas within area 16 in a future climate scenario with sea level rise.

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 climate changes will affect the major part of the high-lying areas seriously during this century. Although, locally

changes are expected, such as: increased discharge of the streams; perhaps erosion in the steepest incised slopes; flooding of the marine forelands and coastal erosion in the most exposed coastal sections.

5.11 Restrictions and limitations

Some areas with permissions for raw material digging are located in the area but these areas are relatively small (e.g. Majgård clay pit in the municipality of Skive and Stoholm clay pit in the municipality of Viborg according to the plan for Region Midtjylland).

There are no NATURA 2000 habitat areas directly located within the three subareas (Fig. 24). However, along the coast and in the Fjord just outside the Vorde and Lyndelse subareas, classified Natura2000 habitat areas are located.

Only very small areas in all three subareas are restricted in accordance to Naturbeskyttelsesloven (nature protection law) (Chapter 6).

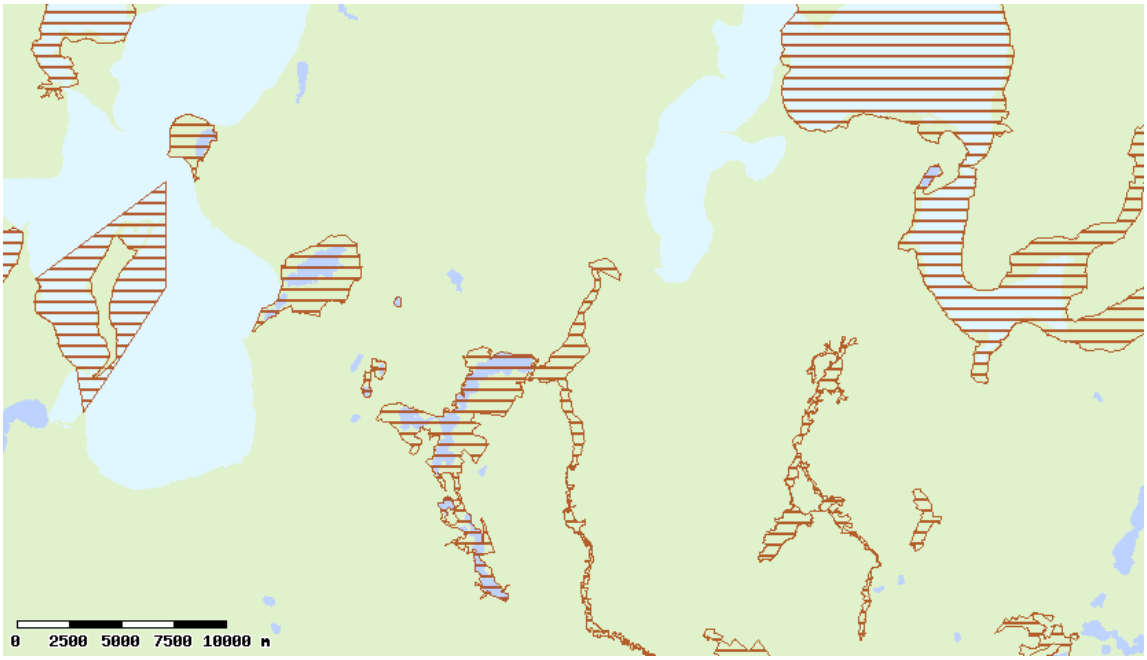


Figure 24. Limfjorden south – Natura2000 habitat areas. (After Ministry of Environment, 2010).

5.12 Summary of area conditions

Amount of data:

Large amount of borehole data but relatively few in the very subareas. Few geophysical surveys.

Homogeneous conditions and isolation of the waste by low, permeability layers:
Perhaps perfect on depth below 20 m down to 110 m but the framework of the fractures below 20 m is unknown. The fracture problem has to be considered in relation to other areas.

Stability
Good stability on surface and depth.

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

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

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 areas are located in the area. Areas with limited or no interests are located along the coast while OD areas occur in the rest of Area 16. Only minor local supplies are present.

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

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

Climate extreme conditions
Climate changes and extremes as heavy precipitation or storms will not have influence on a disposal. Future rising sea level and storms will very probable cause flooding of the marine forelands and coastal erosion in the most exposed coastal sections.

Other restrictions
Apparently no other restrictions will give problems.

5.13 Final remarks

The three subareas represent Elsterian clay deposits from the large area south of Limfjorden. In the main part of this large area, the clays are covering aquifer meltwater sand and gravel which yield fair amounts of groundwater for drinking water purposes. The three subareas are located close to the shore of Limfjorden.

6. Area 17. Hvidbjerg, Thyholm

6.1 The location of the area

The area is situated south of Limfjorden, Jylland (Fig. 25). The area is located on the north-eastern corner of Thyholm in Limfjorden (Fig. 26).

Figure 25. Location of the area. The Thyholm area is situated south of Thy in Limfjorden.

Figure 26. Detailed map of Area 17. The area is located on the northern part of Thyholm, north of Hvidbjerg.

6.2 Terrain, topography and surface processes

The Hvidbjerg area is located on the north-eastern part of the island Thyholm, in the south-western part of Limfjorden. The size of the area is c. 6.6 km^2. The landscape appears rather simple with steady undulations superimposed on the general and gently sloping from the highest terrain in south-west (25 meters above sea level (m.a.s.)) towards north (0 – 10 m.a.s) and north-west (0 m.a.s.). A solitary hill (18 m.a.s.) is located toward east, close to the coastline. Toward west and east, the delimitation follows the coastline. A narrow marine foreland is located along the west coast. The east facing coastal section seems to be characterized by the presence of a low cliff, generally overgrown and almost without erosion (?). No lakes or streams are present in the area.

The area is used for agriculture. Only 1 - 2 % of the area is covered by trees/bushes. Several minor roads cross the area. Scattered houses are located along the roads and a few windmills are found close to Grønholme toward north.

Owing to the very gentle relief and intensive cultivation, the surface processes (soil creep, frost – thaw processes, soil development etc.) proceed slowly and undramatic. The most active surface processes are found at the coast, but the coastal sections are situated in calm waters with very short fetches for wave development.

Figure 27. The landscape seen towards the north-east.

6.3 Surface geology and profiles

The surface geology is dominated of Quaternary deposits. Clayey till is the most widespread sediment in the area and only toward east, meltwater sand and gravel occur. Holocene sediments are found along the northern coast. Only one outcrop, at Nørre Hvidbjerg, occurs in the area but several other outcrops on Thyholm and Jegindø contribute to the knowledge of the geology (Figs. 13 and 28).

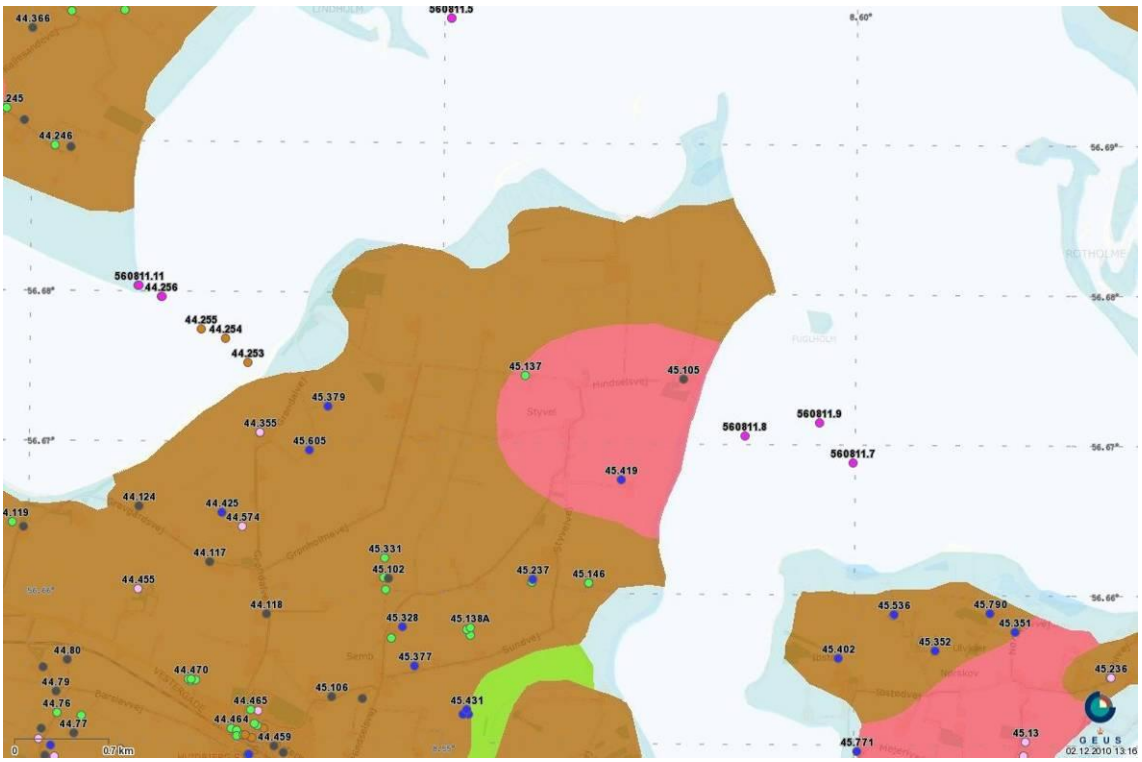


Figure 28. Map of the Surface deposits on Hvidbjerg, Thyholm. (From GEUS´s Homepage, after Pedersen, 1989). Legend: Brown: Clayey till; Red: Meltwater sand and Gravel; Green: Holocene Freshwater deposits; Light blue: Holocene marine deposits. Legend for boreholes: See fig. 29.

6.4 Boreholes

The area is penetrated by several boreholes. The drilling methods normally produce fair samples of the Tertiary and Quaternary sediments. Most of the samples are described lithological but few are related to lithostratigraphical unit and dated by biostratigraphy.

Geophysical surveys are mainly conducted in relation to the area south of area 17, mapping the Hvidbjerg aquifer. The deeper layers around the Uglev (Hvidbjerg) salt structure towards the southwest are also mapped by geophysics.

The locations of the boreholes in the area are seen in fig. 29.

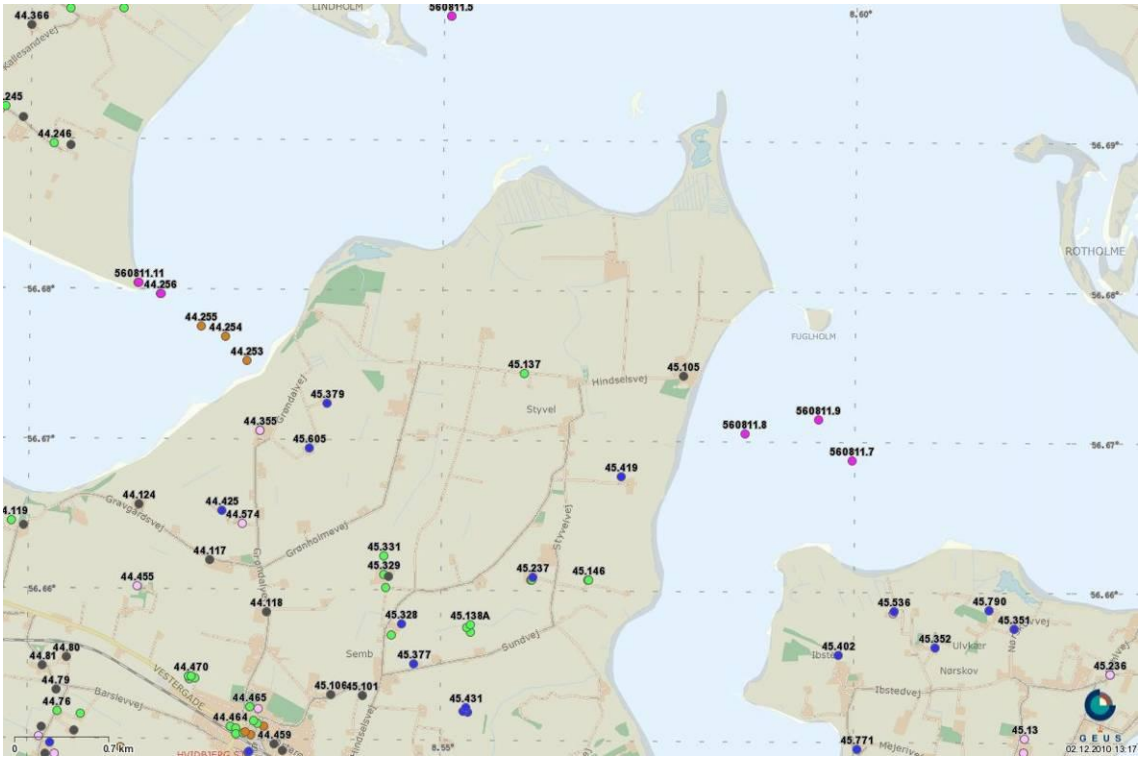


Figure 29. Map of the locations of boreholes from the Jupiter Database at GEUS. Legend: 45. 419: DGU no., Blue dot: Water supply well; Red dot: Geotechnical borehole; Pink dot: Raw material borehole; Green dot: Other borehole; Light red dot: Abandoned borehole; Black dot: Unknown purpose.

Most of the boreholes are wells that supply households, smaller farms and other local needs.

An example of a borehole log is found in fig. 30.

De Nationale Geologiske Undersøgelser for Danmark og Grønland

Udskrevet 26/11 2010 Side 1

BORERAPPORT

DGU arkivnr: 45. 419

Borested : Styvelnørregård. Gyvelvej 8. 7790 Hvidbjerg.
7790 Thyholm

Kommune : Struer
Region : Midtjylland

Boringsdato : 2/11 1977 **Boringsdybde** : 81 meter **Terrænkote** : 12,5 meter o. DNN

Brøndborer : A. Højfeldt A/S
MOB-nr :
BB-journr :
BB-bornr :

Prøver
- modtaget : 6/2 1978 **antal** : 19
- beskrevet : 18/2 1988 **af** : OW
- antal gemt :

Formål : Vandforsyningsboring
Anvendelse : Vandforsyningsboring
Boremetode : Sugeboring

Kortblad : 1116 IISV
UTM-zone : 32
UTM-koord. : 473831, 6280679

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

		Ro-vandstand	Pejledato	Ydelse	Sænkning	Pumpetid
Indtag 1	(seneste)	11 meter u.t.	4/4 1978	2,4 m³/t	3,9 meter	8,5 time(r)
	(første)	11,1 meter u.t.	2/11 1977			

Tilbagepejling

Indtag 1 Tid: 3min Vsp: 11,8m , Tid: 10min Vsp: 11,2m , Tid: 30min Vsp: 11,1m

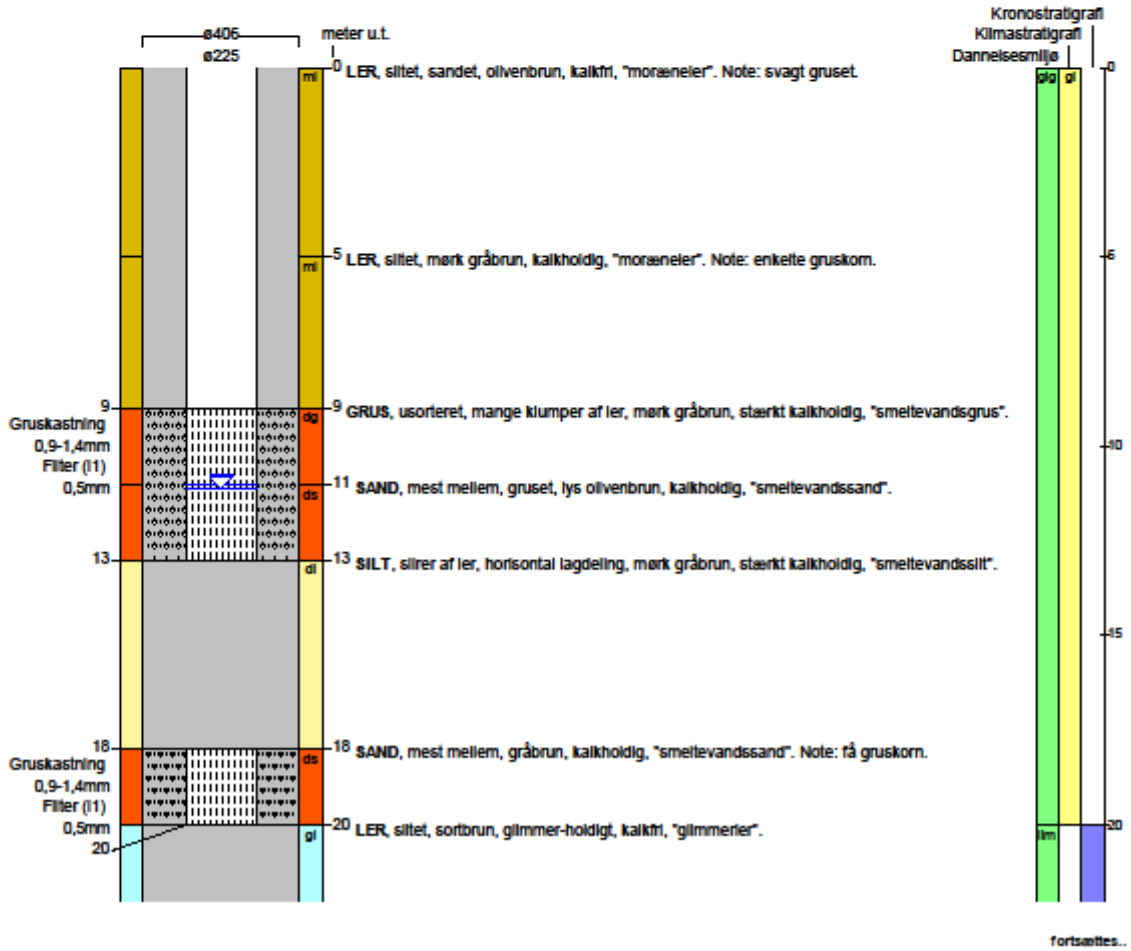


Figure 30. Borehole log from DGU no. 45.419. The upper part of the 81 m deep borehole. Legend: ML: Clayey till; DS: Meltwater sand and gravel; DI: Meltwater silt; GL: Oligocene mica clay.

6.5 Sediment and rock characteristics, mineralogy and chemistry

6.5.1 Pre-Quaternary rocks

The distribution of the pre-Quaternary deposits can be seen in fig. 31.

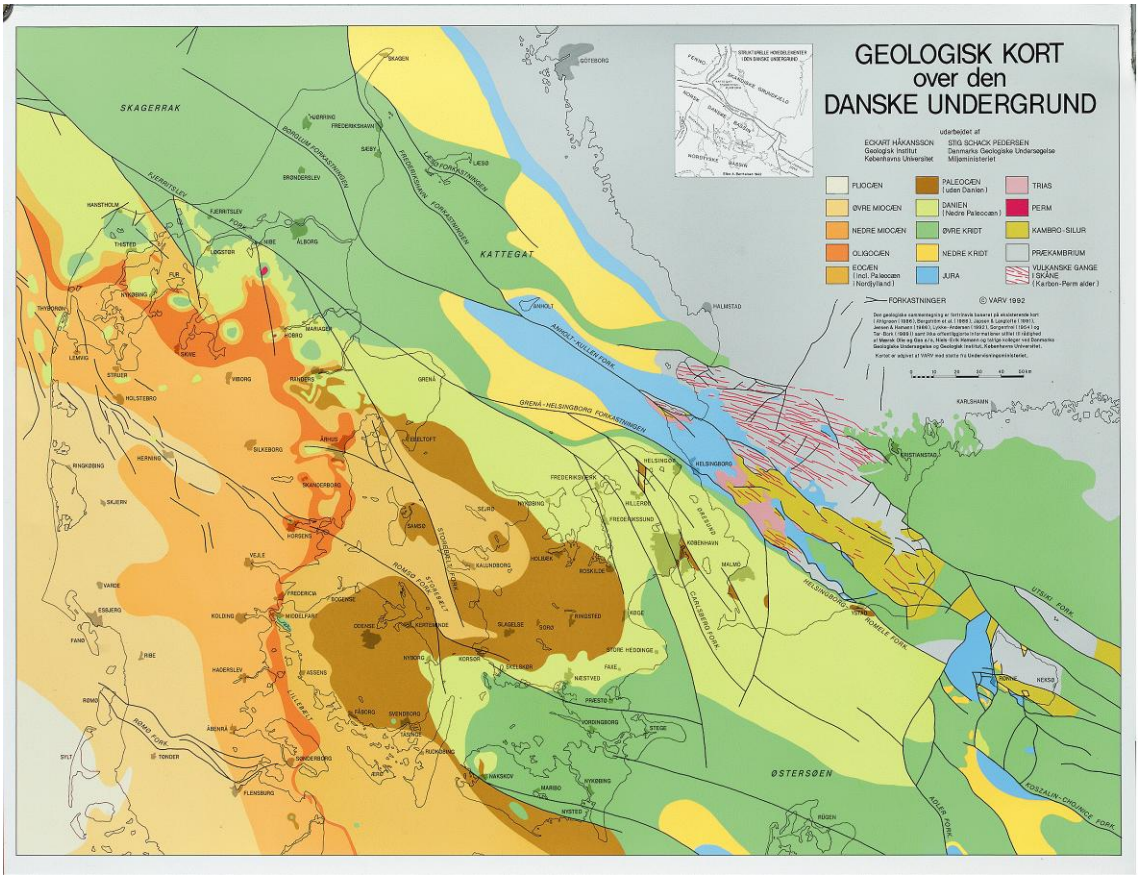


Figure 31. Map of the pre-Quaternary surface: Time units. Original scale: 1:500.000. Legend: Red lines: Precambrian intrusions; Grey: Precambrian; Olive: Cambrian-Silurian; Red: Permian; Light red: Triassic; Blue: Jurassic; Yellow: Lower Cretaceous; Green: Upper Cretaceous; Light green: Danian; Brown: Paleocene; Yellow olive: Eocene; Red brown: Oligocene; Light yellow brown: Lower Miocene; Very light yellow brown: Upper Miocene; White: Pliocene (Håkansson & Pedersen, 1992).

It is expected that the sediments on the pre-Quaternary surface are from the Oligocene. Several boreholes in the area reach Oligocene deposits below 5 - 10 m of Quaternary sediments.

All boreholes of the area are relatively short. Below a thin Quaternary cover, all boreholes reach the Vejle Fjord Formation, often as fine-grained and silty black and black brown micaceous clay, which is slightly calcareous to non-calcareous. Some of the samples are described as limnic Miocene. The Vejle Fjord Formation includes the Upper Oligocene

Brejning clay Member as well as two Lower Miocene Members. So, the limnic Miocene clay is considered a part of the Vejle Formationen. The Formation seems to be at least 60 m thick. Below the black mica clay, fine-grained olive green, non-calcareous clay with glauconite can be followed down to 78 m below terrain. This clay may belong to the Branden Clay Formation. The clay rests on diatomite (mo clay) and volcanic ash from the Eocene (Figs. 32 and 33).

Figure 32. Part of Geological basic data map 1116 II Nykøbing Mors. Original scale 1:50.000 (From Gravesen, 1989). Legend: See fig.11 (From Gravesen, 1989).

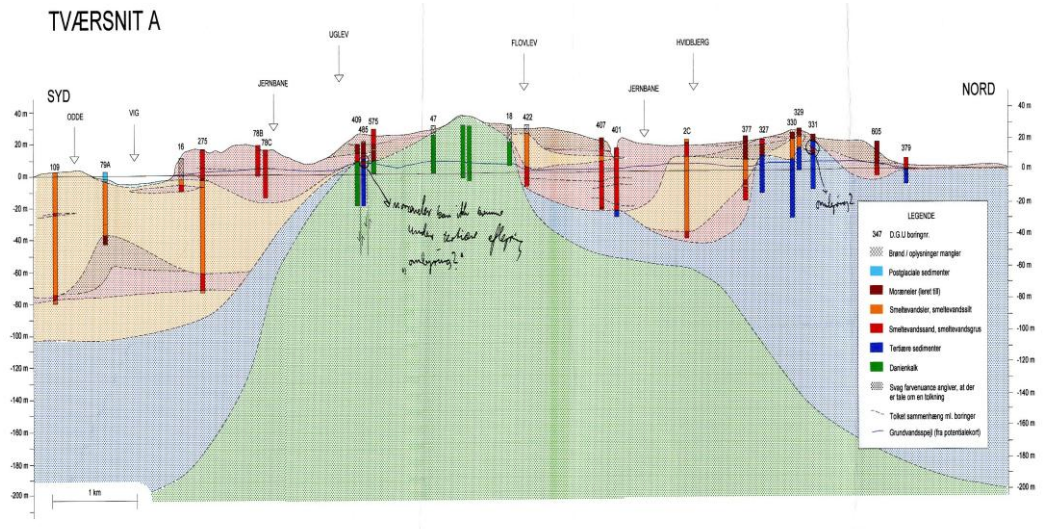


Figure 33. Geological section north-south from Grøntholm to Sunddraget (Fra Clausen & Kronborg, 2001). The section shows the large thickness of the Oligocene sediments on the northern side of the Uglev Salt diaper.

6.5.2 Quaternary deposits

The dominant sediment in the area is clayey till (Figs. 13 and 28). The boreholes show that the silty, gravelly grey brown non-calcareous clayey till is 4 - 11 m thick but meltwater deposits are often underlying the tills; as fine-medium-grained, calcareous sand and gravel and as fine-grained laminated olive grey calcareous clay and laminated silt. Reduced calcareous olive grey clayey till is found in some parts of the area.

Just outside the area, the Quaternary deposits are much thicker, up to 67 m. Towards the south, the boreholes reach Danian limestone below 20 m Quaternary deposits.

6.6 Tectonics, structures and seismic activity

6.6.1 Major tectonic structures

According to the map (Fig. 31), apparently no structures cross the pre-Quaternary surface in area.

The Uglev salt structure on the mid part of Thyholm has determined the sedimentation pattern where movements during and after deposition of the Paleogene may have influenced the deposition distribution and later erosion.

Few glacial floes in the boreholes show that glaciotectonic disturbances have been active.

6.6.2 Fractures

There is no information from the boreholes. From the cliff sections, fractures in the clayey till have been recognized down to 5 m below ground surface.

Fractures in the fine-grained Tertiary clays are expected.

6.6.3 Geological and structural models

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

Model of the area is as follows (Fig. 34):

A. Holocene deposits (Thickness not known but thin)

B. Quaternary clayey tills, meltwater clay, silt, sand and gravel. From 4 m to 20 m thick.

C. Oligocene sand, silt and clay: Vejle Fjord Formation, approx. 60 m thick

D. Oligocene Branden Formation, more than 20 m thick.

E. Danian limestone

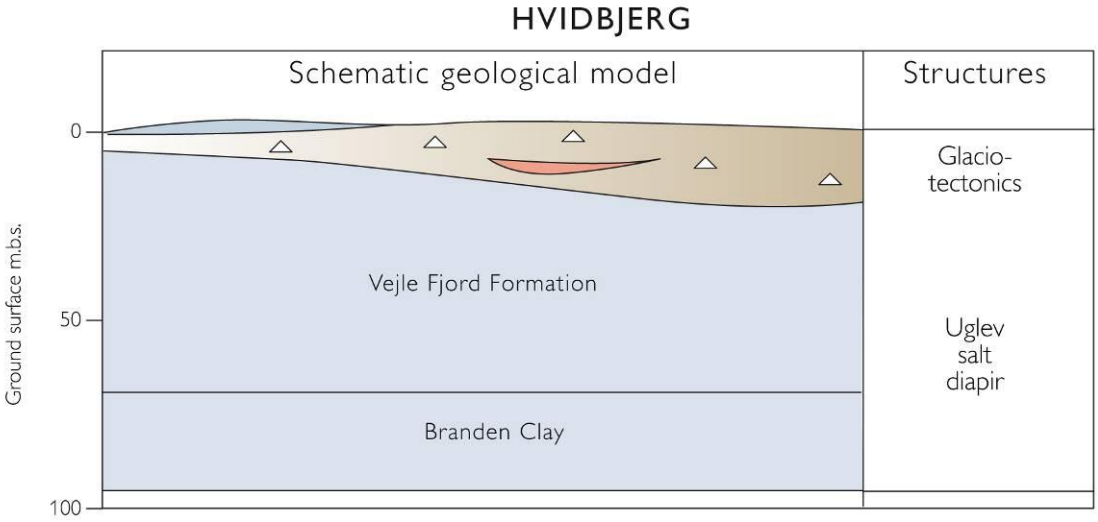


Figure 34. Schematic geological model of Area 17.

6.6.4 Earthquake activity

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The earthquake activity is measured with respect to location, time and size. The activity in Denmark during the period 1929-2003 is very low compared to many other countries.

The seismic activity in the Limfjorden area is very low (Fig. 35). No seismic movement have been registered for the area although a seismic station is located at Mønsted.

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

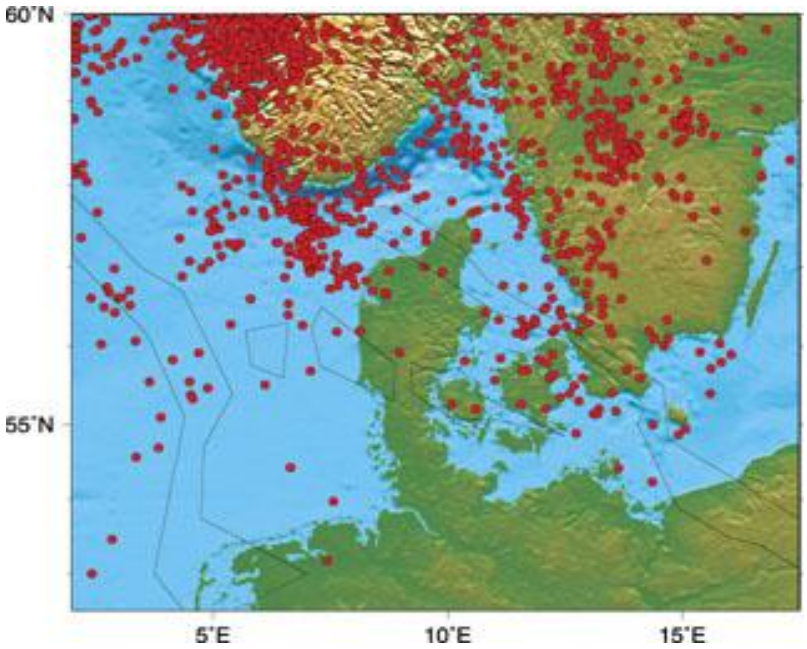

Figure 35. Map of the earthquake epicentres in Denmark and surrounding areas. A red dot shows the location (From GEUS´s Home Page).

6.7 Ground stability

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

6.8 Groundwater hydrogeology

6.8.1 Groundwater characteristics

The Hvidbjerg area is situated on northern part of Thyholm. According to the basisanalysis Part 1 (Basisanalysis Part 1, 2004), Area 17 is characterized by a shallow (DK1.2.1.10), a regional (DK1.2.2.22) and a deep (1.2.3.7) groundwater body (Figs 36, 37 and 38). The shallow and regional groundwater bodies both consist of meltwater sand deposits while the deep groundwater body consists of limestone (KS). The Limfjorden catchment management plan (Hovedvandopland 1.2 Limfjorden) has been described by the Ministry of Environment. The overall assessment of the chemical and quantitative status: shallow GWB (poor due to poor chemical status), regional GWB (good), and deep (good) (see Section 6.9).

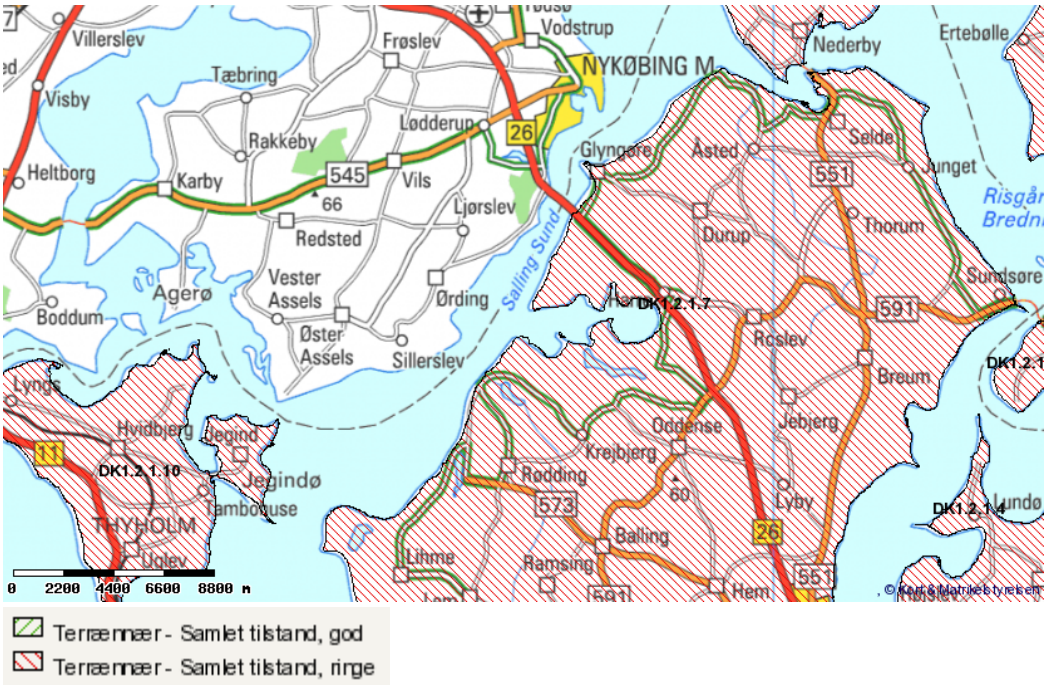

Figure 36. Shallow groundwater bodies within Area 17 (After Ministry of Environment, 2010).

Figure 37. Regional groundwater bodies within Area 17. (After Ministry of Environment, 2010).

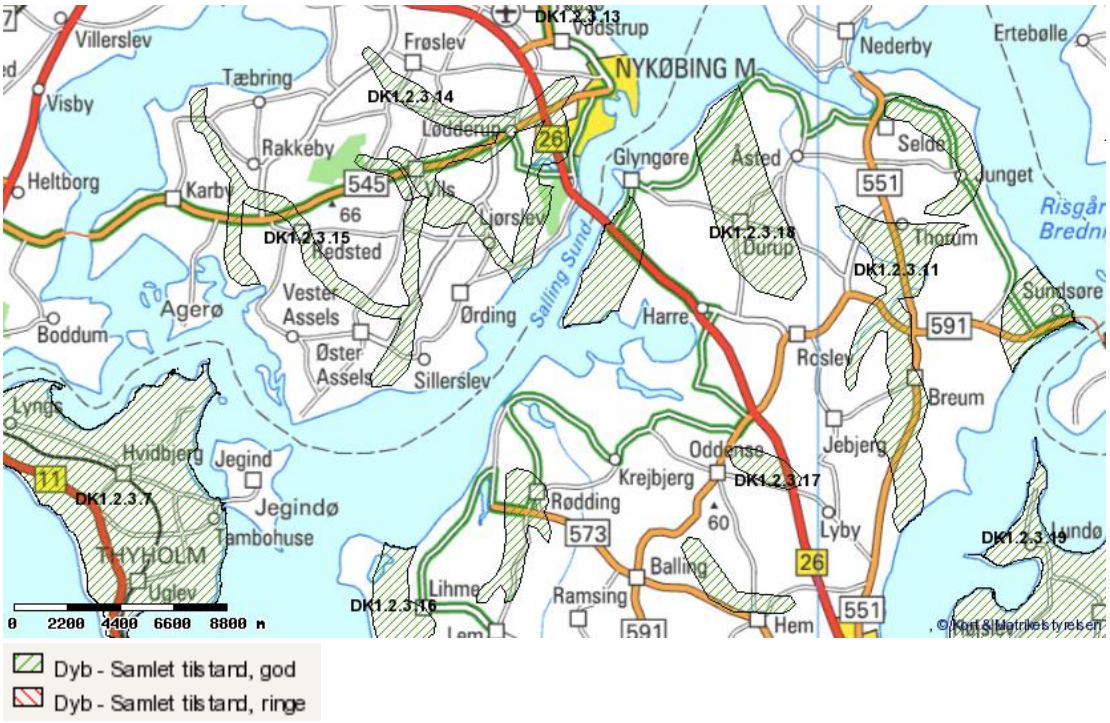

Figure 38. Deep groundwater bodies within Area 17. (After Ministry of Environment, 2010).

6.8.2 Drinking water areas

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

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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.

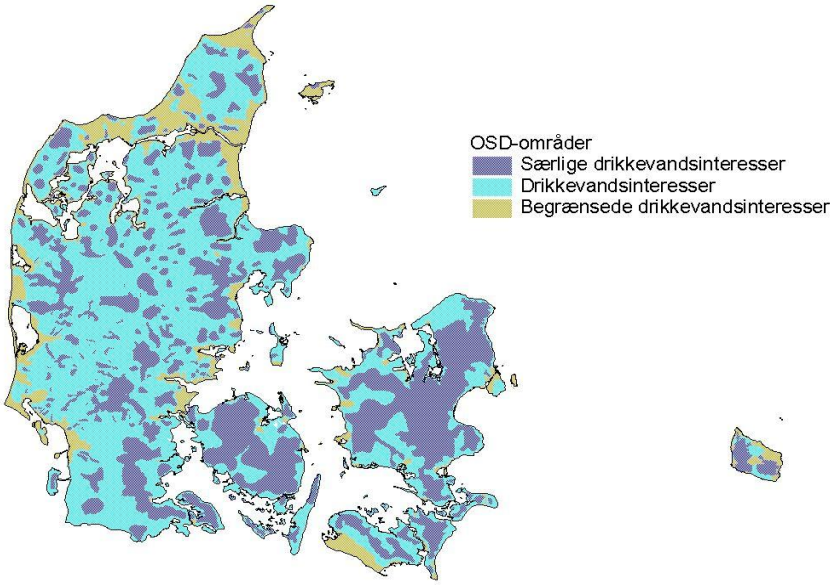


Figure 39. Areas of special drinking water interests (OSD): Dark blue and areas of drinking water interest (OD): Light blue. Area of limited drinking water interest is olive. (/kort.arealinfo.dk/).

The geographical distribution of the drinking water areas in the Limfjorden south area is given in figs. 40 and 41. The Hvidbjerg area is situated in an area with limited or no groundwater interests even that the area is described as having good quality in deep reservoirs.

Figure 40. Distribution of the drinking water areas in the Limfjorden South area (Area 17). 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/).

Figure 41. Map of the drinking water areas in Area 17. Legend: See fig. 40. (http://kort.arealinfo.dk/).

6.9 Groundwater chemistry

The overall groundwater quality aiming for drinking water purpose has been assessed by the Environmental Centre Ringkøbing in the catchment management plan “Hovedvandopland 1.2 Limfjorden“. The groundwater chemistry does not fulfil the EU criteria in the shallow groundwater body due to unacceptable high contents of nitrate and pesticides. No saltwater intrusion problems have been reported in relation to the relevant groundwater bodies in Area 17.

The level of the surface terrain range between 5 and more than 15 meter above present sea level, thus no significant changes in the fresh/saltwater interface is expected to happen due to future sea level rise (climate change).

6.10 Climate and climate changes

The actual climate and the expected future climate changes and sea level development is described in Gravesen et al. (2010, Rep. No. 2). It is not expected that climate changes will affect the area during this century. The expected sea level rise will most probably cause flooding of the low-lying marine foreland toward north-west and increase the erosion of the coast toward east.

6.11 Restrictions and limitations

Protected areas have only very restricted distribution in Area 17 and mainly along the north coast. There are no NATURA 2000 habitat areas directly located within Area 17 (Fig. 42). However, an area along the coast and in the fjord just outside the Hvidbjerg area, is classified as NATURA 2000 habitat area and protected in accordance to Naturbeskyttelseloven (nature protection law).

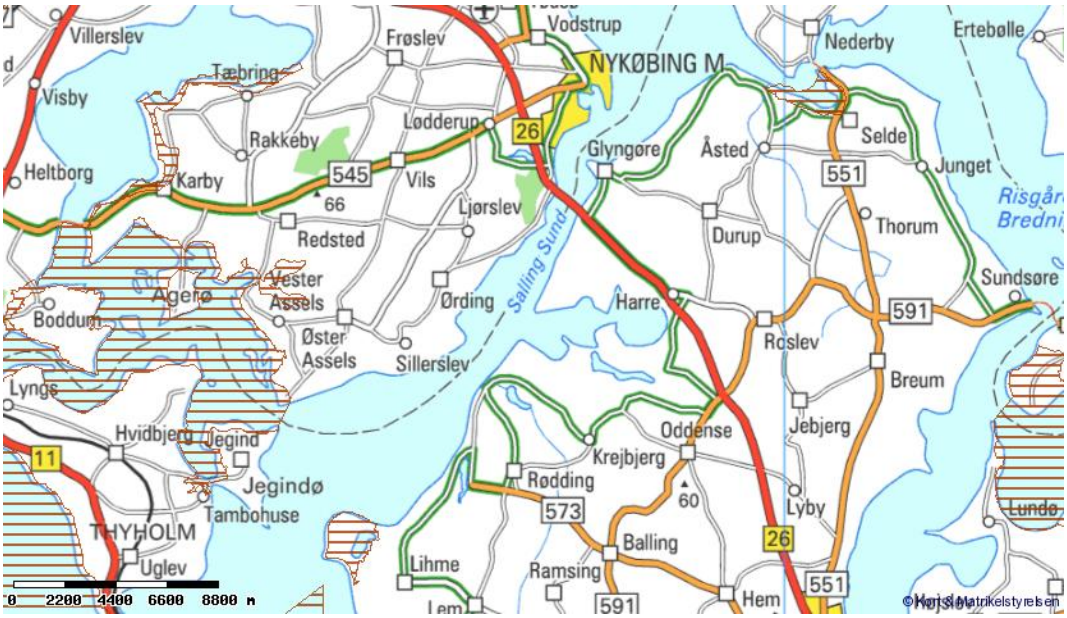


Figure 42. Natura2000 habitat areas (After Ministry of Environment, 2010).

6.12 Summary of the area conditions

Amount of data:
Limited amount of borehole data. Geophysical surveys south of the area.

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

Stability
Good stability on surface and depth.

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

Groundwater conditions

The groundwater conditions in clay should be positive but the variation in the level of the groundwater table has to be analysed if the disposal has to be established under saturated conditions.

The groundwater flow will be towards the coast.

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 areas or OD areas are located in the area while areas of limited interest for drinking water cover Area 17. Only minor local supplies are present.

Groundwater chemistry, non- aggressive components

The groundwater contains apparently no aggressive components.

Ground surface conditions

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

Climate extreme conditions

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

Other restrictions

Apparently no other restrictions will give problems.

6.13 Final Remarks

The area is located on the northern flank of a salt diapir. The relatively isolated area can be in favor as a location of the waste disposal.

7. Area 18. Harre Vig

7.1 The location of the area

The area is located on the south side of Limfjorden on the Salling peninsula just opposite to the island of Mors (Fig. 43). The location of the area can be seen in detail on fig 44.

Figure 43. Location of the area. The Harre Vig area is located in Salling, the middle part of Jylland.

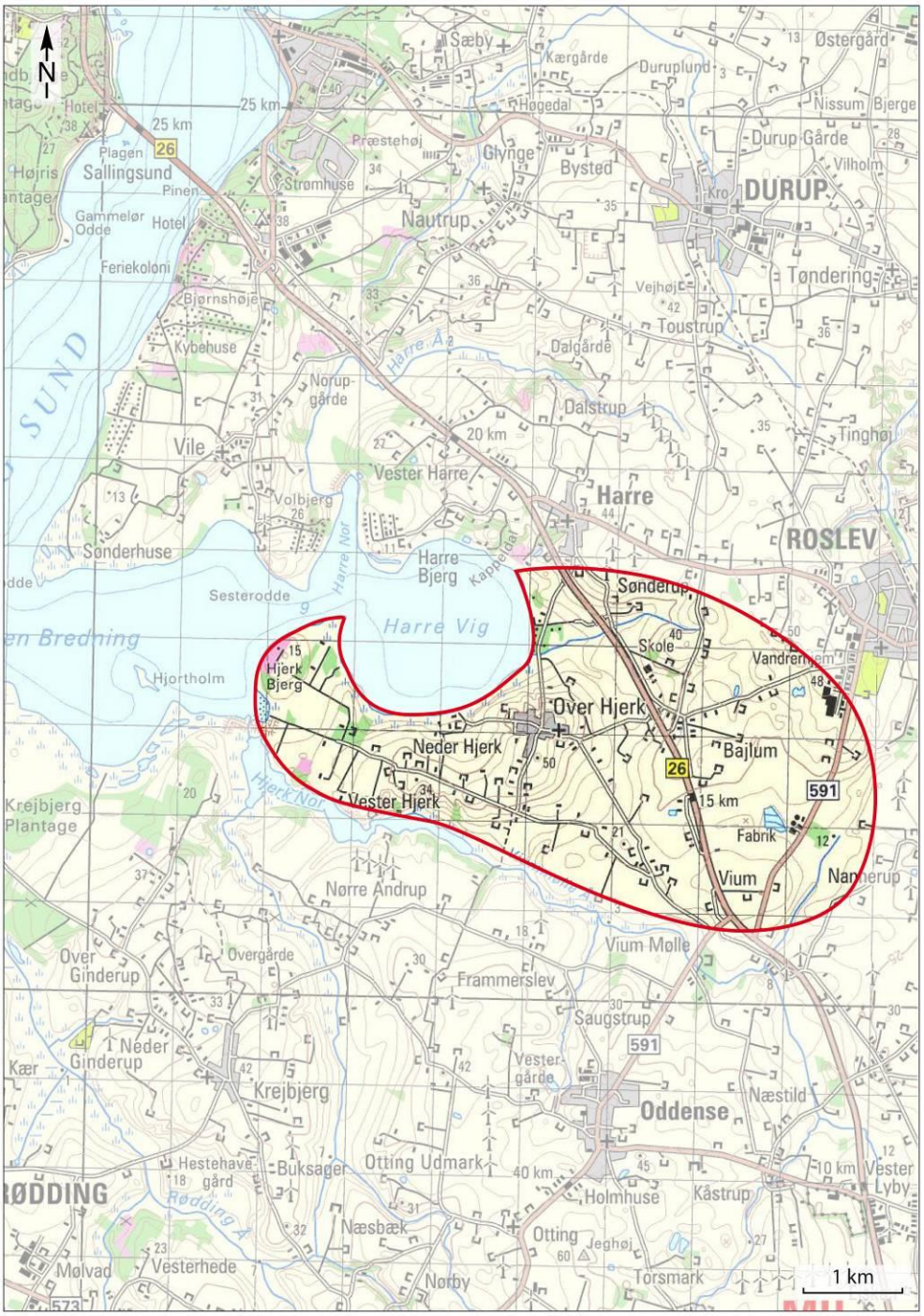


Figure 44. Detailed map of Area 18. The Area 18 is located between Limfjorden-Harre Vig and the village Roslev.

7.2 Terrain, topography and surface processes

The area is located on the large peninsula Salling, in the fjord Limfjorden. The size of the area is c. 17.3 km^2. The area is characterized by a relatively undulating moraine landscape. Toward west, the delimitation follows the coastline of the cove Harre Vig and the promontory Hjerk Bjerg. Harre Vig is via Lysen Bredning connected to Salling Sund. Toward SSW, the area is delimitated by the narrow cove Hjerk Nor and the river valley of Viummølle Å. The remaining delimitation is situated in the undulating moraine landscape. From the high-lying area in the north-eastern part of the area, situated c. 50 m.a.s., the landscape slopes gently toward south and south-west to c. 15 m.a.s. and toward west, to the coast. A large and elongated hill with top level 50 m.a.s. at the village Over Hjerk, turning south and south-west, characterize the central, western part of the area. A smaller, solitary hill, Hjerk Bjerg, reaching 15 m.a.s. is located on the promontory.

The coastline along the cove Harre Vig and the northern point of the promontory is stable. Some longer stretches are bordered by a narrow marine foreland to the landward site and a relatively broad, shallow and sandy near shore zone. In these, larger coastal sections, the coastline is prograding. The west coast of Hjerk Bjerg seems to hold a low, partly erosive, partly overgrown cliff. The coastline along the very calm waters of Hjerk Nor is stable and presumably slowly prograding. The area includes some small ponds and one small stream is located in the north-western part of the area.

The area is used for agriculture. It is crossed (NW – SE) by one main road and (in different directions) by several smaller roads. The small village Over Hjerk is located in the central western part of the area. Some houses are found in the area, primarily located along the roads in the central and southern part of the area. Large areas towards east only hold scattered houses, a factory and a main road to Roslev.

Owing to the relatively gentle relief and intensive cultivation, the surface processes (soil creep, frost – thaw processes, soil development etc.) proceed slowly and undramatic. The most active surface processes are found in the coastal zone. But even here, the processes proceed slowly owing to the protected waters with only short fetches for wave development.

Figure 45. The area around Harre Vig.

7.3 Surface geology and profiles

The surface geology is dominated by Quaternary deposits of which clayey till are the most distributed. At the Vester Hjerk peninsula meltwater sand and gravel occur to the west. Holocene freshwater deposits are located in valleys while marine deposits are found along the coast and in Hjerk Nor (Fig. 46). An outcrop with Oligocene deposits occurs at Harre Vig (Fig. 49).

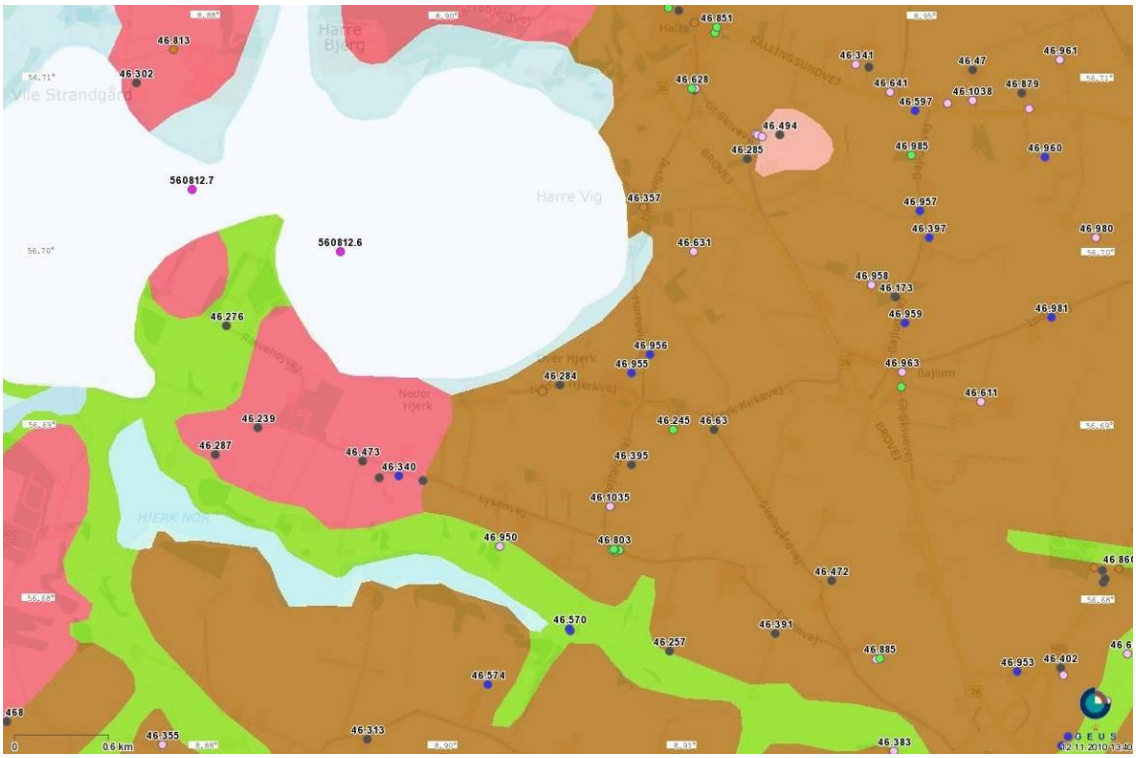


Figure 46. Map of the Quaternary deposits around Harre Vig. (From GEUS´s Homepage, after Pedersen, 1989). Legend: See fig. 3. The legend for the boreholes, see fig. 47.

7.4 Boreholes

The area is penetrated by several boreholes. The drilling methods normally produce fair samples of the Tertiary and Quaternary sediments. Most of the samples are described lithological and related to lithostratigraphical units while few samples are dated by biostratigraphy. The sediment cores and samples from DGU no. 46.611 have been very detailed investigated. Geophysical surveys are mainly conducted in relation to deeper layers. At least one seismic line crosses the area from the Batum salt structure towards the south-west.

The locations of the boreholes in the area are seen in fig. 47.

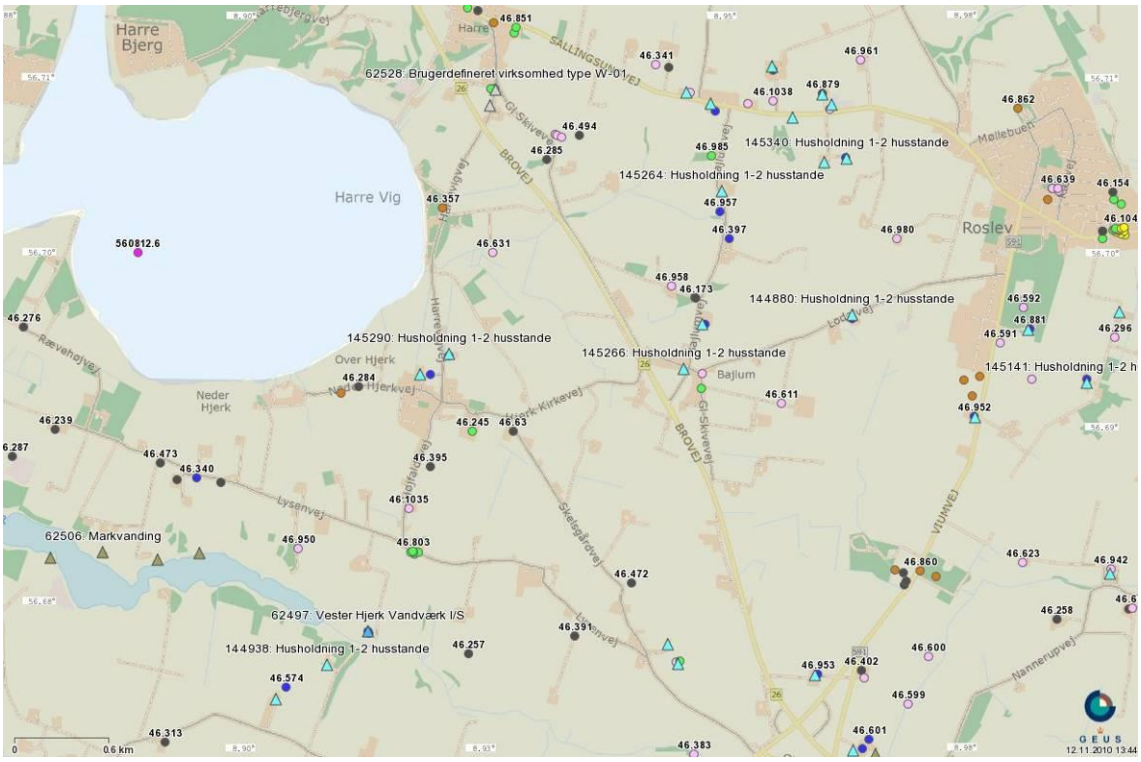


Figure 47. Map of the locations of boreholes from the Jupiter Database at GEUS. Legend: 46. 611: DGU no., Blue dot: Water supply well; Red dot: Geotechnical borehole; Pink dot: Raw material borehole; Green dot: Other borehole; Light red dot: Abandoned borehole; Black dot: Unknown purpose.

Most of the boreholes are wells which supply households, smaller farms and other local needs.

An example of a borehole log is found in fig. 48.

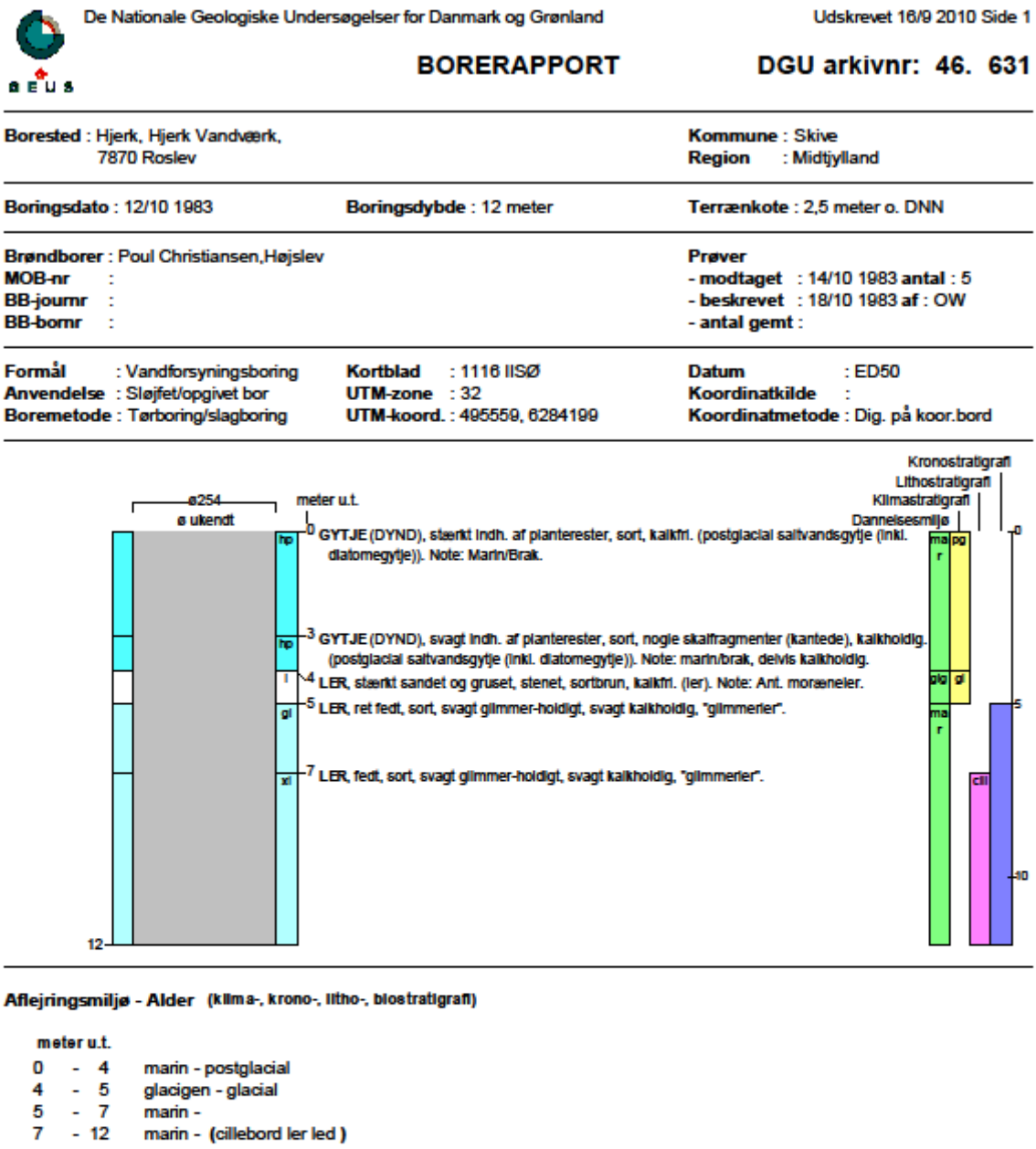


Figure 48. Borehole log from DGU no. 46.631. The borehole is 12 m deep. Legend: HP: Marine Gytja, GL: Micaceous clay.

7.5 Sediment and rock characteristics, mineralogy and chemistry

7.5.1 Pre-Quaternary rocks

The distribution of the Pre-Quaternary deposits can be seen in fig. 49.

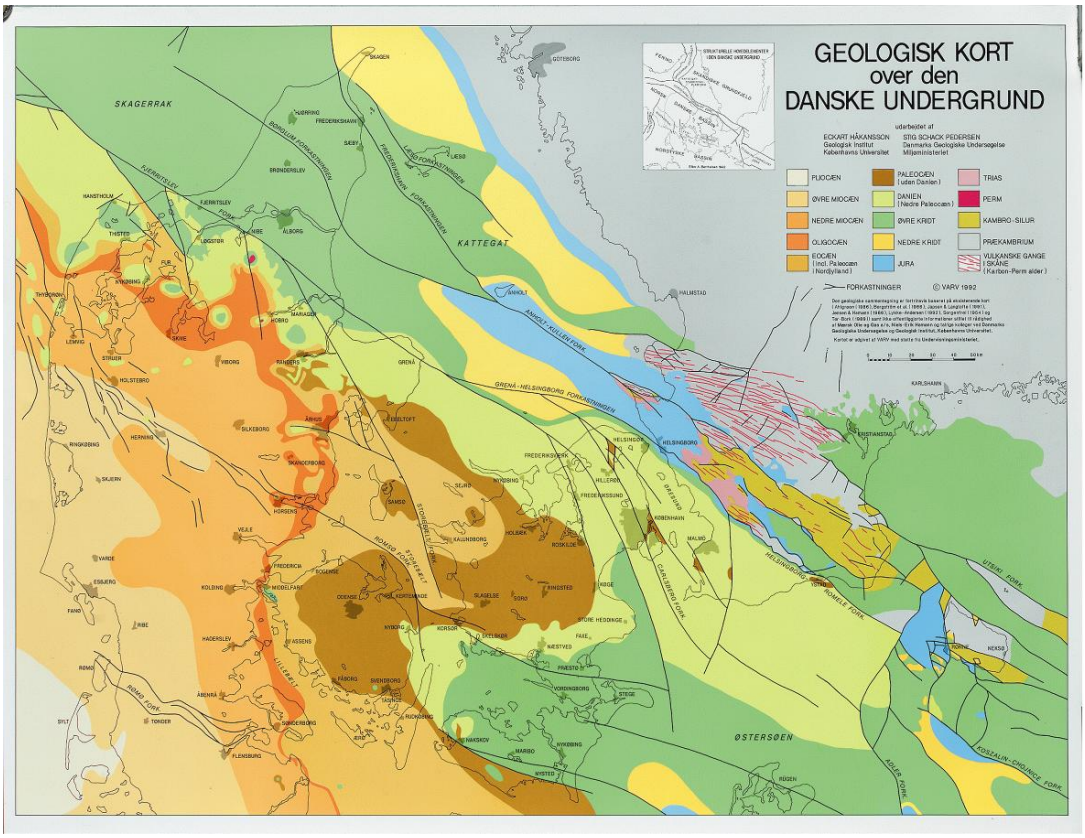


Figure 49. Map of the pre-Quaternary surface: Time units. Original scale: 1:500.000. Legend: Red lines: Precambrian intrusions; Grey: Precambrian; Olive: Cambrian-Silurian; Red: Permian; Light red: Triassic; Blue: Jurassic; Yellow: Lower Cretaceous; Green: Upper Cretaceous; Light green: Danian; Brown: Paleocene; Yellow olive: Eocene; Red brown: Oligocene; Light yellow brown: Lower Miocene; Very light yellow brown: Upper Miocene; White: Pliocene (Håkansson & Pedersen, 1992).

It is expected that the sediments on the pre-Quaternary surface are from the Oligocene and in the Hjerk coastal cliff, Oligocene brown mica clay is found as the bottom layer (Fig. 50).

Figure 50. Coastal cliff at Hjerk Bjerg with Oligocene brown mica clay.
From: http://www.panoramio.com/photo/37736959

Several boreholes in the area reach Oligocene deposits below 5-10 m of Quaternary sediments. A deep borehole, DGU. No. 46.611, penetrates 275 m of Paleogene deposits and the following formations are reached (from the top):

0 - 9.75 m below ground surface: Quaternary deposits
9.75 - 67.5 m: The Oligocene Vejle Fjord Formation: Brown and black micaceous sandy and clayey silt. Become homogeneous and more fine-grained and glauconitic downwards.
67.5 - 119.45 m: The Oligocene Branden Formation: Fine-grained, silty dark green grey clay. Glauconitic towards the base of the formation.
119.45 - 177.5 m: The Oligocene Viborg Formation: Fine-grained silty, dark green grey clay, slightly calcareous. Glauconitic towards the base of the formation.
177.5 - 186 m: The Eocene Lillebælt Clay Formation: Very fine-grained plastic dark green grey non-calcareous clay.
186 - 190.88 m: The Eocene Røsnæs Clay Formation: Dark yellow brown or brown very fine-grained plastic clay, mainly non-calcareous. Some volcanic ash layers.
190.88 - 222 m: The Eocene Ølst and Fur Formations: Light olive grey to greenish grey, non-calcareous, silty and fine-grained clays with volcanic ash layers.
222 - 229.9 m: The Paleocene Holmehus Formation: Very fine-grained green grey to greenish black, non-calcareous clay.
229.9 - 244.5 m: The Paleocene Æbelø Formation: Olive black to dark grey silty slight to non-calcareous clay (probably the Æbelø Formation)
244.5 - 256.9 m: The Paleocene Kerteminde Marl: Fine-grained olive grey calcareous clay.
256.9 - 284.75 m: Danian limestone: Silty limestone with flint layers.

The 285 m deep borehole gives the stratigraphy of the area down to the Danian. All the other boreholes in the area are much shorter. Below a thin Quaternary cover, all boreholes reach the Vejle Fjord Formation often as fine-grained and silty black and black brown micaceous clay down to at least 55 m (Fig. 51).

Figure 51. Oligocene mica clay from the Vejle Fjord Formation.

In a few boreholes, the fine-grained, dark green grey Branden Formation follows down to 100 m (Fig. 52).

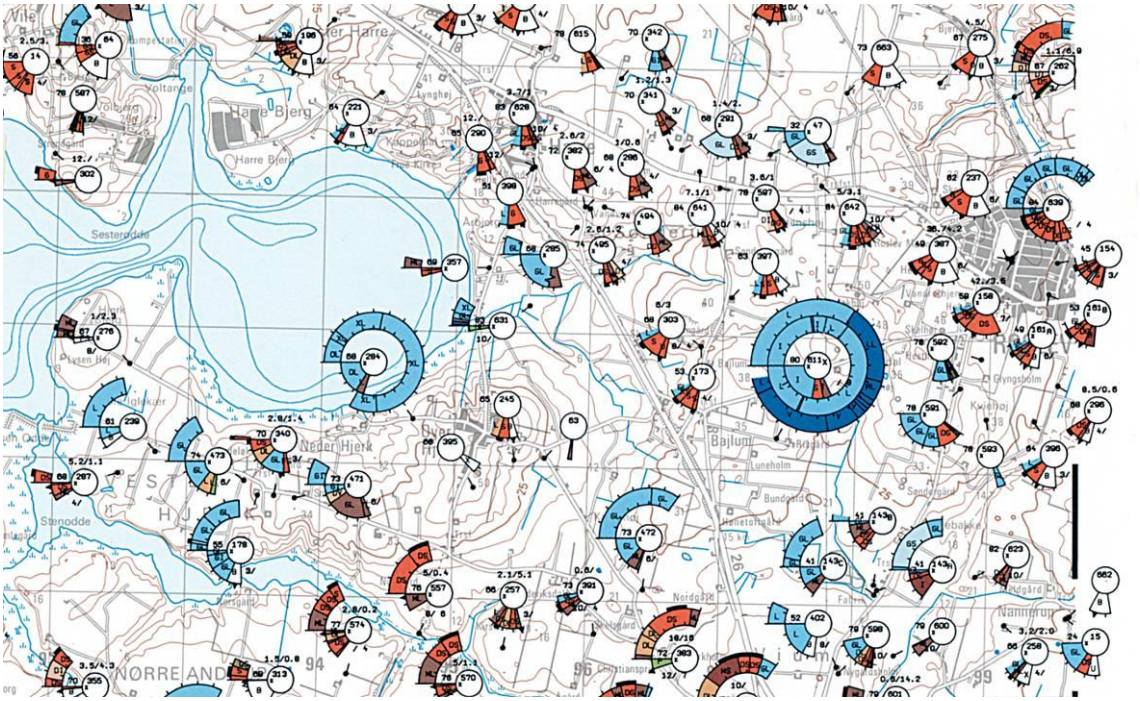


Figure 52. Part of Geological basic data map 1116 II Nykøbing Mors. Original scale 1:50.000 (From Gravesen, 1989). Legend: See fig.11.

7.5.2 Quaternary deposits

The dominant sediment in the area is clayey till (Figs. 13 and 45). The boreholes show that an upper till is sandy, silty, calcareous, olive grey to olive brown and up to 7 m thick. The till is intercalated by fine to medium grained gravelly meltwater sand, often non-calcareous and yellow brown to grey brown and 3.5 m thick. Also thin layers of meltwater clay and silt occur. Up to 30 m thick Quaternary sequences occur in some areas deposited in eroded basins or as glaciotectonic disturbed layers.

The Holocene deposits consist of up to 4 m thick marine gytja with plant material and 0,5 m thick limnic black brown peat.

7.6 Tectonics, structures and seismic activity

7.6.1 Major tectonic structures

According to the map (Fig. 49), apparently no structures crosses the pre-Quaternary surface in the area, but the area is situated southwest of the Batum salt diaper and also close

to the Mors, Uglev and Skive salt structures where movements during and after deposition of the Paleogene may have influenced the deposition pattern and later erosion.

The deposits seem relatively undisturbed and no sign of glaciotectonic disturbances are indicated by the borehole data.

7.6.2 Fractures

There is no information from the boreholes. From the cliff sections, fractures in the clayey till have been recognized down to 5 m below ground surface.

Fractures in the fine-grained Tertiary clays are expected.

7.6.3 Geological model

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

Model of the area is as follows (Fig. 53):

A. Holocene gytja and peat, up to 4 m thick

B. Quaternary clayey tills, meltwater clay, silt, sand and gravel (Saalian and Weichselian). From 10 m to 30 m thick.

C. Oligocene sand, silt and clay: Vejle Fjord Formation, Branden Clay Formation, Viborg Formation, approx. 165 m thick.

D. Eocene plastic clays: Lillebælt Clay Formation and Røsnæs Clay Formation, 13 m thick.

E. Eocene fine-grained and silty clay with volcanic ash: Ølst Formation and Fur Formation, 32 m thick.

F. Paleocene silty and fine-grained clay: Æbelø Formation and Kerteminde Marl, 33 m thick.

G. Danian limestone, 27 m thick.

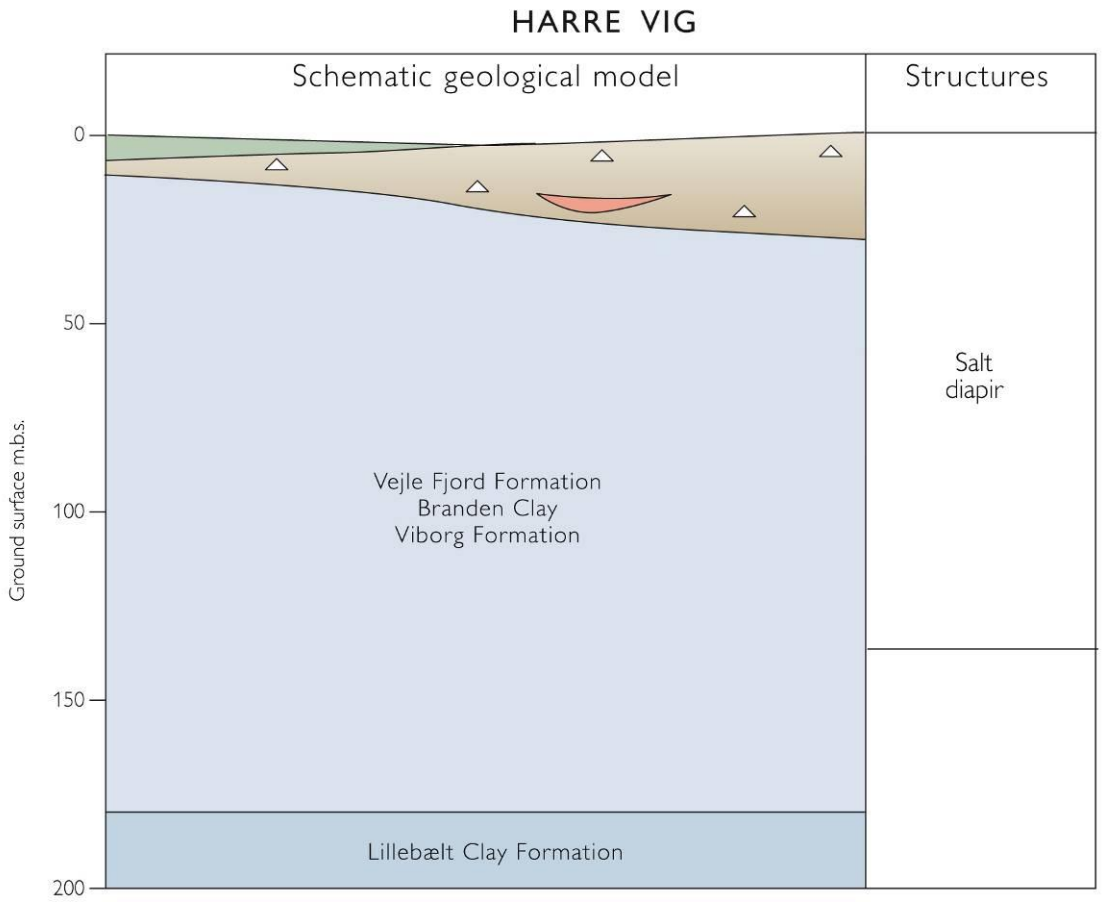


Figure 53. Schematic geological model of Area 18.

7.6.4 Earthquake activity

The seismic station net in Denmark is managed by GEUS and comprises 5 stations of which three stations are located on Sjælland: Gilleleje museum, Vestvolden, København and Lille Linde, Stevns (GEUS´s homepage: www.geus.dk).

The earthquake activity is measured with respect to location, time and size. The activity in Denmark during the period 1929-2003 is very low compared to many other countries and.

The seismic activity in the Limfjorden area is very low (Fig. 54). No seismic activity has been registered for the area although a seismic station is located at Mønsted.

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

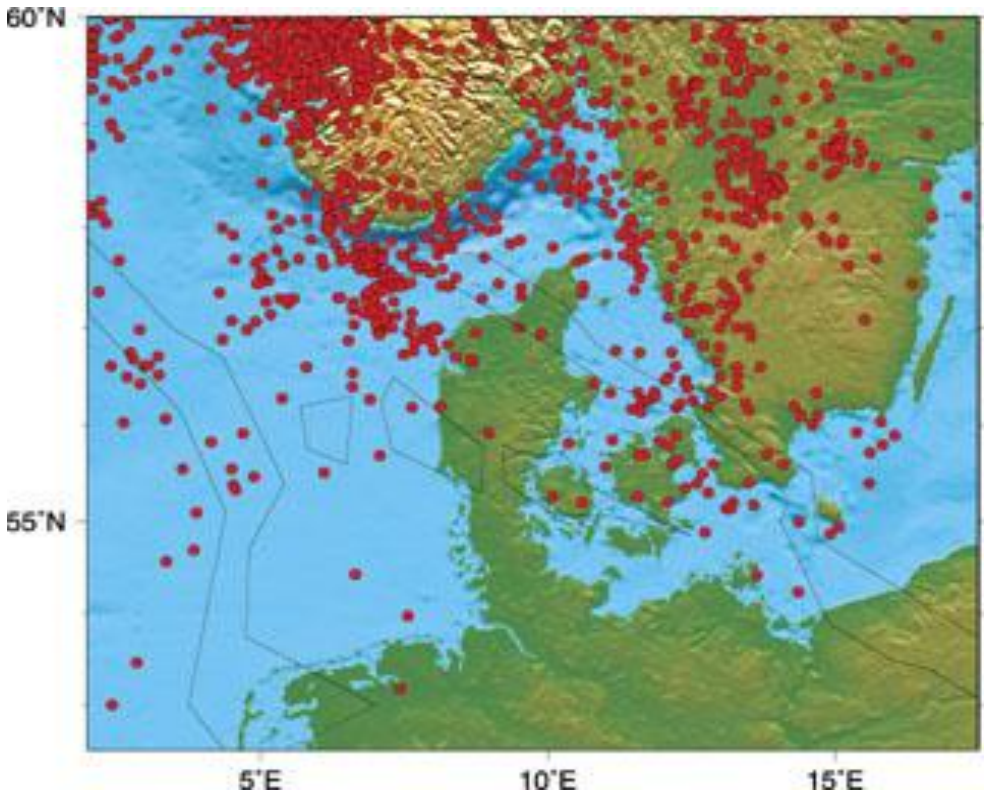


Figure 54. Map of the earthquake epicentres in Denmark and surrounding areas. A red dot shows the location (From GEUS´s Home Page: www.geus.dk).

7.7 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.

7.8 Groundwater hydrogeology

7.8.1 Groundwater characteristics

The Harre Vig area is situated between Glyngøre and Roslev. According to the basisanalysis Part 1 (Basisanalysis Part 1, 2004), Area 18 is characterized by one shallow (DK1.2.1.7) groundwater body (Fig. 55). There are no regional or deep groundwater bodies directly underneath the Harre Vig area (Figs. 56 and 57). The shallow groundwater body consists of meltwater sand deposits. The Limfjorden catchment management plan (Hovedvandopland 1.2 Limfjorden) has been described by the Ministry of Environment. The overall assessment of the chemical and quantitative status in the shallow GWB is poor due to a poor chemical status (see Section 7.9).

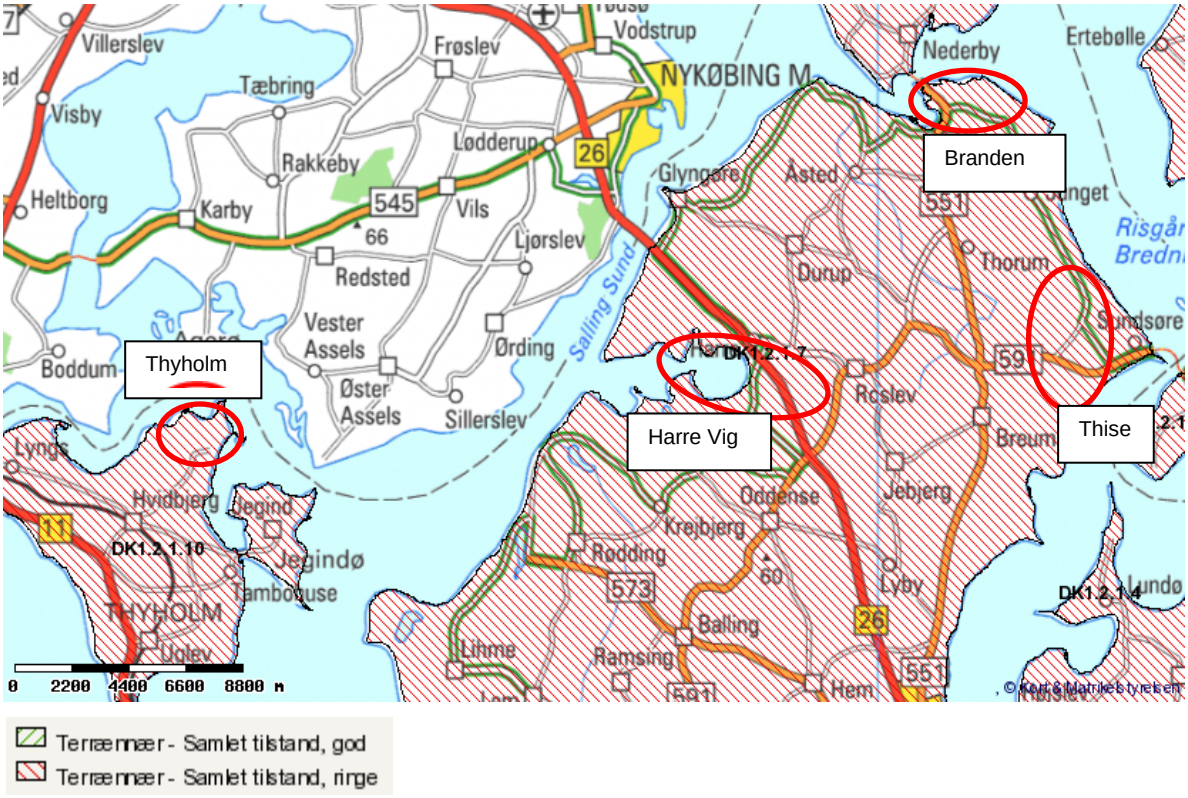


Figure 55. Shallow Groundwater Bodies (After Ministry of Environment, 2010).

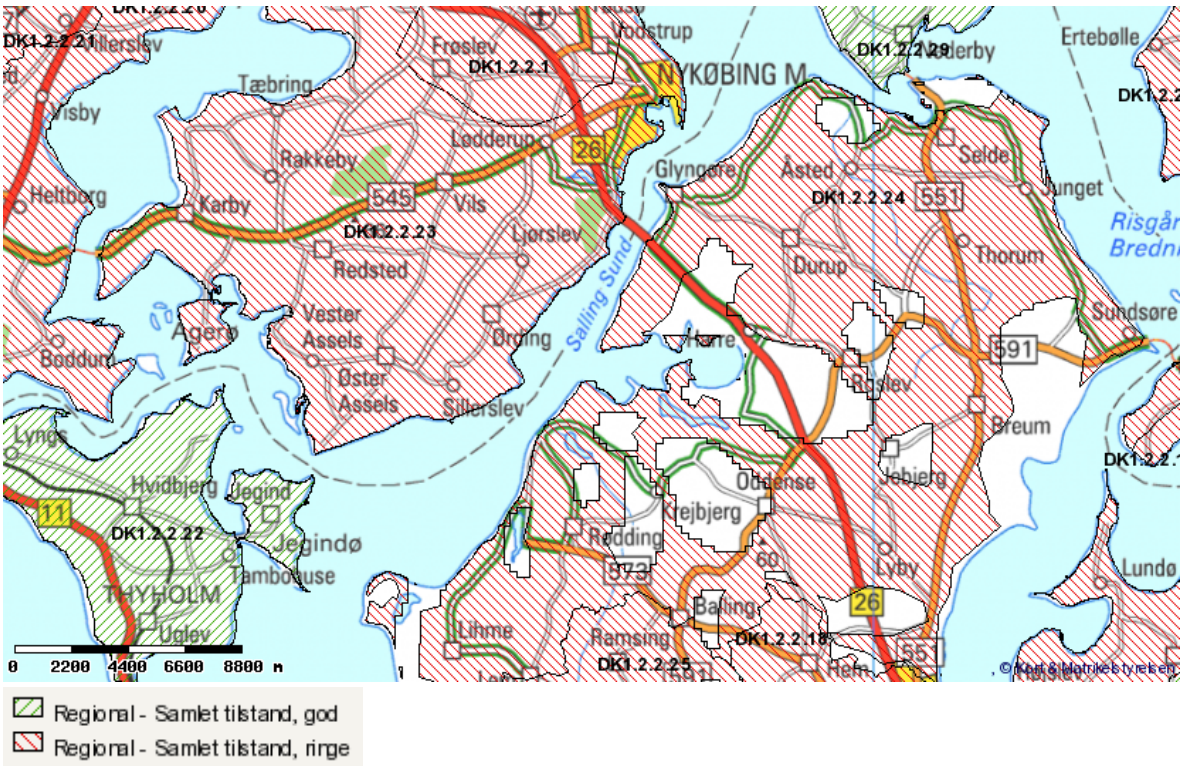


Figure 56. Regional Groundwater Bodies (After Ministry of Environment, 2010).

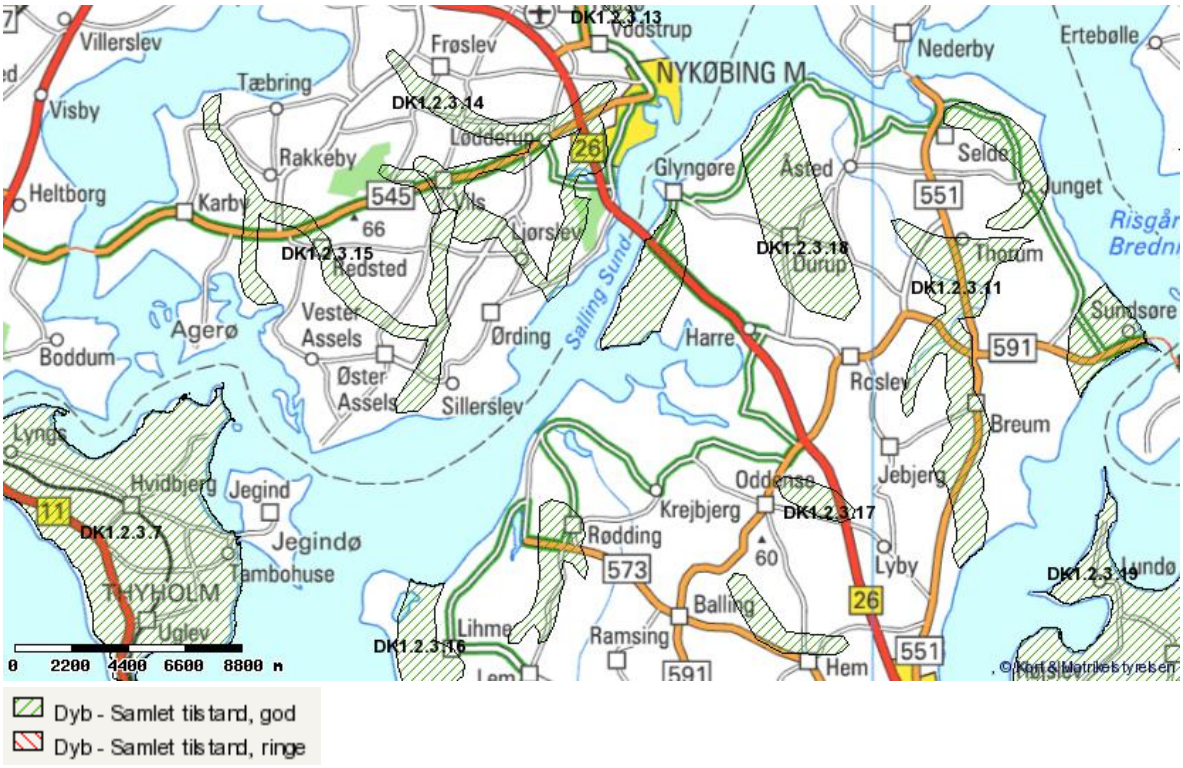


Figure 57. Deep Groundwater Bodies (After Ministry of Environment, 2010).

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. 58).

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.

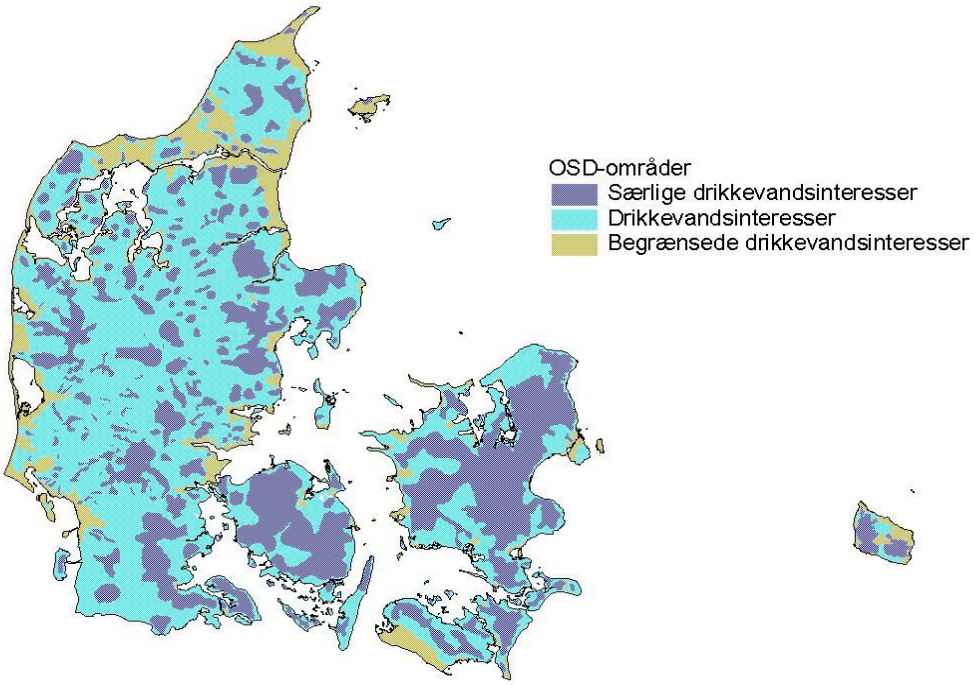


Figure 58. Areas of special drinking water interests (OSD): Dark blue and areas of drinking water interest (OD): Light blue. Areas of limited drinking water interests are olive.

The geographical distribution of the drinking water areas in the Harre Vig area is given in Figs 59 and 60. The Harre Vig area is situated in an area with limited or no groundwater interests along the coast of Harre Vig. Outside, toward east an OD area is located. Still, there are few water wells for local households situated directly within the Harre Vig area. In addition, the Vester Hjerk water work is located in the southern margin of Area 18. Status of the water work is unknown.

Figure 59. Drinking water areas (http://kort.arealinfo.dk/).

Figure 60. Map of the drinking water areas in Area 18. Legend: see fig. 40. (http://kort.arealinfo.dk/)).

7.9 Groundwater chemistry

The overall groundwater quality aiming for drinking water purpose has been assessed by the Environmental Centre Ringkøbing in the catchment management plan “Hovedvandopland 1.2 Limfjorden“. The groundwater chemistry does not fulfil the EU criteria in the shallow groundwater body due to an unacceptable high content of nitrate. No saltwater intrusion problems have been reported in relation to the relevant groundwater bodies in Area 18.

The level of the terrain surface range between 5 and more than 25 meter above present sea level within Area 18, thus no significant changes in the fresh/saltwater interface is expected to happen due to future sea level rise (climate change).

7.10 Climate and climate changes

The actual climate and the expected future climate changes and sea level development is described in Gravesen et al. (2010, Rep. No. 2). It is not expected that climate changes will affect the area during this century. The expected sea level rise will most probably cause flooding of the coastal section along Harre Vig but will not necessarily cause erosion, except from very locally, at the promontory Hjerk Bjerg, where the ongoing cliff erosion is supposed to be intensified.

7.11 Restrictions and limitations

There are no NATURA 2000 habitat areas directly in Area 19 (Fig. 61) and only a small area around Hjerk Church is protected in accordance to Naturbeskyttelsesloven (nature protection law) (Chapter 6). However, attention has to be given to the local water supply for local household and the Vester Hjerk water work.

Figure 61. NATURA2000 habitat areas (After Ministry of Environment, 2010).

7.12 Summary of the area conditions

Amount of data:
Several boreholes in the area. No geophysical surveys in the area.

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

Stability
Good stability on surface and depth.

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

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

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 areas are located in the area. Areas of limited drinking water interest are located along the coast while OD areas occur within the rest of Area 18. Only minor local supplies are present.

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

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

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

Other restrictions
Apparently no other restrictions will give problems.

7.13 Final Remarks

The Area 18 seems to consist of mainly horizontal layers of Paleogene clays below the glacial clayey tills although the Batum salt diapir is situated north of the area.

8. Area 19 Branden-Junget, Salling

8.1 The location of the area

The area is located on the northern tip of Salling south of Fur Sund and Risgårde Bredning (Fig. 62). The area can be seen in detail on fig. 63.

Figure 62. Location of the area. The area is found on northern Salling south of Fur Sund, Jylland.

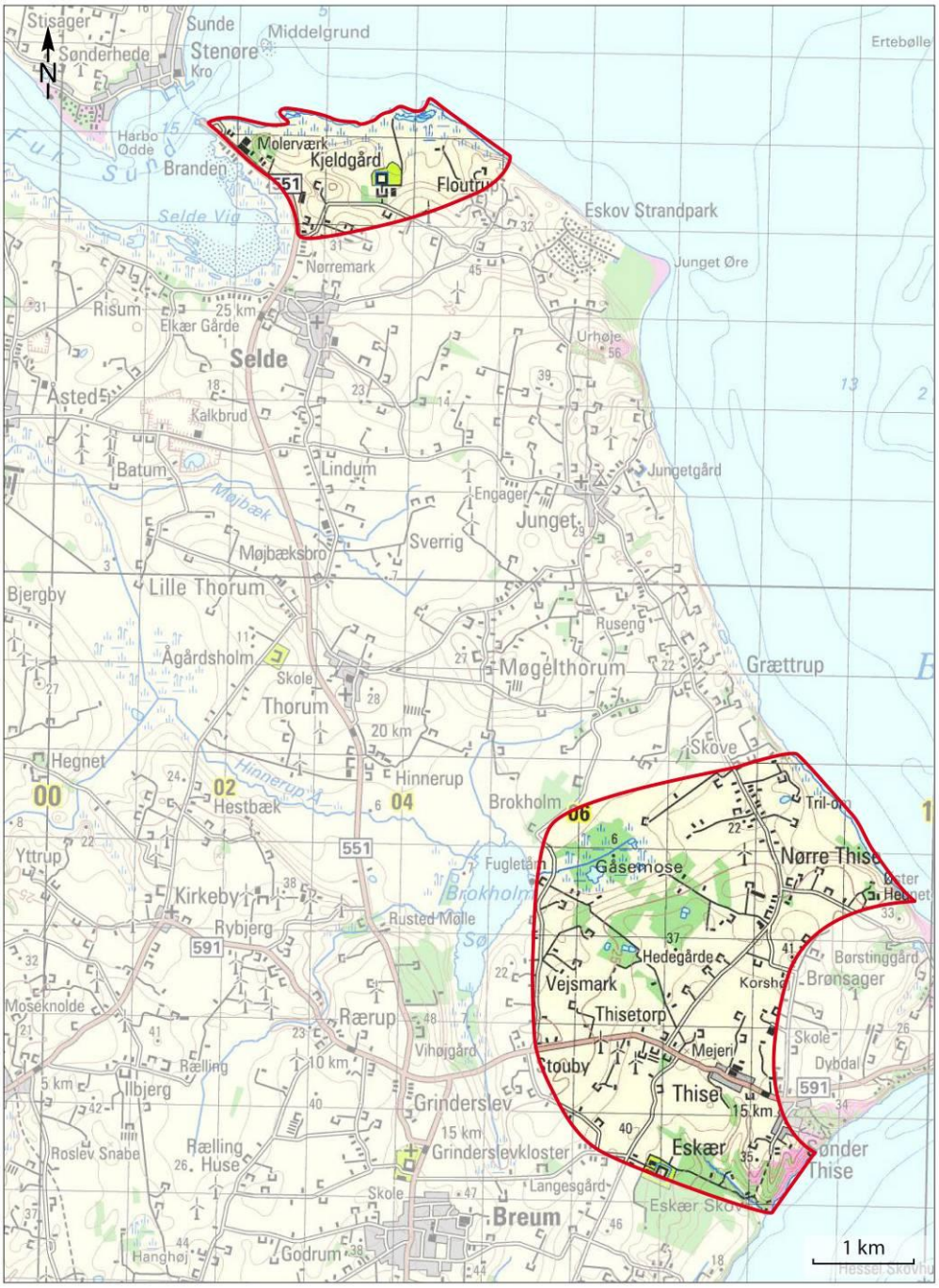


Figure 63. Detailed map of Area 19. Area 19 is located on Northern Salling.

8.2 Terrain, topography and surface processes

The area is located on the northernmost part of large peninsula Salling, in the central Limfjord area. The size of the area is c. 2.9 km^2. The area includes two very different kinds of landscape. The southern and major part is an undulating moraine landscape, situated between 5 and 30 meters above sea level (m.a.s.). The smaller part, toward north, is a low-lying plane marine foreland with a small lagoon and a stable or even prograding coastline

toward north, where the island Fur is located nearby. The coastal section toward northeast is a simplified and rectilinear coast facing a longer fetch and higher wave energy from NE. In spite of this, also this coastal section seems to be stable and not suffering from erosion.

The passage between the two segments is very gentle and hardly visible. Except from the lowest and wettest parts of the marine foreland, the Area 19 is used for agriculture. No streams or lakes (except from the lagoon) are found in the area.

Only one minor road crosses the area. The farm Kjeldgård, the Branden clay pit and a very few houses are located in the area.

Owing to the cultivation and relatively low relief, the surface processes (soil creep, frost – thaw processes, soil development etc.) proceed slowly and undramatic. The most dynamic processes are found in the coastal zone, especially in the section facing NE.

A small area toward north-west is an area of National Geological Interest (no. 23).

8.3 Surface geology and profiles

The surface geology is dominated by Quaternary deposits. The geology varies but with a dominance of clayey till, sandy till and meltwater sand and gravel. These glacial deposits are bordered by Holocene marine deposits along the coast (Fig. 64). An old clay pit is located at Branden.

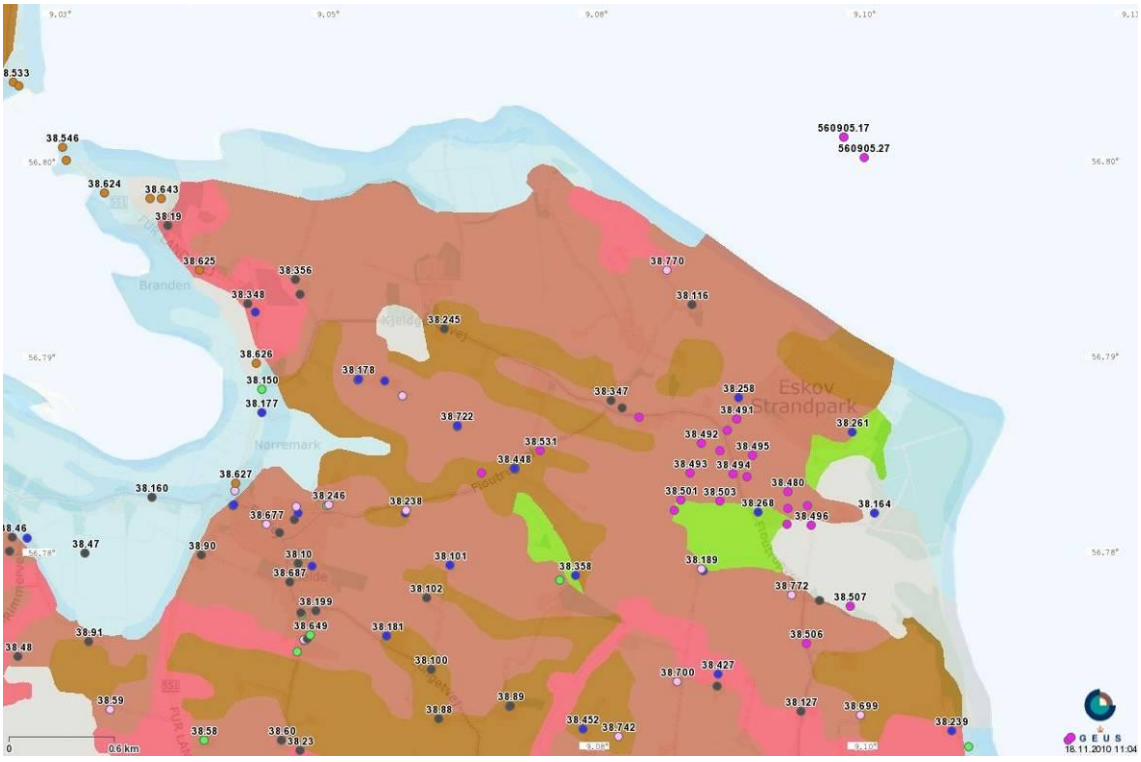


Figure 64. Map of the Quaternary surface deposits. (From GEUS´s Homepage after Pedersen, 1989). Legend: See fig. 3.

8.4 Boreholes

The area is penetrated by few boreholes. The drilling methods normally produce fair samples of the Tertiary and Quaternary sediments. Most of the samples are described lithological and related to lithostratigraphical units while two samples are dated by biostratigraphy.

At least one seismic line crosses the area from the Batum salt structure towards the southwest. Shallow geophysical surveys are performed towards the south, in the Selde-Junget area. Towards the south east, investigations in the Junget mo-clay field have been carried out as boreholes and shallow excavations.

The locations of the boreholes in the area are seen in fig. 65.

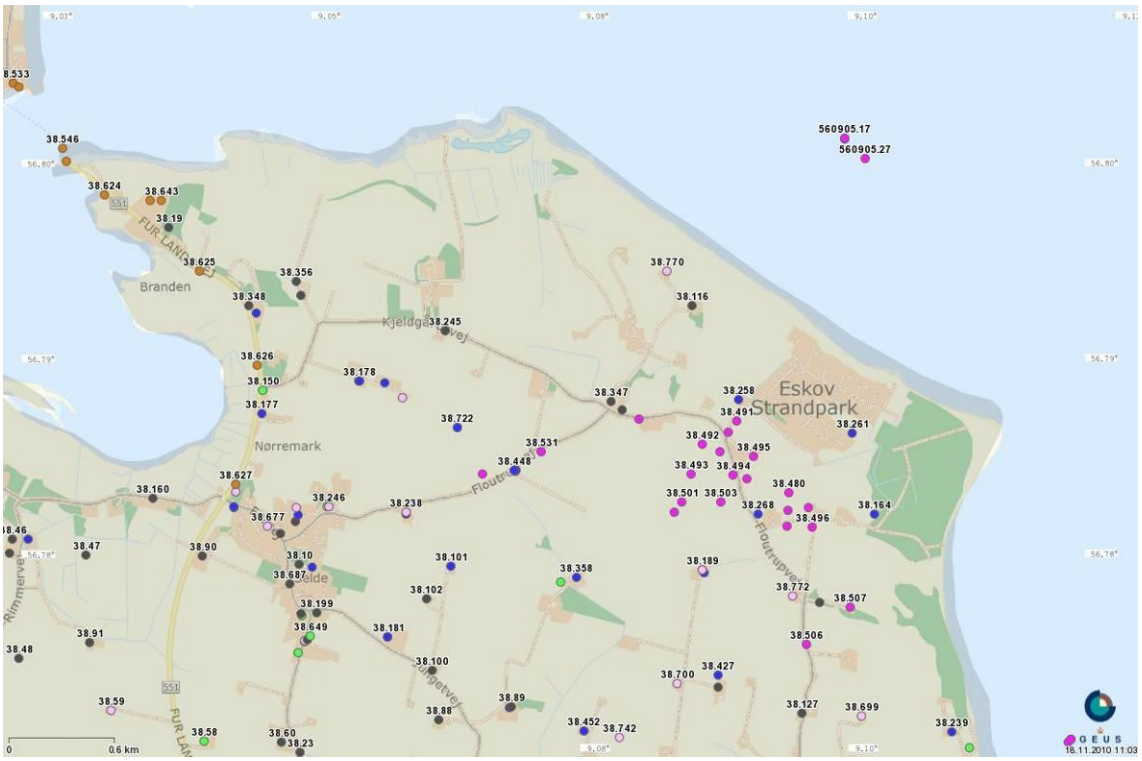


Figure 65. Map of the locations of boreholes from the Jupiter database at GEUS. Legend: 38. 641: DGU no.; Blue dot: Water supply well; Red dot: Geotechnical borehole; Pink dot: Raw material borehole; Green dot: Other borehole; Light red dot: Abandoned borehole; Black dot: Unknown purpose.

Most of the boreholes are wells that supply households, smaller farms and other local needs.

An example of a borehole log is found in fig. 66

De Nationale Geologiske Undersøgelser for Danmark og Grønland

Udskrevet 1/12 2010 Side 1

BORERAPPORT

DGU arkivnr: 38. 641

Borested : Skamol, Branden
7870 Roslev

Kommune : Skive
Region : Midtjylland

Boringsdato : 11/10 2000 **Boringsdybde** : 4 meter **Terrænkote** : 1.82 meter o. DNN

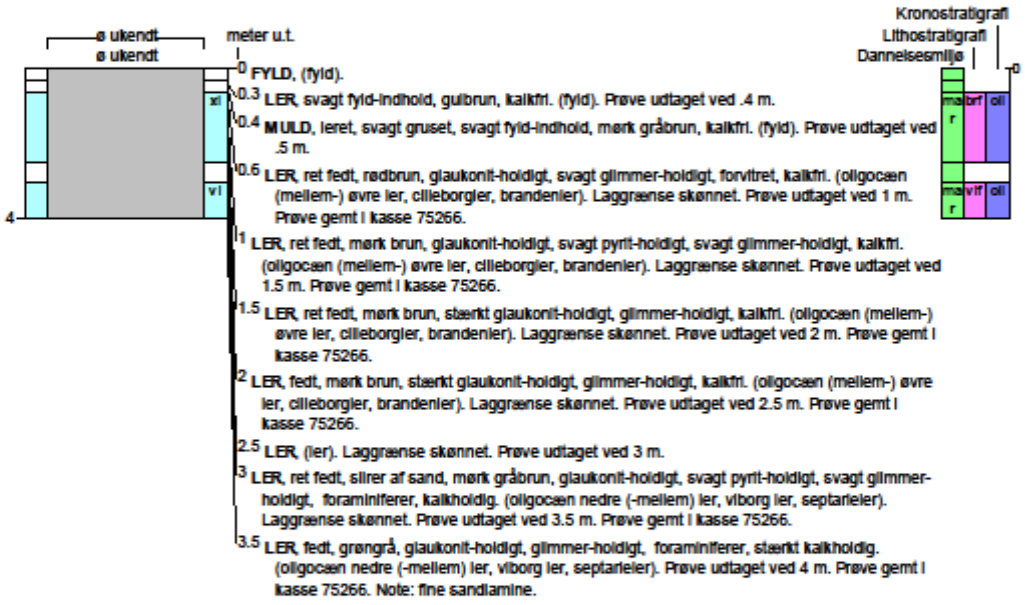
Brøndborer : Andreasen og Hvidberg, Ålborg
MOB-nr :
BB-journr : 82035.2
BB-bornr : 12

Prøver
- modtaget : 2/4 2001 **antal** : 8
- beskrevet : 3/4 2001 **af** : TC
- antal gemt : 6

Formål : Geoteknisk boring
Anvendelse :
Boremetode :

Kortblad : 1216IIINV
UTM-zone : 32
UTM-koord. : 502135, 6295119

Datum : ED50
Koordinatkilde : Geoteknisk firma
Koordinatmetode : Afst. fra kortkanter



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

meter u.t.			
0	-	0.3	mangler
0.3	-	0.6	fyld
0.6	-	2.5	marin - oligocæn (ant. branden formation)
2.5	-	3	mangler
3	-	4	marin - oligocæn (ant. viborg formation)

Figure66. Borehole log from DGU no. 38.641. The borehole is 4 m deep. Legend: XL: Oligocene clay, VL: Oligocene clay.

8.5 Sediment and rock characteristics, mineralogy and chemistry

8.5.1 Pre-Quaternary rocks

The distribution of the pre-Quaternary deposits can be seen in fig. 67.

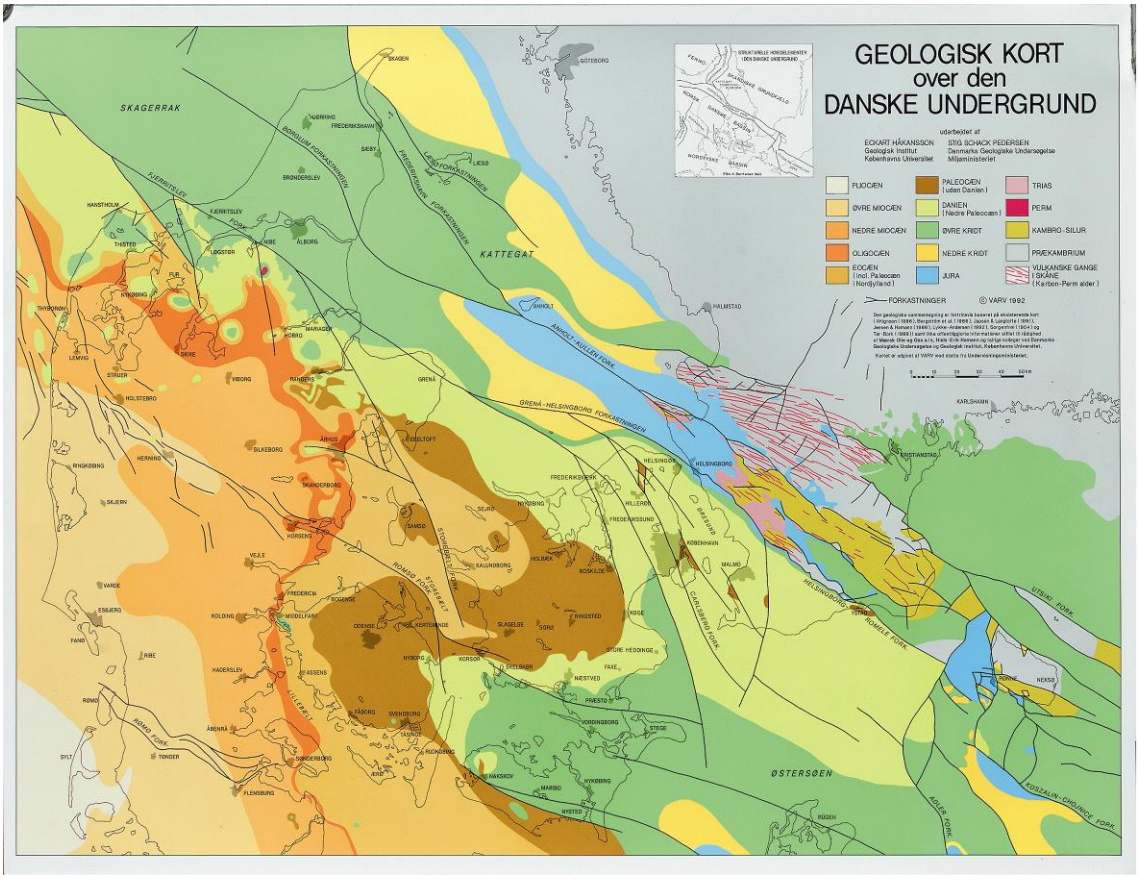


Figure 67. Map of the pre-Quaternary surface: Time units. Original scale: 1:50.000. Legend: Red lines: Precambrian intrusions; Grey: Precambrian; Olive: Cambrian-Silurian; Red: Permian; Light red: Triassic; Blue: Jurassic; Yellow: Lower Cretaceous; Green: Upper Cretaceous; Light green: Danian; Brown: Paleocene; Yellow olive: Eocene; Red brown: Oligocene; Light yellow brown: Lower Miocene; Very light yellow brown: Upper Miocene; White: Pliocene (Håkansson & Pedersen, 1992).

It is expected that the sediments on the pre-Quaternary surface are from the Oligocene. Some boreholes in the area reach Oligocene deposits below 5 - 10 m of Quaternary sediments.

The Oligocene Vejle Fjord Formation, Brejninge Clay Member probably occur in two boreholes towards the north as fine-grained, brown to grey brown glauconitic clay (2.5 m thick). This clay is resting on fine-grained dark green grey and green grey, glauconitic, calcareous

clay from the Branden Formation. The Late Oligocene the Branden clay is at least up to 55 m thick (Fig. 68).

Just to the south of the area, the boreholes reach Paleocene-Eocene clays and Danian limestone, marking the Batum Salt diapir.

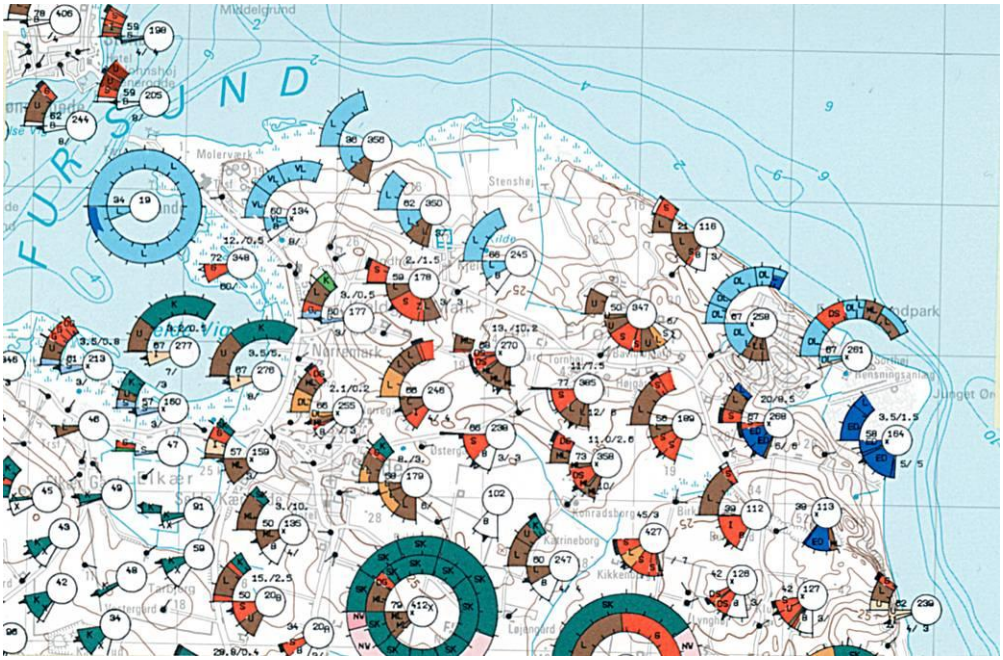


Figure 68. Part of Geological basic data map 1216 III Farsø Original scale 1:50.000 (From Fredericia & Gravesen, 1983). Legend: See fig.11.

8.5.2 Quaternary deposits

The Quaternary deposits are thin. Very few samples point to clayey till as the dominant sediment, but the map of the Quaternary sediments indicate that meltwater sand and gravel and Holocene marine deposits can also be top layers (Figs. 13 and 64).

8.6 Tectonics, structures and seismic activity

8.6.1 Major tectonic structures

According to the map (Fig. 67), apparently no structures crosses the pre-Quaternary surface of the area but the area is situated just north of the Batum salt diaper where movement during and after deposition of the Paleogene may have influenced the deposition pattern and later erosion. The Oligocene layers are inclined towards the north east.

Glaciotectonic disturbances are dominant in the Junget mo-clay field south east of Area 19 where Paleogene (Eocene, Oligocene) and Quaternary sediments are strongly folded and faulted.

8.6.2 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.

8.6.3 Geological model

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

Model of the area is as follows (Fig. 69):

A. Holocene marine deposits (Thickness unknown)

B. Quaternary clayey tills and meltwater sand and gravel, up to 10 m thick.

C. Oligocene clay: Vejle Fjord Formation, Brejninge Clay Member, 2 - 3 m thick.

D. Oligocene Branden Formation, at least 55 m thick.

E. Eocene plastic clays: Lillebælt Clay Formation (and perhaps Røsnæs Clay Formation, Fur Formation).

F. Danian limestone.

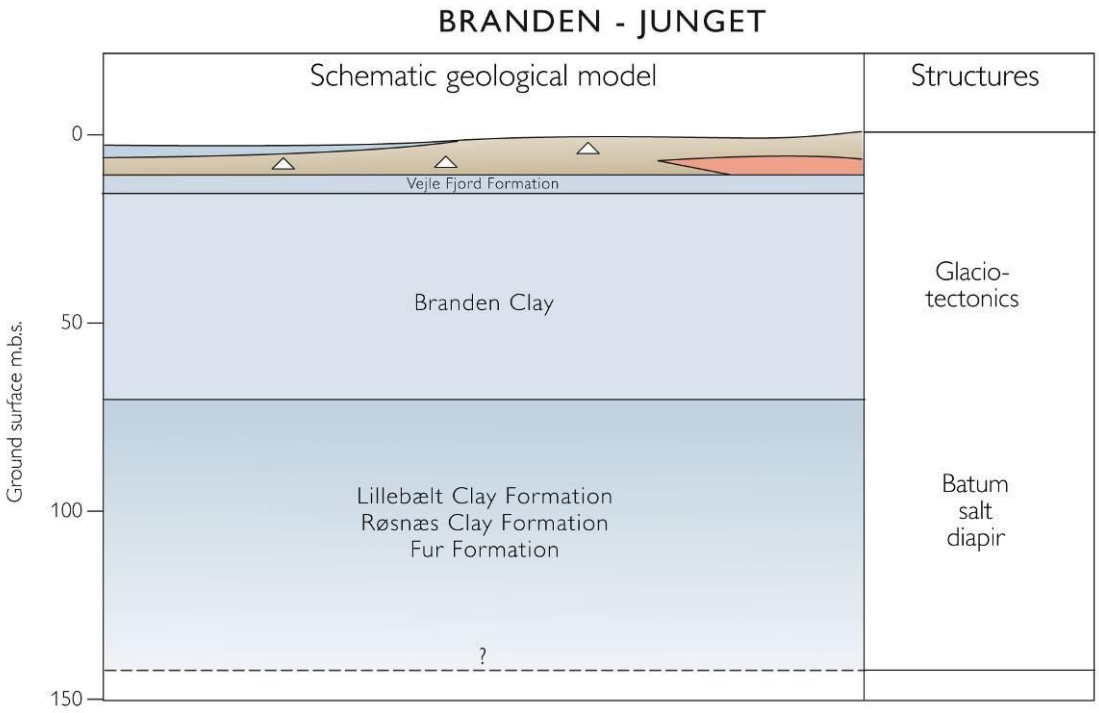


Figure 69. Schematic geological model of Area 19.

8.6.4 Earthquake activity

The seismic station net in Denmark is managed by GEUS and comprises 5 stations of which three stations are located on Sjælland: Gilleleje museum, Vestvolden, København and Lille Linde, Stevns (GEUS´s homepage: www.geus.dk).

The earthquake activity is measured with respect to location, time and size. The activity in Denmark during the period 1929-2003 is very low compared to many other countries.

The seismic activity in the Limfjorden area is very low (Fig. 70). No seismic movement have been registered for the area although a seismic station is located at Mønsted.

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

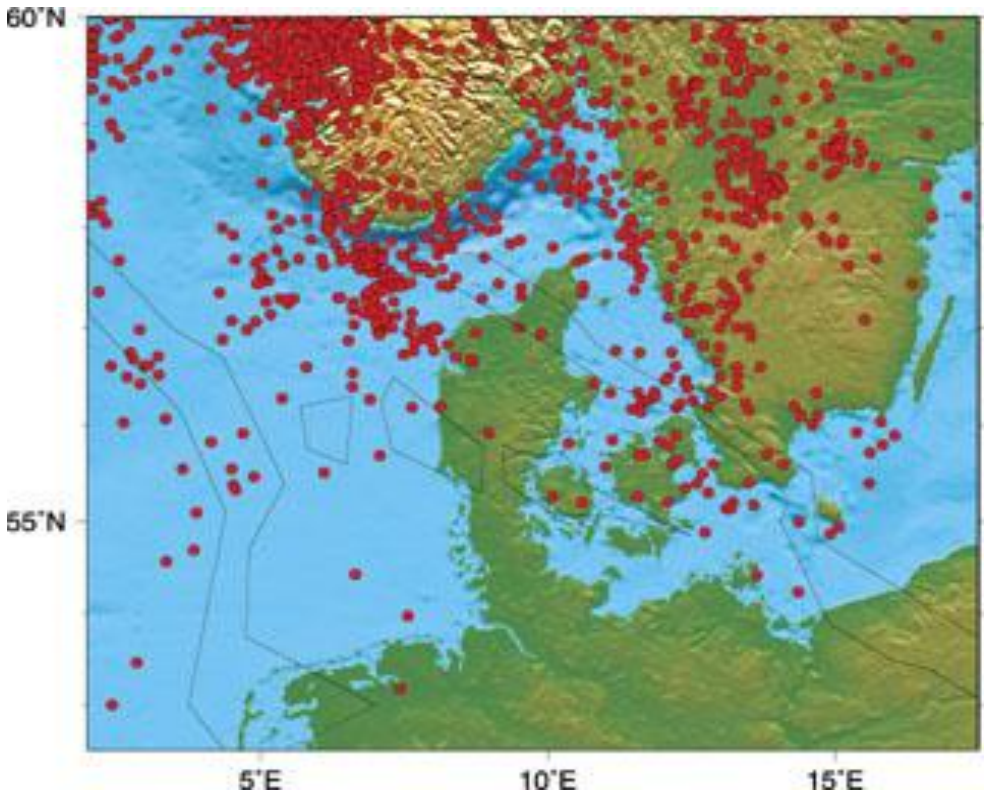


Figure 70. Map of the earthquake epicentres in Denmark and surrounding areas. A red dot shows the location (From GEUS´s Home Page).

8.7 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.

8.8 Groundwater hydrogeology

8.8.1 Groundwater characteristics

The Branden-Junget area is situated on northern part of Salling. Accordance to the basisanalysis Part 1 (Basisanalysis Part 1, 2004), Area 19 is characterized by one shallow groundwater body (DK1.2.1.7). Along the periphery, the regional (DK1.2.2.24) and deep (1.2.3.11) groundwater bodies (Figs. 71, 72 and 73) are located. The shallow and regional groundwater bodies both consist of meltwater sand deposits while the deep groundwater body consists of bryozoan limestone (KS). The Limfjorden catchment management plan (Hovedvandopland 1.2 Limfjorden) has been described by the Ministry of Environment. The overall assessment of the chemical and quantitative status: shallow GWB (poor due to poor chemical status), regional GWB (poor due to a poor quantitative status), and deep (good) (see Section 8.9).

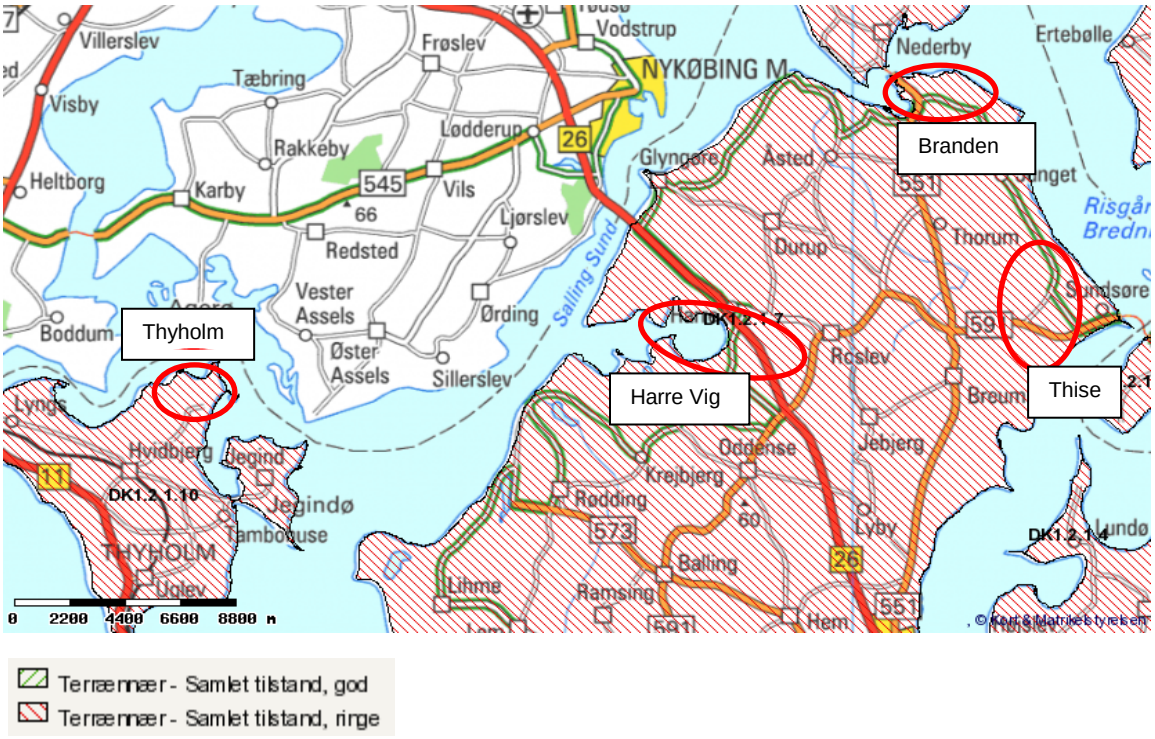


Figure 71. Shallow Groundwater Bodies (After Ministry of Environment, 2010).

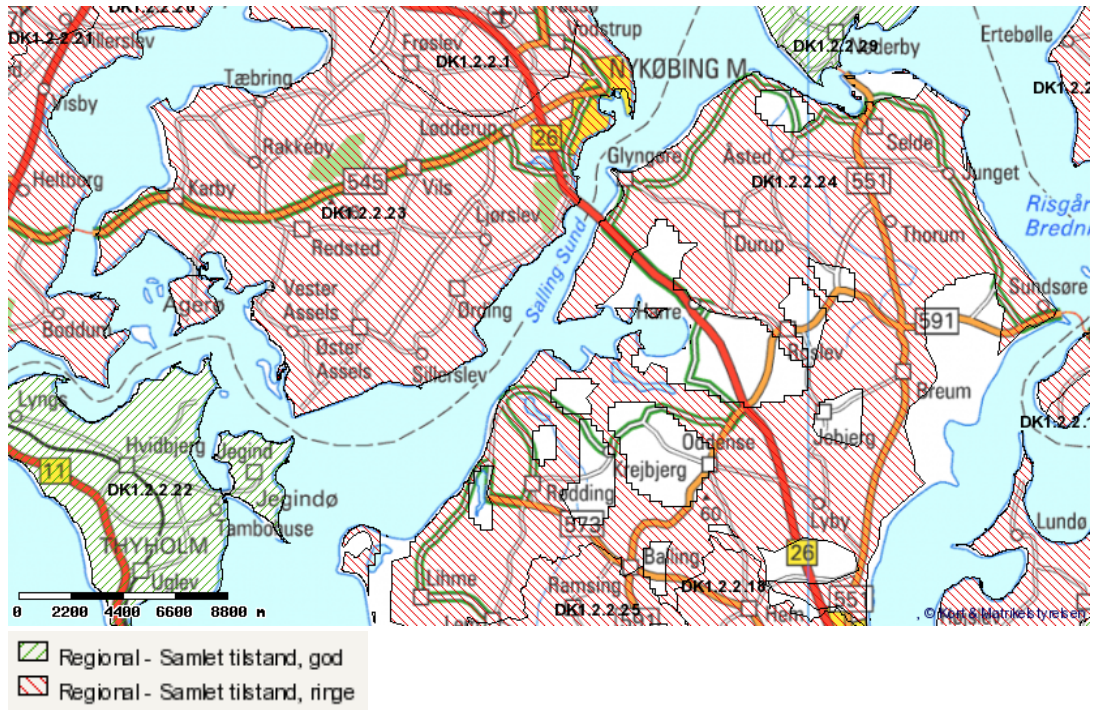


Figure 72. Regional Groundwater Bodies (After Ministry of Environment, 2010).

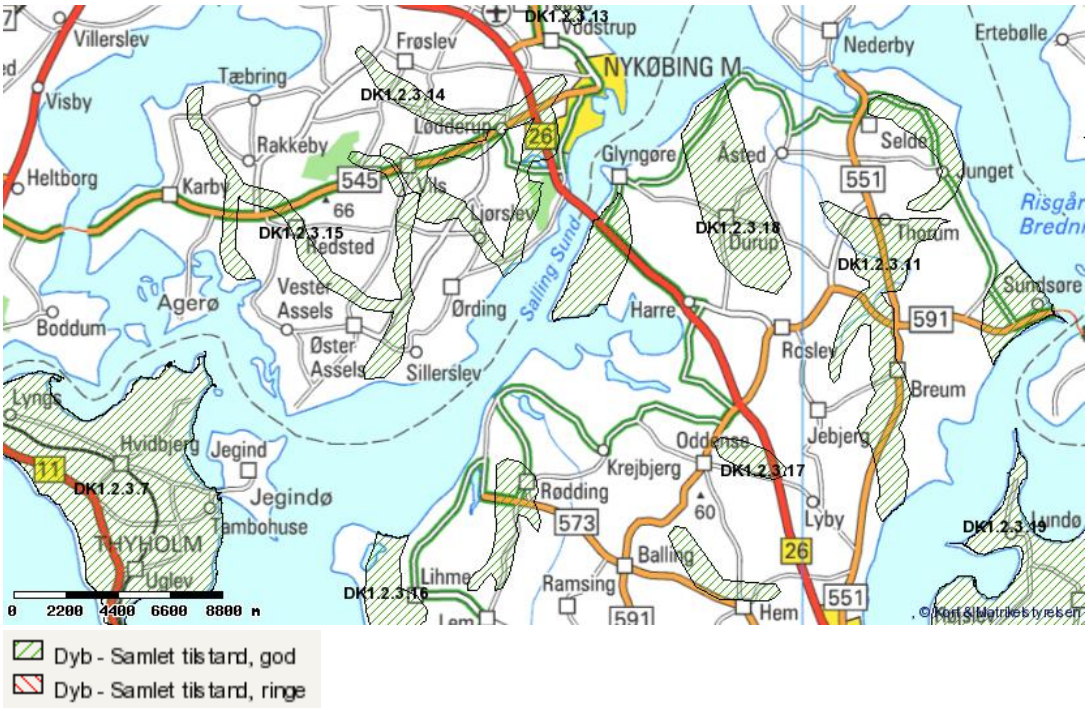


Figure73. Deep Groundwater bodies (After Ministry of Environment, 2010).

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. 74).

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.

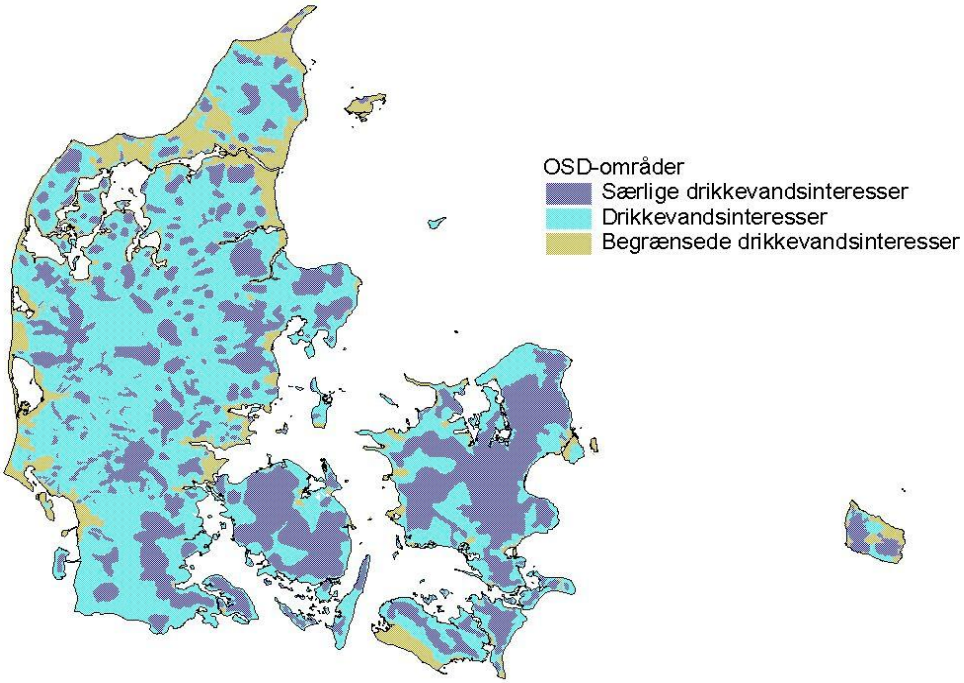


Figure 74. Areas of special drinking water interests (OSD): Dark blue and areas of drinking water interest (OD): Light blue. Areas of limited drinking water interest are olive (/kort.arealinfo.dk/).

The geographical distribution of the drinking water areas in the Branden-Junget area is given in figs 75 and 76. Area 19 is situated at the transition between an OD area and area with limited drinking water interests. However, 1 – 2 km south of Area 19, an OSD area is located. More abstraction wells for Selde water work and additional wells for local household use are situated within Area 19.

Figure 75. Drinking water areas. Legend : See fig. 40 (http://kort.arealinfo.dk/).

Figure 76. Map of the drinking water areas in Area 19. Legend: see fig. 40. (http://kort.arealinfo.dk/).

8.9 Groundwater chemistry

The overall groundwater quality aiming for drinking water purpose has been assessed by the Environmental Centre Ringkøbing in the catchment management plan “Hovedvandopland 1.2 Limfjorden“. The groundwater chemistry does not fulfil the EU criteria in the shallow groundwater body, due to unacceptable high content of nitrate. No saltwater intrusion problems have been reported in relation to the relevant groundwater bodies in Area 19.

The level of the terrain surface ranges between 0 m and more than 25 meter above present sea level within Area 19. Thus, no significant changes in the fresh/saltwater interface is expected to happen due to future sea level rise (climate change) but the most coastal part can be vulnerable.

8.10 Climate and climate changes

The actual climate and the expected future climate changes and sea level development is described in Gravesen et al. (2010, Rep. No. 2). It is not expected that climate changes will affect the high-lying part of the area during this century. The expected sea level rise will most probably cause flooding of the marine foreland and erosion of the coastal section facing NE.

8.11 Restrictions and limitations

There are no NATURA 2000 habitat areas or areas protected by Naturbeskyttelsesloven (nature protection law) (Chapter 6) situated in Area 19 (Fig. 77). However, the bay just west of area 19 has NATURA2000 habitat status. Particular attention must be given to the water supply wells for Selde water work within Area 19.

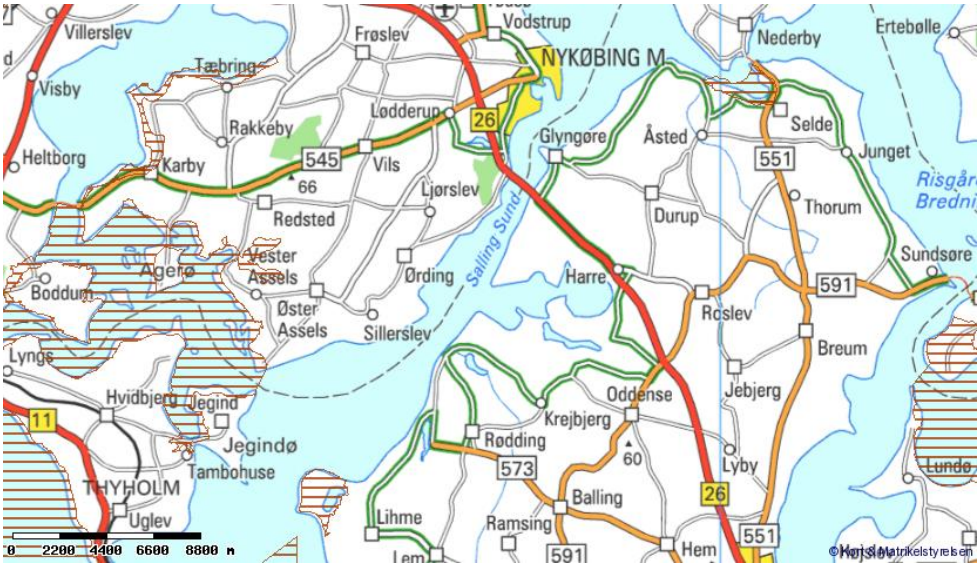


Figure 77. Natura2000 habitat areas (After Ministry of Environment, 2010).

8.12 Summary of the area conditions

Amount of data:
Limited amounts of borehole data. No geophysical surveys in the area.

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

Stability
Good stability on surface and depth.

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

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

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 areas are located in the area. Areas of limited drinking water interests occur along the coast while OD areas occur within the rest of the Area 19. Only minor local supplies are present.

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

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

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

Other restrictions
Apparently no other restrictions will give problems.

8.13 Final Remarks

The small area is rather isolated and could represent a possible area for a waste disposal.

9. Area 20, Thise, Salling

9.1 The location of the area

The area is located northeast of Breum on Saling close to Hvalpsund (Fig. 78). The details of the area can be seen in fig. 79.

Figure 78. Location of Area 20. Breum and Thise are located on the east side of Salling, Jylland.

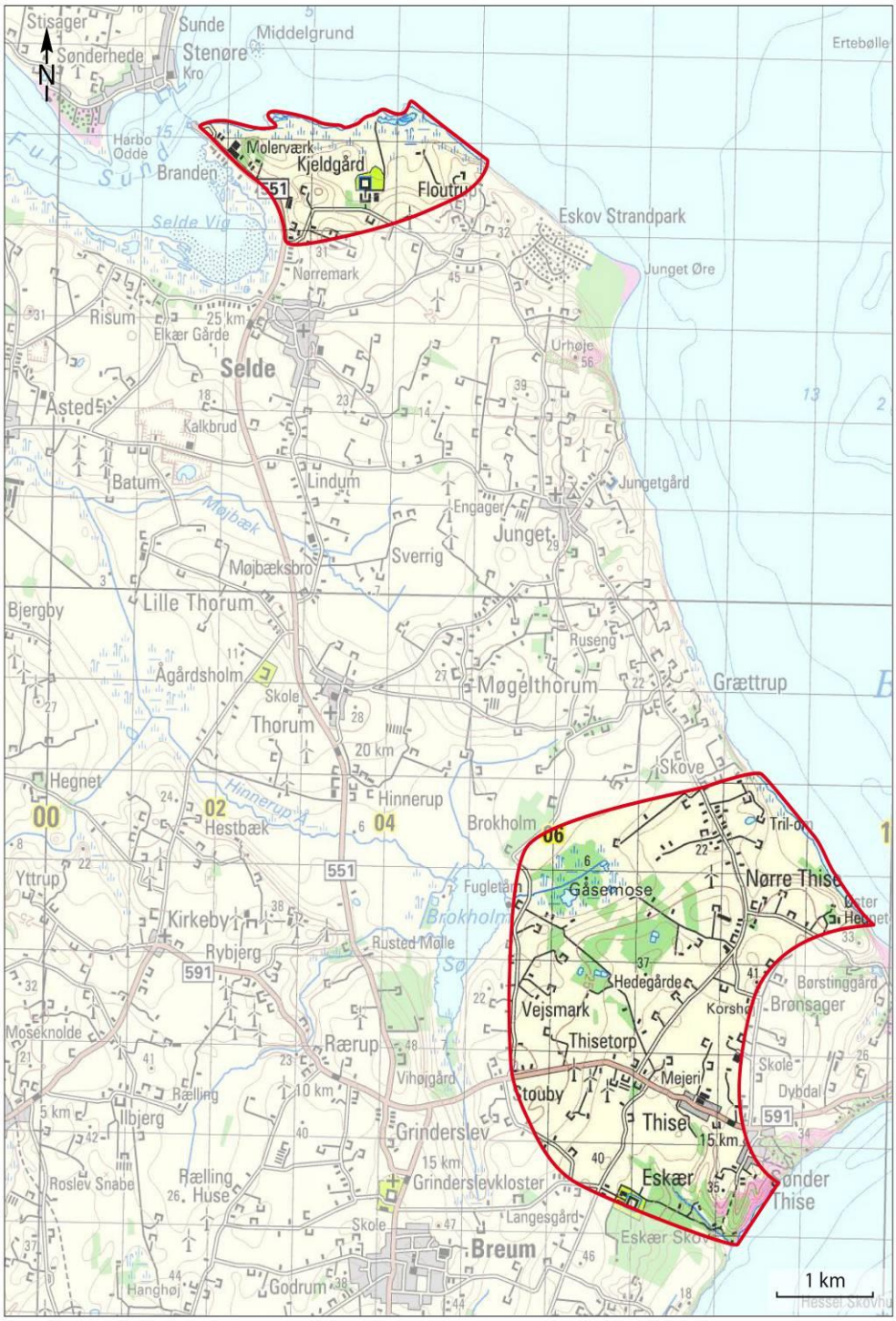


Figure 79. Detailed map of area 20. Area 20 is located on east Salling.

9.2 Terrain, topography and surface processes

The area is located on the central, eastern part of large peninsula Salling, in the central Limfjord area. The size of the area is c. 14 km^2.

The area is marked by a large, high-lying and almost plane plateau, including the major part of the central and south-eastern area. The plateau is situated 25 – 40 meter above sea level (m.a.s.). From the plateau, the landscape slops gently toward west and northwest and a little steeper toward north-east. Directly toward north, another, smaller, plateau is located in the level between 15 and 20 m.a.s. Directly toward south, the slope between the plateau and the stream valley and the coastal zone, respectively, is very steep and highly incised by narrow steep slopes. The coastal section toward south-east seems to be marked by an erosive cliff. The coastal section toward north-east seems to be stable. Furthest toward north, a narrow marine foreland is found. An approx. 1 km^2 large bog (5 - 6 m.a.s.) is located toward north-west, at the foot of the slope from the plateau.

The predominating part of the area is used for agriculture. Woods and the bog make up some c. 10 %. The area is crossed (W – E) by one main road and (N – S as well as W – E) by several smaller roads. The small village Thise is located along the main road. Many houses are located along some of the small roads but the remaining landscape only holds scattered houses. A cluster of windmills is located west of Thise.

Owing to the cultivation and relatively low relief of most of the area, the surface processes (soil creep, frost – thaw processes, soil development etc.) proceed slowly and undramatic. The most dynamic processes are found locally, in the stream and in the coastal zone, especially in the section facing SE.

Figure 80. View over the landscape toward north-west.

9.3 Surface geology and profiles

The surface geology is dominated by Quaternary deposits. In the main part of the area, clayey till dominate but scattered in the area rather large subareas consist of meltwater sand and gravel (Fig. 81). Holocene freshwater deposits occur to the west, especially in the former drained Brokholm Lake area and in the Gåsemose but freshwater deposits are also found in narrow steam valleys.

The Quaternary and Oligocene deposits are exposed in the cliffs at Mogenstrup Strand and Knuds Strand just south of the area Figs. 85 and 86.

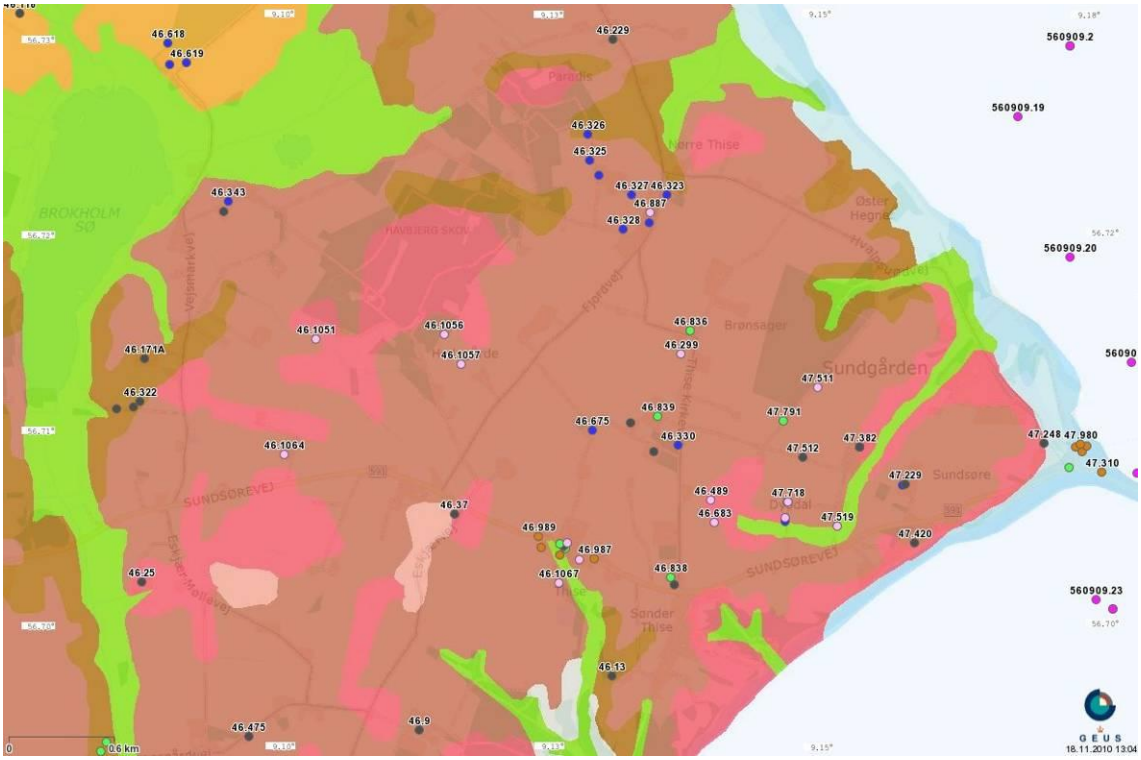


Figure 81. Map of the Quaternary deposits in the Thise area. (From GEUS´s Homepage, after Pedersen, 1989). Legend: see fig. 3.

9.4 Boreholes

The area is penetrated by some boreholes, mainly toward the east, but in the middle part of the area very, few boreholes are drilled. The drilling methods normally produce fair samples of the Tertiary and Quaternary sediments. Most of the samples are described lithological and related to lithostratigraphical units while no samples are dated by biostratigraphy. No geophysical surveys have been performed.

The locations of the boreholes in the area are seen in fig. 82.

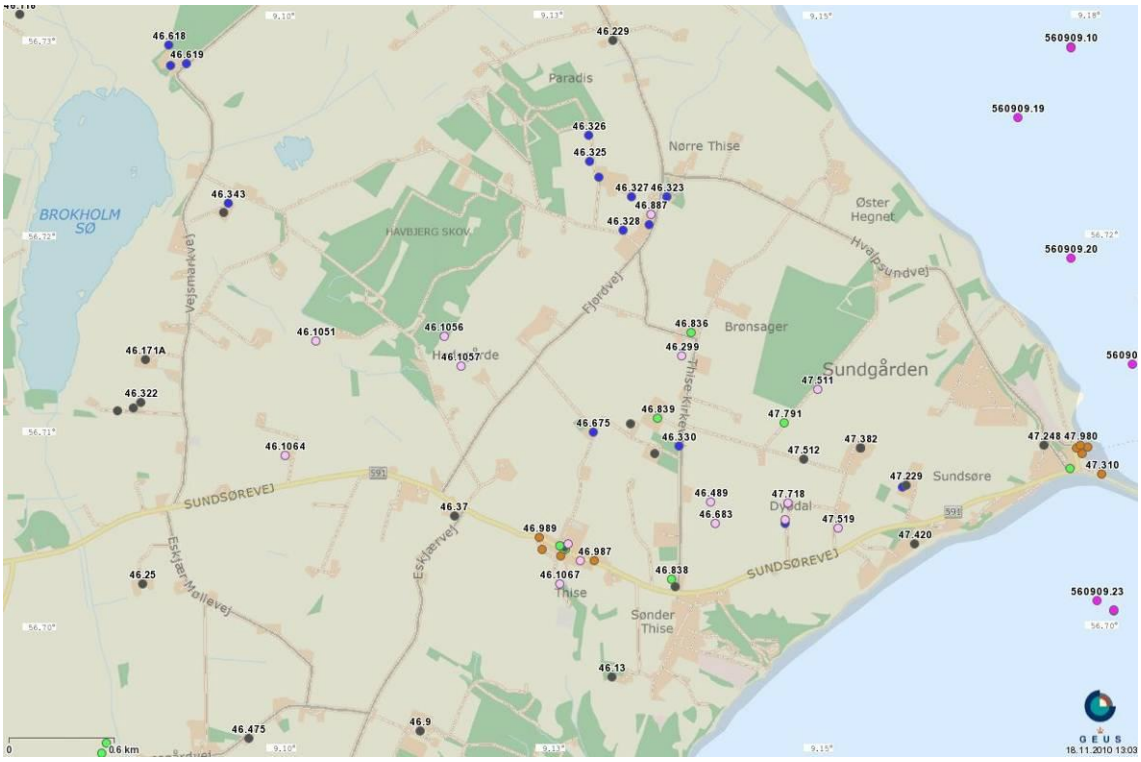


Figure 82. Map of the locations of boreholes from the Jupiter Database at GEUS. Legend: 55. 1066: DGU no.; Blue dot: Water supply well; Red dot: Geotechnical borehole; Pink dot: Raw material borehole; Green dot: Other borehole; Light red dot: Abandoned borehole; Black dot: Unknown purpose.

Most of the boreholes are wells, which supply households, smaller farms and other local needs.

An example of a borehole log is found in fig. 83.

De Nationale Geologiske Undersøgelser for Danmark og Grønland

Udskrevet 29/11 2010 Side 1

BORERAPPORT

DGU arkivnr: 46. 322

Borested : STOVBY JEBJERG GDR SØREN CHR HENRIKSEN BOMLUND
7870 Roslev

Kommune : Skive
Region : Midtjylland

Boringsdato : 10/12 1969 **Boringsdybde** : 45 meter **Terrænkote** : 19 meter o. DNN

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

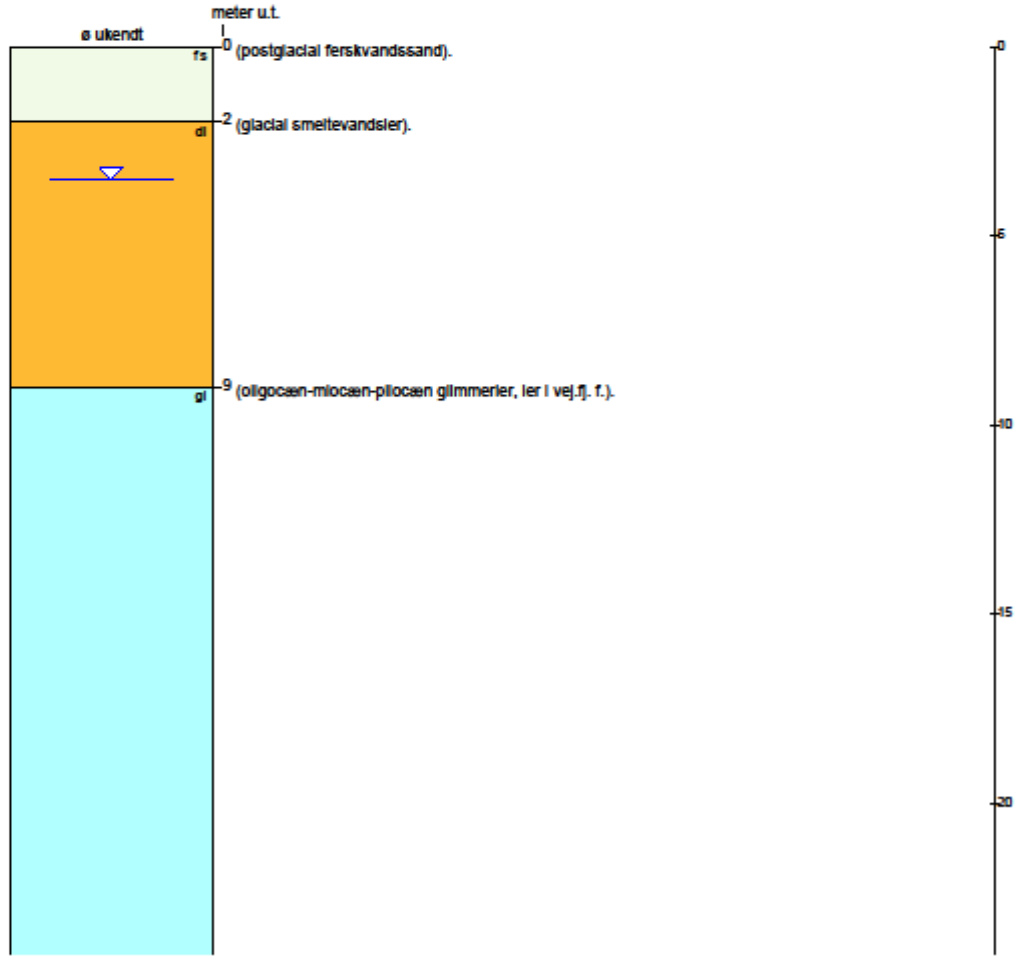
Prøver
- modtaget :
- beskrevet : **af** : G
- antal gemt :

Formål :
Anvendelse :
Boremetode :

Kortblad : 1216IIISV
UTM-zone : 32
UTM-koord. : 505406, 6285479

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

		Ro-vandstand	Pejledato	Ydelse	Sænkning	Pumpetid
Indtag 1	(seneste)	3,5 meter u.t.	1/12 1969			
	(første)	3,5 meter u.t.	12/10 1969			



fortsættes...

Figure 83. Borehole log of the DGU no. 46.322. The Upper part of the 45 m deep borehole. Legend: DL. Meltwater clay, GL: Micaceous clay.

9.5 Sediment and rock characteristics, mineralogy and chemistry

9.5.1 Pre-Quaternary rocks

The distribution of the pre-Quaternary deposits can be seen in fig. 84.

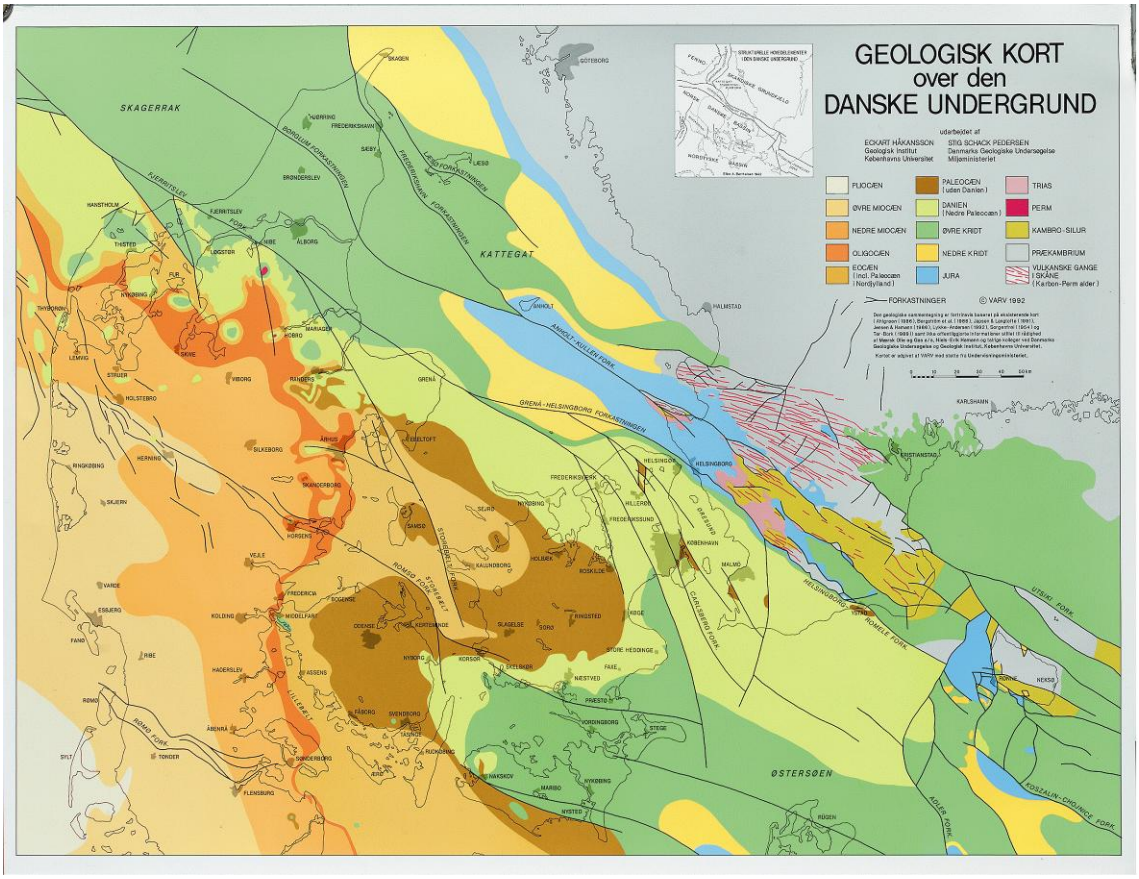


Figure 84. Map of the pre-Quaternary surface: Time units. Original scale: 1:500.000. Legend: Red lines: Precambrian intrusions; Grey: Precambrian; Olive: Cambrian-Silurian; Red: Permian; Light red: Triassic; Blue: Jurassic; Yellow: Lower Cretaceous; Green: Upper Cretaceous; Light green: Danian; Brown: Paleocene; Yellow olive: Eocene; Red brown: Oligocene; Light yellow brown: Lower Miocene; Very light yellow brown: Upper Miocene; White: Pliocene (Håkansson & Pedersen, 1992).

It is expected that the sediments on the pre-Quaternary surface are from the Oligocene. Several boreholes in the area reach Oligocene deposits underneath 5 - 10 m of Quaternary sediments.

The Oligocene Vejle Fjord Formation consists of brown and black micaceous sandy and silty clay. The clay seems homogeneous, but intercalation of clay, silt and sand in thin layers occur. In one borehole, sandstone/claystones are found. The deposits are mainly non-calcareous, but some shells are found. The formation is up to 40 m thick.

Figure 85. The cliff at Mogenstrup strand with layers of brown mica clay from the Vejle Fjord Formation.

Figure 86. Brown mica clay from the Oligocene-Miocene Vejle Fjord Formation.

In three boreholes, the mica clay rest on fine-grained black grey and green grey calcareous clay. These up to 100 m thick clays could belong to the Oligocene Branden Formation (Figs. 87 and 88).

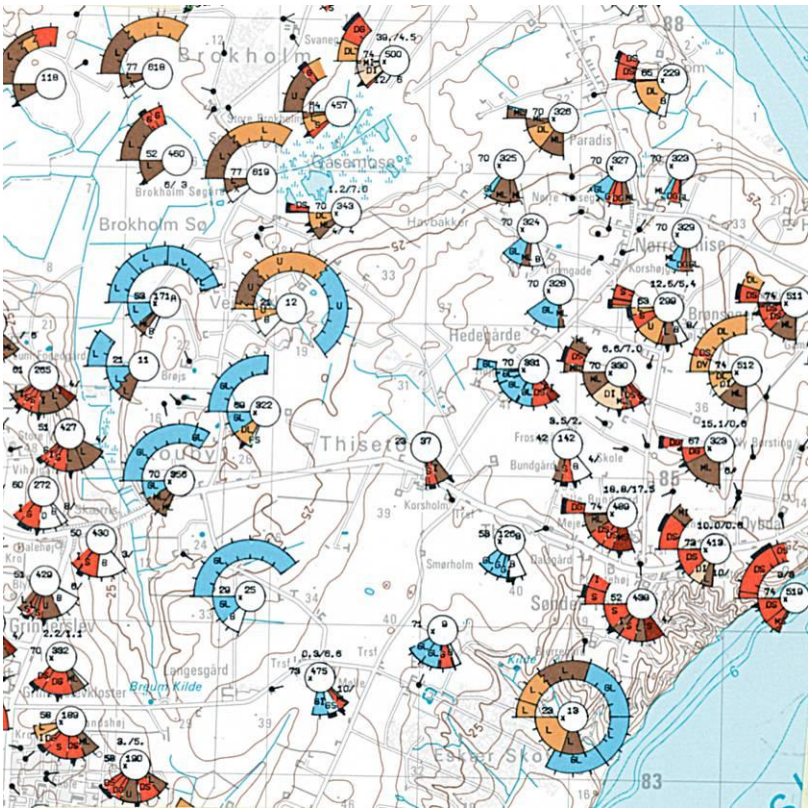


Figure 87. Part of Geological basic data map 1216 III Farsø. Original scale 1:50.000 (From Fredericia & Gravesen, 1983). Legend: see fig. 11.

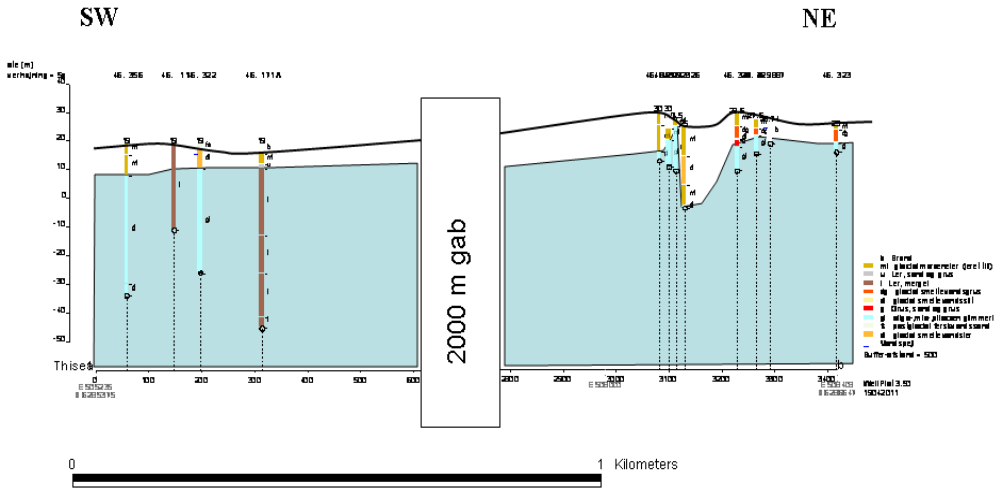


Figure 88. Geological section from Vejsmark (SW) to Nørre Thise (NE). The blue colour represents the Oligocene mica clays below the Quaternary sediments (white).

9.5.2 Quaternary deposits

The dominant sediment in the area is clayey till (Figs. 81 and 89). The boreholes show that the upper clayey till is sandy, silty, non-calcareous, yellow brown and oxidized, 2 - 4 m thick. In some places an olive grey to green grey, calcareous reduced till occur and a thickness of up to 8 m is found below the oxidized till. This till is intercalated by fine to medium or medium to coarse grained gravelly meltwater sand, often non-calcareous and yellow brown to grey brown, but also layers up to 3 - 4 m thick of this meltwater deposits occur. Moreover, layers of silty green grey, calcareous meltwater clay and silt occur scattered in the area. Towards the east, just outside the area, Quaternary sequences up to 90 m thick are found where layers of clayey tills and meltwater deposits are intercalating.

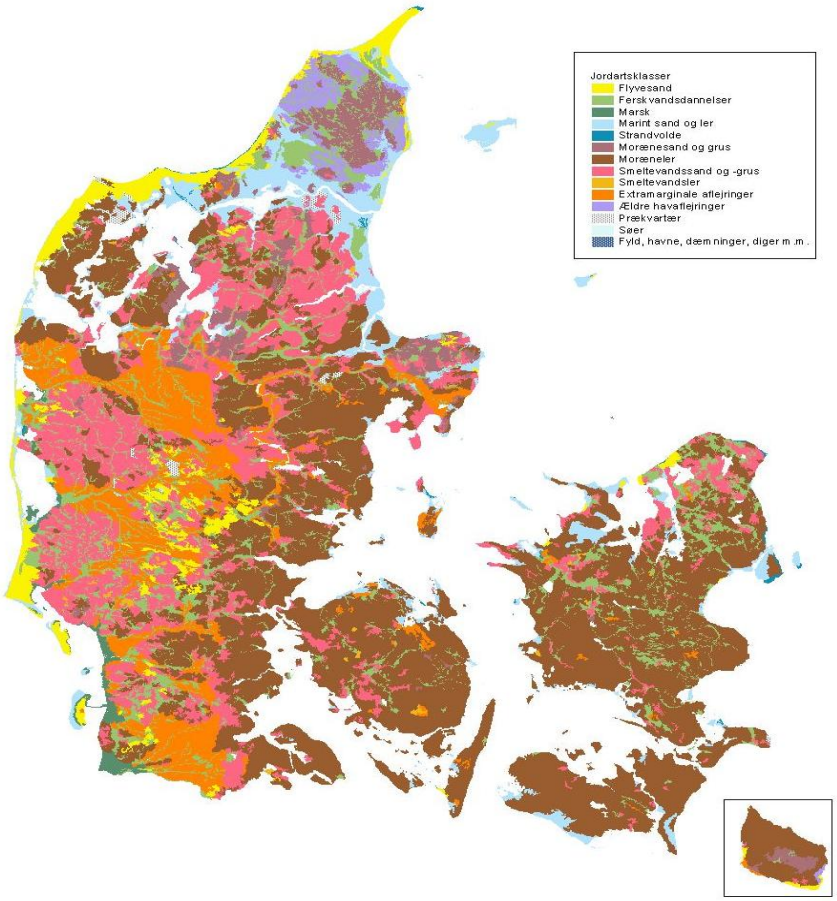


Figure 89. The map of the Quaternary surface deposits. Original scale: 1:200.000. Legend: Brown: Clayey till; Light brown: Sandy till; Red: meltwater sand and gravel; Orange: Sandur sand and gravel; Purple: Late glacial marine deposits; Light blue: Holocene marine deposits. Green: Holocene freshwater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

9.6 Tectonics, structures and seismic activity

9.6.1 Major tectonic structures

According to the map (Fig. 84), apparently no structures crosses the pre-Quaternary surface of the area, but the area is situated southwest of the Batum salt diaper and also close to the Mors, Uglev and Skive salt structures where movement during and after deposition of the Paleogene layers may have influenced the deposition pattern and later erosion. (Fig. 90).

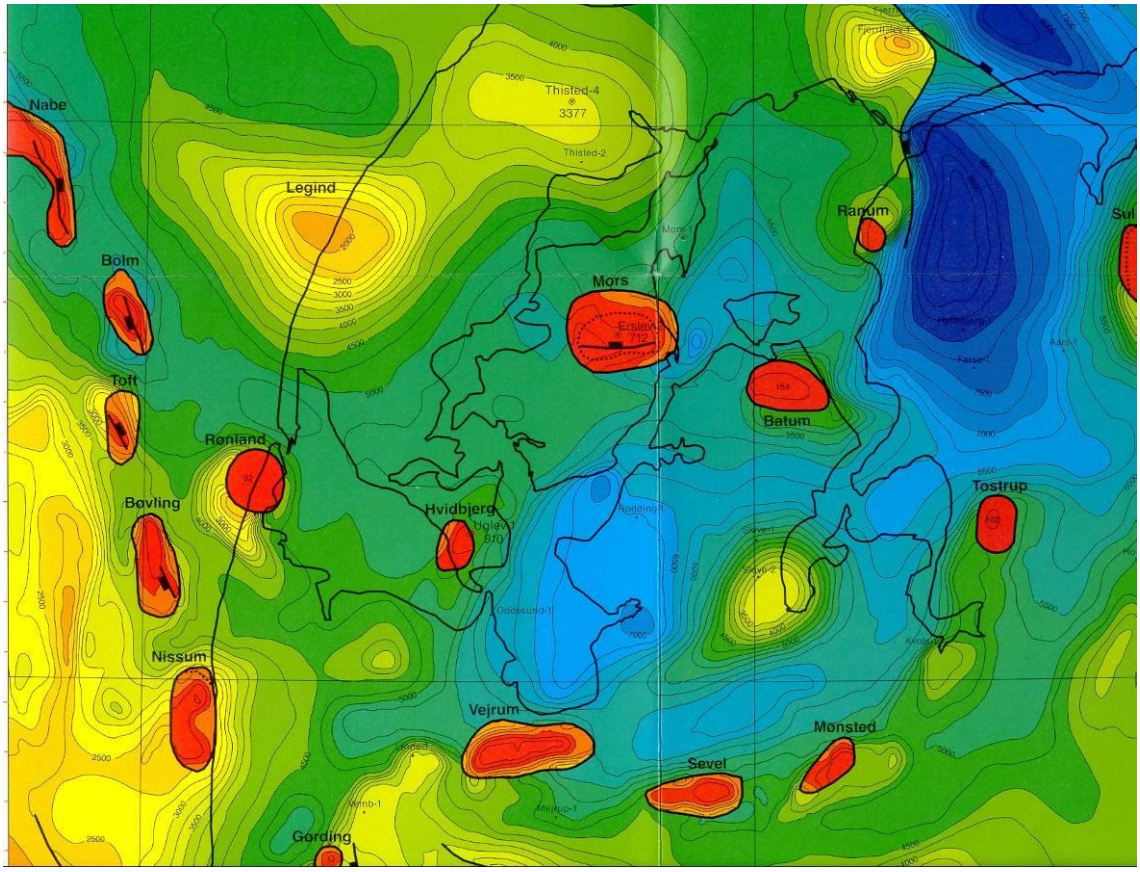


Figure 90. Map of the depth to base Cretaceous. The contours are in m. Blue is the lowest areas, green and yellow the intermediate and red is the most shallow areas. The salt diapirs in Northern Denmark are shown with black lining. Also high-laying structures (possible salt structures) can be seen as circular yellow areas. (From Japsen & Langtofte, 1991).

Some of the boreholes show that glacial floes of micaceous clay (11 m) are found, indicating glaciotectonic disturbances in the area.

9.6.2 Fractures

There is no information from the boreholes. From the cliff sections, fractures in the clayey till have been recognized down to 5 m below ground surface.

Fractures in the fine-grained Tertiary clays are expected.

9.6.3 Geological model

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

Model of the area is as follows (Fig. 91):

A. Holocene freshwater deposits (thickness unknown)

B. Quaternary clayey tills with intercalations of meltwater sand and gravel, up to 10 - 15 m thick.

C. Quaternary meltwater clay and silt (up to 20 m) and meltwater sand and gravel, up to 10 - 20 m thick.

D. Oligocene brown and black silt and clay with sand from the Vejle Fjord Formation, up to 40 m thick.

E. Oligocene Branden Formation (probably), fine-grained green grey clay, approx. 100 m thick.

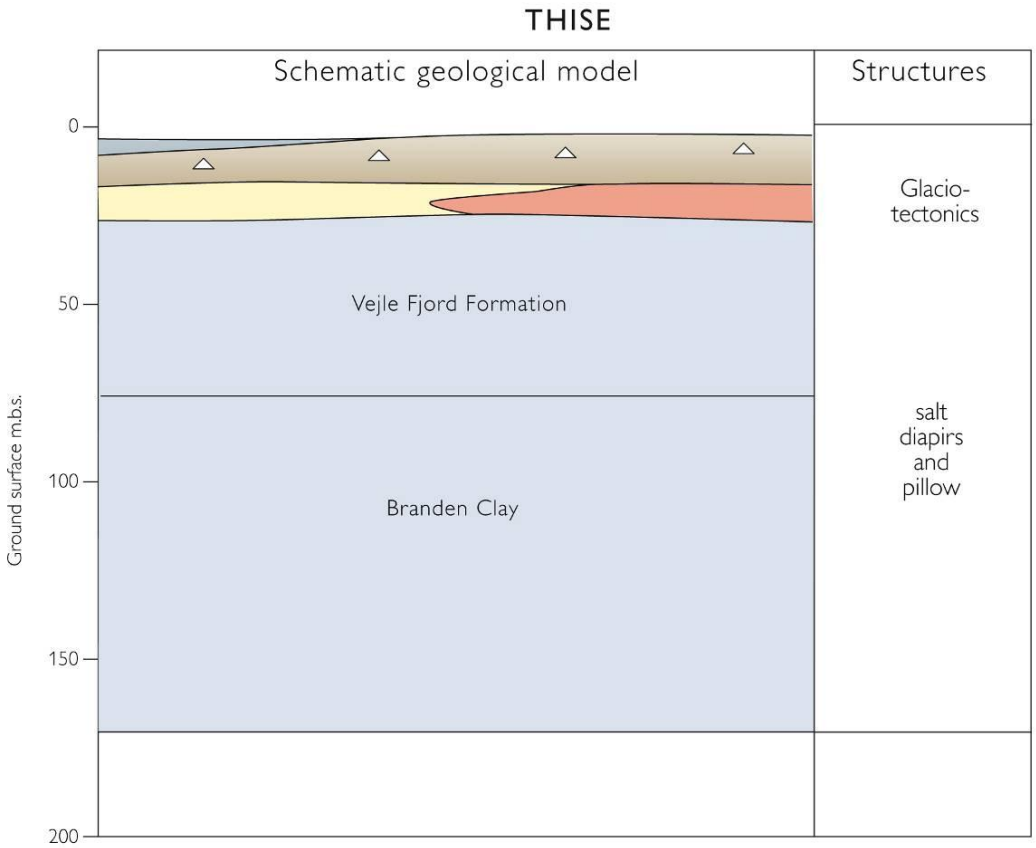


Figure 91. Schematic geological model of Area 20.

9.6.4 Earthquake activity

The seismic station net in Denmark is managed by GEUS and comprises 5 stations of which three stations are located on Sjælland: Gilleleje museum, Vestvolden, København and Lille Linde, Stevns (GEUS´s homepage: www.geus.dk).

The earthquake activity is measured with respect to location, time and size. The activity in Denmark during the period 1929-2003is very low compared to many other countries.

The seismic activity in the Limfjorden area is very low (Fig. 92). No seismic movements have been registered for the area although a seismic station is located at Mønsted.

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

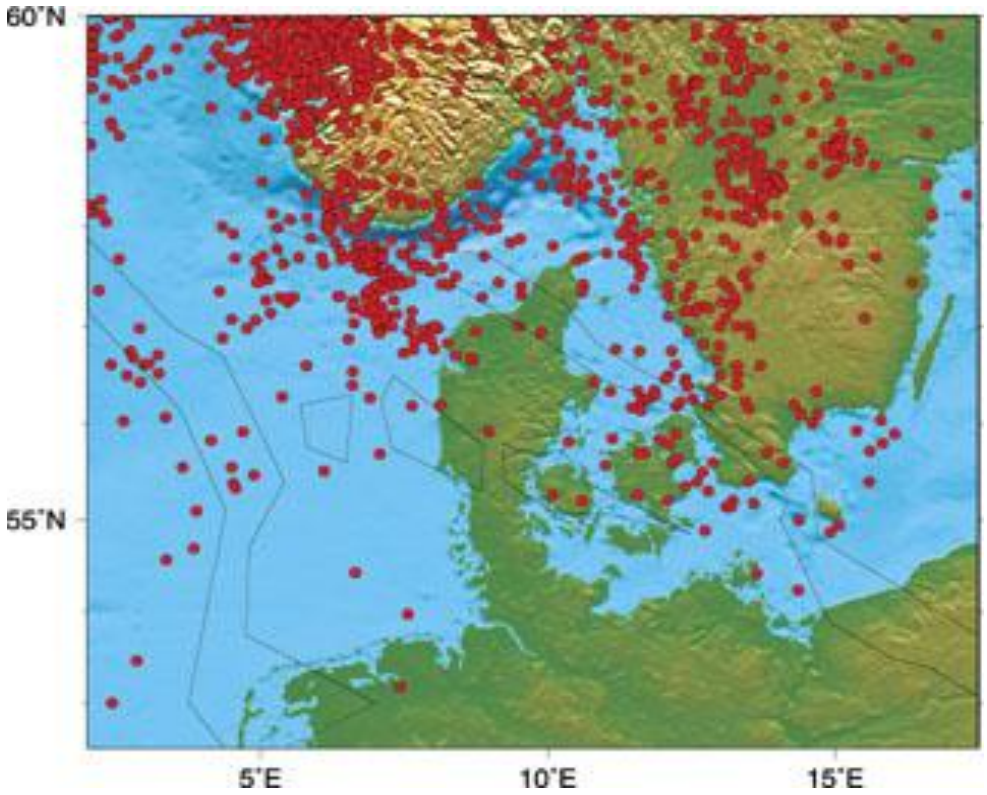


Figure 92. Map of the earthquake epicentres in Denmark and surrounding areas. A red dot shows the location (From GEUS´s Home Page).

9.7 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.

9.8 Groundwater hydrogeology

9.8.1 Groundwater characteristics

The Thise area is situated few km west of Sundsøre. According to the basisanalysis Part 1 (Basisanalysis Part 1, 2004), Area 20 is characterized by containing one shallow groundwater body (DK1.2.1.7) (Fig. 93). There are no regional or deep groundwater bodies directly within Area 20, but adjacent regional and deep aquifers of importance are located along the margin of Area 20 (Figs. 94 and 95). The shallow groundwater body consists of meltwater sand deposits. The Limfjorden catchment management plan (Hovedvandopland 1.2 Limfjorden) has been described by the Ministry of Environment. The overall assessment of the chemical and quantitative status in the shallow groundwater body is classified as poor due to a bad chemical status (see Section 9.9).

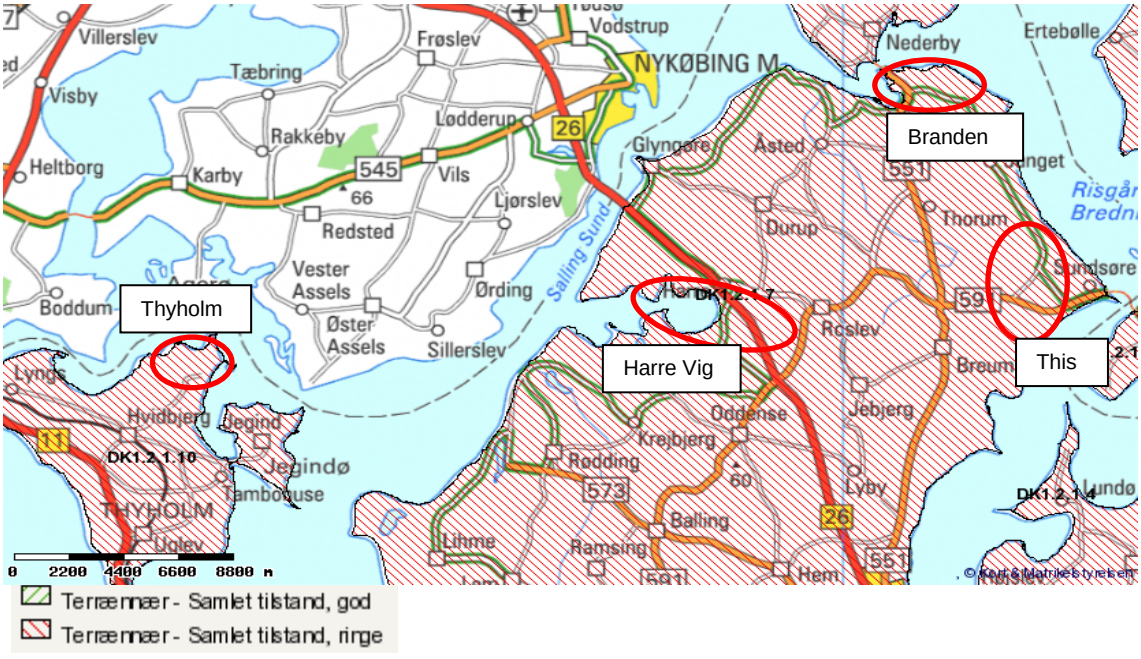


Figure 93. Shallow Groundwater Bodies (After Ministry of Environment, 2010).

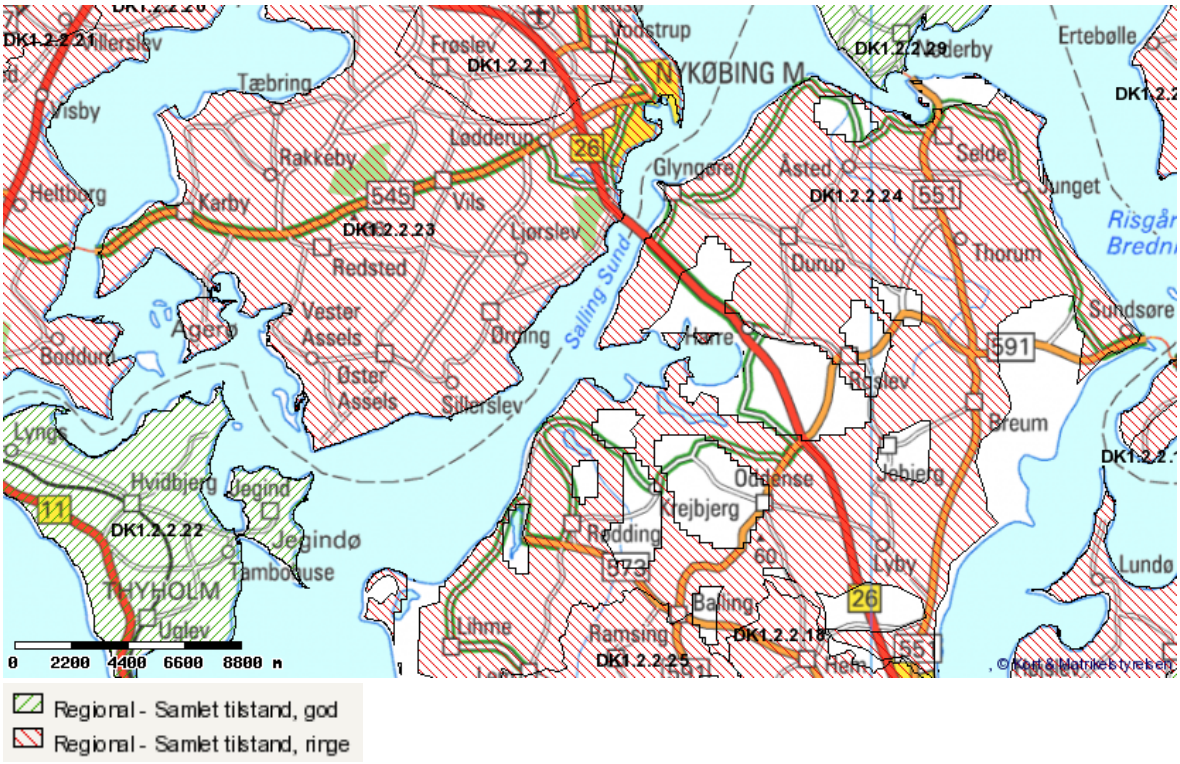


Figure 94. Regional Groundwater Bodies (After Ministry of Environment, 2010).

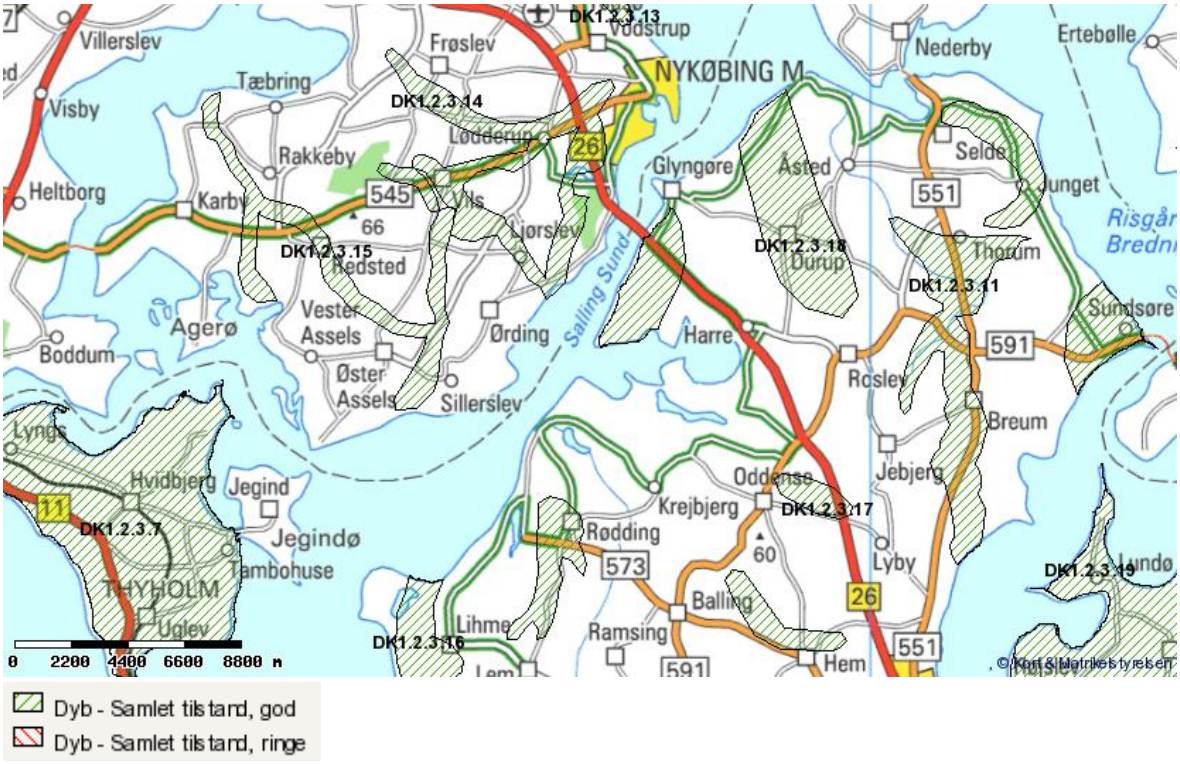


Figure 95. Deep Groundwater Bodies (After Ministry of Environment, 2010).

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. 96).

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.

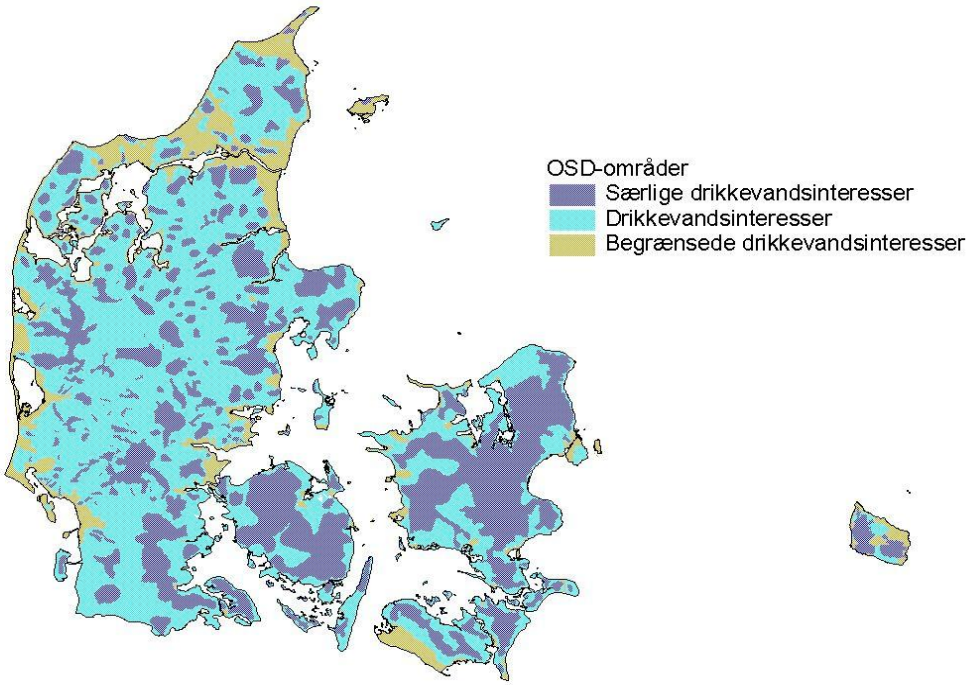


Figure 96. Areas of special drinking water interests (OSD): Dark blue and areas of drinking water interest (OD): Light blue. Areas of limited drinking water interests are olive (/kort.arealinfo.dk/).

The geographical distribution of the drinking water areas in the Thise area is given in Figs. 97 and 98. In Area 20, limited or no drinking interests occur along the coast of Salling to Hvalpsund and Risgårde Bredning, while the rest of the area is an OD area.

Thise water work is situated at the western margin of Area 20. In addition, some water supply wells for 1- 2 households are situated directly in Area 20.

Figure 97. Drinking water areas. Legend: See fig. 40 (http://kort.arealinfo.dk/).

Figure 98. Map of the drinking water areas in Area 20. Legend: see fig. 40 (http://kort. arelinfo.dk/).

9.9 Groundwater chemistry

The overall groundwater quality aiming for drinking water purpose has been assessed by the Environmental Centre Ringkøbing in the catchment management plan “Hovedvandopland 1.2 Limfjorden“. The groundwater chemistry does not fulfil the EU criteria in the shallow groundwater body due to unacceptable high content of nitrate. No saltwater intrusion problems have been reported in relation to the relevant groundwater bodies in Area 20.

The level of the terrain surface ranges between 10 and more than 25 meter above present sea level within Area 20. Thus, no significant changes in the fresh/saltwater interface are expected to happen due to future sea level rise (climate change).

9.10 Climate and climate changes

The actual climate and the expected future climate changes and sea level development is described in Gravesen et al. (2010, Rep. No. 2). It is not expected that climate changes will affect the major part of the high-lying area seriously during this century. Although, locally changes are expected such as: periodically more water in the bog; increased discharge of the stream; perhaps erosion in the steep, incised slopes; increased coastal erosion in the section toward south-east; flooding of the marine foreland toward north-east and maybe also some erosion of this coastal section.

9.11 Restrictions and limitations

There are no NATURA 2000 habitat areas or areas protected by Naturbeskyttelsesloven (nature protection law) (Chapter 6) directly in Area 20 (Fig. 99). It should be noted that the suggested Area 20 is situated directly in an OD area. Particular attention must be given to Thise water work.

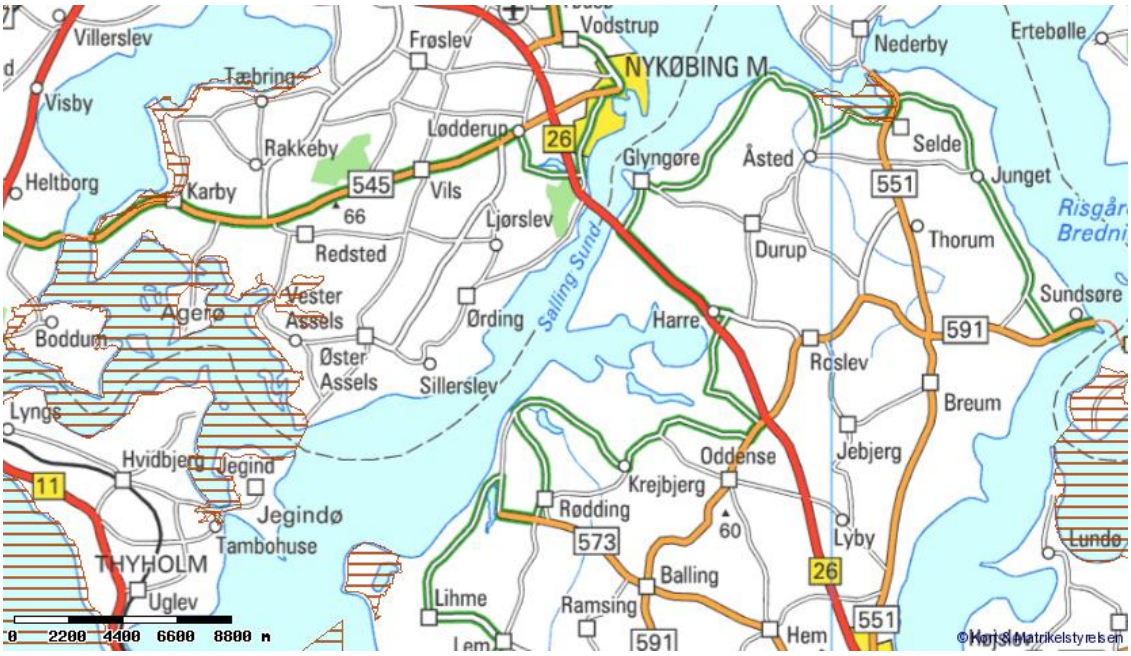


Figure 99. NATURA2000 habitat areas (After Ministry of Environment, 2010).

9.12 Summary of the area conditions

Amount of data:
Several boreholes in the area. No geophysical surveys.

Homogeneous conditions and isolation of the waste by low, permeability layers:
Perhaps perfect on depth below 15 - 25 m but the framework of the fractures below 20 m is unknown. The fracture problem has to be considered in relation to other areas.

Stability
Good stability on surface and depth.

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

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

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 areas are located in the area. Areas of limited drinking water interest occur along the coast while OD areas occur within the rest of the Area 20. Only minor local supplies are present.

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

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

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

Other restrictions
Apparently no other restrictions will give problems.

9.13 Final Remarks

The Oligocene clay deposits in the area may be useful for a waste disposal. The best part with thick clay successions seems to be located in the western part of the area.

10. Area 21 Skive west

10.1 The location of the area

The area is located west of the city of Skive at Skive Fjord, Limfjorden (Fig. 100). The area can be seen in detail on fig. 101.

Figure 100. Location of Area 21. Skive is located at Skive Fjord, Limfjorden, Jylland.

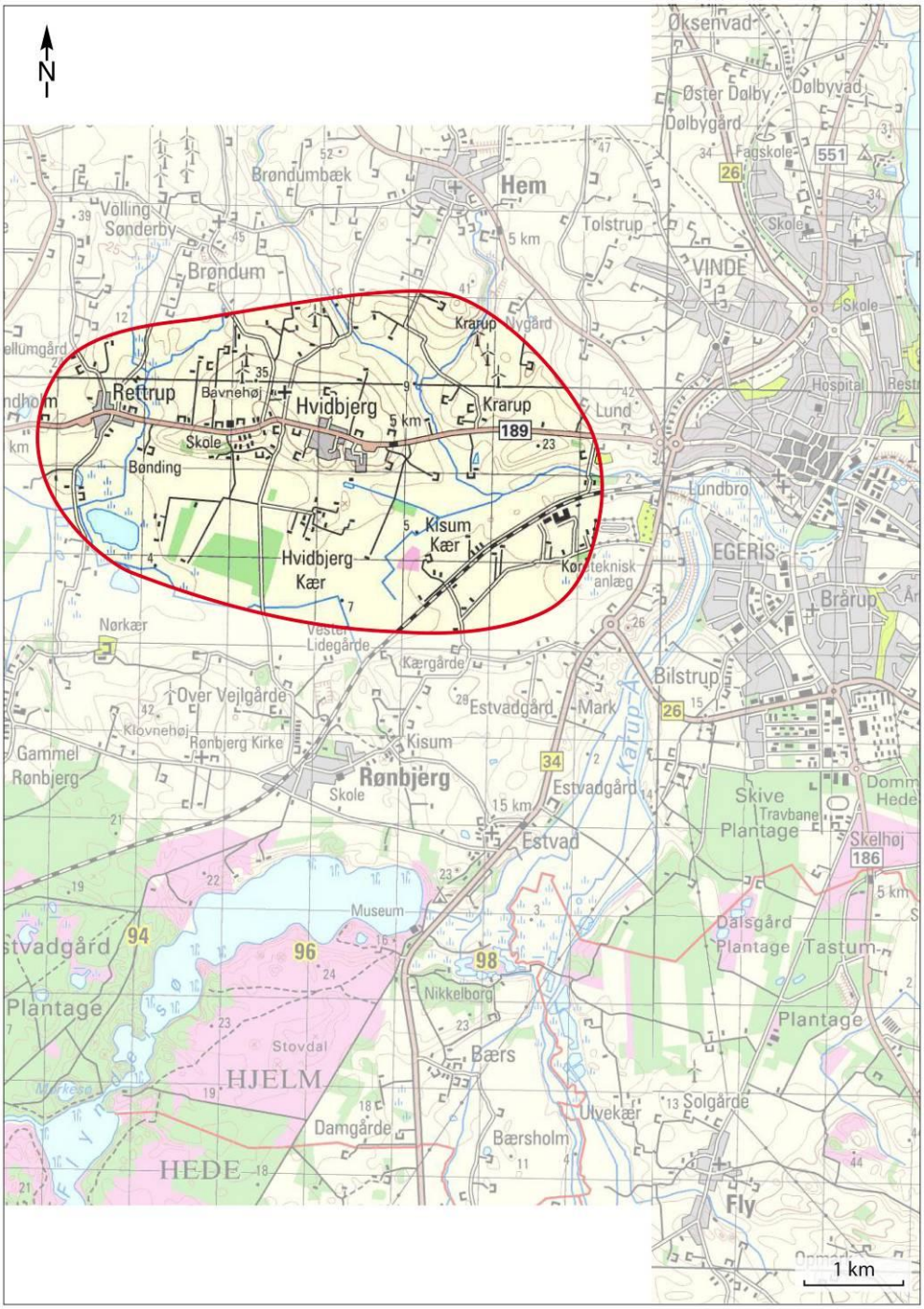


Figure 101. Detailed map of Area 21. Area 21 is located west of Skive.

10.2 Terrain, topography and surface processes

The area is located west of the city Skive, mid between Venø Bugt and Skive Fjord in Limfjorden. The size of the area is c. 18.5 km^2. The area includes two very different kinds of landscape. The northern half part is a high-lying, undulating landscape of clay till and meltwater sand and gravel. This landscape is situated between c. 10 and 40 m above sea level (m.a.s.). It does not include any lakes but it is cut by several streams that merge into two;

one turning toward east and one toward west in the river valley. The two segments are separated by an inactive, overgrown and gently sloping cliff. The southern half part of the area is a low-lying plane river valley, developed in an E–W-oriented former outwash plain. The terrain in most of this area is situated around 5 m.a.s. Parts of the area are water-logged and marked by ponds and water meadows.

The northern part of Area 21 is crossed by a main road and several minor roads. The two small villages Rettrup and Hvidbjerg are located along the main road and some houses are found between the two villages and also evenly distributed in the landscape. Several windmills are found north of the road, NW of Hvidbjerg and N of Krarup. The low-lying area toward south is transacted by a railway in the eastern part. Otherwise, this landscape only holds few minor roads and few houses, primarily concentrated at Hvidbjerg Kær. Both parts of the area are used for agriculture.

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

10.3 Surface geology and profiles

Figure 102. The Skive areas seen from the main road and toward east. Skive is seen in the horizon, in the central part of the photo.

The surface geology is dominated by Quaternary deposits. Towards the north, clayey tills dominate but towards the south, in the valley from Skive and towards the west, to Sønder Lem Vig, meltwater sand and gravel occur. Holocene freshwater deposits cover the meltwater deposits in the middle of the valley. The Karup stream has the outlet at Skive. Marine Holocene deposits are found above the freshwater deposits (Fig. 103).

At the cliff Lyby Klint, Oligocene deposits are exposed and in the clay pit at Hesselbjerg, Oligocene clays are present (Figs. 107 and 108).

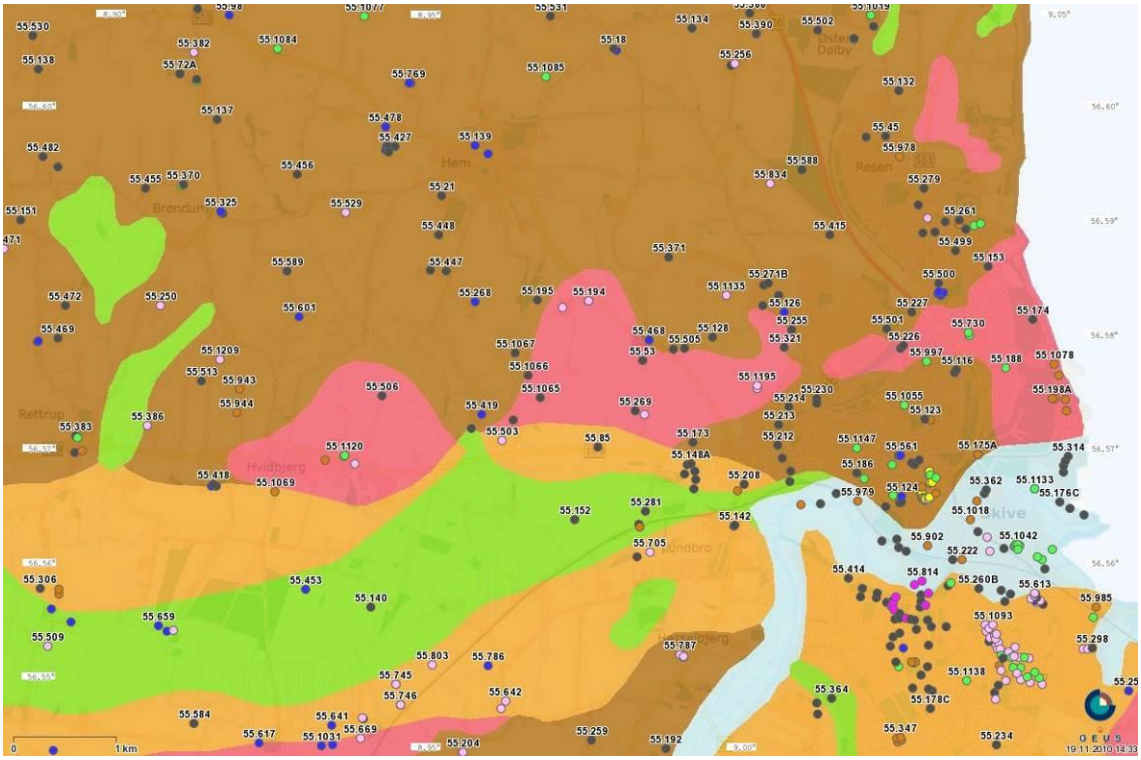


Figure 103. Map of the Quaternary deposits. (From GEUS´s Homepage, after Pedersen, 1989). Legend: See fig. 3. Legend for boreholes: see fig. 104

10.4 Boreholes

The area is penetrated by several boreholes. The drilling methods normally produce fair samples of the Tertiary and Quaternary sediments. Most of the samples are described lithological and related to lithostratigraphical units while few samples are dated by biostratigraphy. No geophysical surveys have been performed.

The locations of the boreholes in the area are seen in fig. 104.

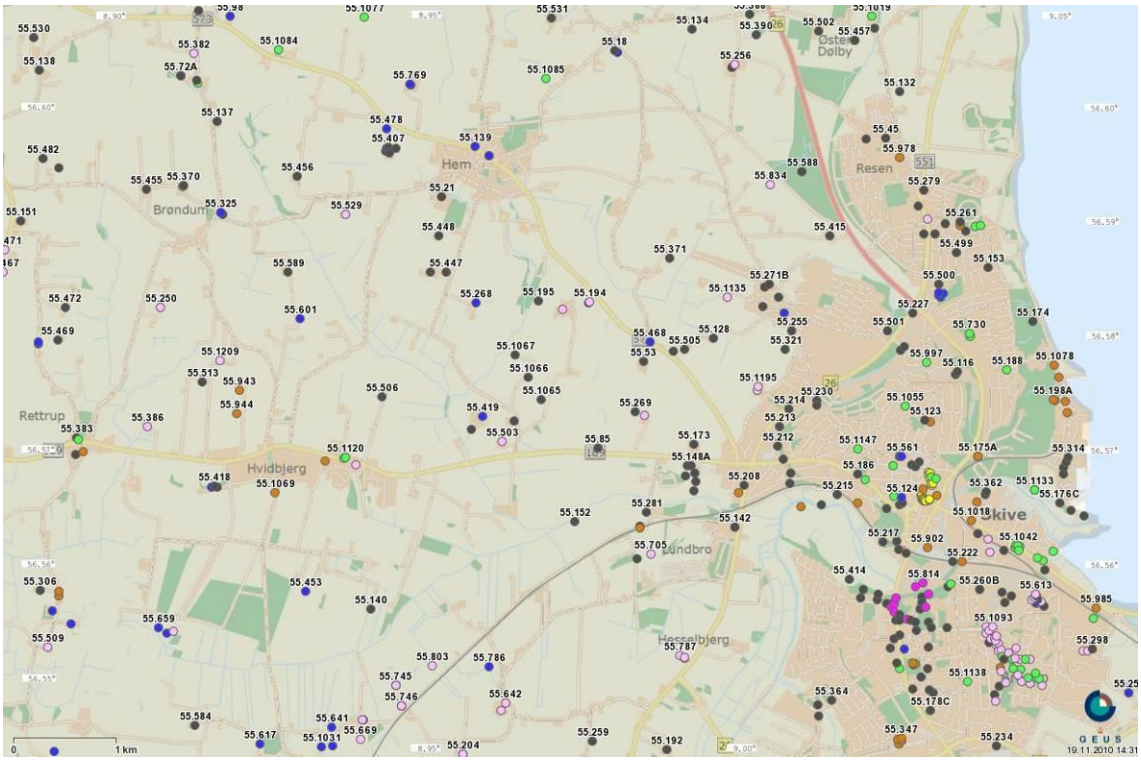


Figure 104. Map of the locations of boreholes from the Jupiter database at GEUS. Legend: 55. 1066: DGU no.; Blue dot: Water supply well; Red dot: Geotechnical borehole; Pink dot: Raw material borehole; Green dot: Other borehole; Light red dot: Abandoned borehole; Black dot: Unknown purpose.

Most of the boreholes are wells which supply households, smaller farms and other local needs.

An example of a borehole log is found in fig. 105.

De Nationale Geologiske Undersøgelser for Danmark og Grønland

Udskrevet 19/11 2010 Side 1

BORERAPPORT

DGU arkivnr: 55. 1066

Borested : Krarupvej, Krarup
7800 Skive

Kommune : Skive
Region : Midtjylland

Boringsdato : 6/6 2002

Boringsdybde : 8 meter

Terrænkote : 24.8 meter o. DNN

Brøndborer : Grontmij-Carl Bro
MOB-nr :
BB-journr : 25.0271.81
BB-bornr : B2

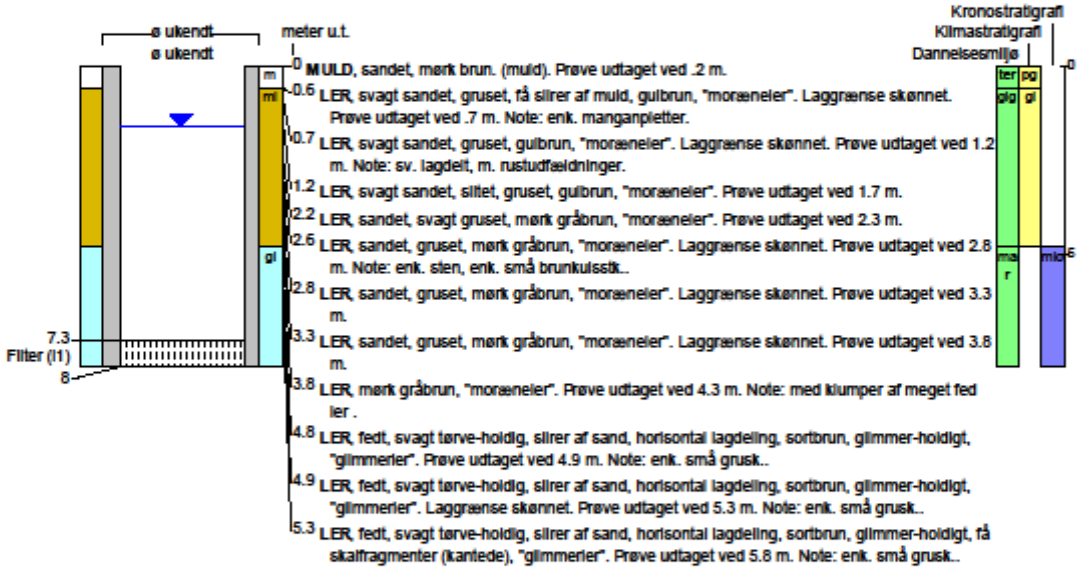
Prøver
- **modtaget** : 7/6 2002 **antal** : 12
- **beskrevet** : 27/6 2002 **af** : DP
- **antal gemt** : 0

Formål :
Anvendelse :
Boremetode : Tørboring/slagboring

Kortblad : 1115 INØ
UTM-zone : 32
UTM-koord. : 498004, 6270438

Datum : ED50
Koordinatkilde : Landinspektør
Koordinatmetode : Landinspektør

	Ro-vandstand	Pejledato	Ydelse	Sænkning	Pumpetid
Indtag 1 (seneste)	1.6 meter u.t.	6/6 2002			



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

meter u.t.			
0	-	0.6	terrigen - postglacial
0.6	-	4.8	glacigen - glacial
4.8	-	8	marin - miocæn/tertiær

Figure 105. Borehole log of the DGU no. 55.1066. Legend: ML: Clayey till, GL: Micaceous clay.

10.5 Sediment and rock characteristics, mineralogy and chemistry

10.5.1 Pre-Quaternary rocks

The distribution of the pre-Quaternary deposits can be seen in fig. 106.

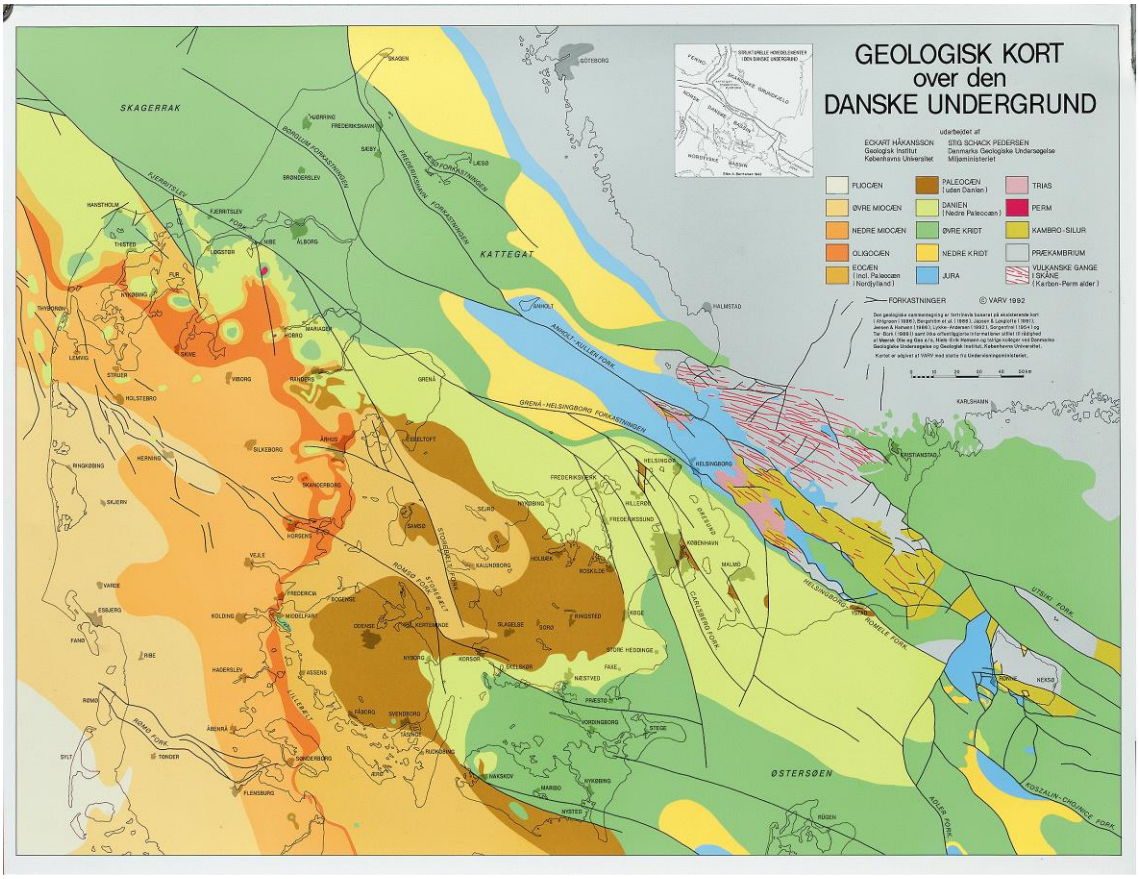


Figure 106. Map of the pre-Quaternary surface: Time units. Original scale: 1:500.000. Legend: Red lines: Precambrian intrusions; Grey: Precambrian; Olive: Cambrian-Silurian; Red: Permian; Light red: Triassic; Blue: Jurassic; Yellow: Lower Cretaceous; Green: Upper Cretaceous; Light green: Danian; Brown: Paleocene; Yellow olive: Eocene; Red brown: Oligocene; Light yellow brown: Lower Miocene; Very light yellow brown: Upper Miocene; White: Pliocene (Håkansson & Pedersen, 1992).

It is expected that the sediments on the pre-Quaternary surface are from the Oligocene. Several boreholes in the area reach Oligocene deposits below 5 - 10 m of Quaternary sediments.

The cliff Lyby klint north of the area exposes black brown and brown micaceous clays and silt with concretions (Krabbeboller) from the Oligocene and some sand deposits with gravel and clay ironstones also belonging to the Oligocene. The deposits belong to the Late Oligocene/Early Miocene Vejle Fjord Formation (Figs. 107 and 108).

Figure 107. Lyby Klint. Black brown micaceous silty clay from the Vejle Fjord Formation.

Figure 108. Lyby Klint. Yellow sand, gravel and stones, probably from the Vejle Fjord Formation. The deposits are glaciotectonic deformed.

At Mogenstrup Strand north of Lyby Strand, the Oligocene sediments are also exposed.

In the south western outskirt of Skive, in a clay pit at Hesselbjerg, Oligocene clay has been dug for several years and the area is still a raw material interest area. The clay is fine-grained and silty, green grey, partly calcareous and partly non-calcareous with mica, glauconite and pyrite. Large concretions (meter size) of jointed clay ironstones (Called Septarian) occur. The clay mineralogy is: 53 % smectite, 26 % illite and 21 % kaolinite. The clay is called Skive Ler and it has the same age as Branden Clay Formation: Late Oligocene.

The shallow boreholes show that the Skive Clay occurs in the eastern part of the area around the clay pit where few boreholes has reached approx. 100 m below surface. The clay varies in color from green, green grey to black green with lamination and few shells and concretions. The age is Late Oligocene and it is based on foraminifera analyses.

In the main western part of the area, the clay from the Vejle Fjord Formation dominates. The clay is black brown or brown, micaceous, silty and sandy and many linses and thin layers of silt and sand can occur. The clay from borehole DGU no. 55.532 at Krarup has been dated to Late Oligocene but the deposits towards the west can very well belong to the Early Miocene part of the formation (Figs. 109 and 110).

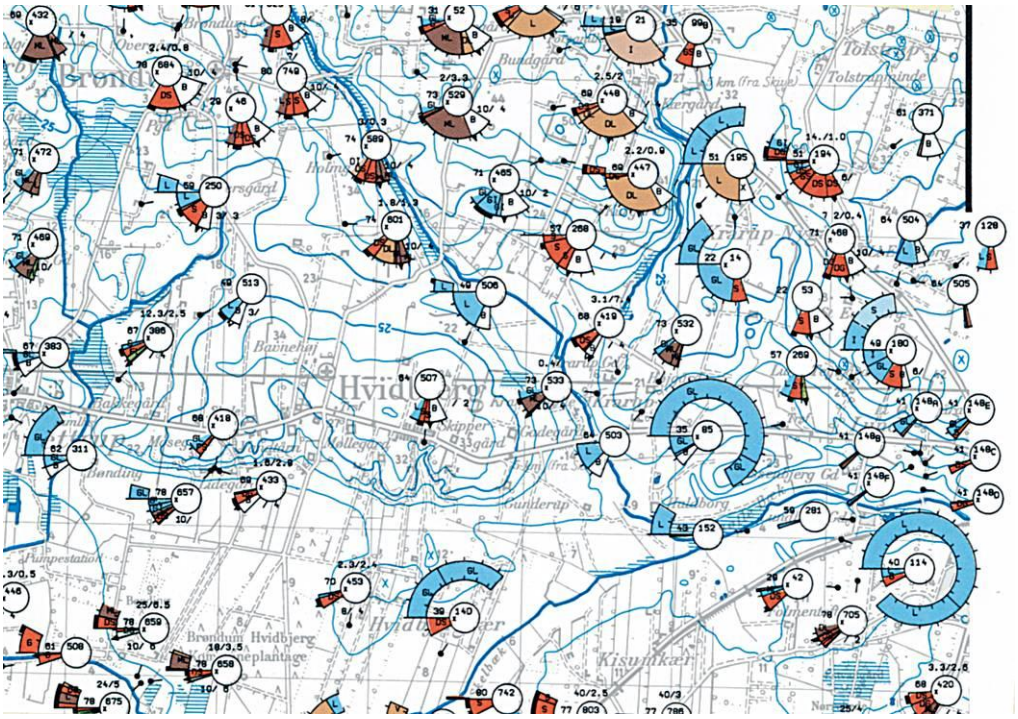
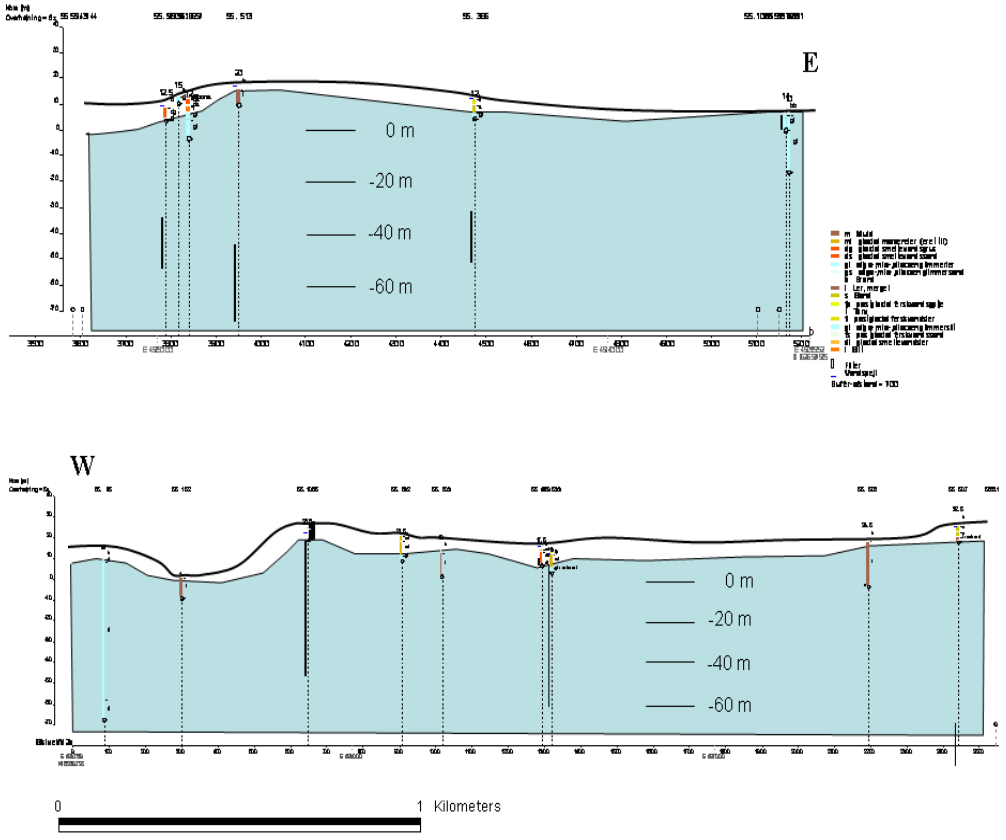
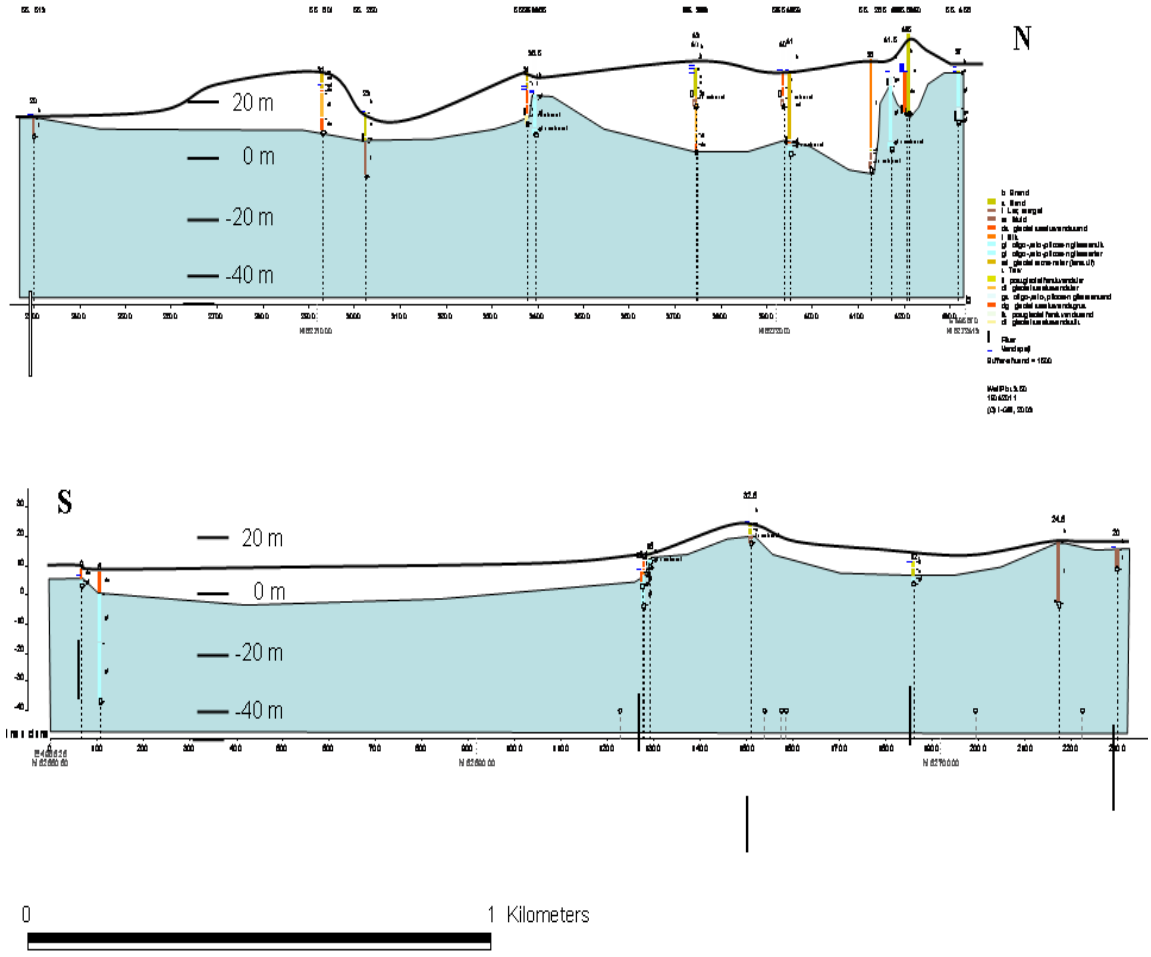


Figure 109. Part of Geological basic data map 1115 I Struer. Original scale 1:50.000 (From Gravesen, 1989). Legend: See fig. 11.



a.



b.

Figure 110. Geological sections. (a) E-W from Lund to Rettrup, (b) N-S from Brøndumbæk to Hvidbjerg Kær. The Oligocene mica clays are marked by blue while the Quaternary is white.

10.5.2 Quaternary deposits

The predominant sediment in the area is clayey till (Figs. 103 and 111). The boreholes show that an upper till is sandy, silty, calcareous, grey brown to olive brown and up to 9 m thick. The till is intercalated by fine to medium grained gravelly meltwater sand, often non-calcareous and yellow brown to grey brown and 3.5 m thick. Also thin layers of meltwater clay and silt occur. In some places along the rim of the area (Hem, Krarup, Hesselbjerg), up to 37 m thick layers of yellow brown and grey, non-calcareous to calcareous meltwater sand and gravel occur.

The Holocene deposit consists of thin marine layers and up to 3 m thick limnic peat and clay.

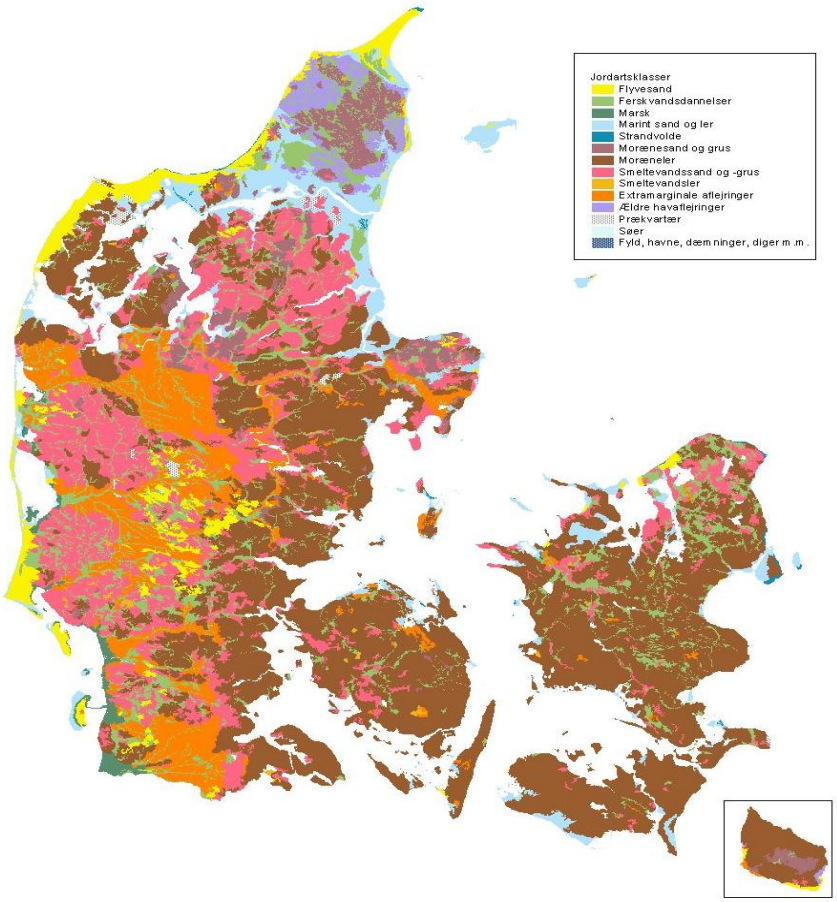


Figure 111. The map of the Quaternary surface deposits. Original scale: 1:200.000. Legend: Brown: Clayey till; Light brown: Sandy till; Red: Meltwater sand and gravel; Orange: Sandur sand and gravel; Purple: Late glacial marine deposits; Light blue: Holocene marine deposits; Green: Holocene freshwater deposits; Yellow: Aeolian sand (From Pedersen, 1989).

10.6 Tectonics, structures and seismic activity

10.6.1 Major tectonic structures

According to the map (Fig. 106), apparently no structures cross the pre-Quaternary surface of the area but the area is situated between a several salt diapirs (Fig. 112). In the Skive salt structure located just below the area, movement during and after deposition of the Paleogene may have influenced the deposition pattern and later erosion. On the Skive structure, the Basis Chalk surface occur 1000 m below sea level and a normal fault cuts the southern part of the structure in this depth. The influence is not known directly.

Examples of micaceous clay floes in the Quaternary sediments show that glaciotectonic disturbances have had some influence.

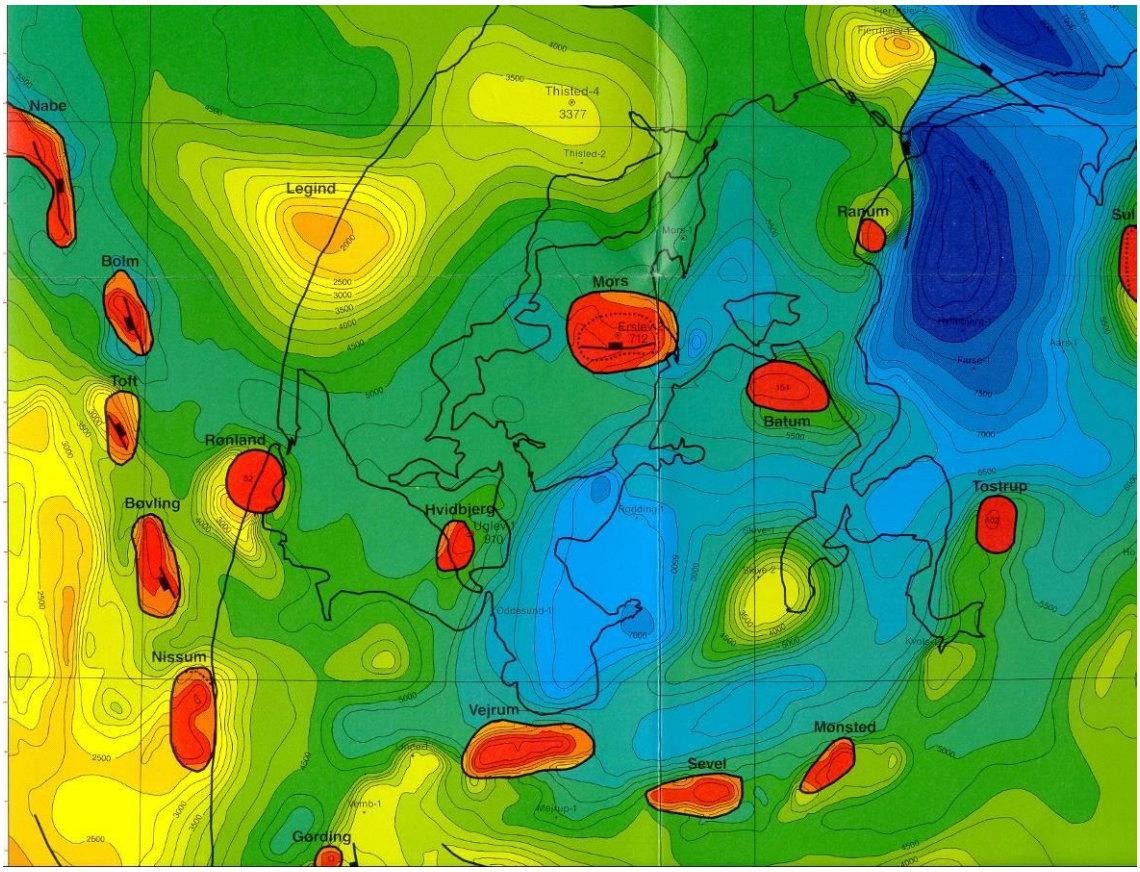


Figure 112. Map of the depth to base Cretaceous. The contours are in m. Blue is the lowest areas, green and yellow the intermediate and red is the shallowest areas. The salt diapirs in Northern Denmark are shown with black lining. Also high-laying structures (possible salt structures) can be seen as circular yellow areas. (From Japsen & Langtofte, 1991).

10.6.2 Fractures

There is no information from the boreholes. From the cliff sections, fractures in the clayey till have been recognized down to 5 m below ground surface.

Fractures in the fine-grained Tertiary clays are expected.

10.6.3 Geological model

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

Model of the area is as follows (Fig. 113):

A. Holocene gytja and peat, up to 3 m thick.

B. Quaternary clayey tills, meltwater clay, silt, sand and gravel (Weichselian). From 5 m to 37 m thick.

C. Miocene-Oligocene brown, micaceous sand, silt and clay: Vejle Fjord Formation/Brejning Formation, 50 - 60 m thick.

D. Oligocene fine-grained green clay from the Skive Clay/Branden Clay, up to 90 m thick.

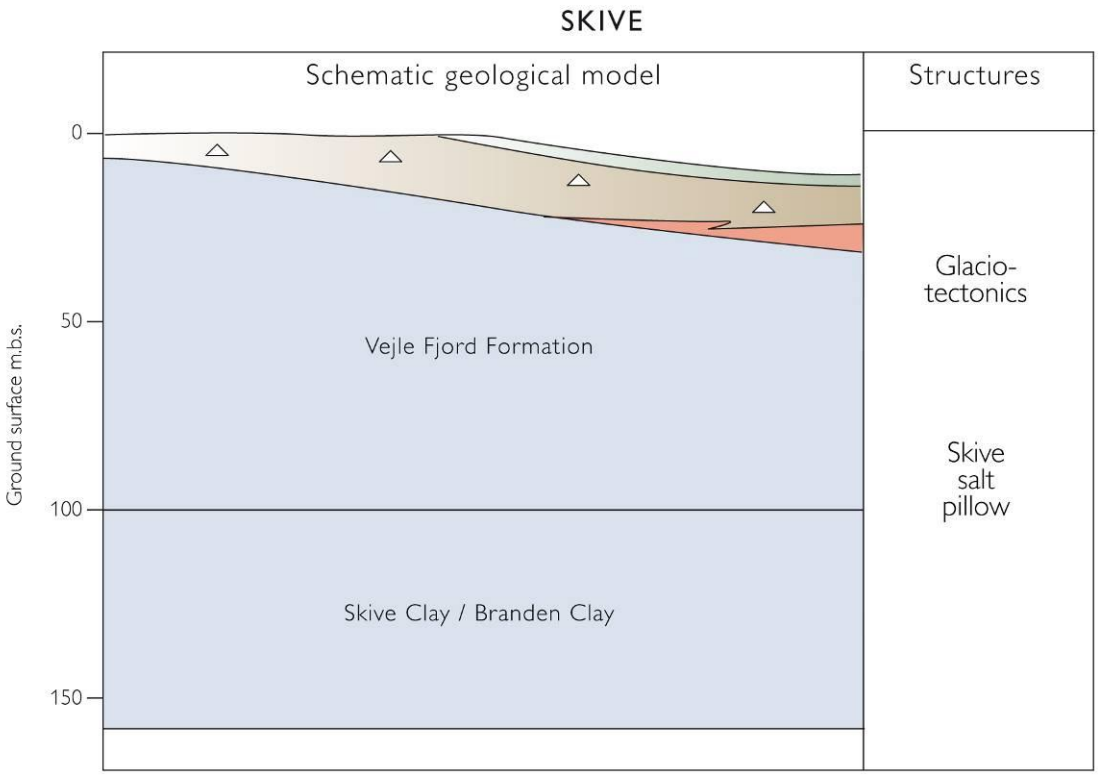


Figure 113. Schematic geological model of Area 21. Legend: Green: Holocene freshwater deposits; Brown: Clayey till; Blue: Oligiocene and Miocene mica clay deposits and fine-grained Oligocene Skive Clay/Branden Clay.

10.6.4 Earthquake activity

The seismic station net in Denmark is managed by GEUS and comprises 5 stations of which three stations are located on Sjælland: Gilleleje museum, Vestvolden, København and Lille Linde, Stevns (GEUS´s homepage: www.geus.dk).

The earthquake activity is measured with respect to location, time and size. The activity in Denmark during the period 1929-2003 is very low compared to many other countries.

The seismic activity in the Limfjorden area is very low (Fig. 114). No seismic movement have been registered for the Area 21 although a seismic station is located at Mønsted.

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

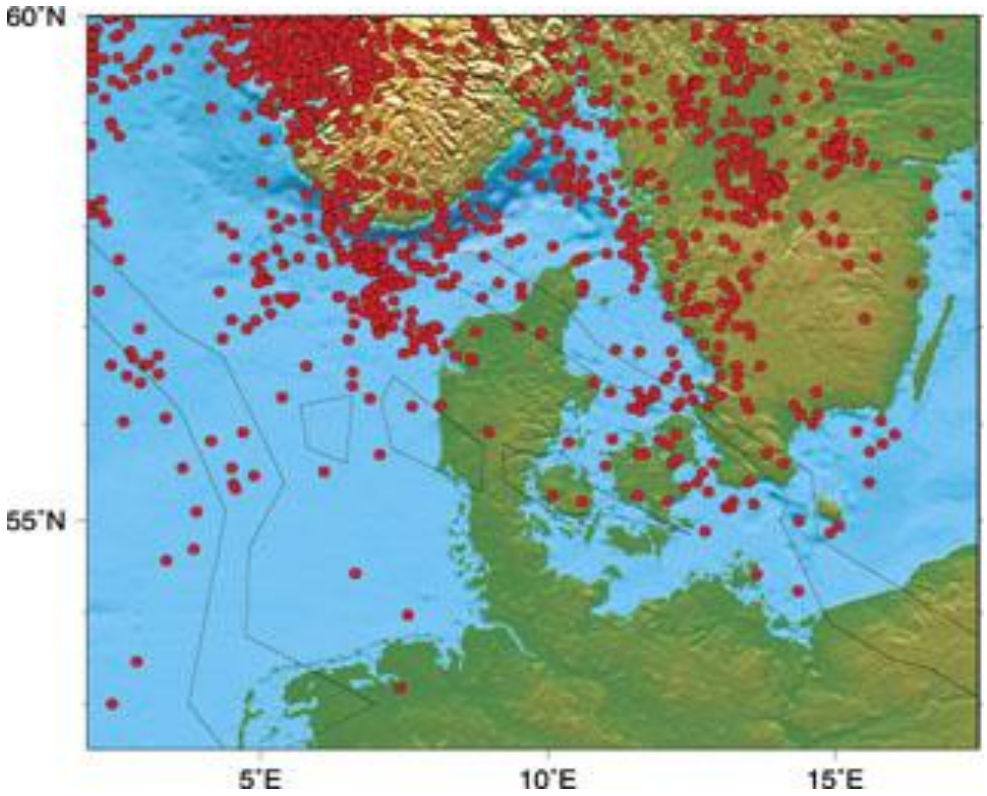


Figure 114. Map of the earthquake epicentres in Denmark and surrounding areas. A red dot shows the location (From GEUS´s Home Page).

10.7 Ground stability

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

10.8 Groundwater hydrogeology

10.8.1 Groundwater characteristics

The Skive area is situated few km west of Skive town. According to the basisanalysis Part 1 (Basisanalysis Part 1, 2004), Area 21 is characterized by containing two shallow groundwater bodies (DK1.2.1.3; 1.2.1.7) and a regional groundwater body (Dk1.2.2.18) (Figs. 115 and 116). There are no deep groundwater bodies directly within Area 20 (Fig. 117). Both

the shallow and regional groundwater bodies consist of meltwater sand deposits. The Limfjorden catchment management plan (Hovedvandopland 1.2 Limfjorden) has been described by the Ministry of Environment. The overall assessment of the chemical and quantitative status is: both the shallow groundwater bodies DK1.2.1.3 and DK1.2.1.7 have a poor chemical status and in addition, DK1.2.1.7 has a poor quantitative status (see Section 10.9). The regional groundwater body has a poor quantitative status.

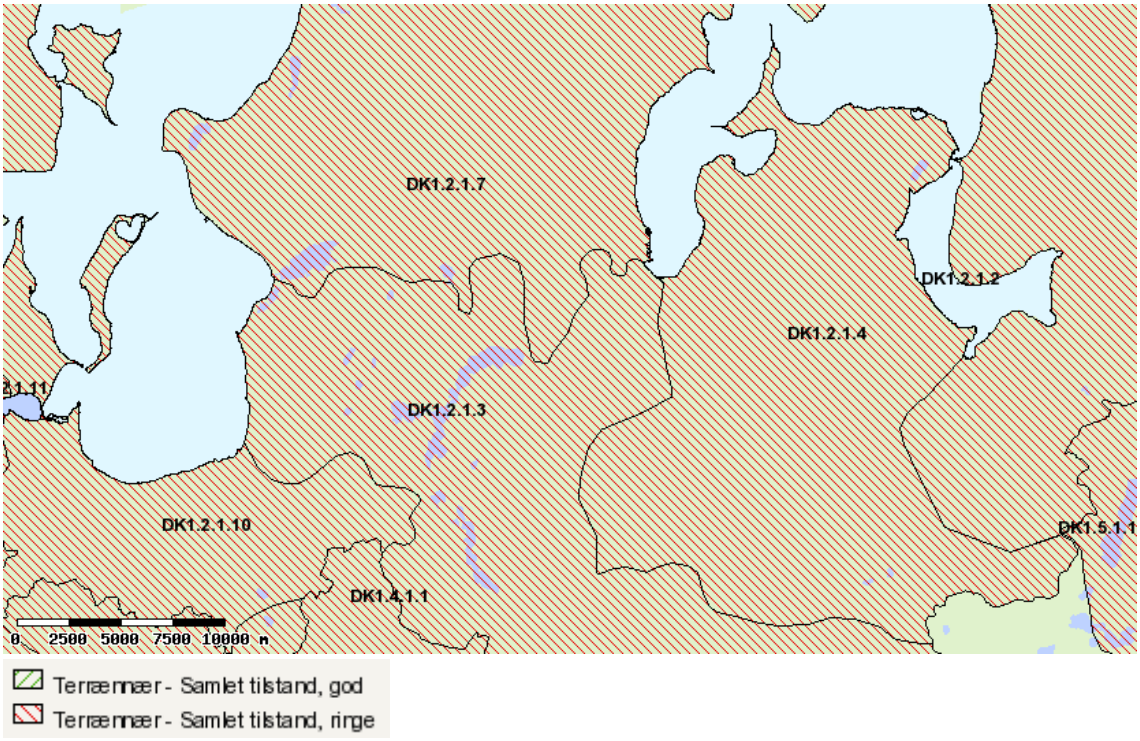


Figure 115. Shallow groundwater bodies within Area 21 (After Ministry of Environment, 2010).

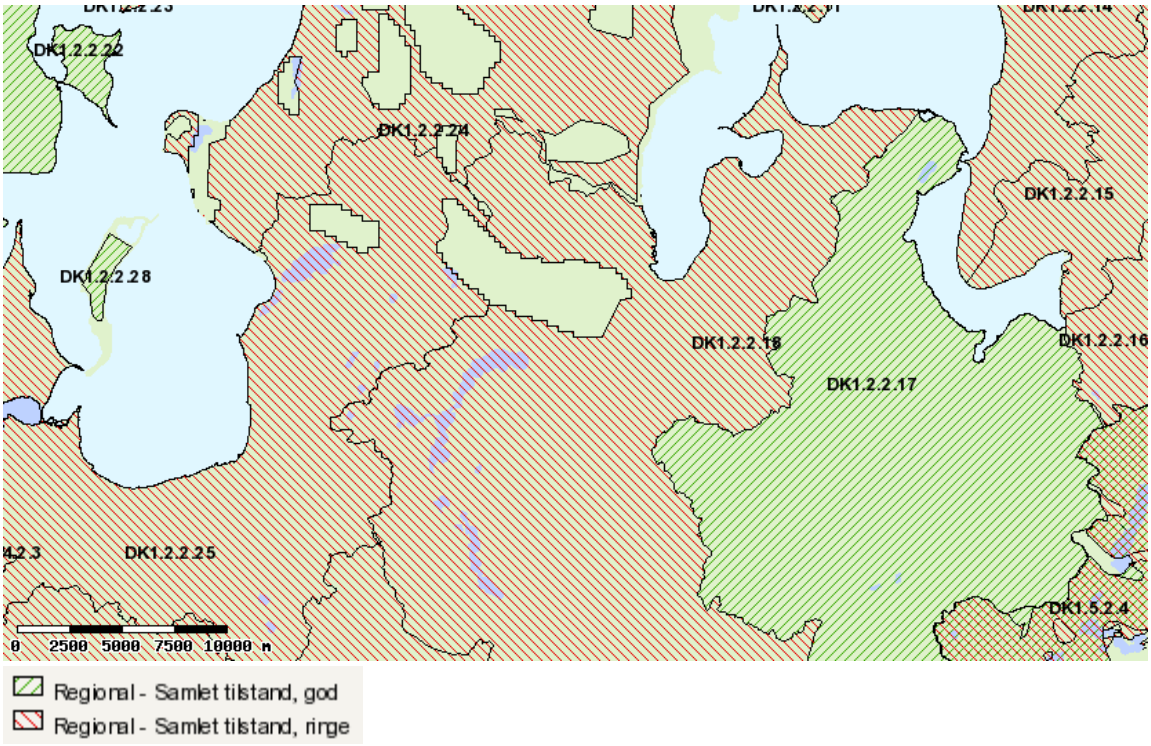


Figure 116. Regional groundwater bodies within Area 21 (After Ministry of Environment, 2010).

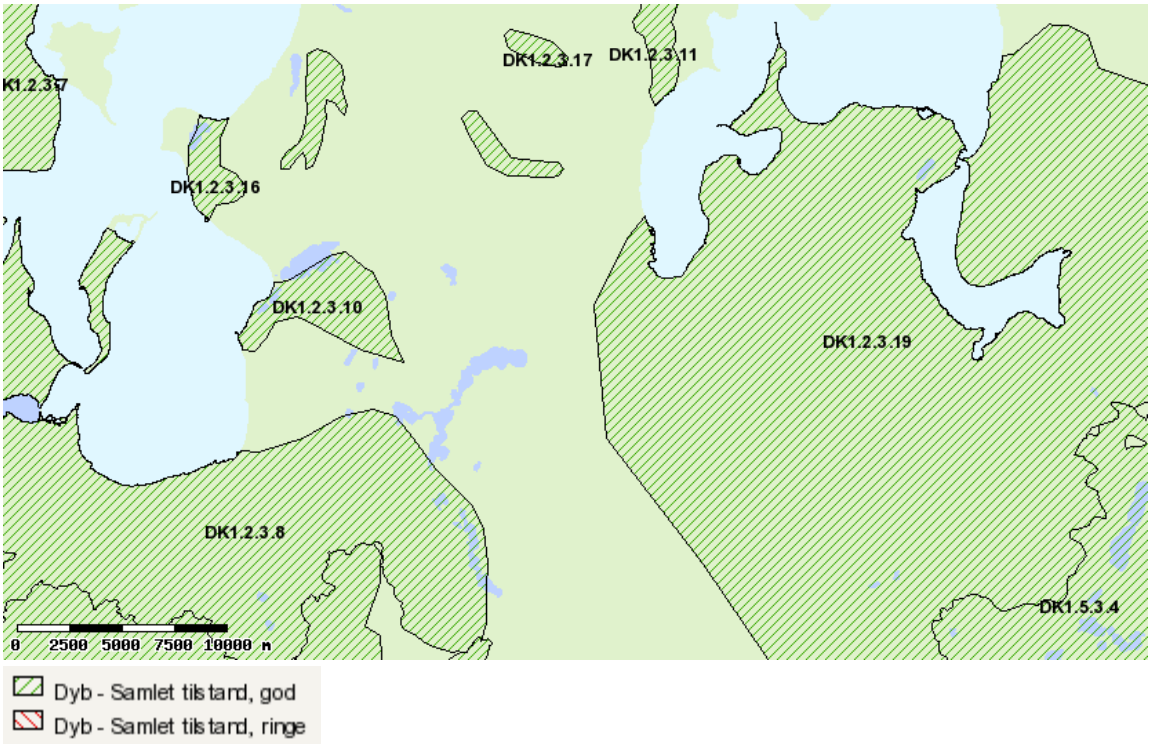


Figure 117. Deep Groundwater Bodies (After Ministry of Environment, 2010).

10.8.2 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. 118).

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.

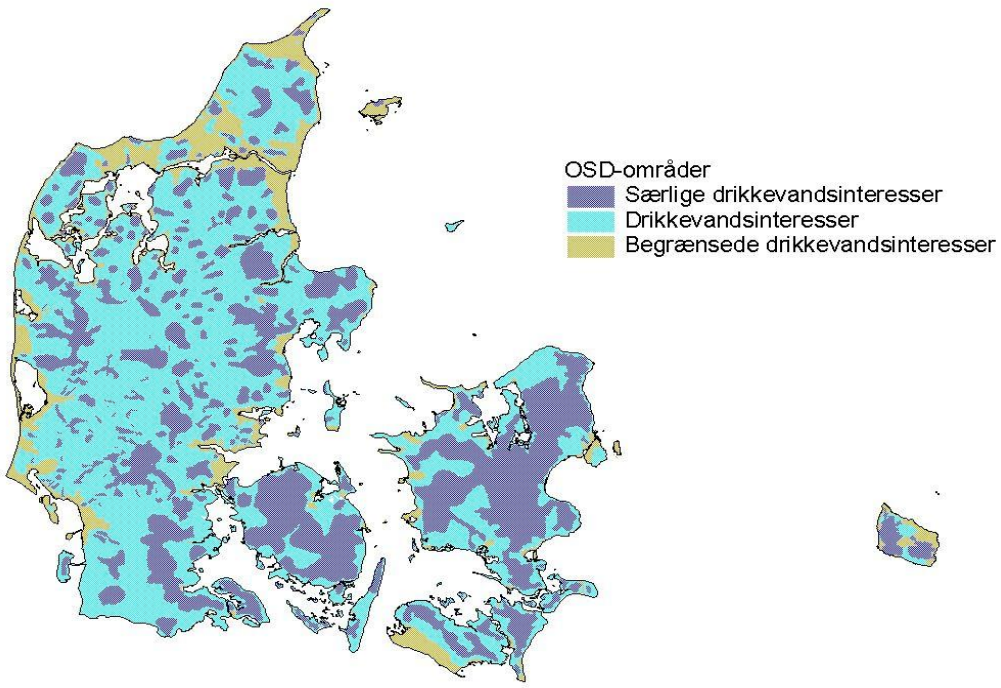


Figure 118. Areas of special drinking water interests (OSD): Dark blue and areas of drinking water interest (OD): Light blue. Areas of limited drinking water interests are olive (/kort.arealinfo.dk/).

The geographical distribution of the drinking water areas in the Skive area is given in Figs. 119 and 120. Area 21 is mainly classified as an area with limited or no drinking water interests and is partly situated in an OD classified area. No water works are situated directly in Area 21, but more local water supply wells for household purposes are identified.

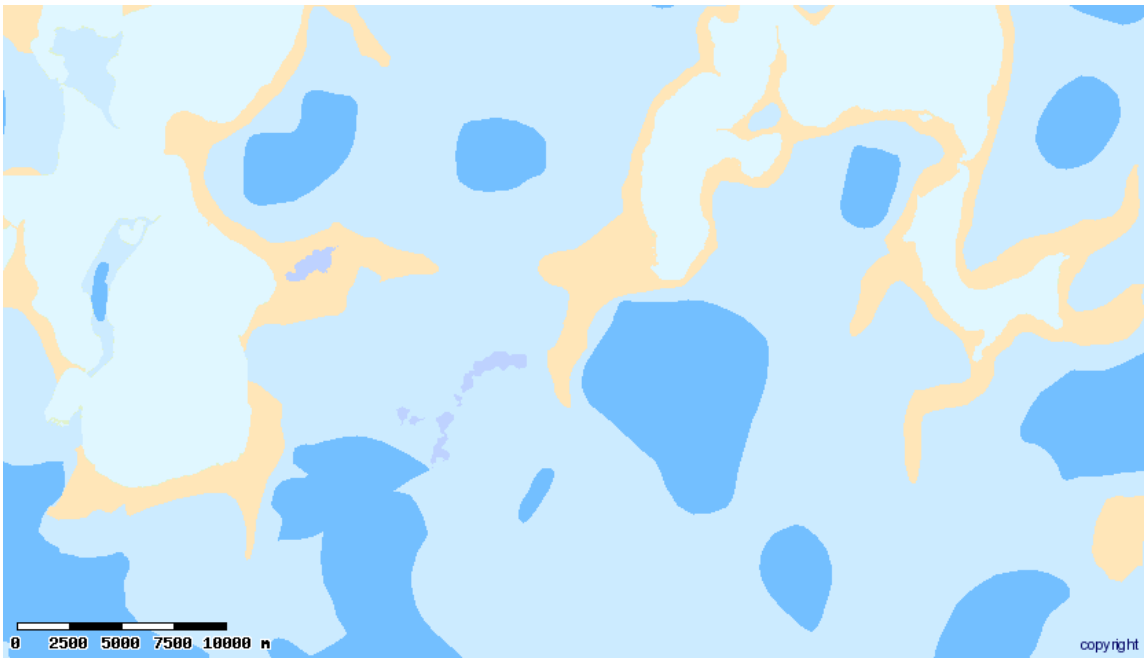


Figure 119. Distribution of the drinking water areas in the Limfjorden South area (Area 21). Dark Blue: Areas of special drinking water interests (OSD); Light blue: Areas of some drinking water interests (OD); Yellow: Areas with limited or none drinking water interests (http://kort.arealinfo.dk/).

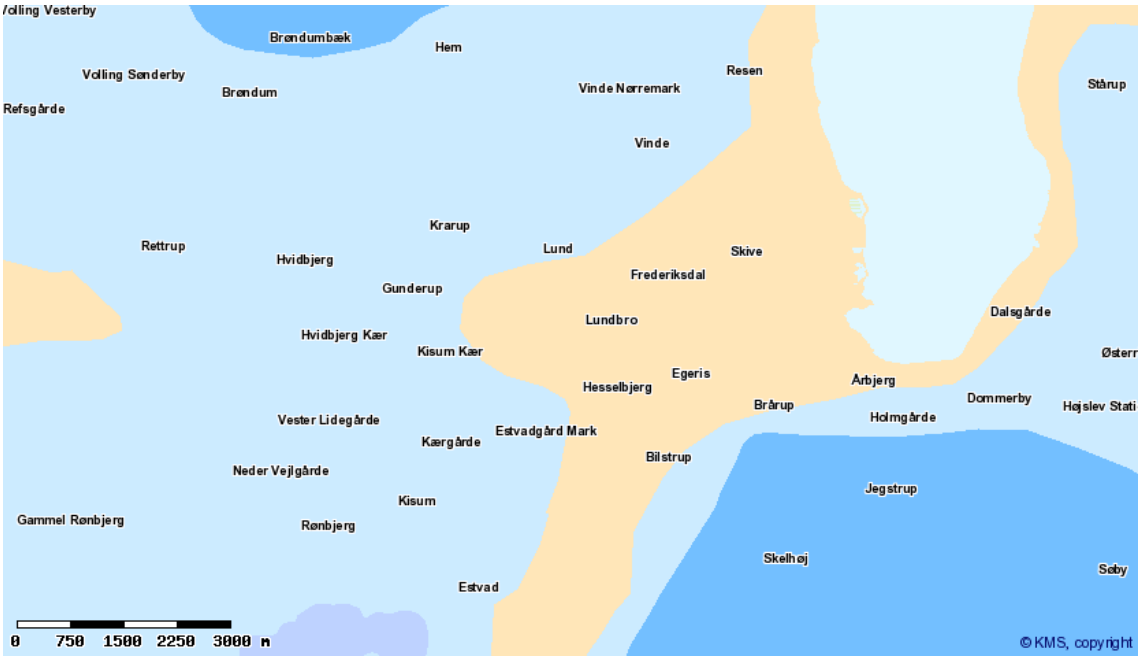


Figure 120. Map of the drinking water areas in Area 21. Legend: see fig. 119. (http://kort.arealinfo.dk/).

10.9 Groundwater chemistry

The overall groundwater quality aiming for drinking water purpose has been assessed by the Environmental Centre Ringkøbing in the catchment management plan “Hovedvandopland 1.2 Limfjorden“. The groundwater chemistry does not fulfil the EU criteria in the shallow groundwater body due to unacceptable high content of nitrate. No saltwater intrusion problems have been reported in relation to the relevant groundwater bodies in Area 21.

The level of the terrain surface ranges between 10 and more than 40 meter above present sea level within Area 21. Thus, no significant changes in the fresh/saltwater interface are expected to happen due to future sea level rise (climate change).

10.10 Climate and climate changes

The actual climate and the expected future climate changes and sea level development is described in Gravesen et al. (2010, Rep. No. 2). It is not expected that climate changes will affect the high-lying part of the area during this century, although more and more intense rain will increase the discharge of the streams. The low-lying area will most probably suffer more from water logging problems and perhaps also flooding from the streams.

10.11 Restrictions and limitations

Protected areas have only very restricted distribution in Area 21. According to the raw material plan for the area, the Hesselbjerg clay pit is located in a digging area. There are no NATURA 2000 habitat areas directly in Area 21 (Fig. 121). In addition, few very small areas (around churches) are protected in accordance to Naturbeskyttelsesloven (nature protection law) (Chapter 6). There is a relatively high density of groundwater abstraction wells directly in or in close the vicinity of Area 21. Purposes of the wells are for local households, crop irrigation and for supply to nearby water works.

Figure 121. NATURA 2000 habitat areas in the Skive area neighborhood (After Ministry of Environment, 2010).

10.12 Summary of the area conditions

Amount of data:
Many borehole data. No geophysical surveys.

Homogeneous conditions and isolation of the waste by low, permeability layers:
Perhaps perfect on depth below 10 - 30 m but the framework of the fractures below 20 m is unknown. The fracture problems have to be considered in relation to other areas.

Stability
Good stability on surface and depth.

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

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

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 areas are located in the area. Areas of limited drinking water interests dominate the area while OD areas occur towards the west, within the Area 21. Only minor local supplies are present.

Groundwater chemistry, non- aggressive components

The groundwater contains apparently no aggressive components.

Ground surface conditions

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

Climate extreme conditions

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

Other restrictions

Apparently no other restrictions will give problems.

10.13 Final Remarks

The Oligocene clay deposits of the area could be suitable for the waste disposal area. The clay deposits seem to be found in-situ over a large area.

11. Reports from the project

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

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

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

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

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

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

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

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

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

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

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

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

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